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Forsmark

Bedrock mapping

Stage 1 (2002) – Outcrop data including fracture data

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Geological Survey of Sweden

February 2003

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Keywords: mapping, bedrock, inferred outcrops, observed outcrops, outcrop data, fracture data.

Contents

1 Introduction

This document reports the location of inferred and observed outcrops in the Forsmark area as well as the various outcrop data, including some fracture characteristics, acquired during stage 1 (2002) of the project entitled “Bedrock mapping at Forsmark, 2002–2003”. This project is one of the activities performed within the initial site investigation programme at Forsmark.

The bedrock mapping project aims to present a new, detailed geological map of the bedrock in the candidate area at Forsmark and its surroundings at the scale 1:10 000. The area selected for mapping is constrained by the coordinates shown in Table 1-1 and is shown in Figure 1-1.

The project has been organized into several distinct working phases which are planned to be executed during two time stages, 2002 and 2003. The material generated during stage 1, which is reported here, consists of four types:

1. Location of inferred outcrops and sites where the Quaternary cover deposits are less than 50 cm thick.
2. Location of observed outcrops.
3. Outcrop data, including rock type and various rock type attributes, from 1054 observation points. Each of the 1054 observation points is identified with an ID-code (PFM-number).
4. The position and orientation of fractures judged to be longer than 100 cm at 44 outcrops. These outcrops are situated principally within the candidate area at Forsmark. Each line is identified with an ID-code (LFM-number).

Work within the bedrock mapping project has been carried out on the basis of the method description for bedrock mapping (SKB MD 132.001). Since a detailed description of the technique to be used during mapping of fractures is lacking in this description, the scan line technique recommended in the method description for detailed fracture mapping (SKB MD 132.003) was adapted during this part of the work.

Table 1-1. Coordinates of the area selected for detailed bedrock mapping in the Forsmark area.

Corner ID	Northing in RT 90, 2.5 gon V (metres)	Easting in RT 90, 2.5 gon V (metres)
1	6706371	1632471
2	6698593	1640249
3	6691522	1633178
4	6699300	1625400

Figure 1-1. Location of the area selected for detailed bedrock mapping at Forsmark.

2 Objective and scope

Infra-red aerial photographs over the study area, taken at a height of 2700 m, were interpreted in order to locate either the position of outcrops where the bedrock is exposed at the Earth's surface or sites where the bedrock lies beneath a thin (< 50 cm) cover of Quaternary deposits. These data were critical for the planning and execution of the field activities.

It was aimed to map all the outcrops in the mainland part of the study area during stage 1 of the project. These data will be integrated with both bedrock analytical data and the interpretations obtained from the study of airborne geophysical data in order to produce a bedrock map over the study area.

In order to gain some information on the regional variation in the frequency and orientation of fractures over the candidate area, a documentation of the position and strike and dip of fractures longer than 100 cm was carried out at 44 outcrops (Figure 2-1). This work will also help in the selection of outcrops where detailed fracture analysis will be carried out during a later stage of the site investigation programme.

Field work associated with stage 1 of the project initiated in the candidate area during June 2002. Field activities then continued in the coastal area to the northeast, in the area north of 6700000 N to the northwest of the candidate area and in the inland area to the southwest. Field activities ceased during September 2002. Both descriptive and numerical data from the 1054 observation points have been included in an outcrop database. Primarily on account of the complexity of the outcrops visited and, as a consequence, the longer time required for the field activities, a large part of the area south of road 76 was not mapped during 2002.

