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The potential for ore and industrial minerals in the Forsmark area

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March 2004

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This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the authors and do not necessarily coincide with those of the client.

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Summary

On behalf of Svensk Kärnbränslehantering AB, SKB (the Swedish Nuclear Fuel and Waste Management Company), a survey has been made of existing information concerning the potential for ore and industrial minerals in and near the candidate area for a deep repository in Forsmark. A deep repository for spent nuclear fuel should not be located in a rock type or an area where mineral extraction might be considered in the future, since this would make it impossible to exploit this natural resource. Avoiding such areas reduces the risk that people in the future will come into contact with the deep repository through mineral prospecting or mining activities.

The survey has made use of all the geoscientific information that was compiled in the more regional investigations in Östhammar Municipality in 1996–97. In cooperation with the Geological Survey of Sweden (SGU), a new, more detailed mineral resources map has been prepared. The map shows areas with an ore potential that may be unsuitable or unfavourable for siting of a deep repository.

The results of the recently completed geophysical helicopter surveys of the Forsmark area are presented in a special chapter. The judgement of the area's ore potential is in part based on the geophysical evaluation of these measurements. Furthermore, the survey obtained information from ongoing deep drillings from the site investigation in Forsmark. In order to better be able to judge the ore potential, the survey has initiated a geochemical investigation of activated soil samples, plus an ore geology sampling of a section in the deep borehole KFM02A, where a hydrothermally altered zone was detected in 2003. The first results from these samplings are presented in the report, which also discusses prospecting efforts in the area as well as relevant Swedish mining legislation. Some suggestions are made for further ore geology investigations.

The mineral resources map shows that there is an elongate northwest-southeast zone south and southwest of the candidate area which has a potential for skarn iron ore, and possibly for copper and zinc, although to a lesser degree. The candidate area is covered by granitic rocks and can be described as sterile from an ore viewpoint. The small iron ores in the Forsmark area have no economic value, and this judgement is probably also valid in the long time perspective. There are no deposits of industrial minerals or commercial stone in the area. Existing pegmatites are uninteresting from an ore viewpoint.

Models of selected magnetic anomalies and geological observations indicate that zones with iron ores are steeply dipping, thin and not very persistent. Most dip towards the southwest or southeast, i.e. away from the candidate area. Comparisons with the iron ore in Dannemora show that an ore of this size cannot occur either on the surface or at mineable depth in Forsmark.

The final judgement is that an area south of the candidate area in Forsmark has a small ore potential for iron, but that this type of ore is of no interest whatsoever, now and in the future. Compared with central parts of Bergslagen, the Forsmark area's ore potential is insignificant. There is no interest for prospecting in the area. The entire candidate area is free of ore potential.

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1 Introduction

1.1 Background and problem formulation

A deep repository for spent nuclear fuel should not be located in a rock type or an area where mineral extraction might be considered in the future, since exploitation of this natural resource would then be blocked. Avoiding such areas reduces the risk that people in the future will come into contact with the deep repository through mineral prospecting or mining activities. According to the Environmental Code, areas that contain valuable substances or materials shall be protected against measures that may be prejudicial to their extraction /Environmental Code, 1998/. A deep mine greatly affects groundwater conditions as well due to drainage.

An important part of SKB's feasibility studies has been to identify and analyze, based on generally available information, geoscientific conditions that could be unsuitable or unfavourable for the siting of a deep repository /SKB, 2000a,b/. Such a condition that should be avoided is the occurrence of rocks with ore potential or rocks of interest for mineral extraction. The feasibility study in Östhammar included a special survey of the potential of ores and minerals within the municipality /Lindroos, 1996/. The survey showed that around one third of the municipality of Östhammar can be regarded as having ore potential, and that an area several kilometres south of the Forsmark Nuclear Power Station has ore potential, mainly for iron. There was at that time no interest in mining of or prospecting for iron ore of the type occurring in the municipality. This is still generally true, but in recent years certain base metals and gold have been found near the iron ores in Bergslagen, and it is mainly this fact that has led to increased interest in ore exploration.

SKB stated the following in a report on siting criteria and requirements /Andersson et al, 2000/: "If large deposits of ore-bearing minerals or valuable industrial minerals are encountered within the repository area, the site should be abandoned". In practice it is of great importance to be able to demonstrate that the selected site does not have a potential for ore or industrial minerals. This requirement is repeated in the general execution programme /SKB, 2001; SKB, 2000b/. The question of how the presence or absence of ore on a site can be demonstrated is not touched upon in the reports. The authorities have since raised questions concerning which methods and criteria should be used to judge an area's ore potential. SKB therefore initiated this survey, which covers the candidate area in Forsmark and its immediate environs. An important part has been to update the geological picture for Forsmark and to make a site-specific assessment of the ore potential. The survey has been carried out in close cooperation with geologists and geophysicists in the Forsmark site project.

The information from the 1996 municipal survey has been utilized to make a new, more detailed mineral resources map, and for evaluation and modelling of selected geophysical anomalies. The work has included field checks and field visits to key areas. Moreover, the survey has obtained information from ongoing deep drillings and also been able to make proposals for additional work such as supplementary samplings in boreholes and geophysical surveys. In addition, the survey has initiated a geochemical investigation of soil samples taken in the Forsmark area /SKB, 2003/. The purpose has been to obtain a better basis for an ore geology assessment. The geochemical study has primarily been aimed at an assessment of the area's gold potential, something which has never been studied before. The preliminary results are presented in this survey (6.3).

The utilization of SGU's recently compiled "Bergslagen map" and the associated, very extensive register of mineral deposits has permitted regional comparisons between Forsmark and the rest of Bergslagen.

The geological map included in the report covers the part of the investigation area surveyed to date (October 2003) by SGU. There are therefore two "white" areas on the map, a narrow one in the southern part of the map, and a larger area out at sea. However, collected geological information from these areas has been passed on to the survey orally. There is therefore little uncertainty in the assessment of the area's ore potential.

In summary, the much more detailed geological map that has now been compiled by SGU, together with the evaluation made by GeoVista AB of the geophysical measurements in Forsmark and presented in a special section, have permitted a much more reliable ore geology assessment compared with the one in the municipal survey.

1.2 Account

The report begins with a description of the survey's objective and methodology, and general comments about information sources and map scales. This is followed by a brief ore geology overview where the Forsmark area is put in its regional geological context. Comparisons are primarily made with the ore-rich district of central Bergslagen. Furthermore, a brief historical retrospective is given of mining in this part of Sweden. Then the individual ore and mineral deposits are described, along with new and potential mineralisations. The deposits are presented on an overall geological map and in tabular form. Particular weight in the assessment of ore potential has been placed on the candidate area and its immediate environs. The end product of the survey is a mineral resources map. It summarizes the survey's assessment of where areas of ore potential exist and thereby which areas are unfavourable or unsuitable for a deep repository from this point of view.

The new information after the municipal survey includes extensive geophysical measurements from both the air and the ground. This part is presented in a special chapter and also includes an account and assessment of different geophysical anomalies, plus a modelling of selected anomalies for the purpose of obtaining in-depth information. The geophysical account includes maps, profiles and tables as well.

The results of geochemical till sampling and geological bedrock and borehole sampling carried out to date are reported in a special chapter.

The report also sheds light on recent exploration activities. Modern ore prospecting methods are discussed, along with Swedish legislation on prospecting and mining. The question of whether the Forsmark area has a future exploration interest is answered. Finally, proposals are made for further ore geology samplings and continued geophysical investigations.

The list of references at the end of the report includes public maps or reports which have some kind of bearing on Forsmark and the Bergslagen district. Information on mining legislation has been taken from SGU's website (Mining Inspectorate of Sweden). A glossary explaining some of the most common geological and geophysical terms used in the text is included as an appendix.

1.3 Information sources and map scales

The study is based on existing data from previous general siting studies, mainly geological and ore geology surveys /Antal et al, 1998; Bergman et al, 1996, 1998; Lindroos, 1996/ as well as on new information from the ongoing site investigations in Forsmark. It has involved updating all available geoinformation and transferring it to the right map scale in relation to the site investigation scale. The bedrock geology map of the central part of the Forsmark area (Figure 3-3) has been compiled by SGU . As mentioned previously, the mapping and compilation work is still under way. The central portion, here presented, is the most important in the context of the study, however. It covers the entire candidate area and the area south of it, which has been identified in previous surveys as having ore potential /Lindroos, 1996/.

An important regional map is the one SGU recently presented of parts of central Sweden, the “Bergslagen map”, as well as the associated, very extensive mineral deposits map. This information has been utilized in the survey. In addition, certain results of SKB’s deep drillings have been shared with the survey. For example, an interesting section of a drill core in deep borehole KFM 02 A has been studied, and the first results of an ore sampling of this core section are given in this report (6.1). The till samples included in the geochemical investigation (6.3) are the same as those taken by SGU in the site investigation’s Quaternary geology programme /Sohlenius et al, 2002a/.

Information collected on the ground by SGU and/or GeoVista AB is digital, and the accuracy of the coordinates set with GPS is better than 10 metres. Certain older iron ore deposits, in the terrain often in the form of water-filled pits or mine holes, probably have less accurate coordinates on the printed geological map of Östhammar /Stålhös, 1991/. SGU has therefore, after field checks in the Forsmark area, corrected the coordinates from the older compilations, and the new coordinates measured by GPS have been used consistently in this study. Investigation data

to the year 2002 have been transferred to SKB’s GIS database SDE and the geodatabase SICADA.

In summary, the existing information within the study area’s land areas is very extensive and the observations have good coverage (outcrops, exposed rock). Following the 1996 municipal survey, a large quantity of geological observations have been added to the map picture, such as studies of exposed rock in dug pits and trenches, as well as data from percussion or cored boreholes. Accordingly, the basis for delineating the area of ore potential in this survey must be considered satisfactory.

2 Definitions

An ore is by definition a metalliferous mineral deposit that can be mined with economic gain. In daily speech, the word ore is used for a major concentration of one or more metals, known as a mineralisation, regardless of the economic value of the deposit. Sometimes the word ore is also used genetically, i.e. to describe an ore formation process. Rockbound natural resources that are uneconomical today may become economical, i.e. “ore”, in the future. This is determined by factors such as metal prices and the costs of mining, dressing and environmental protection. In this report, older known iron ores are described as “ores” regardless of whether they have been mined with economic gain or not. Newer, usually smaller deposits that have not been investigated in detail are described as mineralisations or mineral deposits.

An area where several ore deposits of the same type are located near each other is usually called an orefield. There is an older iron orefield in the Forsmark area with ten or so deposits, some of which have been mined. Several similar orefields within a geographical region form an ore province. Northern Uppland constitutes the northernmost offshoot of the Bergslagen ore province, where most of the ores are associated with supracrustal rocks, mainly acid metavolcanics, and contain the metals iron, copper, lead, zinc, silver and gold /Lindroos, 1996/. As in the rest of the ore province, the iron ores in the Forsmark area all occur in areas with supracrustal rocks that include magnetite ore and skarn rocks. Skarn is an antiquated Swedish term for silicate gangue, i.e. rock that is barren of ore, but is rich in minerals such as pyroxene, amphibole and serpentine. The skarn iron ores in the Forsmark area all contain iron-bearing sulphides, and the most important minerals of this type are pyrite and pyrrhotite.

Areas with known ore deposits or other conditions of ore-related interest are termed “bedrock with ore potential” in this description. Such areas may also occur at great depth below the ground surface. A crucial question in the survey has been whether bedrock with ore potential can occur within the envisaged repository area in Forsmark, and in particular at a depth of around 500 metres. Great importance has therefore been attached to the judgement of the dip and vertical extent of the superficial bedrock near the candidate area.

The report also gives a brief account of the possible potential for industrial minerals and commercial stone. By “industrial minerals” is meant rocks and minerals that can be used directly or in industrial processes. For example, limestone is an industrial mineral with many applications ranging from anti-acidification agents to, in its purest form, an additive or filler in e.g. the paper industry. By “commercial stone” is meant a rock that can be used in the construction or manufacturing industries either as such or as a fabricated product. For example, granite can be quarried and sold as blocks or sawn and ground to slabs and tiles. It can also be crushed and used as aggregate.

The survey has been limited to the types of mineralisations that have traditionally been mined. No predictions are made regarding future shortages, for example of Rare Earth Metals (REMs). The repository itself as an orebody, i.e. copper and radioactive materials as resources, has also been excluded. The recently completed helicopter-borne radiation survey indicates that uranium- and thorium-bearing pegmatites probably occur to a greater extent than has previously been known. Their possible ore potential has not been more closely examined, but they are judged in relation to known pegmatite deposits in the region.

3 Ore geology overview

3.1 Prospecting methods

Searching for economically valuable mineral deposits has been and is still an important activity in Sweden if the country is to be able to maintain its position as a mineral producer. The goal of prospecting is to discover new deposits to take the place of those already exhausted. All mining can be said to begin with prospecting.

Prospecting has undergone rapid development in modern times, and today computers play an important role in constructing evaluation models that are crucial for the work to be carried out quickly and cost-effectively. The most common prospecting methods include geological, geophysical and geochemical surveys. In recent years, the authorities in Sweden have tried to encourage increased prospecting by amendments to the mining legislation (3.2). In addition, government agency databases have been made accessible to the private sector. Free access to SGU's geodatabases, including the results of older prospecting, have made it much quicker and easier for mining companies to choose the right target area for their operations. Prospecting for ores and minerals follows a logical procedure that starts with regional efforts and ends with detailed characterization.

When prospecting is begun in an area, it must be determined by means of a geological survey whether the bedrock there is of a potentially ore-bearing character. Mineral deposits are often associated with certain rock types or structures in the bedrock. Geologists also look for alteration zones that have been created where a hot aqueous fluid (called a hydrothermal fluid) has circulated in the Earth's crust. These zones usually surround certain ores, for example many sulphide ores in Bergslagen (see in 3.3). Ores may also have been formed by these types of hydrothermal processes.

Another important geological method is drilling, usually in the form of coring or percussion drilling. This enables a direct picture to be obtained of the bedrock and the mineralization or minerals of interest. Samples are taken from drill cores for mineralogical investigations and chemical analysis.

Boulder prospecting can be said to be a special geological prospecting method. The idea is to try to trace the source rock of ore-bearing boulders which have been torn loose from their substrate by the continental ice sheet and are now embedded in the till.

In most cases the bedrock is covered with till or other Quaternary deposits. Ores covered by soil layers can rarely be indicated by geological methods. Because ores and alteration zones often deviate in their physical properties from surrounding rocks, they can be detected by means of geophysical methods. The most common geophysical methods are magnetic, gravimetric, electrical, seismic and radiometric. Measurements can be performed on the ground, from airplanes or helicopters and in boreholes. The geophysical methods that have been used in Forsmark, and how they can find a mineralization, are described in Chapter 5.4.

The primary purpose of the measurements of natural radioactivity in the Forsmark area have been to map different rocks and Quaternary deposits.

Geochemical prospecting includes sampling, analysis of the samples and evaluation of the analysis results. The geochemical mapping done at SGU is aimed at determining the distribution of principal and trace elements in soil and water. Large parts of Sweden are covered today by modern geochemical soil maps. Samples taken of till reflect the natural chemical composition of the soil, and the maps can also be used for ore prospecting. Samples can also be taken from rock, most often using a small drilling rig to obtain drill cuttings from the upper surface of the bedrock.

SGU recently completed a Quaternary geology sampling in the Forsmark area. Samples of Quaternary deposits were taken using a small drilling rig from a total of 63 sampling points, which means a coverage of more than one sample per square kilometre. At the author's recommendation, some of the collected samples were analyzed for several trace elements, and for gold. The intention was to produce a geochemical map of the Forsmark area and see if there are any elevations in metal concentrations (geochemical anomalies) that could be of further prospecting interest. A report of the results of this geochemical study is in preparation, but the results of the investigation have been taken into account in this survey (6.3).

In conjunction with the bedrock mapping, SGU analyzed some 50 samples taken of the area's typical rocks for principal and trace elements, and those that are of interest from an ore geology viewpoint are described in Chapter 6.2.

In summary, the Municipality of Östhammar and the Forsmark area are covered by relatively modern geological, geophysical and geochemical maps. These maps can be used for both scientific and prospecting purposes.

3.2 Swedish mining legislation

Foreign mining companies are showing greater interest today in prospecting in Sweden. One reason for this is the renewal of the Minerals Act from 1992. According to this law there are no restrictions on foreign ownership of mining and mineral rights in Sweden. The Minerals Act provides that exploration may be carried out only by the holder of an exploration permit (previously a mining concession) and exploitation only by the holder of an exploitation concession (previously a staked claim in a concession). It is the Mining Inspector who issues exploration permits.

The Minerals Act has been amended since 1992, and was adapted as of 1 January 1999 to the new Environmental Code, which entered into force on the same date. An exploitation concession is reviewed by the Mining Inspector and the County Administrative Board with an EIA under chapters 3-4 of the Environmental Code. An agreement with the landowner and a land acquisition are also required. Questions relating to e.g. water supply and groundwater are reviewed by the Environmental Court. A municipal building permit shall also be obtained for the buildings and plants built in connection with the mine. Thus, an extensive regulatory review is required before a mine can start operating.

