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Forsmark

Detailed fracture mapping at the KFM02 and KFM03 drill sites

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April 2003

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1 Introduction

SKB performs site investigations for localisation of a deep repository for high level radioactive waste. The site investigations are performed at two sites; Forsmark and Oskarshamn. This document reports the data gained in Detailed fracture mapping of the KFM02 and KFM03 drillsites which is one of the activities performed within the site investigation at Forsmark during September and October 2002. The bedrock mapping of the KFM02 and KFM03 drill sites is presented in Appendix.

The detailed mapping campaign was conducted according to the activity plans AP PF 400-02-15 and AP PF 400-02-11 (SKB internal controlling documents).

2 Objective and scope

The activity aimed at collecting fracture data to be used in discrete fracture analysis and discrete fracture modelling in the regional and local site investigation stage. The survey was expected to indicate the geometric properties for fractures in the trace length interval between 0.5 m to 10 m in the area around the cored drill sites. The results are indicative of the properties of the local fracture network and can provide important information of the variability of the fracturing between the drill sites.

The two investigated outcrops, AFM000053 and AFM000054, were located at the position of the planned boreholes KFM02 and KFM03, respectively, see Figure 2-1. The outcrops were only partly natural and the main parts were cleared from the soil cover prior to mapping. Both outcrops were approximately 600 m^2.