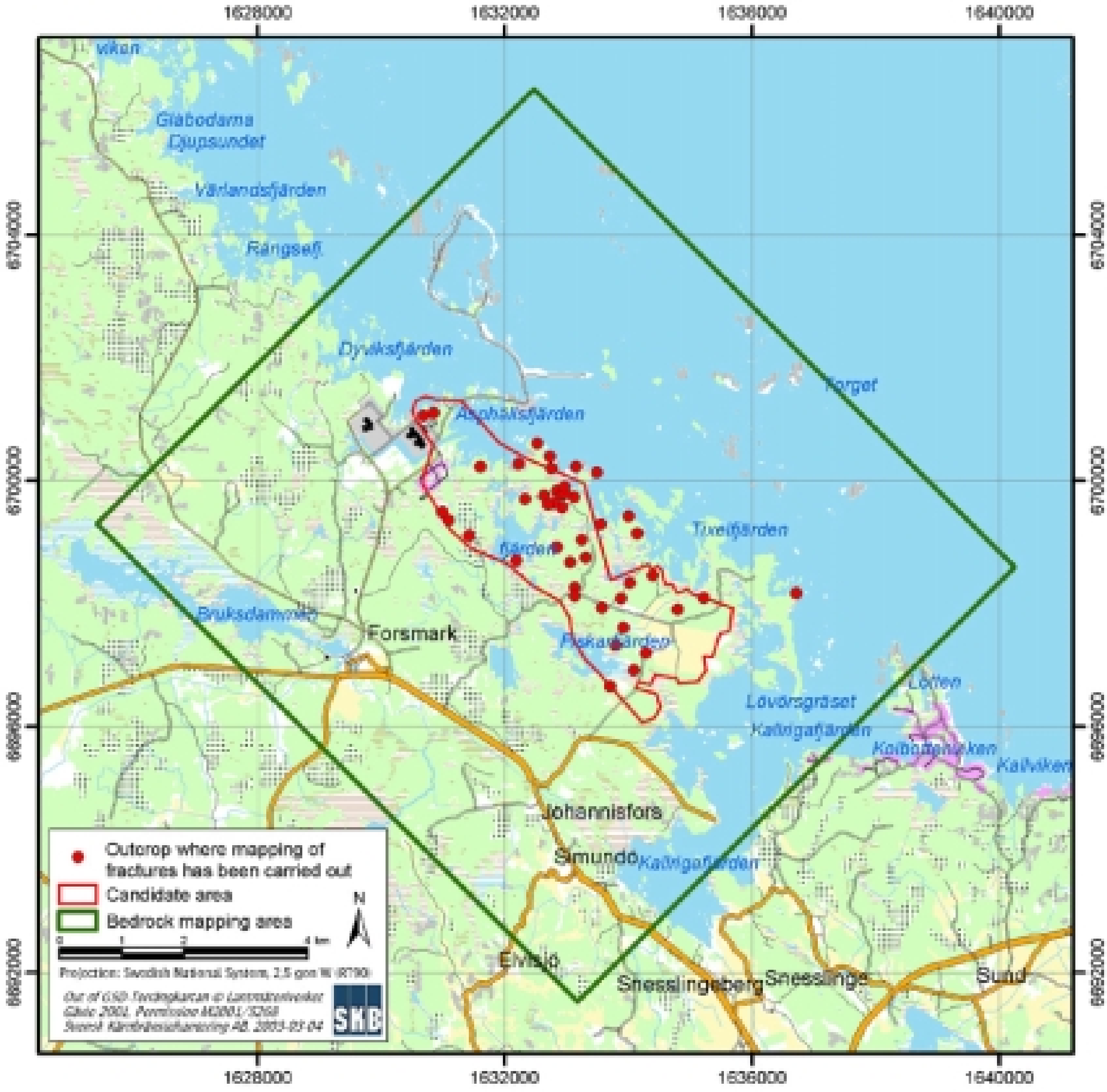

Figure 2-1. *Location of outcrops where mapping of fractures longer than 100 cm has been carried out.*

3 Equipment

3.1 Description of equipment

The interpretation of the infra-red aerial photographs was carried out with the help of a stereo instrument with variable magnification.

The following equipment was used during the field investigations (Figure 3-1):

- Garmin GPS 12.
- Silva compass.
- Instrument to measure magnetic susceptibility (Geoinstruments, Finland).
- Camera.
- Hammer.
- Brush.
- Magnifying lens.
- Magnet.
- Measuring tape.
- Sample bags.
- Topographic field map at the scale 1:10 000 generated from the orthorectified aerial photographic data.
- Field notebook with standard observation protocol.
- Various complementary material including pencils, tape, safety equipment etc.

Transport to the field area was carried out with the help of hired cars.

Figure 3-1. *Standard field equipment used in connection with the bedrock mapping work.*

4 Execution

4.1 Preparations

Much of the preparation work which involves the documentation of previous work carried out in the area was completed and reported in connection with the feasibility study in the Östhammar municipality. Key descriptions of the geology of the Forsmark area and its immediate surroundings are presented in /Stålhös, 1991; Hansen, 1989; Carlsson and Christiansson, 1987/. Relevant summaries of the geology which assess this earlier work and which were completed in connection with the feasibility study, include /Bergman et al, 1996, 1998; Bergman and Isaksson, 1996; Lindroos, 1996; Stephens and Isaksson, 2000/. An updated summary of the geology can be found in the version 0 site descriptive model for the Forsmark area /SKB, 2002/.