Special rules apply within areas protected under Chapter 7 of the Environmental code (national parks, nature reserves, cultural reserves, different types of protected areas). Permits and exemptions from the regulations are obtained from the County Administrative Board. According to Chapter 12 of the Environmental Code, consultations are required even within non-protected areas if the work will have a significant impact on the natural environment. It should also be pointed out that when an exploitation concession has been granted for an area, the public interest for mineral extraction has considerable strength. It is in the public interest that extraction of ores and minerals be secured within the country.

The Minerals Act is not applied within a public water area in the sea. The Continental Shelf Act from 1966 (amendments from 1998) governs mineral extraction in Sweden. By the continental shelf is meant the seabed within public water areas and the marine area outside Sweden's territorial limit. According to this law, the right to explore and extract the continental shelf's natural resources belongs to the state. The Government, or an authority designated by the Government, can issue a permit for someone other than the state to explore the continental shelf by means of geophysical surveys, drilling or other means and to extract natural resources from it. An exploitation must also be examined under the Environmental Code, and an EIA shall be included in the permit application. A permit for sand, gravel or stone quarrying on an area situated within a public water area in the sea is issued by the Geological Survey of Sweden. The survey area herein known as the Forsmark area is thus subject to two different laws as regards investigation and exploitation of ores and mineral resources.

3.3 The Forsmark area in a regional geological context

Much of the bedrock in central Sweden was formed and metamorphosed about 1900–1750 million years ago during and after the Svecokarelian orogeny, a mountain-forming process giving rise to igneous supracrustal and plutonic rocks as well as sedimentary rocks. The metamorphic alteration and deformation took place at a maximum depth of about 15–20 km in the Earth's crust and at a temperature in the range of 400–800 degrees. Rocks of volcanic and sedimentary origin are in many cases ore-bearing in Bergslagen, and the Forsmark area is located on the north-eastern edge of this Central Swedish ore province (Figure 3-1), where there are more than two thousand iron deposits and several hundred sulphide deposits (Figure 3-2). The province can be said to be unique in three respects: 1) nearly all ore deposits occur in supracrustal rocks of volcanic or sedimentary origin, 2) there is a geologically close connection between the occurrence of iron ores and sulphide ores, and 3) an extensive hydrothermal alteration has taken place in the ore-bearing country rock /Frietsch, 1975, 1986; Lundström and Papunen, 1986/. The alteration is characterized by a country rock containing extreme concentrations of sodium or potassium as well as silicic acid.

Acid volcanic rocks of rhyolitic composition dominate in the central parts of Bergslagen. Many large sulphide and iron ores are associated with these rhyolitic volcanics. Rhyolites also occur in the Dannemora field in the eastern part of the province, but not in the Forsmark area. Intermediate volcanic rocks of dacitic composition are more common there. The Forsmark area also lacks purely sedimentary rocks, including limestones, which are common in the western and central portions of Bergslagen.

A general geological bedrock map of the central portion of the Forsmark area, compiled by SGU, is shown in Figure 3-3. Mapping work is still in progress in the northern part of the map area, the seacoast, and in the southernmost part south of Forsmark (October 2003). These areas (white on the map) have therefore not been included in the map in Figure 3-3. Field observations there show that the bedrock consists primarily of plutonic rocks, and there is nothing to indicate the occurrence of mineralizations or rocks and minerals of interest from an ore geology viewpoint.

As mentioned previously, there is a connection between the types of rocks and the occurrence of ores. The geological map in Figure 3-3 has therefore been simplified to clarify this. Deformation zones have thereby also been omitted from SGU's original map.

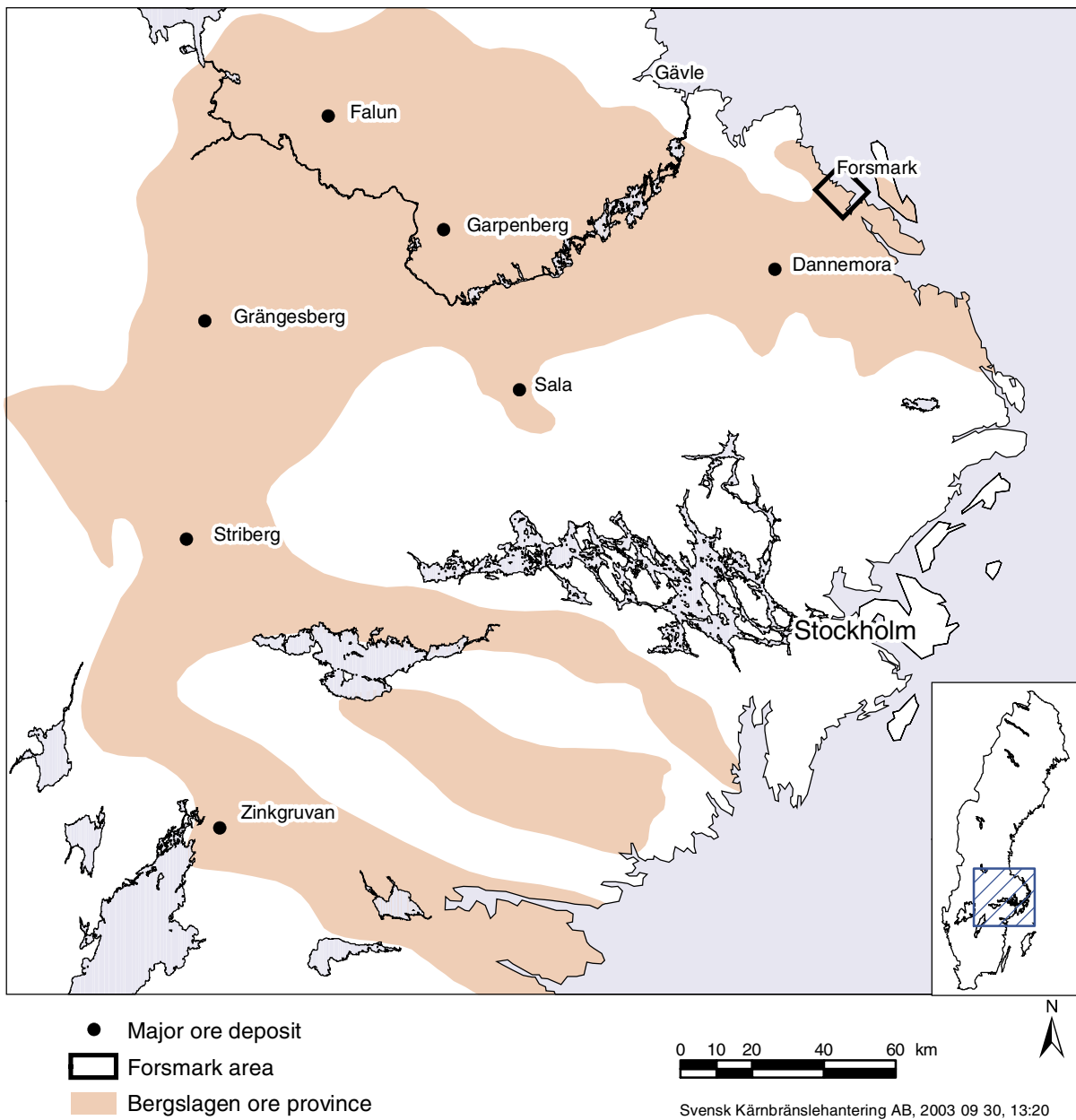
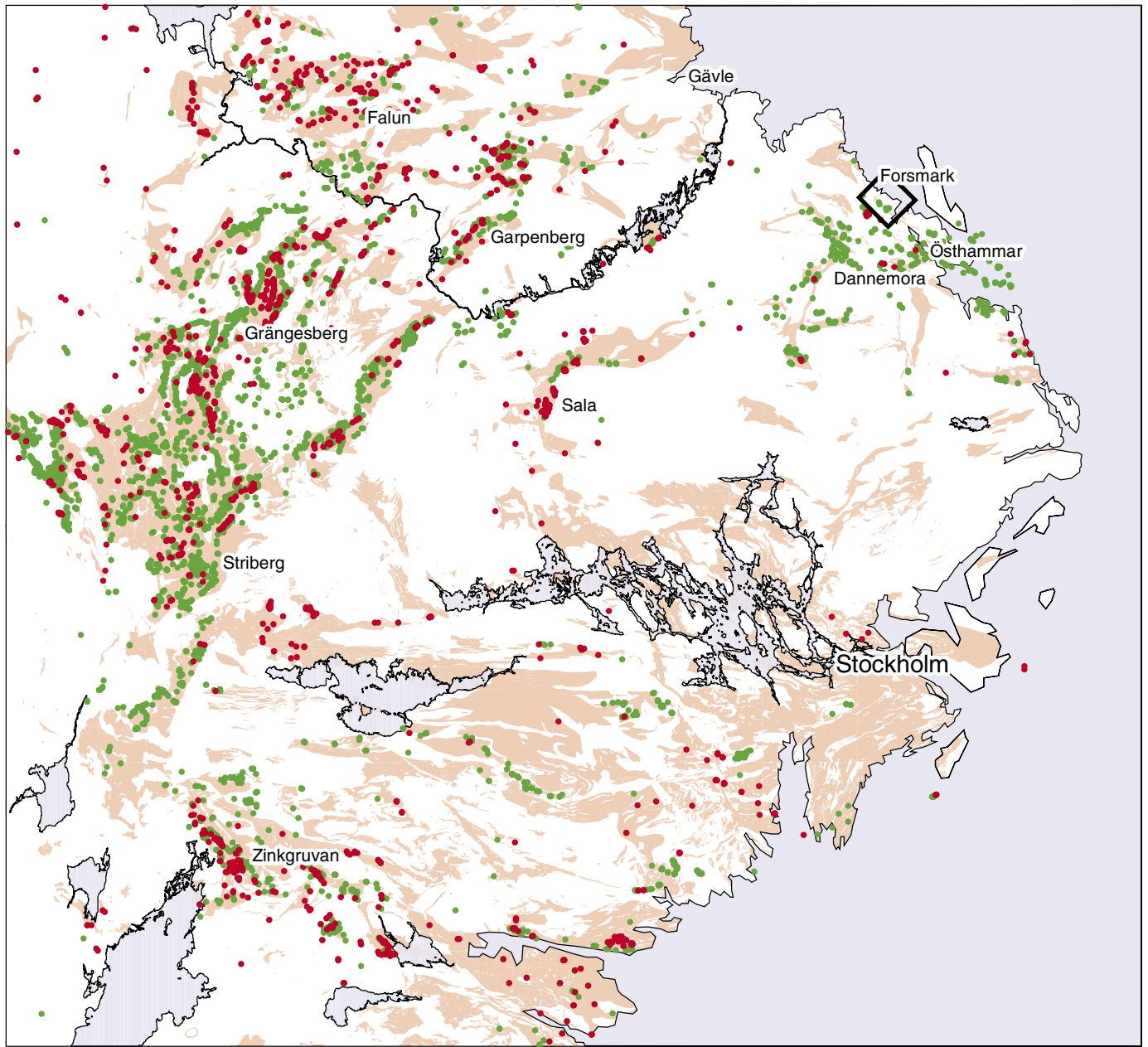


Figure 3-1. Location map. Position of the Forsmark area in relation to the Bergslagen Ore Province (based on information from SGU).



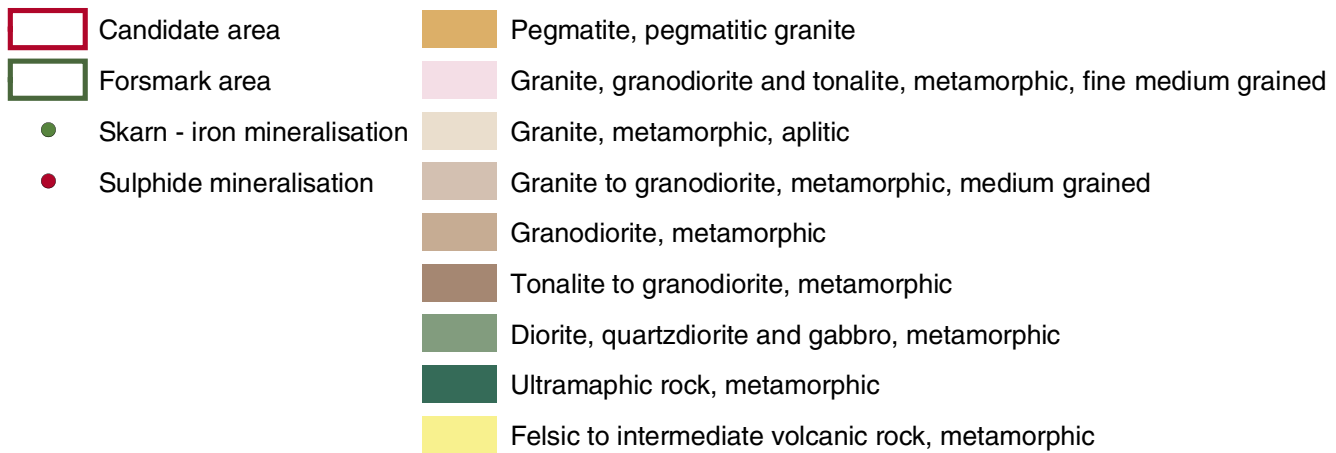
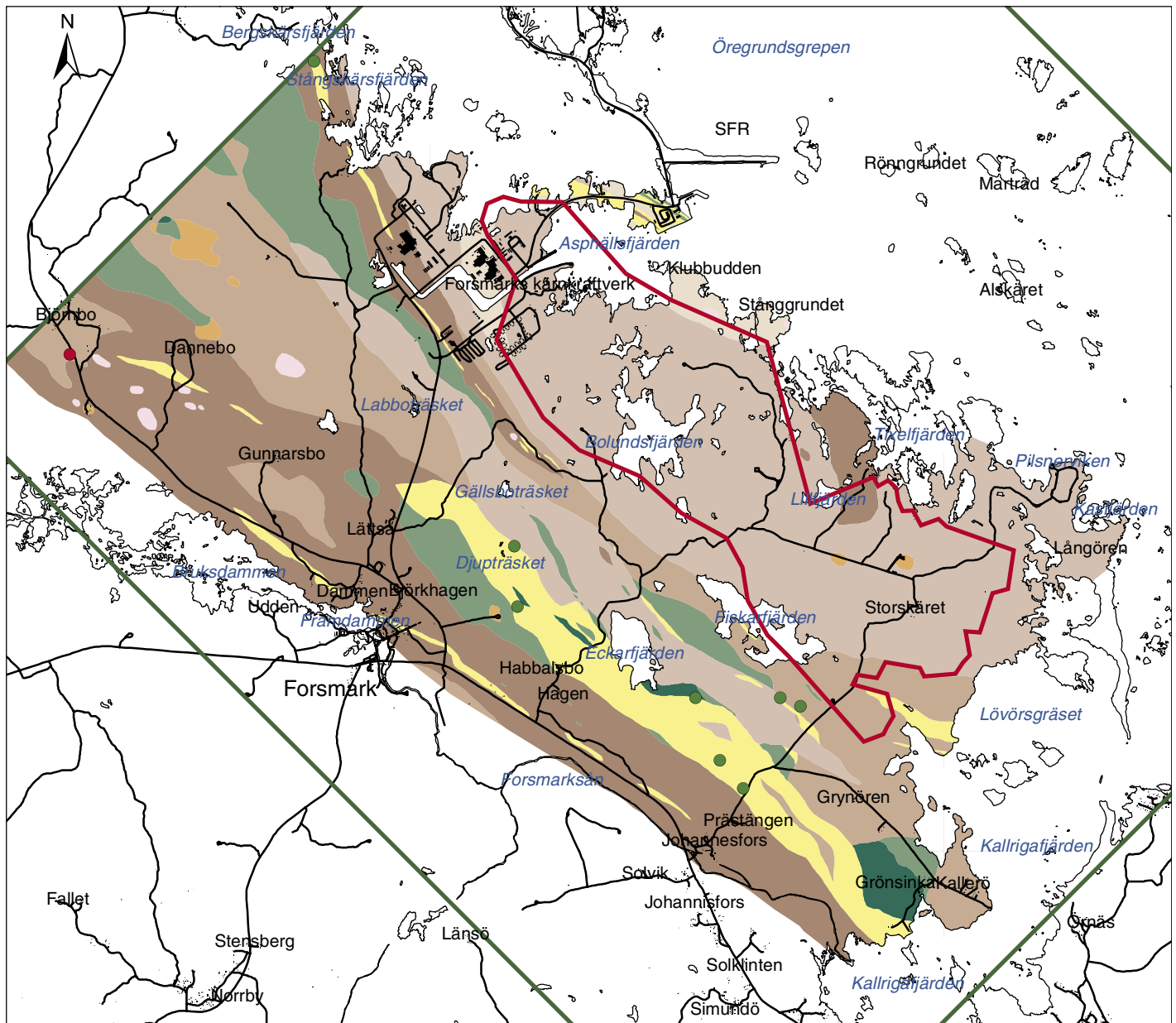
- Sulphide ore
- Iron ore
- Forsmark area
- Supracrustal rocks

0 10 20 40 60 km



Svensk Kärnbränslehantering AB, 2003 09 30, 13:25

Figure 3-2. Extent of supracrustal rocks (volcanic and sedimentary rocks) and iron and sulphide ores in Bergslagen (based on information from SGU).