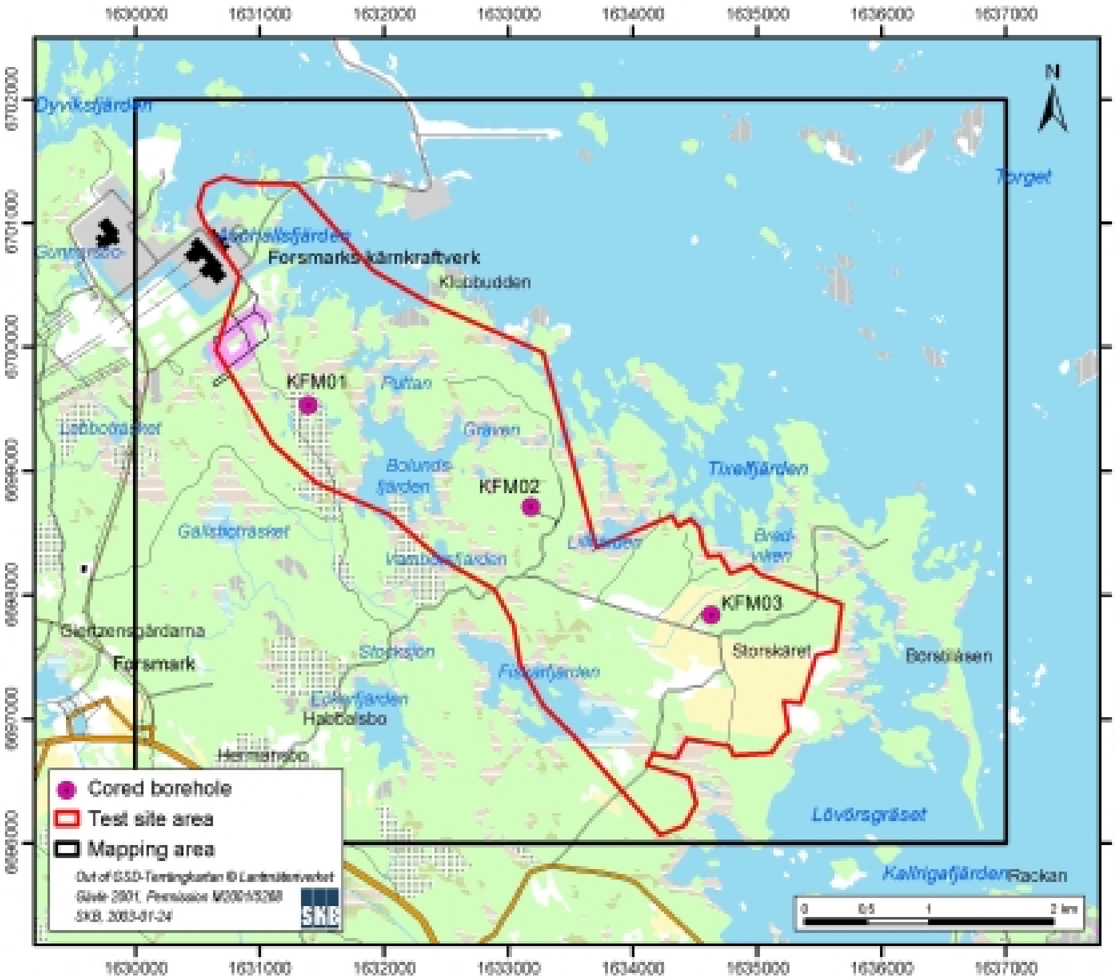

Figure 2-1. *The location of outcrops AFM000053 (BP2) and AFM000054 (BP3) in the Forsmark area.*

3 Equipment and methods

The fracture trace geometry was measured with a theodolite. In theory, the theodolite gives an accuracy of the position (x, y and z) of less than 3 mm. However, this accuracy is based on the assumption that the measuring lath is held in a perfectly vertical position. Since this is not always possible to achieve, the total error is larger. Each measurement is therefore estimated to be performed with an x, y accuracy of 1 cm. The elevation accuracy is estimated to be less than 0.5 cm.

The orientation of the fracture was calculated based on the theodolite measurements of the fracture trace. The accuracy of the orientation depends on the number of measured points along the fracture trace as well as the three dimensional spread of the data points. The number of points measured along each fracture trace varies between 2 and up to more than 7 depending on the complexity of the trace and the rock surface. More measurements result in a better definition of the orientation. However, an increasing number of measurements slow down the survey substantially. The work was performed such that there was a balance between mapping speed and degree of detail of the mapped fracture traces.

All other fracture parameters were mapped by hand.

The mapping was performed using standardized protocols following methods described in method description for detailed fracture mapping at outcrops, SKB MD 132.003 (SKB internal controlling document).

4 Execution

4.1 Preparations

The theodolite was positioned outside the outcrop and calibrated against at least three fix points on each outcrop. These fix points have also been measured by the regional coordinate survey performed by SKB and thus provided the coordinate translation to our local outcrop systems. The theodolite was calibrated against the fix points after each time data was downloaded from the instrument or at the beginning of each fieldwork session.

The instrument was also recalibrated to reflect temperature changes during the day.

The theodolite measurements were converted to the RT90 system after each completed survey.

4.2 Execution of tests/measurements

The methodology for mapping fractures follows the suggested method presented in SKB MD 132.003 (SKB internal controlling document). The work process was conducted as follows:

1. An approximately square shaped 5x5 m pattern of plastic bands, cf Figure 5-1, was applied over the outcrop as a help to subdivide the outcrop into smaller sub domains during the mapping campaign. These squares have no imprint on the collected data.

2. A theodolite was calibrated against known and appointed fix points in the vicinity to the outcrop.

3. Each fracture trace was marked with a metal marker on the outcrop to keep track of measured fractures. The used truncation length for mapping fracture traces was 0.5 m.

4. Each fracture location and length was measured with two or more points with the theodolite. The number of measured points on each fracture was controlled by the complexity of the structure. Special attention was made to the ending of each fracture to capture fracture termination behaviour.

5. Each fracture was mapped with respect to the given geological parameters outlined in SKB MD 132.003 (SKB internal controlling document), also given in Table 5-1.

6. Scan line measurements were performed along two 10 m long orthogonal scan lines.

7. Fracture locations were measured along the scan line. The used truncation length for scan line measurements was 0.2 m.

8. Each fracture was mapped with respect to the geological parameters given in SKB MD 132.003 (SKB internal controlling document).

9. The outcrop was cleared from markers.

10. Digital conversion of theodolite data to RT90-RHB70 coordinate data.

11. Construction of an AutoCad DWG 14 file of fracture traces, square pattern and outcrop boundary.

12. Quality control of the survey data and consistency check with theodolite digital data with the mapping protocols.

13. Report production.

4.3 Data handling

The deliverables to SKB for the mapping of the AFM000053 and AFM000054 outcrops includes:

1. Geological parameters for the areal mapping of the outcrops. The data is stored in the SKB SICADA database under field note Forsmark 49.