An ongoing separate activity within the Forsmark site investigation programme aims to assess and feed into various databases the geological data which were generated in connection with the building activity in the vicinity of both the Forsmark nuclear power station, and the final repository for low- and medium-active nuclear waste (SFR). No further work with these historical data was carried out in connection with the preparatory work for the bedrock mapping project.

All preparation work which involved the assembly of field maps and equipment as well as other practical arrangements for field activities were completed prior to the initiation of field work. Two preparatory field visits to the study area were carried out during May 2002.

4.2 Execution of tests/measurements

The location of outcrops and sites with thin (< 50 cm) Quaternary cover was interpreted directly from the infra-red aerial photographs. The interpretation made use of the colour scale, the form of the topographic surface as well as information bearing on vegetation characteristics and landscape use in these images. The earlier interpretation of outcrops presented in /Persson, 1985, 1986/ was also utilized in the interpretation.

At the start of each day's field activities during August and September, the geologist visited one of two fixed points to test the drift in the coordinate values (RT 90, 2.5 gon V) obtained from the Garmin GPS 12 instrument used by the geologist. The average coordinate values for the fixed point were registered after a few minutes. The results of this test were delivered to SKB in connection with the completion of the field activity diaries (*aktivitetsdagbok*) during August and September.

The dominant rock type at each observation point was marked on the topographic field map at the scale 1:10 000. Different pen colours were used in order to distinguish different rock types. 1054 observation points were designated an ID-code (PFM-number) and both the date and the coordinates estimated by the Garmin GPS 12 instrument were documented in a standard observation protocol. In general, an attempt was made to apply the ID-code to the area which is 10 m or less from the point at which the GPS coordinates were registered. In some larger outcrops, the field survey documents a larger area (>10 m) around the measured point. In well-exposed areas outside the candidate area, where the bedrock was similar in the different outcrops, some observation points were not assigned an ID-code but simply plotted on the topographic field map with the help of the coloured pen system.

Both descriptive and numerical data were registered in the standard observation protocol. These data include:

1. Object (predominantly outcrop but also uncertain outcrop, prospect/excavation and abandoned mine).
2. Rock type.
3. Occurrence of rock type.
4. Texture.
5. Structure.
6. Grain size (groundmass).
7. Grain size (megacryst).
8. Colour.
9. Key mineral.
10. Occurrence of key mineral.
11. Stratigraphic position.
12. Measurements of mesoscopic structures.
13. Measurements of magnetic susceptibility.
14. Reference sample number.
15. Photograph (how many?).
16. Sketch (how many?).
17. Comments in free text form.

Documentation of points 1–2 and 13 is compulsory for each observation point. Completion of points 3–12 and 14–17 varies from outcrop to outcrop and is dependant on the character of the bedrock at the outcrop. Since the bedrock in the Forsmark area is generally complex, some comments in free text form were registered in the observation protocol for virtually all of the outcrops. If more than one rock type occurs at an outcrop, the rock types are presented in their order of spatial importance in the outcrop (rock type 1, rock type 2 etc), and the documentation of points 2–14 is repeated for each rock type. Structural measurements of predominantly ductile mesoscopic structures were carried out. Eight measurements of the magnetic susceptibility in, at least, the dominant rock type were completed at most observation points.

Following each day's field activities, key information for all the observation points, predominantly rock type and structural measurements, were plotted on a clean outcrop map at the scale 1:10 000 at the field office. This process was necessary in order to plan carefully the following day's field activities.

The mapping of fractures at the 44 outcrops was carried out using the orthogonal scan line technique described in the method description for detailed fracture mapping (SKB MD 132.003). The position and orientation (strike and dip) of fractures longer than 100 cm were documented along 50 lines which trend 360^{o} (North) and 48 lines which trend 90^{o} (East) at these outcrops. The following procedure was followed at each outcrop:

1. The ID-code (PFM-number), date and RT 90 2.5 gon V coordinates for the outcrop were noted and the relevant information at the outcrop, according to points 1–17 above, was documented in the standard observation protocol.
2. Two or more orthogonal lines with trends 360° and 90° were selected and marked on the outcrop with the help of chalk. The lines in the two orthogonal directions were chosen so that their total lengths in the two directions were as close as possible to each other and, if possible, c.10 m. The conditions of exposure at each outcrop naturally steer line selection. Each line was allocated an unique ID-code (LFM-number).
3. In the case where observations were made initially along a line which trends 360°, the coordinates of the southern end point were noted as a start point. Both the position of the fracture intersections and the position of the intersection point of the line(s) which trend(s) 90° were all noted down to a 1 cm level, from south to north along the line. The position(s) of the 90° line(s) was (were) calculated using the position of the intersection point(s) on the 360° line. A similar procedure was followed in the case where observations were made initially along a line which trends 90°. In this case, the coordinates of the western end point were noted as a start point and the fractures and line intersection(s) documented from west to east.
4. The strike and dip of the fractures were measured along the orthogonal lines with the help of the right-hand-rule.
5. Key features (e.g. minerals which fill fractures, cross-cutting relationships between fractures) were noted in free-text format as comments.

4.3 Data handling

The inferred outcrops and sites with thin (< 50 cm) Quaternary cover in the Forsmark area were transferred to ArcView format with the help of the digital, orthorectified aerial photographic data. The data were delivered to SKB as an ESRI-shape file. This data is archived in the SKB GIS database (identity: SDEADM.SGU_FM_GEO_1282).

The observed outcrops in the Forsmark area were delivered to SKB as an ESRI-shape file and archived in the SKB GIS database (identity: SDEADM.SGU_FM_GEO_1303.

With the assistance of a special programme developed at the Geological Survey of Sweden for the handling of bedrock outcrop data (BGDATA, version 1.6), the data documented in the 1054 standard observation protocols were transferred into an Access database. Information on reference samples and photographs were not included at this stage. The outcrop data were delivered to SKB as an Access file. In order that they could be included in SKB's SICADA database, the outcrop data were organized in this Access file into key groups (see below), following contact with and after recommendations from SKB. The data were subsequently exported to the SKB SICADA database and stored under field note Forsmark 22.

The scan line data from the 44 outcrops were transferred into an Excel file and delivered to SKB accordingly. This data is stored in the SKB SICADA database under field note Forsmark 22.

4.4 Analytical work

The bedrock mapping project aims to generate the following bedrock analytical data in representative bedrock samples from the Forsmark candidate area and its surroundings:

- Physical properties including :
  1. Magnetic susceptibility.
  2. Anisotropy of the magnetic susceptibility.
  3. Magnetic remanence.
  4. Electrical resistivity.
  5. Density.
  6. Porosity.
  7. Gamma-radiation.
- Petrographic properties including modal analyses (QAP-analysis).
- Geochemical properties (major, minor and trace elements including REE)
- Geochronological data.

No analyses of bedrock samples were carried out in connection with the activities described in this report. All the analytical data listed above will be documented in separate P-reports.

5 Results

5.1 Inferred and observed outcrops

The interpretation of the infra-red aerial photographic data yielded 1575 inferred outcrops of variable size in the stage 1 study area (Figure 5-1). Subsequent field activities showed that the bedrock is indeed exposed at most of these localities. However, some of the inferred outcrops proved to be, for example, block concentrations. Furthermore, several small outcrops were detected in the study area during the mapping which were not recognized during the interpretation of the infra-red aerial photographs. For these reasons, the outcrops inferred from the infra-red aerial photographic data do not exactly match the outcrops presented in the later date batch. The outcrops which retain the label “inferred” have so far not been visited. Both the outcrops inferred from the interpretation of infra-red aerial photographs and the outcrops observed during stage 1 of the bedrock mapping project are illustrated in Figure 5-2. The outcrop data are archived in the SKB GIS database (see section 4.3 above).

Figure 5-1. Inferred outcrops and sites where the Quaternary cover is less than 50 cm thick.