Ur GSD Fastighetskartan © Lantmäteriet Gävle 2001, Medgivande M2001/5268
Svensk Kärnbränslehantering AB, 2003 09 30, 14:00

Figure 3-3. Geological map of the central part of the Forsmark area. Candidate area marked with a red line. Simplified geology after an original by SGU (October 2003).

Known iron ore deposits are plotted on the map. Most are located within a northwest-southeast zone that extends from the region of Forsmark to Kallerö on Kallrigafjärden. All iron ores are skarn iron ores and are all associated with supracrustal rocks (see under 4.2). Furthermore, there is a small sulphide mineralization in a plutonic rock at Björnbo in the northwestern part of the map.

The map in Figure 3-3 shows that the candidate area at Forsmark consists of an oval-shaped granitoid belonging to the c.1890–1870 million year old plutonic rocks. The bedrock here consists primarily of granite to granodiorite and secondarily tonalite to granodiorite. Furthermore, there are several small bodies of younger granite and pegmatite. The area is described as the least complex and least plastically deformed bedrock in the Forsmark area /Bergman et al, 1998; Isaksson et al, 2003/. A large part of the area is covered by a weakly foliated, but lineated, red to greyish-red granite.

Outside the above-mentioned oval granitoid are narrower and wider zones with supracrustal rocks and with small lenticular massifs with diorite, gabbro or ultramafic rocks (green colours in Figure 3-3). There is a large area with heavily foliated supracrustal rocks just south of the candidate area from the region of Forsmark in the northwest to Kallerö in the southeast. Geophysically, this area is characterized by dense magnetic bands with moderate to high magnetization /Bergman et al, 1998/ (see also under Chapter 5). Furthermore, foliated granitoids occur, and locally dykes of fine-grained granite and pegmatite. The acid to intermediate quartz- and feldspar-dominated volcanics (yellow colour in Figure 3-3) are probably the most interesting rocks from an ore viewpoint in that most of the skarn iron ores are associated with this rock type (cf. 4.2). Observations by SGU at older mine holes indicate that most of the skarn iron ores are enclosed in a grey, fine-grained volcanic rock of roughly dacitic composition (SGU's mineral deposit database).

In the northern part of the map area, at Asphällsfjärden, there is a folded zone with volcanic rocks surrounded by a wider zone with granite. This thin volcanic zone does not contain any known mineralizations of iron or sulphide minerals. This is also true of several scattered elongate zones with acid-intermediate volcanic rocks outside the wider volcanic zone in Forsmark. An exception is a small skarn iron ore situated at Stångsskärsfjärden in the northern part of the map area (cf. 4.2).

There is a lenticular ultramafic rock in the southeastern part of the map area at Kallerö containing the iron- and magnesium-bearing minerals pyroxene, olivine, serpentine and amphibole (SGU's sample no. PFM 001205 A). This ultramafite contains local sulphide mineral, but an analyzed sample does not reveal any interesting metal concentrations of e.g. nickel and copper, nor does the sample contain gold or platinum (see under 6.2). There is an electrically conductive zone in the ultramafite (see under 5.2) that is probably caused by the sulphide minerals iron pyrite and pyrrhotite, which have no economic value. Sampling is nevertheless inadequate, and supplementary geophysical measurement and increased sampling are proposed in Chapter 7.

As previously noted, there is a difference in the type of volcanic rocks in central and western Bergslagen compared with the Forsmark area. This difference in chemical composition reflects a difference in mode of formation and thereby also geological environment for different ore formation processes. Rhyolites are parent rocks for the province's major iron and sulphide ores. For example, Bergslagen's biggest iron ore, the phosphorus-rich apatite iron ore in Grängesberg, is associated with an acid metavolcanic rock of rhyolitic composition /Magnusson, 1973/. The major sulphide ores in Bergslagen also occur, at least to some extent, in rhyolites. A possible explanation of why the Forsmark area is relatively poor in ore may thus be the lack of rhyolites of the type that are found widely in central and western Bergslagen.

In conjunction with SGU's preparation of the "Bergslagen map", information on hydrothermal alteration associated with ore formation has also been compiled in a surface map showing that large areas with alteration are concentrated in the western and central parts of Bergslagen. Only the Dannemora field in the eastern part of the province exhibits a more extensive hydrothermal alteration. Alteration associated with ore formation in the Forsmark area is of a small extent. In simplified terms, it can be said that the alteration described here, which occurs in the form of aureoles around the ore zones, reflect the strength of the actual ore formation process. Wide alteration zones indicate a large scale of hydrothermal processes that both leach the country rock of metals and precipitate and form ores in the form of circulating metalliferous aqueous solutions. It is a general view among geologists that the majority of Bergslagen's sulphide ores were formed on an ancient seabed by volcanic processes /Frietsch, 1982; Vivallo, 1984; Lagerblad et al, 1983; Baker et al, 1988/. Briefly, this type of ore deposit is characterized by an extensive leaching zone, an infiltration zone ("supply channel"), and the precipitation of compact sulphide ore bodies near a volcano. This ore type sometimes grades into a more zinc- and lead-containing type of mineralization that was originally located further away from volcano centres and is usually associated with limestones, i.e. chemical sediments. For example, the different sulphide ores in the Garpenberg field were formed in such a volcanic-sedimentary environment /Vivallo, 1984/. The Forsmark area, however, lacks at least three important criteria for the occurrence of large sulphide ores like those in central Bergslagen: 1) the almost total absence of rhyolitic volcanism, 2) the absence of large hydrothermal alteration aureoles, and 3) the absence of pure sedimentary rocks and limestones.

The regional tectonics of the Östhammar area have been described previously /Bergman et al, 1994/, and the Forsmark area has been studied in greater detail and presented in a number of maps /Bergman et al, 1998/. Tectonic movements result in e.g. ductile deformation zones, fracture zones and faults. They have been described with a common name: deformation zones. These are elongated zones of weakness in the bedrock.

Certain shear zones may be connected to mineralizations, and this applies to certain fracture zones as well. Mineralizations containing gold, for example, occur frequently in fracture zones, usually together with quartz and/or carbonate minerals. For example, some known mineralizations with gold in northern Sweden are related to relatively elongate and deep fracture zones, and alterations of a special character occur in the country rock /Weihed, 2001/. Minerals such as chlorite, calcite, albite (sodium-rich feldspar) and hematite are examples of "alteration minerals" related to gold mineralizations. Sulphide minerals such as chalcopyrite, pyrite and arsenopyrite often occur in gold-bearing quartz dykes.

Most deformation zones are soil-covered and difficult to find by direct observation. They can, however, be indicated by geophysical methods and by e.g. elevation data. Such a survey has been conducted in the site investigation in Forsmark /Isaksson et al, 2003/.

Deformation zones and geophysical anomalies which may have ore potential in the Forsmark area are described in Chapter 5. In summary, certain regional deformation zones in the Swedish crystalline basement may be of potential ore interest. For this reason, this survey has initiated a geochemical analysis and evaluation of the soil samples that were recently taken in the Forsmark area in conjunction with the site investigation's Quaternary geology programme. The preliminary results are reported in 6.3 and have been taken into consideration in the ore geology assessment.

One hydrothermally altered zone reminiscent of the one described in the literature under the designation "episynenite" has been indicated in deep borehole KFM02A in Forsmark /Möller et al, 2003/. A proposal for an ore geology sampling focused on gold in parts of the drill core in this borehole is described under 6.1. A brief summary of the results of the

chemical analysis of principal and trace elements in the area's most commonly occurring rocks is given in 6.2. In summary, the rocks' content of e.g. gold is low or very low, around or less than 1 ppb (cf. glossary).

Low concentrations of gold are found in several iron deposits in western Bergslagen in particular, and their geographic extent suggests that they may have a connection with the younger granites common there /Ripa, 2001/. There are no reports of gold deposits of this type in the eastern part of the province.

In recent years the mining companies have also become interested in a "new" type of ore deposit called IOCG (IronOxide-Copper-Gold) containing primarily the iron oxides magnetite and hematite plus copper and gold (cf. also Chapter 7). This type of copper-gold mineralization has been found e.g. in northern Sweden /Weiher, 2001/. It is not known in the Forsmark area, but cannot be dismissed entirely since no prospecting has been conducted specifically for this type of ore.

3.4 Mining in Bergslagen – a historical retrospective

The oldest and historically most important Swedish ore province is the Bergslagen district in central Sweden. It contains a large number of orefields with ores containing primarily iron, copper, zinc, lead, silver and gold. The Dannemora and Forsmark fields in northern Uppland belong to this ore province, which in all hosts more than 2,000 ore deposits, of which more than 1,000 are iron ores. Mining has been carried on without interruption for nearly 900 years. It has been established that mining of copper in the Falun Mine commenced just before the year 1100. The heyday of the Falun Mine was during the 17th century, when at times the mine accounted for nearly two thirds of the total global production of copper. The mine gradually declined in importance and other types of ore, mainly iron ores, took copper's place. The biggest of the iron ores are the phosphorus-containing Grängesberg ore and the manganese-containing Dannemora ore. Both were mined almost without interruption for several centuries, and the iron ore trade was an important industry from the 19th century up to the middle of the 20th century. The number of mines in Bergslagen has gradually declined /Frietsch, 1975, 1986/, and ore production culminated around 1960 when as many as 68 iron ore bodies were still being mined (Table 3-1). The province's last iron ore was mined in Dannemora, where mining ceased in 1992. Today only sulphide ore is mined in four mines: two in the municipality of Hedemora and two in the municipality of Askersund /SGU, 2002/. These mines are all deep underground mines. In summary, the mining industry in Bergslagen today is small, and there are no mines in operation in the northeastern parts of the province since the closure of the Dannemora Mine.

Table 3-1. Number of mines and their aggregate ore production in Bergslagen during the past 130 years.

Year	Sulphide ores	Annual output (metric tons)	Iron ores	Annual output (metric tons)
1873	16	90 000	646	823 000
1960	11	933 000	68	5 510 000
1964	5	1 500 000	2	2 238 000
2002	4	2 301 937	0	0

4 Compilation of geological information bearing on ore potential

4.1 The mineral resources map of the Forsmark area

The mineral resources map, Figure 4-1, shows the extent of bedrock with ore potential in the Forsmark area. The map is based on the geological map (Figure 3-3), the geophysical account (Chapter 5 and Figure 5-3) and ore deposits in SGU's mineral deposit database.

The connection between the bedrock's geology and the occurrence of a given ore type (cf. 3.3) has been an important factor in plotting the map.

Within the study area there is an up to 1 kilometre wide northwest-southeast zone composed mainly of a narrower zone with felsic to intermediate volcanic rocks (yellow in Figure 3-3) and lenticular bodies consisting of diorite, quartz diorite and gabbro (light green in Figure 3-3). The surrounding bedrock consists of older granitoids (brown colours in Figure 3-3). There are 7 known skarn iron ores in the volcanic bedrock in particular.

The geophysical picture shows the occurrence of several relatively small and narrow magnetic anomalies (Chapter 5 and Figure 5-3), some of which coincide with known iron ores, while others can be interpreted as possible magnetite mineralisations or as supracrustal bedrock with moderate-to-high magnetization. In some cases, magnetic anomalies lie in the strike direction of known iron ores, and these may indicate previously unknown magnetite deposits.

According to the geophysical survey, there are also a number of electrical conductors in the area of ore potential. They are generally described as narrow zones several hundred metres in length. The anomalies may have many various explanations – in some cases they may indicate sulphide mineralisations. Such indications described in Chapter 5 have been taken into account in demarcating the bedrock with ore potential.

The area with ore potential mainly has a potential for iron in the form of skarn iron ore, and possibly for the base metals copper and zinc, though to a lesser degree. There is a small sulphide mineralization near Björnbo (no. 2 in Figure 4-1) in an older granitoid. A small lenticular area there may have a small potential for copper and zinc (cf. 4.2). An electromagnetic anomaly (no. 6 in Figure 5-3), located northeast of Björnbo, may also derive from a weak to moderately strong sulphide mineralization.

Finally, there is a small iron ore at Stångskärsfjärden (no. 1 in Figure 4-1). A small area there has been designated as having iron ore potential.

Chemical analysis of 50 rock samples typical of the Forsmark area /Stephens et al, 2003b/ does not show any anomalous concentrations of e.g. base metals and gold (6.2). The gold content of the rocks is low or very low, usually around or less than 1 ppb. Concentrations of certain gold-indicating elements, such as arsenic (As) and bismuth (Bi), are also insignificant.

A recently analyzed sample (KAL 0306) from a weak sulphide mineralization containing mainly iron sulphides in the ultramafite at Kallerö (Figure 4-1) shows moderate concentrations of nickel (Ni) and copper (Cu) and very low concentrations of platinum (Pt) and gold (Au).

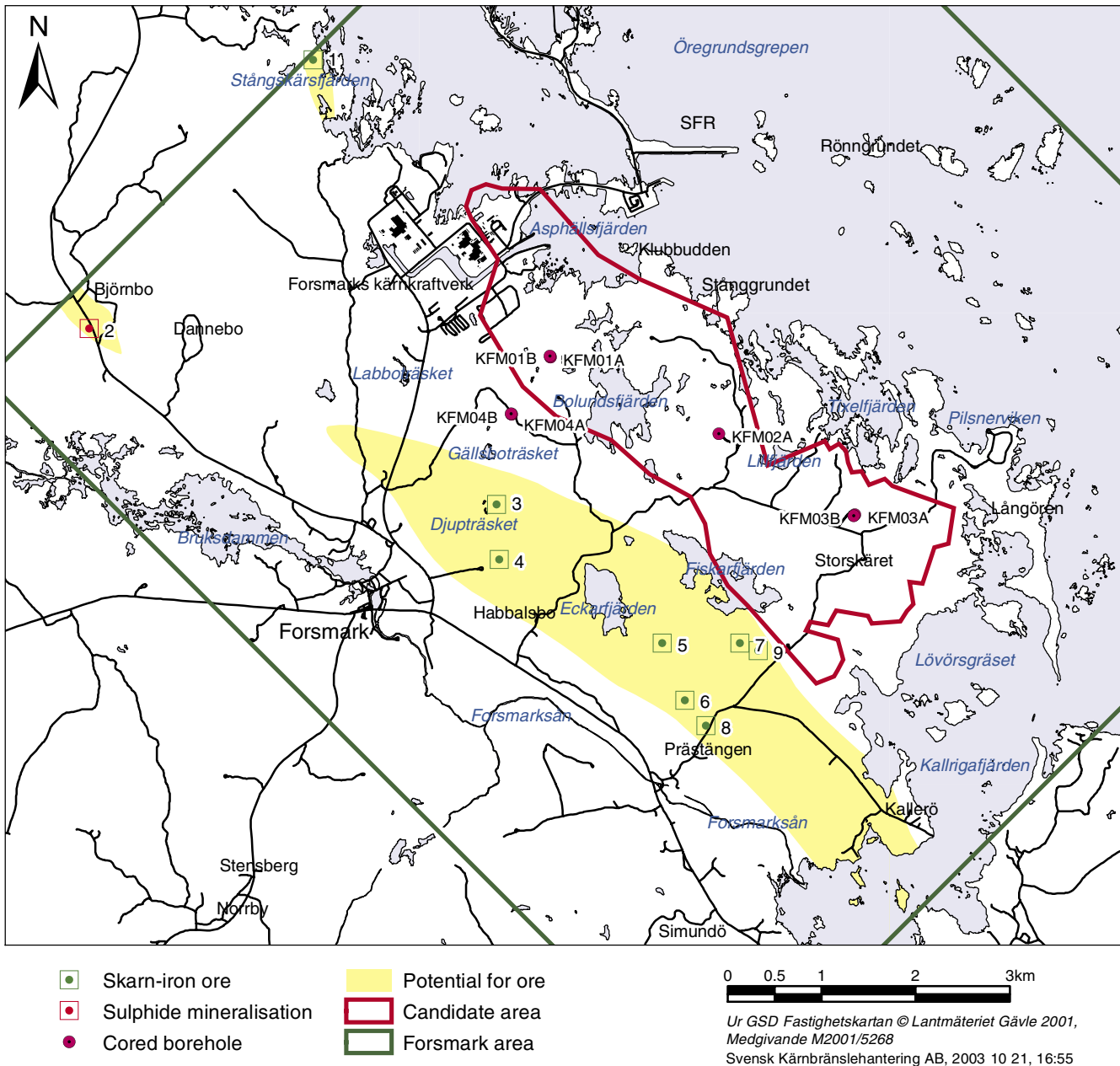


Figure 4-1. Mineral resources map of the Forsmark area. The area with ore potential is shown in yellow. The candidate area is bounded by a red line. The numbering of the ore deposits refers to the description in Chapter 4.2.

In summary, only the large, more coherent area south and southwest of the candidate area has an ore potential of any significance. The boundaries in the map are mainly based on superficial information. Field observations at or next to the large iron ores indicate steep lateral dips towards the southwest, and there is nothing to indicate that the iron ores dip inwards towards the candidate area. The geometry of some mine holes suggests that the “ore” has taken the form of a steeply dipping, usually southwest-striking, small lens with a southeastern field dip.

The geological map currently only includes the central portion of the Forsmark area. Parts of the area on the seacoast and an area at the far southwest (Figure 3-3) have also been mapped by SGU, and the preliminary geological information has been utilized in this survey. There is nothing to indicate the occurrence of ore or industrial minerals in this area.

The candidate area is covered in its entirety by a granite bedrock without potential for ore or industrial minerals. There are no geophysical anomalies within the candidate area (see Figure 5-3) that can be related to ore or mineral deposits. Rock samples of granitoids (6.2) show a relatively normal content of e.g. gold. The geochemical investigation of the till’s metal content (6.3) does not show the occurrence of anomalous metal concentrations, including gold. Samples from borehole KFM02A (6.1 and Figure 4-1) show that an alteration zone does not contain gold or other metals in concentrations of interest from an ore geology viewpoint. The mapping of the other deep boreholes drilled to date does not show anything of ore-related interest either.

The pegmatites that have been plotted on the bedrock geology map (Figure 3-3), including the uranium-, thorium- and potassium-elevated anomalies detected in the helicopter-borne survey of radioactivity (Figure 5-3 /Isaksson et al, 2003/), are not judged to contain minerals or metals of economic interest. The pegmatites studied are so-called simple pegmatites containing the commonly occurring minerals quartz, feldspar and mica.

Gamma-ray spectrometer measurements on bedrock surfaces indicate a relatively normal content of uranium (U) and thorium (Th). In some cases, however, pegmatites with anomalous uranium concentrations occur.

There are no known deposits of industrial minerals within the investigated area. Limestones, which have been subject to exploitation in other parts of the county are also absent.

There are no deposits of commercial stone (ornamental stone, building stone and/or rock crushing material) currently of interest within the area. The municipality of Östhammar has good access to e.g. aggregate material at several locations /Lindroos, 1996/.

4.2 Known deposits of iron, base metals, industrial minerals and pegmatites

As is evident from the bedrock geology map (Figure 3-3), there is an elongate area, approximately one kilometre in width, of surface bedrock east of the community of Forsmark. Dominant rock types there are acid (felsic) to intermediate volcanic rocks. Some small skarn iron ores occur primarily within these rocks. Skarn iron ores are magnetite ores with a varying sulphide mineral content. All deposits have been visited in the field and their coordinates have been measured by SGU using GPS (accuracy better than ten metres). The deposits are numbered on the map (1 to 9) and Table 4-1 shows the coordinates and the former designations of the deposits, mainly from the municipal survey /Lindroos, 1996/ and the bedrock map of Östhammar Municipality /Stålhös, 1991/. There is

Table 4-1. Known iron ores and mineralizations in the Forsmark area. Numbering refers to the map in Figure 4-1.

No. of deposit (Figure 4.1)	Obsolete designation	Type of deposit	X coordinate	Y coordinate	Comment
1		Skarn iron ore	6702688	1628870	Older deposit, not on maps from municipal survey
2	Björnbo	Sulphide mineralization	6699831	1626493	On older maps skarn iron ore
3	Djupträsket	Skarn iron ore	6697966	1630821	Also called "Skomakare" Mine
4	Bromsmossen	Skarn iron ore	6697377	1630850	Also called "Habbalsbo" Mine
5	Eckarfjärden	Skarn iron ore	6696490	1632584	
6		Skarn iron ore	6695884	1632822	
7	Botvidsbäck	Skarn iron ore	6696490	1633408	
8	Prästängen	Skarn iron ore	6695610	1633045	
9		Skarn iron ore	6696410	1633605	New deposit, found 2003

also a small sulphide mineralization in the area at Björnbo (no. 2 on the map). The individual deposits are described in the following with reference to SGU's mineral deposit database, older compilations and mineralogical descriptions by SGU /Stephens et al, 2003b/.

There is a small iron ore mineralization in the northernmost part of the area (no. 1), which was found in 1995 by SGU and had not previously been registered. There is a magnetite ore impregnated with pyrite in a two-to-four metre pit. The skarn consists of actinolite, quartz and secondary garnet. This insignificant skarn iron ore is intercalated in a stratified quartz-feldspar-rich supracrustal rock of probable volcanic origin.

Next to the highway at Björnbo (no. 2) is a sulphide mineralization in a narrow hydro-thermally altered zone bearing chlorite, mica minerals and quartz in a foliated granodiorite. There is a small, water-filled mine hole about forty square metres in size. Sulphide minerals are pyrrhotite, pyrite and chalcopyrite. Small quantities of sphalerite have been noted in the chalcopyrite. There is probably only a small amount of copper and zinc, however, and the deposit is of no economic value. The deposit is the only one now known in the area that is associated with a plutonic rock. In older descriptions /Stålhös, 1981/, Björnbo is designated as a skarn iron ore. Measurements of the bedrock's magnetization on exposed surfaces and blocks indicate very low magnetization, and it is unlikely that there is any large quantity of magnetite in Björnbo.

There is an electromagnetic anomaly (no. 2 in Figure 5-5 and Chapter 5.3) a few hundred metres northeast of Björnbo that could be a sulphide mineralization. The area of ore potential at Björnbo has therefore been extended to include this electrically conductive zone.

The biggest skarn iron ore in the Forsmark area is located on the eastern edge of Djupträsket (no. 3). The deposit has also been called Djupträsket and/or Skomakare Mine. The deposit is a partially compact magnetite ore bearing moderate to large amounts of sulphide minerals, mainly pyrrhotite and pyrite. There are large quantities of mining waste next to a fifteen by fifteen metre mine hole. The dominant skarn minerals are actinolite and garnet. A pegmatite occurs at the edge of the mine hole. The ore zone is largely conformable with the foliation in the country rock (320 degrees), which consists of a foliated volcanic rock of roughly dacitic composition. Samples from waste heaps show that there are small amounts of

chalcopyrite in the most sulphide-rich parts. The amount of copper is judged to be far too insignificant to be of economic interest.

There is a small skarn iron ore around a half a kilometre north of Habbalsbo (no. 4), which in older compilations is called Bromsmossen or the Habbalsbo Mine. The mining waste next to a five to ten metre mine hole consists of actinolite-(garnet)-quartz-magnetite skarn. The iron ore has probably been removed and the deposit is relatively insignificant.

Between Eckarfjärden and Prästängen (Figure 4-1) there are three very small skarn iron ores (nos. 5, 6 and 8). Moderate quantities of magnetite with varying concentrations of sulphide minerals occur in actinolite-rich skarn. At Prästängen (no. 8), a fine-grained quartz-feldspar-biotite-bearing rock interpreted as a dacitic volcanic rock is exposed at the edge of the mine hole. A couple of hundred metres northwest of this deposit is a large outcrop consisting of a greyish-white acid (felsic) volcanic rock with bands and inclusions of a basic rock (interpreted as a metabasalt). On the outcrop there is a small waste heap consisting of magnetite-actinolite skarn deriving from a small, overgrown mine hole (no. 6).

South of Fiskarfjärden are two small skarn iron ores (nos. 7 and 9). The larger of these, also called Botvidsbäck (no. 7), includes a mine hole ten times twenty metres in size with a slightly larger waste heap consisting of skarn containing actinolite, epidote and quartz, as well as the ore minerals magnetite (moderate amount) and pyrite (large amount). The nearby deposit (no. 9) is not previously known. It consists of moderate concentrations of magnetite in a skarn containing actinolite, hornblende, quartz and garnet.

In summary, there is in the Forsmark area a more coherent northwest-southeast zone of supracrustal bedrock dominated by acid to intermediate volcanic rocks. This bedrock has an ore potential for primarily iron (cf. Figure 3-3 and Figure 4-1). The survey shows the occurrence of seven “known”, relatively small or insignificant iron ore deposits within this area. In addition, some geophysical anomalies have been interpreted as possible magnetite mineralizations (Chapter 5.3 and Figure 5-3). The compilation of the geophysical anomalies (Table 5.1) shows that many magnetic anomalies coincide with known skarn iron ores, while others may comprise previously unknown deposits or may have other causes, e.g. reflect a magnetite-banded volcanic rock which in itself is of no ore interest.

The geophysical modelling of selected magnetic features (Chapter 5.3) uniformly indicates steep dips towards the west or southwest, in other words “outward” from the candidate area. The dip calculations must be taken with some caution, due to the fact that most anomalies are “point anomalies” of small geographic extent, and that the remanent magnetization of the cause of the anomaly is not known.

The small quantities of base metals (copper and zinc) that have been found in connection with the iron ores and at Björnbo are not of economic interest.

There are no known deposits of industrial minerals within the Forsmark area. Limestones are completely absent, and rocks containing industrial minerals such as wollastonite, not unusual in parts of Uppland, have not been encountered. The nearest limestone deposit at Liängen /Lindroos, 1996/ is situated outside of the map area.

In Älvkarleby there are some pegmatite deposits that have been investigated for potash feldspars for porcelain manufacture /Bergman et al, 2000/. By contrast, the pegmatites in Forsmark are of simple mineralogical composition and do not contain any large accumulations of potash feldspar or other minerals of economic interest. The large exposed pegmatite bodies are plotted on the map (Figure 3-3). The areas of elevated gamma radioactivity (cf. Figure 5-3), for the most part situated west of the candidate area, can be partially explained as pegmatite deposits. No uranium-bearing minerals have been encountered.

The ultramafic rock at Kallerö (Figure 3-3) is locally sulphide mineral-bearing with a small to moderate content of copper and nickel (see in 6.2). Pentlandite, the economically most important nickel mineral, has not been observed. Concentrations of gold and platinum are very low. Altered ultramafic rocks may be of industrial interest, for example one such rock has been mined for rock wool production in Gimo /Lindroos, 1996/. Today, rock or mineral wool is made from dolerite.

4.3 New and potential mineralizations

A new iron ore deposit (no. 9) was discovered during SGU's mapping work. Furthermore, the deposit at Björnbo (no. 2) has been judged to be a small sulphide mineralization and not an iron ore. The deposit at Stångskärsfjärden (no. 1) has not previously been documented either.

The geophysical interpretation shows anomalies that may be of ore interest (Table 5.1). Most are low-persistent magnetic disturbances that may indicate small, not previously known magnetite mineralizations, or they may be due to the occurrence of magnetically banded rocks. The magnetic survey does not reveal any major iron ore deposit. Most of the magnetic anomalies are situated within the circled area of ore potential (Figure 4-1).

4.4 Comparisons with the rest of Bergslagen

The Forsmark area is relatively poor in ore deposits compared with large parts of Bergslagen. This probably has a geological explanation. The absence of rhyolitic volcanic rocks and purely sedimentary rocks and limestones is judged to be the most important reason. The recently concluded geochemical investigation in parts of the Forsmark area does not reveal any marked elevations of e.g. base metals. There is practically no gold at all. This also applies to drill core samples taken from borehole KFM02A (Chapter 6.1). The comparison with Bergslagen must, however, be regarded in the light of the fact that prospecting has historically been focused on areas with already known major ore deposits, and in this context the Forsmark area has not attracted much interest. The granite bedrock in the candidate area is in this context completely sterile of ore minerals and contains common minerals such as quartz and feldspar.

5 Geophysical investigations

5.1 Geophysical surveys and field checks performed

In 2002, the Geological Survey of Norway, NGU, carried out a detailed airborne geophysical survey of the Forsmark area by helicopter. The measurements were conducted in two directions, N–S and E–W, and included measurements of natural gamma radiation and VLF, as well as magnetic and electromagnetic methods. The measurements were conducted for the most part with a line spacing of about 50 metres and with sensors at an altitude of about 30–60 metres. The execution of the survey is further described in an NGU Report /Rønning et al, 2003/. A structural interpretation of the measurements is in preparation /Isaksson et al, 2004/. Figure 5-1 shows the geographic coverage of the different measurements, and Figure 5-2 shows an example of a presentation of the total magnetic field recorded over the Forsmark area.

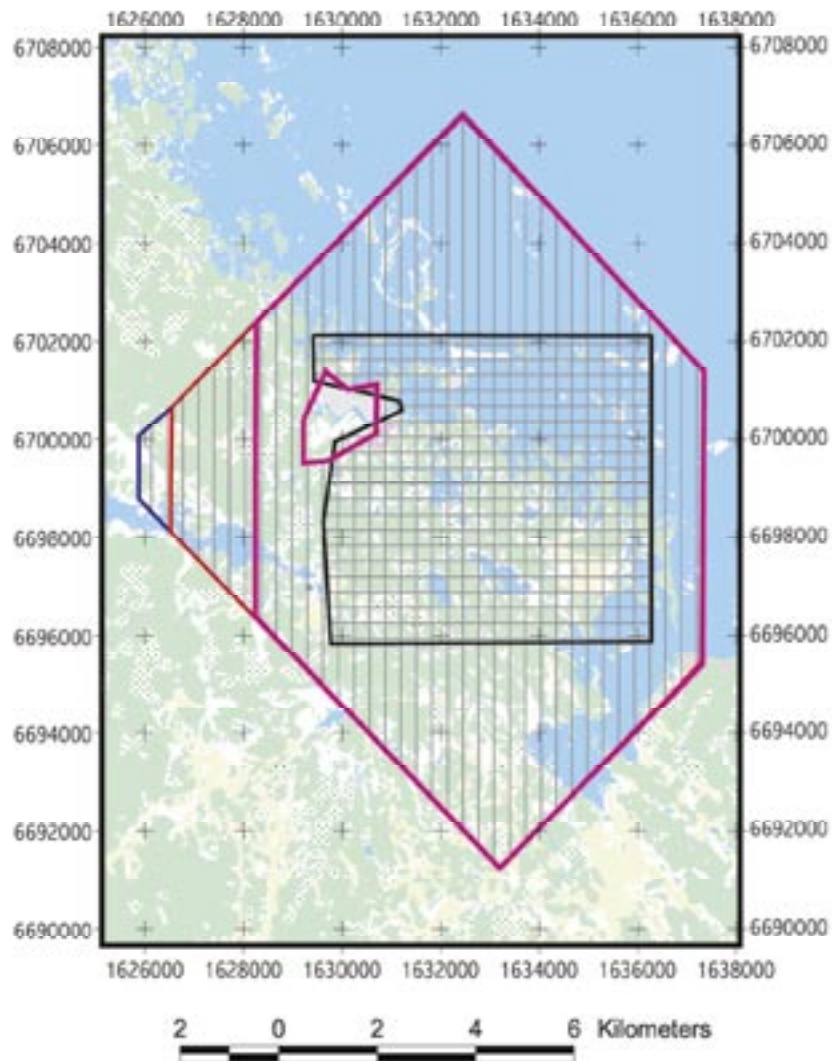


Figure 5-1. Map showing data coverage of the different geophysical methods used in the helicopter-borne survey performed by NGU in 2002 /Isaksson et al, 2004/. Purple: VLF N–S lines, red: EM and magnetometry N–S lines, blue: gamma spectrometry N–S lines, black: all methods E–W lines. No data were acquired around the nuclear power plant.

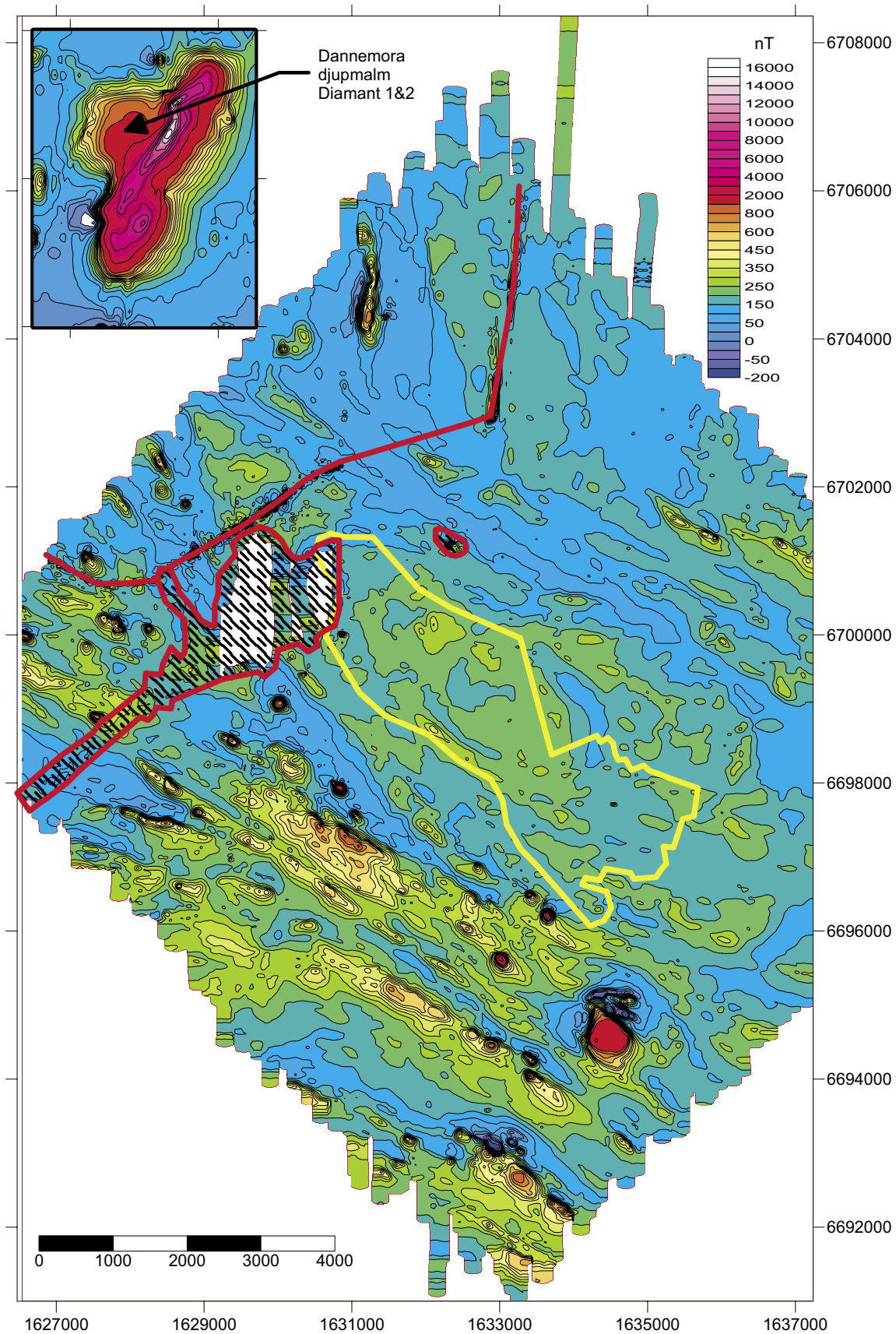


Figure 5-2. Airborne magnetics, total field, N–S survey (IGRF anomaly). The candidate area is bounded by a yellow line. Red lines bound areas with a disturbed geophysical signal or a less dense survey grid. The inset map at the top left shows the corresponding magnetic field from the Dannemora iron ore for comparison, see also Chapter 5.4.