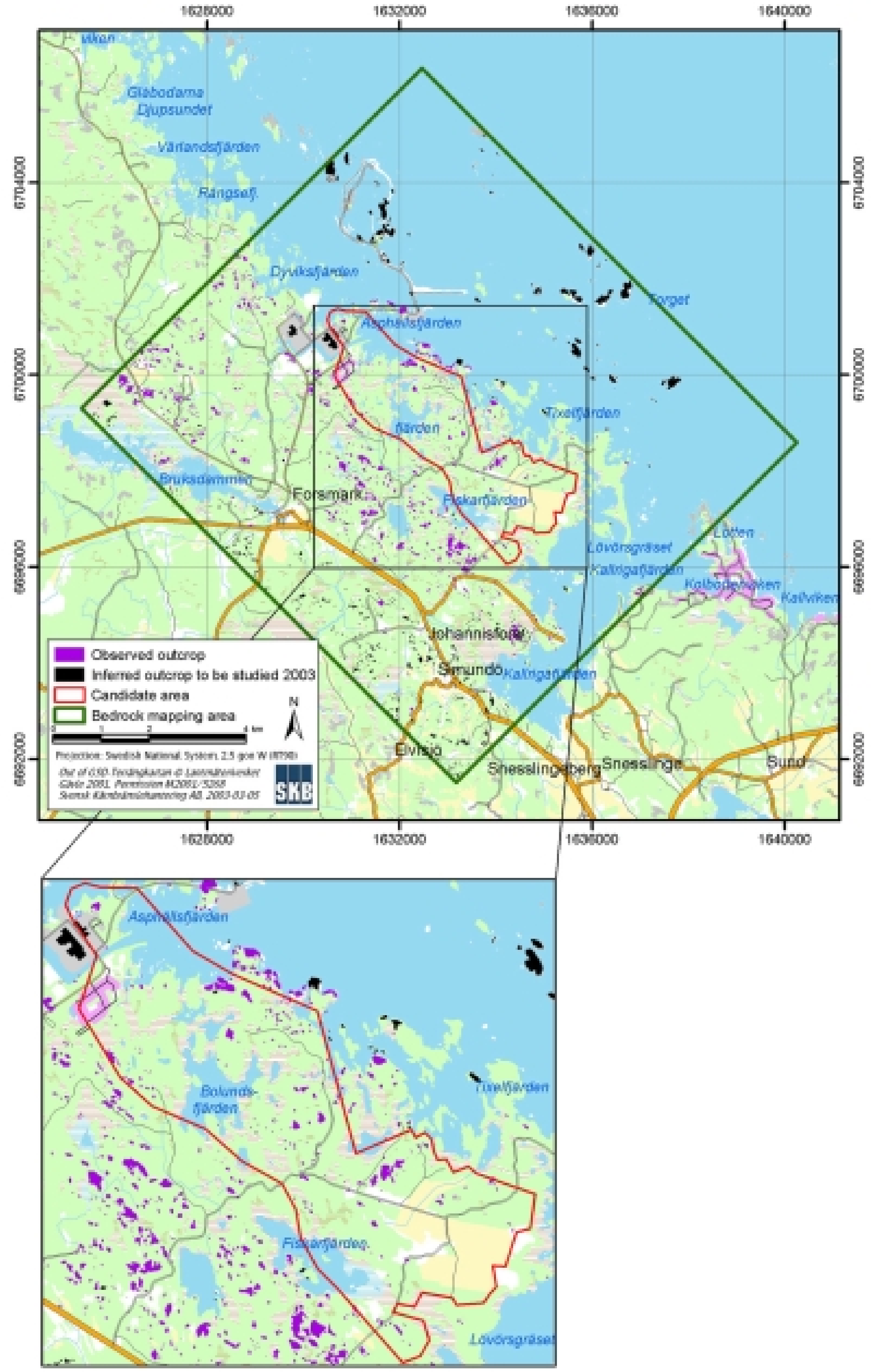

Figure 5-2. *Outcrops observed during stage 1 of the bedrock mapping project. The inferred outcrops and the sites where the Quaternary cover is less than 50 cm thick, which were not visited during 2002, are also shown.*

5.2 Outcrop data

The outcrop data at the 1054 observation points have been organized into the following groups:

- Outcrop coordinates and date.
- Outcrop rock type, occurrence, stratigraphic position, photographs and samples.
- Outcrop rock type, texture.
- Outcrop rock type, structure.
- Outcrop rock type, groundmass grain size.
- Outcrop rock type, megacryst grain size.
- Outcrop rock type, key minerals.
- Outcrop rock type, structure orientation.
- Outcrop rock type, magnetic susceptibility.
- Observation comments.

A brief summary of these data is provided in Table 5-1.

A description of the outcrop in free text form is available at 1053 of the 1054 observation points. No further analysis of the outcrop data is presented in this report. The outcrop data are archived in SKB's SICADA database *(Field note Forsmark 22*).