A limited number of field checks were performed during 2003 aimed at geophysical anomalies with possible ore potential. The results are reported in Chapters 5.2 and 5.3.

5.2 Geophysical anomalies of possible exploration interest

In this study, special emphasis has been placed on evaluating the new airborne geophysical information with respect to an increased ore potential in and around the candidate area in Forsmark. Magnetic and electromagnetic data have been processed in such a manner that anomalies that may be caused by a mineralization of magnetic minerals (mainly magnetite), or conductive minerals, have been enhanced.

The magnetic anomalies in Forsmark caused by a mineralization of magnetic minerals are in most cases small and of point shape. Due to the fact that the size of the anomaly is defined by the relationship between volume and concentration, it is difficult to distinguish the anomalies caused by e.g. a volcanic rock with high magnetization from those that might be caused by richer magnetite mineralizations. Anomalies of this character have been marked as highly magnetic connections (Figure 5-3). Those magnetic anomalies that have been interpreted as a richer mineralization of magnetite (such as skarn iron ore) or as an electric conductor corresponding to a sulphide mineralization are described in greater detail. Of 16 selected anomalies with elevated ore potential (Table 5.1), 6 coincide with known ore deposits, and in some cases with the probable extension of the deposit in the strike direction.

Electromagnetic data and VLF have been studied with regard to a) indications of coinciding magnetic anomalies and electrical conductors, and b) EM anomalies that do not coincide with e.g. wetlands, but are located on upland areas with a presumably thin soil cover. Some of these indications have been interpreted as a possibly increased ore potential.

Magnetic modelling has been performed on three selected geophysical anomalies: anomalies 1, 2 and 3. Electromagnetic modelling has been performed on anomaly 2.

Areas with elevated natural gamma radiation have been classified from gamma spectrometer data in previous investigations /Isaksson et al, 2004/. These areas are located in a belt southwest of the candidate area. They can be explained by the presence of pegmatites, which normally exhibit an elevated level of radiation. In some cases, elevated levels of radiation coincide with known pegmatite occurrences.

The geophysical anomalies that are judged to be of possible exploration interest are shown in Figure 5-3. Most anomalies are situated in a belt west and southwest of the candidate area, and many are located within the area of ore potential described in Chapter 4 and Figure 4-1. Other anomalies are more spread out and may be due to other causes, e.g. wetlands, muddy shorelines, etc. No geophysical anomaly has been identified that can be related to bedrock with ore potential within the candidate area.

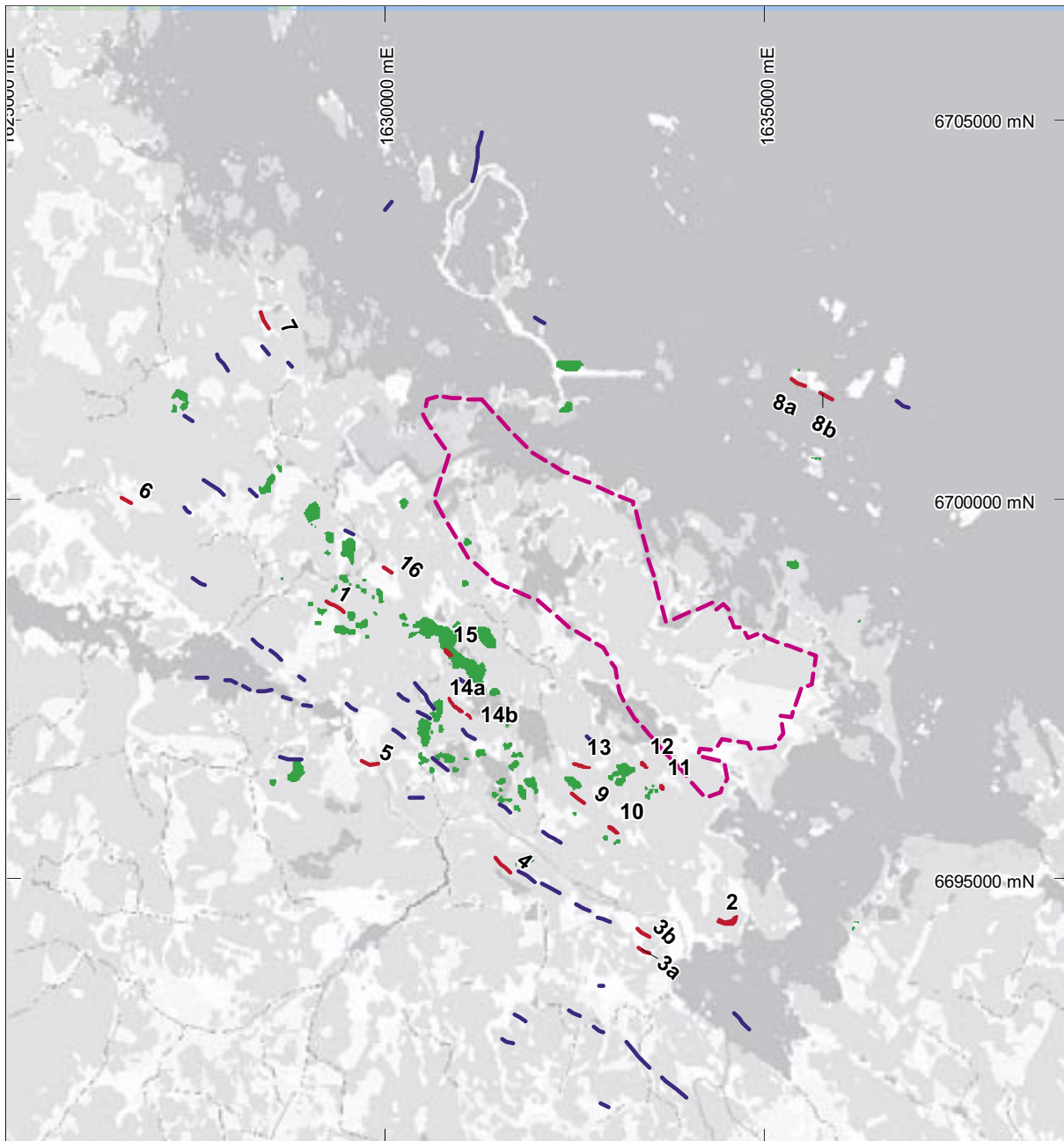


Figure 5-3. Geophysical indications of increased ore potential are shown in red and numbered with reference to Chapter 5.3. Blue lines indicate highly magnetic connections. Green areas have enhanced gamma radiation and may have a potential for pegmatite deposits. The area of ore potential is shown in yellow. The area bounded by a dashed purple line is the candidate area in Forsmark. The black, toothed lines show the approximate extent of the airborne magnetic and EM surveys in 2002 (see also Figure 5-1).

5.3 Description of geophysical anomalies

Anomaly 1

This is a weak electromagnetic anomaly in an area with a moderately conductive soil cover. The EM anomaly coincides with a highly magnetic connection, Figure 5-4. The cause of the anomaly is judged to be located in the bedrock. The airborne magnetic anomaly has an estimated length of 250–300 metres. A model of the magnetic anomaly is shown in Figure 5-5.

What makes this anomaly particularly interesting is inventories of older data from Vattenfall /Keisu and Isaksson, 2003/. In conjunction with the KBS investigations in the 1970s, a seismic survey was performed in a profile (W 0377) over the anomaly (1) /Vattenfall's archive (1)/. This was probably caused by the identification of a conductor in the new airborne survey performed in 1977 using the VLF method. A 10 metre wide seismic low-velocity zone was interpreted in roughly the same position as a magnetic anomaly, see Figure 5-6. This work was then followed up by a ground geophysical profile survey using slingram and VLF, Figure 5-7, which verified that the low-velocity zone was also a weak conductor, about 10 metres wide and with a strike of N70°W and a dip of 70°S /Vattenfall's archive (2)/.

Two new outcrops were found in the area during the field check. However, neither of them lies exactly on the magnetic anomaly.

Anomaly 1 is located within the map's area of ore potential, mainly for geological reasons. Since the cause of the anomaly is not known, further investigations are proposed in Chapter 7.2.

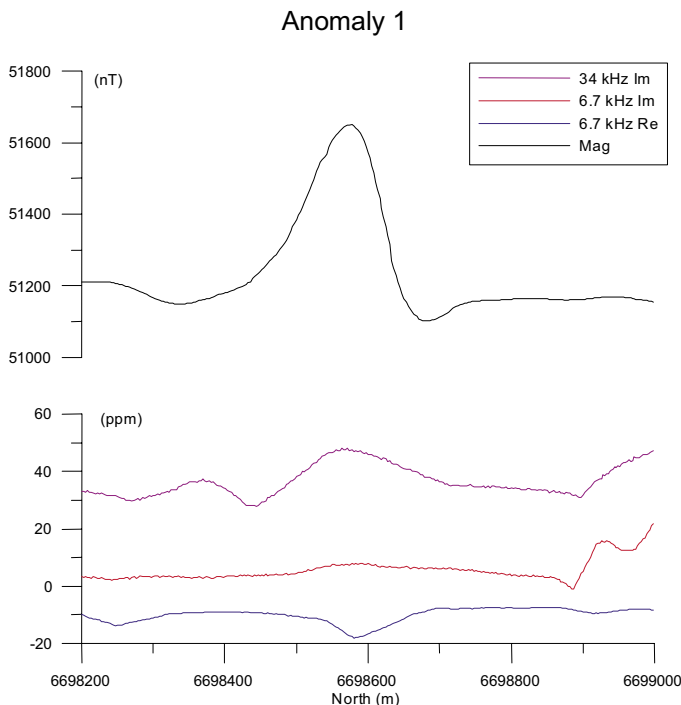


Figure 5-4. Magnetic and electromagnetic indication, Anomaly 1.

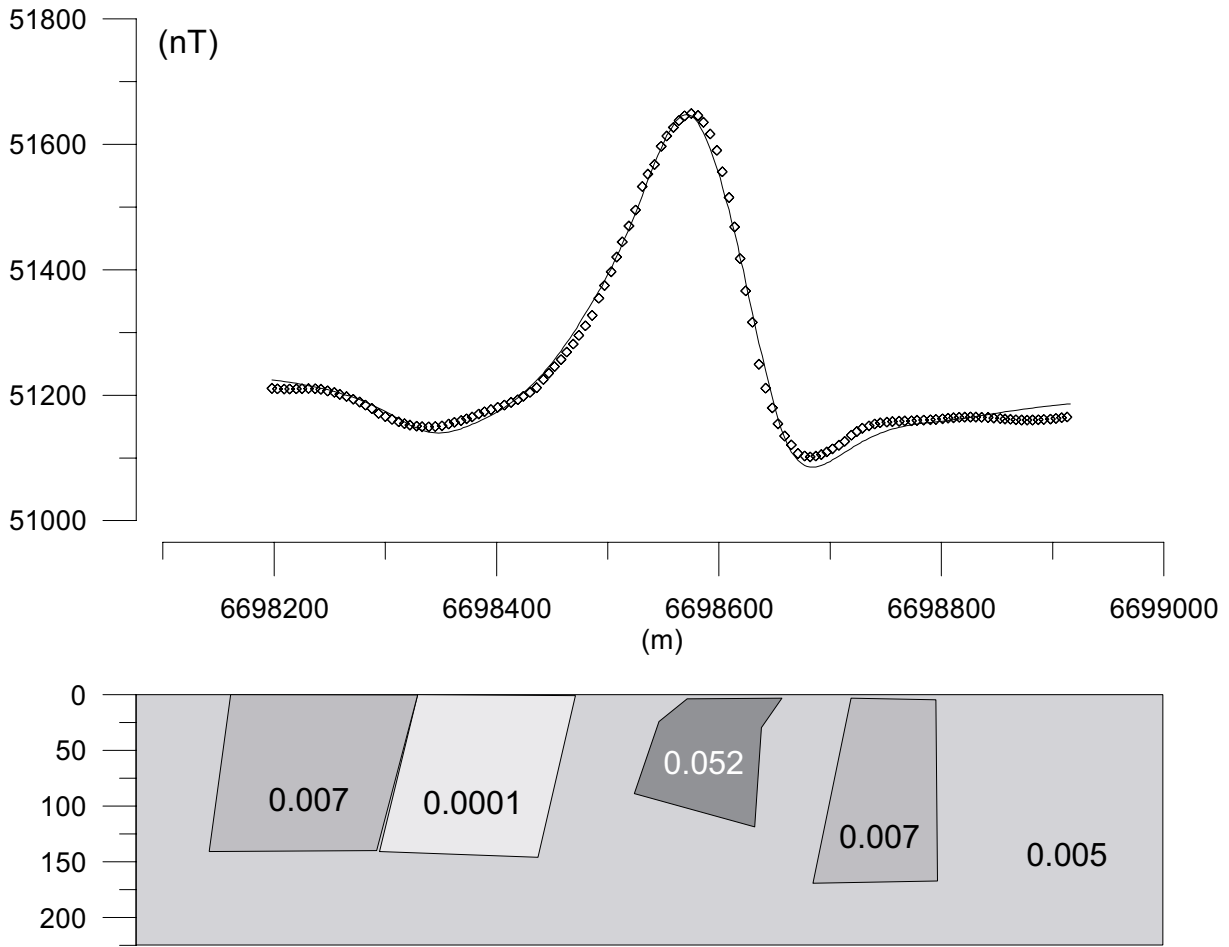


Figure 5-5. Magnetic model, Anomaly 1. The numbers in the model indicate magnetic susceptibility in SI units.

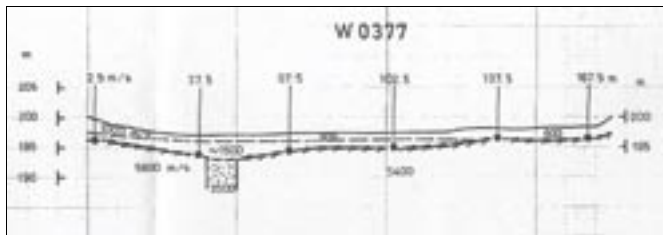


Figure 5-6. Seismic refraction profile, Anomaly 1. Low-velocity zone (3,500 m/s) in the same position as the magnetic anomaly (with the magnetic susceptibility 0.052 in Figure 5-5).

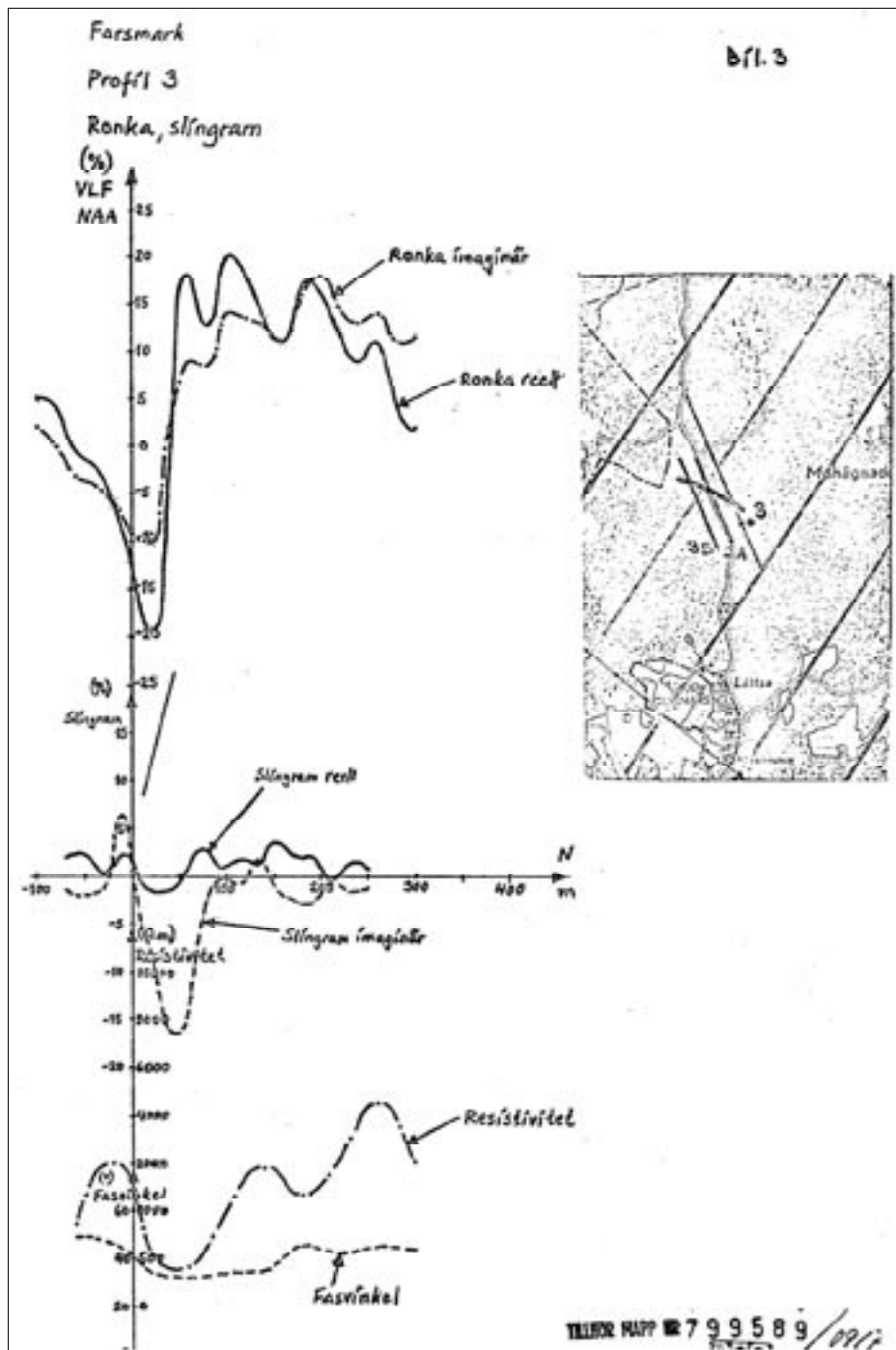


Figure 5-7. Slingram and VLF profile, Anomaly 1.

Anomaly 2

This is an electromagnetic anomaly near Kallerö in the southwestern part of the area (Figure 5-3), which indicates a good conductor in an area with thin soil cover and several outcrops. The conductor is located in the southeastern margin of a semicircular magnetic anomaly associated with an ultramafic intrusion, Figure 5-8 (see also the geological map, Figure 3-3). Figure 5-9 shows a magnetic model of the anomaly. The model indicates a strong magnetization and a dip towards the north. A model of the EM anomaly, Figure 5-10, indicates a plate-shaped electrical conductor 300 metres long and 300 metres deep. The conductance of the conductor is 0.9 Siemen. The dip is about 70° towards the north, which agrees well with the magnetic model. The resistivity in the country rock is about 2,000 ohm-metres (Ωm), which can also be regarded as an increased electrical conductivity. The content of certain metals in the ultramafite is presented in Chapter 6.2. Sampling shows slightly increased concentrations of copper, but near zero concentrations of gold and platinum. Since the samples are few and taken from a limited area in the margin of the anomaly, supplementary investigations are proposed in Chapter 7.2. The anomaly is located within the area of ore potential in Figure 4-1.

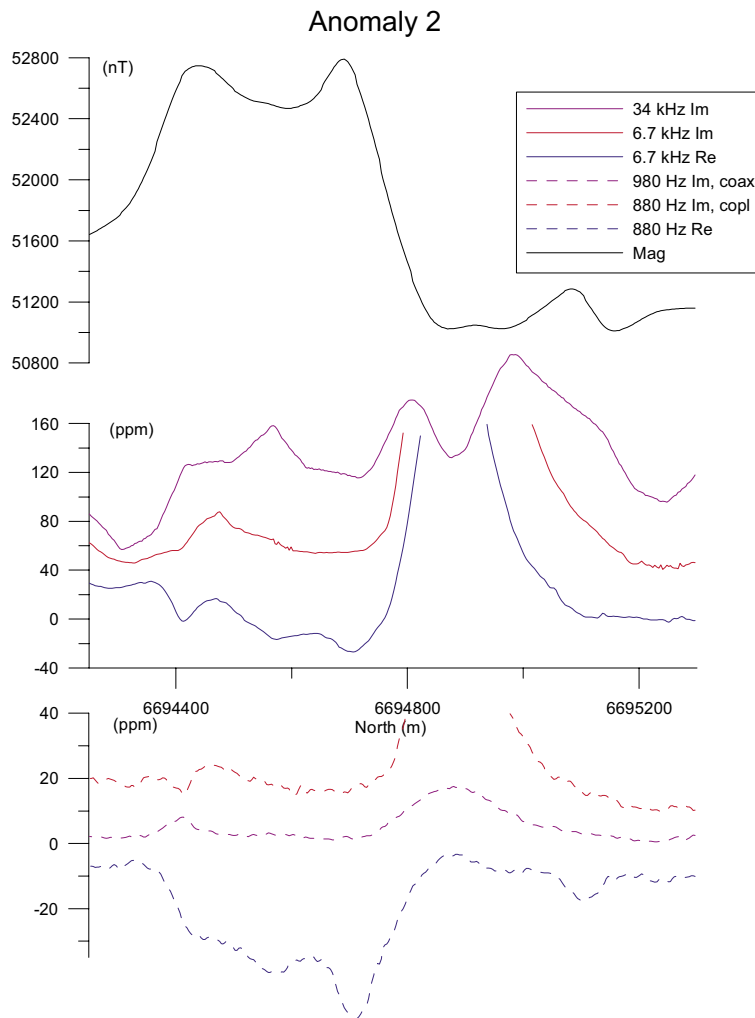


Figure 5-8. Magnetic and electromagnetic indication at 6694410 N, Anomaly 2.

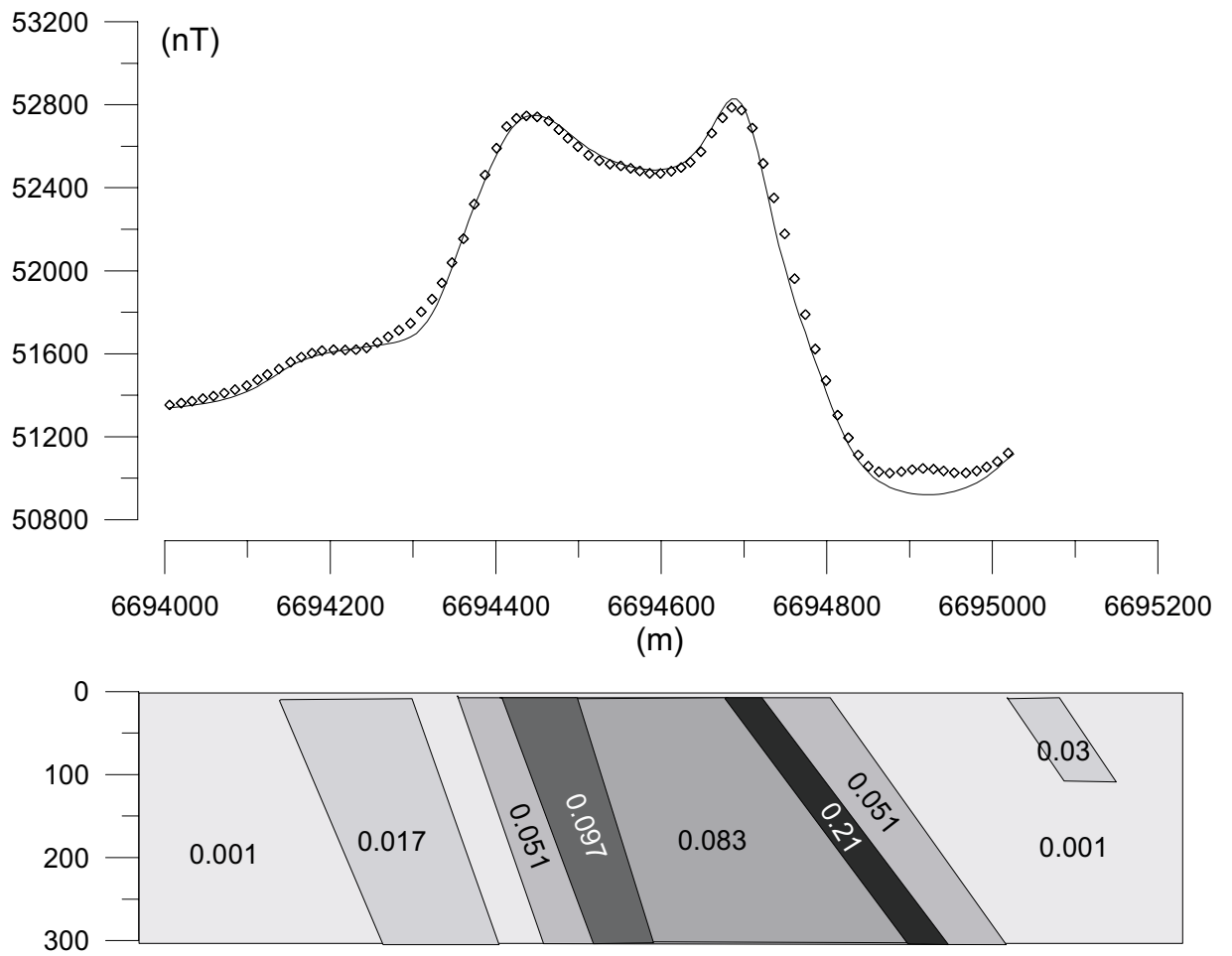


Figure 5-9. Magnetic model, Anomaly 2. The numbers in the model indicate magnetic susceptibility in SI units.

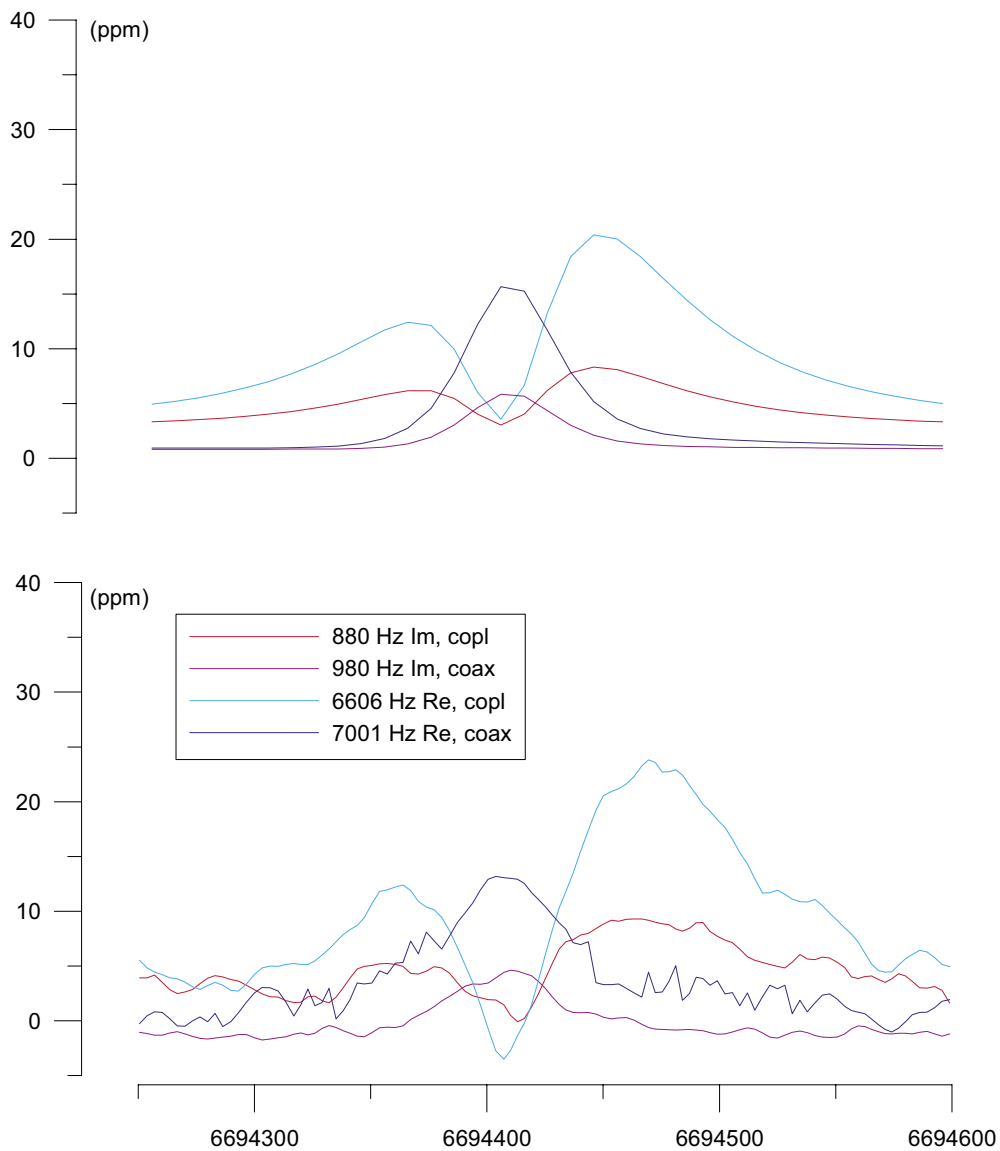


Figure 5-10. Electromagnetic model, Anomaly 2. The lower part shows measured data. The top part shows the response from the model indicated below. Plate-shaped electric conductor at 6694410N. Conductivity: 0.9 Siemen. Dip: 70° to north. Size: 300x300 metres. Depth to top surface: 5 metres. Resistivity in country rock: 2000 Ωm . Linear trend not shown. The real components of lower frequencies have been subtracted.

A field check of parts of the anomaly was performed under snowy conditions in October 2003. An aerial power line running in a WNW direction through the area was noted. However, due to the shape and size of the electromagnetic anomaly, the judgement is that the cause of the good conductivity should be found in the underlying bedrock. The bedrock in the area is relatively well-exposed and should be visited and documented under better field conditions.

Anomaly 3

Anomaly 3 is a wide electromagnetic anomaly associated with wetlands near the coast at Kallrigafjärden. Two local maxima within the wide anomaly are located near magnetic connections, Figure 5-11. Magnetic anomalies in the real component of lower frequencies (in the same position as maxima in the imaginary component) are displaced about 25 metres from static magnetic maxima. The EM anomaly is interpreted as being primarily caused by conductive soil, but a connection with a magnetic source in the bedrock cannot be ruled out. A magnetic model of the anomaly source is shown in Figure 5-12. A dip towards the SW is indicated. The anomalies are located outside the marked area of ore potential (Figure 4-1). There is no known mineralization in the NW-SE zone that includes the geophysical anomalies 3 a, 3 b and 4 (Figure 5-3).

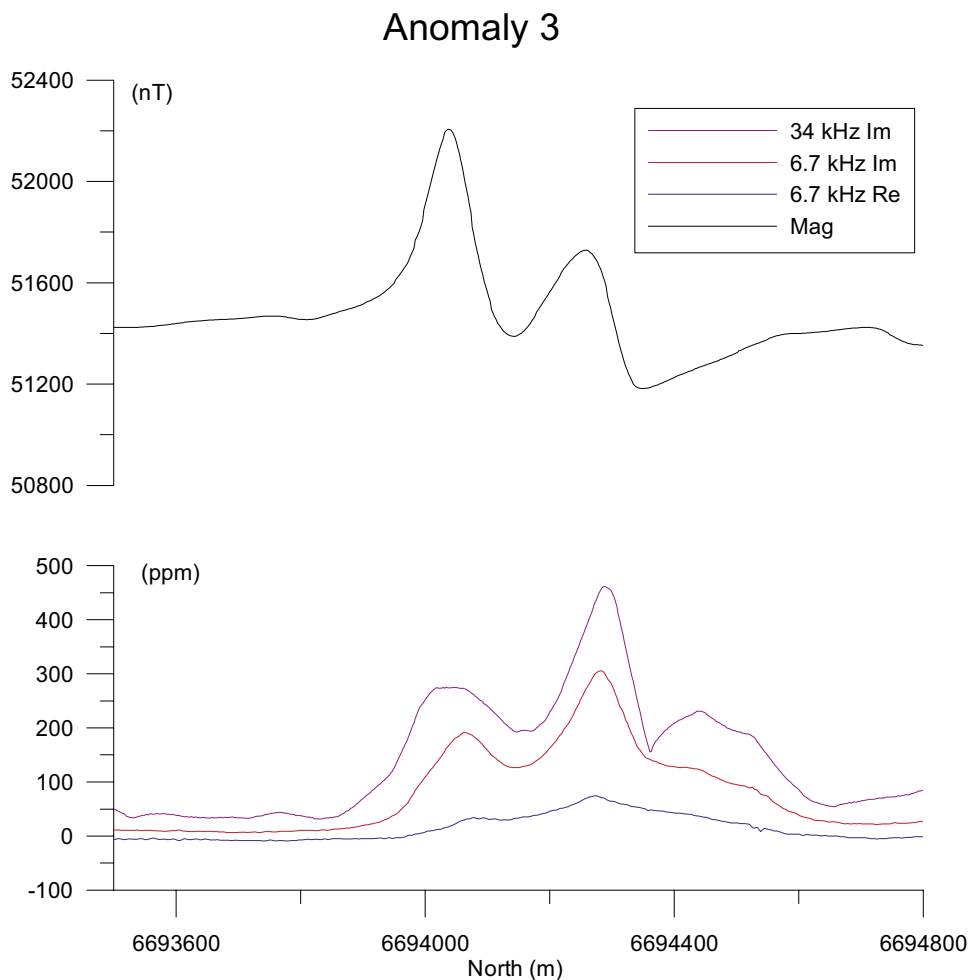


Figure 5-11. Magnetic and electromagnetic indication, Anomaly 3.