5.3 Fractures longer than 100 cm

The following information has been documented at the 44 outcrops where orthogonal scan line mapping of fractures longer than 100 cm has been carried out:

- ID-code, line (LFM-number).
- ID-code, outcrop (PFM-number).
- Date.
- Coordinates for the start point of the line (northing, RT 90 2.5 gon V).
- Coordinates for the start point of the line (easting, RT 90 2.5 gon V).
- Line trend.
- Line length.
- Fracture ID-number.
- Position of fracture along the line, measured from south to north (line trend 360^{o}) or west to east (line trend 90^{o}).
- Strike and dip of the fracture.
- Where relevant, descriptive information in free text form, including the nature of fracture filling.

Table 5-1. Summary of bedrock outcrop data.

Rock type, order 1 – dominant rock type at the 1054 outcrops	
Rock type	The main rock types are: 1. Granite (26%) 2. Tonalite (15%) 3. Granodiorite-granite (13%) 4. Felsic volcanic rock (8%) 5. Pegmatitic granite (7%) 6. Granodiorite (6%) 7. Diorite (6%) 8. Tonalite-granodiorite (4%) Skarn-associated, magnetite mineralization forms the dominant rock type at six outcrops and sulphide mineralization at one outcrop. All these objects are either abandoned, small mines or excavations carried out in connection with exploration work.
Occurrence	Since most of the rock types judged to be dominant in an outcrop occur as parts of larger mappable rock units, the type of occurrence has generally not been documented.
Stratigraphic position	Svecofennian supracrustal rocks and early Svecokarelian intrusive rocks are present in the Forsmark area. The stratigraphic position of younger intrusive rocks has not been specified.
Texture	These data document the predominance of equigranular rocks in the Forsmark area.
Structure	Virtually all rocks are metamorphic in character. Both the Svecofennian supracrustal rocks and the early Svecokarelian intrusive rocks were affected by metamorphism under amphibolite-facies conditions. However, in most cases, the primary character of these rocks (volcanic, sedimentary or intrusive) can still be recognized. The data document the importance of banded, lineated and foliated rocks in the Forsmark area. The occurrence of mylonitic, highly fractured or cataclastic rocks, which formed under lower-grade metamorphic conditions (ductile or brittle), has also been documented.
Groundmass grain size	The groundmass grain-size data are variable. There is an important component of medium-grained rocks. Note that the grain size of pegmatites and pegmatitic granites has seldom been documented in this data set.
Megacryst grain size	There is very little documentation of this parameter for rock type, order 1. This reflects the generally equigranular character of the rocks (see texture).
Key minerals	Various key minerals have been documented. Note especially the occurrence of mineral fillings in fractures that transect rock type, order 1. Epidote and quartz dominate these fracture fillings. Other minerals include hematite, chlorite and magnetite.
Structure orientation	735 measurements have been carried out.
Magnetic susceptibility	6434 measurements have been carried out.

Rock type, order >1 – subordinate rock types at the 1054 outcrops	
Rock type	The main rock types are: 1. Pegmatite (25%) 2. Amphibolite (22%) 3. Granite (11%) 4. Tonalite (6%) 5. Felsic volcanic rock (5%) 6. Pegmatitic granite (4%) Skarn and skarn-associated, magnetite mineralization associated with felsic volcanic rock occur as a subordinate rock type at twelve outcrops. Excavation in connection with exploration activities has been carried out at one of these outcrops.
Occurrence	Various modes of occurrence have been documented for the subordinate rock types at the 1054 observation points. The most common are band and dyke.
Stratigraphic position	Svecofennian supracrustal rocks and early Svecokarelian intrusive rocks are present in the Forsmark area. The stratigraphic position of younger intrusive rocks is not specified.
Texture	These data document the predominance of equigranular rocks in the Forsmark area.
Structure	Virtually all rocks are metamorphic in character. Both the Svecofennian supracrustal rocks and the early Svecokarelian intrusive rocks were affected by metamorphism under amphibolite-facies conditions. However, in most cases, the primary character of these rocks (volcanic, sedimentary or intrusive) can still be recognized. The data document the importance of banded, lineated and foliated rocks in the Forsmark area. The occurrence of mylonitic, highly fractured or cataclastic rocks, which formed under lower-grade metamorphic conditions (ductile or brittle), has also been documented.
Groundmass grain size	The groundmass grain-size data are variable. The documentation of finer-grained rocks is more frequent in the subordinate rock types relative to the rock type, order 1. Note that the grain size of pegmatites and pegmatitic granites has seldom been documented in this data set.
Megacryst grain size	There is very little documentation of this parameter for rock type, order >1. This reflects the generally equigranular character of the rocks (see texture).
Key minerals	Various key minerals have been documented. Note especially the occurrence of mineral fillings in fractures that transect the subordinate rock types in the outcrops studied. Epidote and quartz dominate these fracture fillings. Pyrite has also been observed.
Structure orientation	1105 measurements have been carried out.
Magnetic susceptibility	5258 measurements have been carried out.

The tables below summarize information concerning the fracture frequency in three subareas. Subareas 1 and 2 are situated northwest and southeast, respectively, of a lineament which trends in a northeasterly direction through Lillfjärden /SKB, 2002/, between boreholes KFM02 and KFM03. This lineament divides the candidate area up into two segments, a northwestern segment and a southeastern segment. 24 of the 27 outcrops in subarea 1 are situated in the northwestern segment of the candidate area, while 11 of the 12 outcrops in subarea 2 lie within the southeastern segment. Subarea 3 is situated in the coastal area northeast of and outside the candidate area. The fracture frequency in the two line directions, 360° and 90°, is summarized separately for each subarea.

Figure 5-3. Location of subareas 1, 2 and 3.

Subarea 1 is dominated by metamorphosed granite and granodiorite with subordinate amounts of amphibolite, metamorphosed aplitic granite, pegmatite and younger, felsic dykes, which are, in part, also metamorphic in character. The bedrock is, in general, poorly exposed in subarea 2. The available outcrop data in this subarea indicate the occurrence of metamorphosed tonalite, granite and granodiorite, amphibolite and a more frequent occurrence of pegmatitic granite. The bedrock in subarea 3 is strongly inhomogeneous and is dominated by metamorphosed aplitic granite, metamorphosed granite, amphibolite and various younger, felsic dykes, which are, in part, also metamorphic in character. The bedrock units in subarea 3 define a conspicuous banded structure which strikes in a northwesterly direction and dips steeply to the southwest. Subarea 3 is inferred to lie in an area of higher ductile deformation relative to that in the candidate area. The tectonic banding structure formed as a result of this high ductile deformation under amphibolite-facies metamorphic conditions.

Table 5-2. Fracture frequency (fractures/m) from 27 outcrops in subarea 1, which corresponds predominantly to the northwestern part of the candidate area.

Value	Subarea 1 Line direction 360°	Line direction 90°
Number of calculations of fracture frequency	27	27
Maximum value (fractures/m)	2.60	3.70
Minimum value (fractures/m)	0.40	0.30
Mean value (fractures/m)	1.38	1.30
Standard deviation (fractures/m)	0.50	0.64
Median value (fractures/m)	1.40	1.10
Number of fractures measured	296	273

Table 5-3. Fracture frequency (fractures/m) from 12 outcrops in subarea 2, which corresponds predominantly to the southeastern part of the candidate area.

Value	Subarea 2 Line direction 360°	Line direction 90°
Number of calculations of fracture frequency	12	12
Maximum value (fractures/m)	2.60	2.30
Minimum value (fractures/m)	0.70	0.50
Mean value (fractures/m)	1.30	1.26
Standard deviation (fractures/m)	0.60	0.48
Median value (fractures/m)	1.10	1.15
Number of fractures measured	133	131

Table 5-4. Fracture frequency (fractures/m) from 5 outcrops in subarea 3, which is situated in the coastal area with high ductile strain northeast of and outside the candidate area.

	Subarea 3	
Value	**Line direction 360°**	**Line direction 90°**
Number of calculations of fracture frequency	5	5
Maximum value (fractures/m)	4.50	2.80
Minimum value (fractures/m)	1.20	1.60
Mean value (fractures/m)	2.60	2.26
Standard deviation (fractures/m)	1.41	0.49
Median value (fractures/m)	2.60	2.50
Number of fractures measured	129	111

Further analysis of these regional fracture data, including assessment of fracture orientation and comparison between the different subareas, has not been carried out within the context of this report. The outcrop data are archived in SKB's SICADA database under field note Forsmark 22.

5.4 Discussion

The work carried out during stage 1 (2002) differs in two aspects from the original plan for the field activities:

1. The mapping south of road 76 was not completed.
2. The documentation of reference samples and field photographs was not completed in digital format prior to the deadline for delivery of outcrop data.

Both these pieces of work will be carried out during 2003 and the data delivered together with that established during stage 2 of the bedrock mapping project.

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