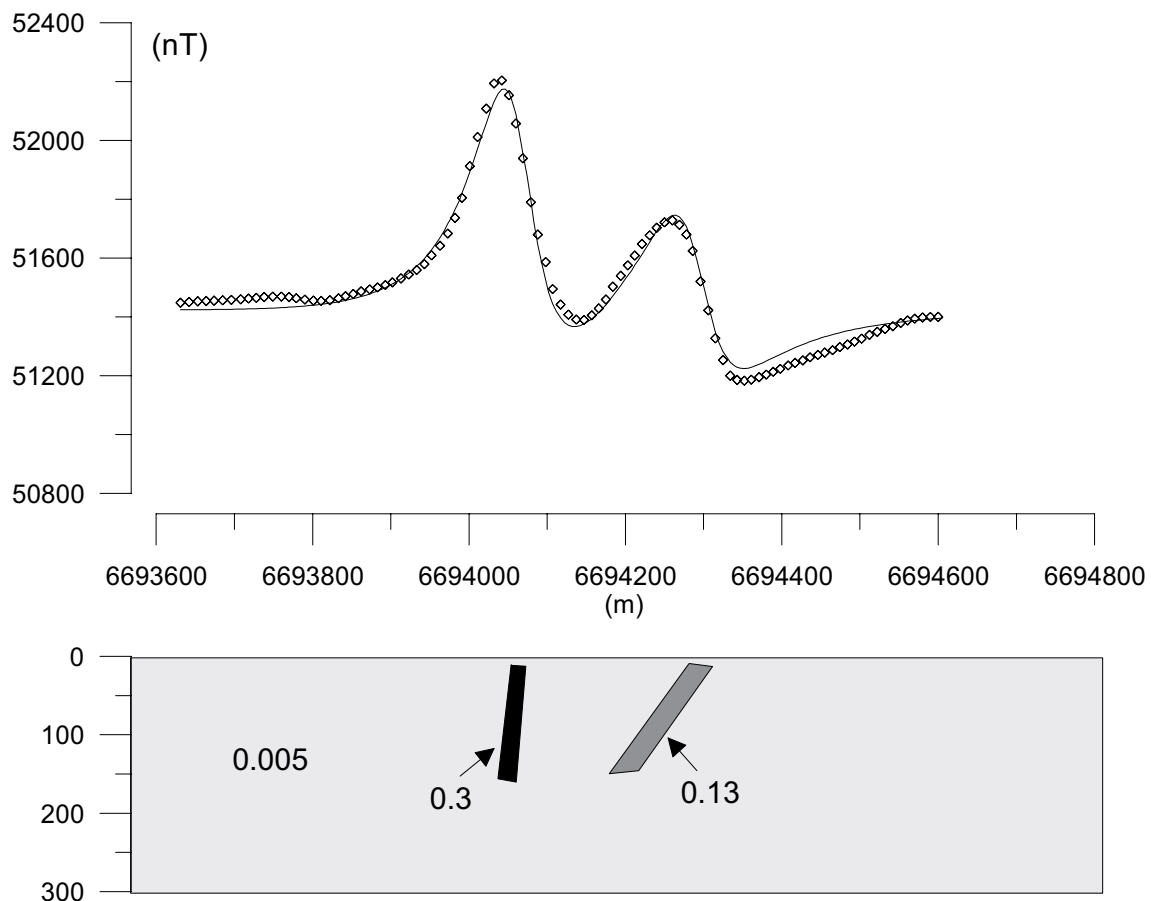


Figure 5-12. Magnetic model, Anomaly 3. The numbers in the model indicate magnetic susceptibility in SI units.

Anomaly 4

A weak electromagnetic anomaly that is situated approximately 100 metres south of a highly magnetic connection. The anomaly is probably caused by a conductor in the bedrock, but is not directly related to the magnetic anomaly. The anomaly is located outside the marked area of ore potential (see under Anomaly 3).

Anomaly 5

A weak electromagnetic anomaly and highly magnetic connection, which is located in a flat area with farmland in the community of Forsmark. The anomaly is probably caused by a conductive cover, possibly in combination with fractured bedrock. A small mineralization cannot be ruled out either. The anomaly is located outside the marked area of ore potential.

Anomaly 6

A weakly electromagnetic anomaly of considerable length which partially coincides with a highly magnetic connection. The EM anomaly follows a zone with farmland and is probably caused by clayey soil, possibly in combination with fractured bedrock. However, the anomaly remains interesting due to its nearness to the small sulphide mineralization at Björnbo (no. 2 in Figure 4-1). The anomaly is located in an area of ore potential.

Anomaly 7

An electromagnetic anomaly located near a highly magnetic connection. The anomaly is located outside the delineated area of ore potential. The anomaly coincides with a wetland, which may be the cause of the anomaly. The geological map (Figure 3-3) shows that the area is occupied by diorite, a rock that is not known within the region to contain any type of economically interesting mineralizations.

Anomaly 8

A long linear electromagnetic anomaly in the “880 Hz coaxial component”, which coincides with a highly magnetic connection. The EM anomaly is situated in the sea and edge effects from a nearby shoreline on a small, parallel oriented island (Marträäd) cannot be ruled out. The anomalies are located outside the marked area of ore potential.

Anomaly 9

A weak electromagnetic anomaly located about 30 metres south of a highly magnetic connection. The two anomalies probably have different causes. The anomaly is located in an area of ore potential in a strike direction towards the northwest from the Prästängen skarn iron ore (see also Anomaly 10).

Anomaly 10

An electromagnetic anomaly that is caused by magnetic effects. The anomaly coincides with a high magnetic anomaly and a known occurrence of skarn iron ore, Prästängen (no. 8 in Figure 4-1). The anomaly indicates a possible continuation of this skarn iron ore, extending about 100–150 metres towards the northwest from the known occurrence.

Anomaly 11

A magnetic point shape anomaly situated near a road. A field check revealed a small outcrop close to the road with a volcanic rock (probably dacite) and increased magnetization. However, a possible small magnetite mineralization should be located further towards the northwest from the road in a nearby marsh. An artificial cause, e.g. a vehicle on the road, can be ruled out. The shape and size of the anomaly indicates that the cause has a log-like shape with a plunge towards the SE. The anomaly is located in an area of ore potential near the insignificant skarn iron ore no. 9 in Figure 4-1.

Anomaly 12

An area has been delineated that may indicate the location of a magnetite mineralization. The area coincides with the skarn iron ore named Botvidsbäcken (no. 7 in Figure 4-1).

Anomaly 13

An area has been delineated that may indicate the location of a magnetite mineralization. It coincides with the location of the skarn iron ore at Eckarfjärden (no. 5 in Figure 4-1).

Anomaly 14

The anomaly coincides at the northwest end with the location of the Bromsmossen skarn iron ore 4 (no. 4 in Figure 4-1). Two areas have been delineated which may indicate that the deposit has a continuation up to 400 metres towards the southeast. The whole anomaly (14 a and b), along with anomalies 12 and 13, is located in an area of ore potential.

Anomaly 15

An area has been delineated that may indicate the location of a magnetite mineralization. It coincides with the Djupräsket skarn iron ore, also called the Skomakare Mine (no. 3 in Figure 4-1).

Anomaly 16

A line has been marked which may indicate the location of a magnetite mineralization. The anomaly comprises a point shape anomaly near a road. However, the shape of the anomaly indicates a greater depth to the top surface, which should rule out an artificial source. A field check of the anomaly was performed under snowy conditions in October 2003. An artificial cause of the anomaly can be ruled out, which is confirmed by the fact that the anomaly also appears in SGU's airborne survey from 1976. Outcrops at a road intersection show that the soil cover over the anomaly is relatively thin, and an outcrop was encountered at the coordinates $x = 6699099$, $y = 1630058$. The outcrop could not be documented due to the snowy conditions. The area should be visited under better conditions to study the encountered outcrop and to locate any other outcrops at the anomaly.

The shape of the anomaly indicates a probable plunge towards the SE. The interpretation of the cause of the anomaly is uncertain. It is located outside the delineated area of ore potential. The geological map (Figure 3-3) shows that the bedrock consists of granite-granodiorite. A zone of mylonite in a deformed metagranite immediately northwest of the anomaly exhibits a high magnetic susceptibility, on average around 0.02 SI.

The selected and described geophysical anomalies are listed in Table 5-1.

Table 5-1. Compilation of geophysical indications with increased ore potential. The coordinates refer to the centre of the indication or the position of a known ore deposit.

Anomaly no.	Anomaly type	East coordinate	North coordinate	Comment
1	Magnetic and EM	1629353	6698585	Seismic low-velocity zone
2	Magnetic and EM	1634426	6694443	In the margin of an ultrabasic intrusion. Good conductivity and high magnetization.
3	EM \pm Magnetic	1633400	6694150	Two objects
4	EM \pm Magnetic	1631560	6695161	
5	EM and Magnetic	1629787	6696513	
6	EM \pm Magnetic	1626597	6699983	Near sulphide mineralization at Björnbo (no. 2 in Figure 4-1)
7	EM and Magnetic	1628408	6702357	
8	Magnetic and EM	1635630	6701440	Situated in the sea, two objects
9	EM \pm Magnetic	1632555	6696045	
10	Magnetic and EM	1633045	6695610	Magnetic effect in EM. Coincides with iron ore at Prästängen (no. 8 in Figure 4-1)
11	Magnetic	1633647	6696201	
12	Magnetic	1633408	6696490	Iron ore at Botvidsbäck (no. 7 in Figure 4-1)
13	Magnetic	1632584	6696490	Iron ore at Eckarfjärden (no. 5 in Figure 4-1)
14	Magnetic	1630850	6697377	Iron ore at Bromsmossen (no. 4 in Figure 4-1) Extension in two objects towards the SE.
15	Magnetic	1630821	6697966	Iron ore at Djupräsket (no. 3 in Figure 4-1).
16	Magnetic	1630035	6699070	

5.4 Detection of a mineralization of ore potential by means of geophysical methods

In mineral exploration an attempt is made to obtain a balanced appraisal of geology, geophysics and geochemistry in order to assess an area's ore potential. As far as geophysical methods are concerned, it should be pointed out that flat-lying, deep mineralisations can be particularly difficult to identify from the ground surface. This chapter discusses in general terms the geophysical response from ore types that can occur in a geological environment typical of Bergslagen.

The airborne magnetic surveys indicate the occurrence of highly magnetic connections where the extent of the anomalies in the longitudinal direction is very limited. To demonstrate how a magnetite ore could appear, an airborne magnetic map of the Dannemora Mine has been inset in Figure 5-2. The magnetic anomaly of the steeply dipping Dannemora ore is over 3 km long with an intensity of over 2,500 nT, and with large parts exceeding 5,000 nT. The strongest anomaly is 15,800 nT. It should then be borne in mind that large parts of the ore had been mined out at the time of the airborne geophysical survey in 1982. By comparison, the strongest anomaly in the Forsmark area is about 2,500 nT, and there is no anomaly comparable in size and strength to the one at Dannemora. The flight altitude in the two cases was comparable, around 30–40 m above the ground.

There are deeper-situated ores in the northwest hanging wall, the ones known as Diamant 1 at a depth of 150–200 m, and Diamant 2 at a depth of 500 m /Lager, 2001/. The location of these ores has been marked on Figure 5-2 to show how a deeper-situated magnetite ore could appear. No indications of a similar nature can be noted in the Forsmark area.

A superficially situated massive iron ore of hematite gives no magnetic anomaly, but would probably be indicated by the electromagnetic airborne methods due to the size required. A hematite ore would also give a considerable mass excess. The regional gravity survey performed in the Forsmark area /Aaro, 2003/ has not given any such indications to date. Hematite ores are normally also accompanied by considerable magnetite occurrences.

From a geophysical viewpoint, the potential of magnetite and hematite for iron ores is therefore judged to be low in the Forsmark area.

As far as iron oxide, copper-gold mineralisations are concerned (IOCG deposits, see Chapter 7.1), such deposits cannot be ruled out from a geophysical viewpoint alone. The geophysical characteristics of such deposits are often complex and of a varying nature /Smith, 2002/. The environment in the marked area of ore potential in Forsmark, with a varied magnetic anomaly relief, could be suitable for this type of mineralization.

Aside from Anomaly 2, situated in the ultramafite on Kallerö, no good conductor has been indicated in the airborne electromagnetic survey data. This fact suggests that the potential for a superficially situated mineralization of massive sulphide ore in the Forsmark area is small. However, such mineralisations at greater depths, >50–100 m, or massive zinc ores, cannot be ruled out by the currently available geophysical measurements.

No circular “bullseye” magnetic anomaly, which could indicate a potential for kimberlite (diamond) or carbonatite (apatite), has been found in the area. The semicircular magnetic anomaly at Kallerö is caused by an ultramafic intrusion.

6 Geochemical investigations

6.1 Sampling in existing boreholes.

In conjunction with the ongoing site investigation in Forsmark, extensive measurements in boreholes and samplings of drill cores or drill cuttings are being performed for various geoscientific investigations. A site-specific programme has been prepared for the investigations in Forsmark /SKB, 2001/. It was considered urgent that this information, not all of which has been reported yet, could be utilized in the survey of ore potential.

Geological mapping of the first deep boreholes did not reveal the presence of minerals or metals of interest from an ore geology viewpoint (SKB personal communication). However, a rugged and hydrothermally altered zone was discovered in 2003 in a granite in borehole KFM02A (see Figure 4-1). The phenomenon has been investigated /Möller et al, 2003/ and can be described as a leaching of quartz in the form of vugs or pores which have in a later phase been partly filled with chlorite, hematite, albite and with quartz druse. Alteration of the granite's plagioclase to albite (sodium feldspar), degradation of biotite to chlorite, and precipitation of iron oxides, mainly hematite, have also occurred. The alteration bears similarities to a so-called episyenitization. In northern Sweden, uranium mineralizations sometimes occur in episyenites /Hålenius et al, 1983; Smellie, 1984/ and albite-rich rocks can sometimes also contain gold mineralizations /Grip and Frietsch, 1973/. The weathered and altered zone in borehole KFM02A starts at about 263 metres (counting along the drill core) and continues with varying strength to a depth of about 296 metres. The dominant rock type is a greyish-red, usually medium-grained metagranite with weak to moderate foliation. In the granite are decimetre-wide dykes of pegmatite and fine-grained dykes of aplitic granite. In addition there are narrower bands or dykes of amphibolite. The alteration is characterized by vugs in the granite where the primary quartz has been dissolved and, in a later phase, partially reformed as idiomorphic crystals in the vugs. The altered granite is reddish-brown to reddish-purple, probably due to iron oxide precipitation. In some places, the porous vuggy is crushed, and pulverized rock occurs in places.

There are no visible sulphide minerals in the examined drill cores. Nor are there any large quartz-filled fractures or any minerals that could be related to a gold mineralization. The proposed test sampling is therefore aimed at a number of representative samples of the drill cores. Five samples have been analyzed for a number of elements, including gold. The results of the gold analysis are presented in Table 6-1. Acme Analytical Laboratories Ltd. is a Canadian laboratory that holds an international certificate (no. 378/96 and ISO 9002) for analysis of geological materials with regard to principal and trace elements, including precious metals (gold, silver, platinum group of metals).

The analyzed samples contain very low concentrations of gold. The content of other trace elements is normal for granitic rocks. The absence of sulphide minerals is underscored by a very low sulphide content, on average about 0.04% S for the five samples. There is nothing to suggest that the alteration zone in borehole KFM02 A has any ore potential.

There is, however, good reason to continue to check the drill cores from the site investigation with regard to ore geology.

Table 6-1. Gold content in samples taken from drill core in borehole KFM 02 A.

Person in charge of sampling: Hardy Lindroos Analysis laboratory: Acme, Canada Gold content in ppb reported 23 Oct. 2003 by Acme to MIRAB			Date: 1 October 2003 Place: Forsmark	
Section (m)	Sample no.	Rock	Special reason	ppb Au
249.17–249.36	KFM02A-1	Pegmatite	Abundant hematite and chlorite	0.7
258.00–258.20	KFM02A-2	Pegmatite	Granulated feldspars with hematite in fractures	0.5
291.87–292.00	KFM02A-3	Pegmatite/Granite	Contact with chlorite and quartz	< 0.2
292.00–292.20	KFM02A-4	Altered granite	Type sample	< 0.2
307.00–307.15	KFM02A-5	Unaltered granite	Type sample	0.3

6.2 Geochemical sampling of the bedrock

In conjunction with the bedrock mapping in the site investigation in Forsmark /Stephens et al, 2003a/ analyses of 50 samples of the area's typical rocks have been carried out /Stephens et al, 2003b/. In this survey, the content of certain base metals and gold in the samples has been studied.

The following brief summary in Table 6-3 comprises 50 samples. The analysis was performed using the ICP-ES method at Acme's laboratory in Canada.

The gold content is comparatively very low for the basic rocks and roughly normal for the acid rocks. Other elements such as arsenic (As) and bismuth (Bi), which can often be related to gold, occur in very low concentrations on the ppb level (not reported here).

One sample of ultramafite in Kallerö (PFM 001205) exhibits a normal concentration (630 ppm) of nickel. The ore-forming nickel mineral pentlandite has not been observed, on the other hand. The sample's gold content is nearly 0 ppb. Some parts of the ultramafite contain more sulphide, so a new bedrock sample was taken from an outcrop with a moderate concentration of pyrite and pyrrhotite as well as traces of chalcopyrite. The sample is located near an electrically conductive zone, geophysical anomaly no. 2 in Figure 5-3. The sample (KAL 0306) contains 0.2% nickel, 0.27% copper, 7 ppb gold and 0 ppb platinum (gold and platinum analyzed by the Fire-Assay method at Acme). The ultramafite at Kallerö probably does not have much ore potential for the metals mentioned above.

The analysis of the results discussed here suggest that there are not anomalous concentrations of metals in the typical rocks of the Forsmark area.

Table 6-3. Gold content in bedrock samples from the Forsmark area. Based on /Stephens et al, 2003b/.

Rock group	Rock types	Gold (Au) content in ppb
Granitoids (26 samples)	Pegmatite, aplitic granite, granite, granodiorite, tonalite	1.5 ppb on average
Acid–intermediate volcanic rocks (7 samples)	Acid volcanic rock, dacite	< 1.0 ppb on average
Basic rocks (17 samples)	Amphibolite, ultramafite, diorite, gabbro	< 1.0 ppb on average

6.3 Geochemical sampling of till samples

One step in the site-specific programme consists of collecting, describing and storing geological data on Quaternary deposits /SKB, 2001/. Part of this work has been carried out and the results reported /Sohlenius et al, 2002, 2003/. In order to be better able to analyze the area's ore potential, this survey proposed that SKB carry out a geochemical characterization of the metal content of the Quaternary deposits. The purpose of the study was to visualize and evaluate the distribution pattern of trace elements, especially base metals and gold, in the upper portion of the till's C horizon with respect to possible mineralizations in the Forsmark area. The project started in October this year and the results will be reported in November. Table 6-4 provides a summary of the preliminary information available at this time with a bearing on the analyzed till samples' content of gold (Au) and the base metals copper (Cu), nickel (Ni), zinc (Zn) and lead (Pb). The metals' distribution pattern, in combination with knowledge of the ice movements in the area, permit an interpretation of the occurrence of mineralizations and their strength in the area.

The geochemical investigation /Nilsson, 2003/ shows low to very low concentrations of all ore-related metals (Table 6-4). Only two samples are slightly anomalous with regard to zinc (Zn). There are no samples that can be interpreted as geochemical anomalies related to a mineralization containing e.g. base metals or gold.

For a more detailed description and evaluation, the reader is referred to the report

/Nilsson, 2003/ that also contains geochemical maps and the complete analysis results in tabular form.

Table 6-4. Concentrations of gold and certain base metals in till samples from the Forsmark area /after Nilsson, 2003/.

Analyzed metal	Concentration range	Median value	Anomalous samples
Gold (Au)	0.1–2.6 ppb	0.2 ppb	None
Copper (Cu)	5.56–15.88 ppm	10.5 ppm	None
Nickel (Ni)	3.0–31.9 ppm	6.75 ppm	None
Zinc (Zn)	18.7–140.8 ppm	32.3 ppm	2 samples
Lead (Pb)	5.2–25.04 ppm	7.8 ppm	None

Number of analyzed samples: 28. Laboratory: Acme, Canada.

6.4 Conclusions regarding the ore potential investigation

The area's gold potential is deemed to be small, and nearly zero for the candidate area. The reasons for this assessment are as follows:

The regional geochemical survey shows that gold does not occur in anomalous concentrations in the till.

The geological survey cannot trace structures or alterations that could be related to a gold mineralization – certain sulphide minerals that are often associated with gold, e.g. arsenopyrite, and certain gold-indicating minerals, e.g. turmaline, have not been observed. This is also true of wide quartz dykes that could be gold-bearing.

The candidate area's dominant plutonic rock, tonalite or granodiorite, is of a type and age that is not known in Sweden to host gold or base metals.

Core samples from an alteration zone in borehole KFM02 A does not contain gold.

7 Exploration potential in the Forsmark area and future investigations

7.1 Is the Forsmark area of future exploration interest?

The study area described in the report, the Forsmark area, covers more than 100 km², of which about one third is marine area. Available information mainly from the land area has been compiled in a mineral resources map (4.1), and new geophysical and geological survey results have thereby been evaluated with regard to potential for ores and industrial minerals. The survey results have been compared with known ores and/or mineralizations, and in some cases model calculations have indicated the shape and geometry of interesting anomalies at great depth. Information from the ongoing deep drilling work, as well as the detailed mapping and sampling of rock and Quaternary deposits that was recently carried out, has been included in the assessment. According to this there is a slightly larger area, about 1–1.5 km wide and 8 km long southeast of Forsmark that has an ore potential, primarily for iron and secondarily for copper and zinc. Proven ore deposits or mineralizations are nevertheless small or insignificant. The geochemical sampling of the till shows only low to moderate metal concentrations, and very low for gold. The candidate area for the deep repository is covered by plutonic rocks and can as a whole be regarded as sterile from an ore viewpoint.

According to the ongoing geological investigations, the supracrustal rocks in Forsmark that bear a number of relatively small or insignificant iron ores, in some cases with a sulphide mineral content, have a chemical composition that deviates from the ore-rich supracrustal rocks located in western and central Bergslagen (cf. 3.3). The comparatively more intermediate composition of the Forsmark area's volcanic rocks may be a reason why this part of Bergslagen is relatively poor in ore, particularly large sulphide ores. Thus, there are no major deposits of sulphide minerals containing the base metals copper, lead and zinc in the Forsmark area.

The feasibility study showed that there was a possible potential for zinc in particular in connection with the older iron and sulphide ores, for example those in Dannemora, Vigelsbo and Norrby /Lindroos, 1996/. Furthermore, certain limestones contain lead and silver in concentrations of prospecting interest. However, only zinc and lead associated with the iron ore in Dannemora have been mined on any large scale historically.

The comparison between Dannemora and Forsmark shows a big difference in the geological picture. In Dannemora, beds of rhyolitic volcanic rocks ("hälleflinta") alternate with thick dolomitic limestones, skarn and skarn iron ores. The manganese-rich iron ore there is associated with thick dolomitic limestones that occur in high stratigraphic levels in the acid volcanic rocks /Lindström et al, 1991; Lager, 1986/. In contrast, there are few examples of rhyolitic rocks in Forsmark, and limestones are absent. Similarly, only the iron ores in Dannemora are surrounded by major alteration zones /Lager, 1986/, an important indication of a large ore body.

An iron ore of the size of the Dannemora one can easily be indicated by geophysical methods (5.4). In the whole Forsmark area there are no magnetic anomalies of the same size and strength as in Dannemora.

The ultramafite at Kallerö is not judged to be of interest either in terms of industrial minerals or as an ornamental stone, mainly because minerals such as talc and chlorite are absent. These minerals are common in what are known as “soapstones”, which can be used as ornamental stone.

In connection with the iron ores there are narrow horizons of skarn and skarn-bearing carbonate stone (not shown on the map in Fig. 3-3). There is, however, no exploitation interest for impure limestones. The possible potential of limestones for minerals such as wollastonite (an industrial mineral) has not been investigated. Known wollastonite deposits just west of Uppsala County, northeast of Sala, are very large and not yet exploited. There is nothing to suggest that the Forsmark area contains any major deposit of wollastonite. This mineral is normally formed by contact-metamorphic processes in close connection with major granite massifs (younger granitoids) where silica and lime have reacted and formed the fibrous mineral wollastonite. There are no major massifs of younger granites in the Forsmark area, nor limestones as possible lime components in a possible metamorphic process.

There is today no interest in mining iron ore of the type that occurs in the municipality of Östhammar and the Forsmark area. Even viewed in a long-term perspective, it is highly unlikely that there will be any new prospecting for iron ores of the type found there. Since zinc and copper have previously been found in the more silicon-rich, usually larger iron ore mines, it is mainly such areas that could be of interest for future prospecting, for example the Dannemora field.

It has recently been found, for example in Australia, that certain relatively iron-poor iron ores (or iron-rich rocks) can also contain interesting concentrations of copper and gold. These new types of ores, called IOCG (Iron Oxide-Copper-Gold) are also believed to occur in northern Sweden and Finland /Weihed, 2001/. Foreign mining companies conduct active prospecting there. A few mining companies have obtained mining concessions for older iron ore zones in central parts of Bergslagen as well, and it can be presumed that primarily copper and gold are of interest there. By comparison, there is no such prospecting in the more eastern parts of Bergslagen, and there are no exploration permits in Forsmark and its vicinity today (August 2003). Usually, large peripheral or deeper parts of the older iron or sulphide ores are of interest. Since there are no such ores in Forsmark, nor can they be traced by means of geophysical and geological methods used to date, it is unlikely that there will be any new prospecting for IOCG ores in the relatively small and less geologically interesting Forsmark area.

There are no deposits of commercial stone in the project area. There are ample resources of commercial stone such as aggregate and block stone in the municipality of Östhammar /Lindroos, 1996/ and the crushed rock in Hargshamn is an indication of good conditions as regards suitable rock types and good harbour connections. A possible rock quarry, with quarrying in a shallow open pit, would only marginally limit the siting of a deep repository. On the other hand, relatively large quantities of rock for crushing will be produced in conjunction with the construction of a deep repository, and such a production could possibly be competitive on a local scale at least.

It is highly unlikely that prospecting will take place in the coastal and marine area off Forsmark in the near future. Circumstances counterindicative of this are environmental aspects and the fact that large areas are protected by law. It is probably also expensive to prospect and exploit an ore or mineral deposit out at sea.

Even though there is a zone of bedrock with ore potential in the Forsmark area according to the mineral resources map (Figure 4-1), it is unlikely that the area will be of interest for ore or mineral prospecting in the future. Although there is a small potential for iron, the much more iron-rich ore reserves in Norrland, for example, are very large and far from exhausted. The assessment by the municipal survey /Lindroos, 1996/ that the iron ores of the Dannemora field are also uninteresting from an iron viewpoint still stands. The candidate area for the deep repository is virtually sterile from an ore viewpoint.

7.2 Proposals for supplementary geophysical surveys

Proposals for geophysical follow-up surveys are recommended for three situations:

Anomaly 1

Most factors indicate that this electrical conductor coincides with a high magnetic anomaly from the airborne survey. However, it is not absolutely certain that the magnetic anomaly coincides with the slingram anomaly and the seismic low-velocity zone, due to the uncertainty in the positioning for both the airborne survey and the earlier ground surveys. Clarifying this requires a new magnetic and slingram survey in 1–3 profiles traversing across the anomalies. Based on the results, a short cored drill hole can then determine whether the cause of the anomaly is a mineralization (e.g. a sulphide mineralization) or a deformation zone (e.g. a water-bearing fracture or crushed zone).

Anomaly 2

A follow-up is recommended in the form of several geophysical profiles plus an expanded documentation and sampling of anomaly 2, the electrically conductive portion of the ultramafite at Kallerö. Outcrops in the most conductive formation has been mapped as a rust-weathered ultrabasic rock, and a sulphide-bearing sample from the central part of the ultrabasic (cf. 6.1) contains approximately 7% sulphur (S), indicating a moderate content of sulphide mineral. Samples taken for analysis (see 6.2) do not show any economically interesting concentrations of e.g. copper and nickel or elevated concentrations of gold and platinum. But the sampling is inadequate (2 samples) and covers only a small part of the conductive area.

Anomaly 16

Anomaly 16 should be checked in the field to document an unmapped outcrop and to locate any other outcrops at the anomaly. Besides a magnetite mineralization of the traditional type, the anomaly may be caused by a magnetite enrichment in a heavily deformed mylonitic metagranite.

8 References

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Glossary of terms

Acid rock. Igneous rock that contains more than 65 percent SiO_2 . Synonymous term: felsic.

Aggregate. Gravel, stones and crushed rock used in concrete and in road and railway construction.

Area of ore potential. An area or volume in the bedrock that has the geological potential for hosting ores of a certain kind. Prospecting can yield new finds in this area.

Base metal. Copper (Cu), lead (Pb) and zinc (Zn).

Basic rock. Rock with < 45–52 percent by weight SiO_2 .

Carbonatite. An igneous rock composed of at least 50% carbonate minerals, sometimes found together with kimberlites.

Chalcopyrite. A copper sulphide mineral (CuFeS_2). The most important mineral for extraction of copper.

Commercial stone. A type of rock that can be utilized technically and commercially.

EIA. Environmental Impact Assessment.

Galena. An ore-forming lead mineral (PbS).

Geochemical methods. Use of the geochemical methods in ore prospecting is based on the fact that rocks, Quaternary deposits, vegetation, groundwater and surface water near an ore occasionally exhibit elevated concentrations of the elements that comprise the ore. This elevation is termed a geochemical anomaly.

Hällefrinta. An obsolete Fennoscandian term for a metamorphosed volcanic glass, sometimes in ash form.

Hematite. Iron oxide mineral (Fe_2O_3). Common iron ore mineral.

Hydrothermal fluid. Hot ($>375^\circ\text{C}$) aqueous fluid of metamorphic, magmatic or geothermal origin. Certain ores are formed by hydrothermal processes.

Industrial minerals. Any rock, mineral, or other naturally occurring substance of economic value, exclusive of metallic ores, mineral fuels, and gemstones.

Intermediate rock. Rock with 52-65% SiO_2 .

Kimberlite. A normally porphyritic plutonic rock containing abundant megacrysts of olivine and mica in a fine-grained groundmass. Kimberlite occasionally contains diamonds.

Leptite. An obsolete Fennoscandian term for a metamorphosed acid volcanic rock.

Magnetite. Magnetic iron mineral, an iron oxide (Fe_3O_4). Important mineral for extraction of iron. An obsolete term for magnetite ore is black ore.

Mining waste. Waste from old mining operations. The mining waste was normally stacked in waste heaps next to the mining area.

nT. nanoTesla = 10^{-9} Tesla, SI unit for the magnetic field (flux density).

Ωm . Ohm-metre, SI unit for electrical resistivity.

Ore. A concentration of minerals or metals that is economically mineable. The term is sometimes also used genetically, i.e. to describe an ore formation process.

Orefield. An area where several ore deposits of the same type are located near each other.

Pentlandite. A nickel iron sulphide mineral. Pentlandite is the principal ore of nickel.

Platinum group of metals. A group of six heavy precious metals where the metals platinum (Pt) and palladium (Pd) have wide technical use and commercial importance.

ppb. parts per billion. One billionth. A thousandth of a ppm (cf. ppm).

ppm. parts per million. One millionth. Common way of expressing low concentrations.

Precious metals. Silver, gold and the platinum group of metals (see Platinum group of metals).

Prospecting. Searching for economically valuable deposits of ore. Synonymous term: exploration.

Pyrite. Common sulphide mineral containing sulphur and iron (FeS_2).

Pyrrhotite. Weakly magnetic iron sulphide mineral (FeS).

Siemen. Unit, SI, for electrical conductance, i.e. the ratio between thickness and resistivity for a thin sheet or a thin layer.

Skarn. An old Swedish term for silicate minerals rich in calcium and/or magnesium that are associated with iron and sulphide ores. Skarn is the gangue (valueless rock) in an ore deposit.

Sphalerite. A brown, yellow or black sulphide mineral (ZnS). The most important mineral for extraction of zinc.

Static magnetic field. Magnetic field that shows no variation in time. In magnetic measurements the static field is measured unlike at electromagnetic measurements.

Sulphide ore. Ore that contains sulphide mineral (sulphur-bearing metal compound).

Ultrabasite. A plutonic rock having an extremely low silica content (<45 percent SiO_2). Synonymous term: ultramafite.

Wollastonite. A greyish-white fibrous calcium silicate mineral; an industrial mineral.