2. Geological parameters for the scan line mapping of the outcrops. The data is stored in the SKB SICADA database under field note Forsmark 49.

3. Coordinate points of each theodolite measurement of the fracture traces. The data is stored in the SKB SICADA database under field note Forsmark 49.

4. Data files with the boundary of the outcrop. The data are archived in the SKB GIS database under the identities: SDEADM.GOL_FM_GEO_1341 (AFM000053) and SDEADM.GOL_FM_GEO_1342 (AFM000054).

5. AutoCad DWG R14 files for the outcrop boundary and fracture traces. The DWG trace map file has one fracture trace on each layer. The DWG files were converted to shape format before transfer to the SKB GIS database where the data are stored under the identities: SDEADM.GOL_FM_GEO_1343 (AFM000053) and SDEADM.GOL_FM_GEO_1344 (AFM000054).

6. Digital photos and description from the outcrops.

7. Controlling document for metadata for GIS archiving.

8. Report (this).

5 Results

The results of the fracture mapping campaign include data tables and AutoCad drawings of:

- Areal fracture mapping.
- Scan line fracture mapping.

However, in addition to the method described in the activity plan, fractures has been surveyed directly by using theodolite measurements on several locations along each fracture trace, and not mapped not by hand on a drawings as suggested in AP PF 400-02-15 (SKB internal controlling document). This method results in a very high degree of accuracy of the shape, location and length of each trace as compared to hand drawings. The method is also more time efficient as hand drawn data does not need to be converted into digital form.

Based on experience from work in crystalline basement outcrops, it was prior to the field investigation estimated that there would be approximately two fractures (over the truncation trace length) in each m^2 of the outcrop, corresponding to ca 1200 fractures per outcrop. The estimate for 1200 fractures per outcrop turned out to be approximately correct when using a truncation trace length of 0.5 m for the areal mapping, i.e. all fractures > 0.5 m are mapped. The AFM000053 and AFM000054 outcrops contained 986 and 1235 fractures respectively.

The scan line mapping was performed along two 10 m long lines in the centre of each outcrop, one along North and one along West in a perpendicular crosscutting pattern. The truncation length for fracture traces in the scan line survey was 0.2 m. The fracture frequency along the North trending scan lines (on both outcrops) varies between 2.3 to 3.4 fractures per meter and along the East-West trending scan lines between 2.9 to 3.0. Of the two outcrops, KFM02 shows the lowest fracture frequencies in both scan line directions. However, the sub samples of fractures along the scanlines are to few (< 35) to draw any definite conclusions of similarities of the fracture intensity, differences between different scan line orientations or differences between the outcrops. A proper fracture analysis of the complete outcrop data (> 2000 fractures in total) is necessary.

Table 5-1 presents the mapped geological parameters on each fracture trace. The parameters have been coded according to a specified system that is appropriate for retrieving from SICADA, the SKB data base for the site investigations.

Figure 5-1 shows the outcrop boundary with the survey pattern, and Figure 5-2 the actual trace maps of the two outcrops.

Table 5-1. Mapped geological parameters and coding of the data tables (in Swedish)

1	**Bergartsbeskrivning** Sveriges Geologiska Undersökning's kodsystem har använts avseende ursprungsbergart, struktur, kornstorlek och färg	
	Ursprungsbergart	**kod**
	granit	1058
	pegmatit	1061
	amfibolit	2017
	pegmatitgranit	1098
	leukogranit	1059
	struktur	**kod**
	stänglig	45
	metamorf	98
	diskordans	12
	ådrad	52
	bandad ospec.	53
	kornstorlek-grundmassa	**kod**
	finkornig	2
	fint medelkornig	3
	medelkornig	9
	grovkornig	4
	färg	**kod**
	ljust röd	11
	röd	10
	gråröd	19
	rödgrå	18
	grå	4
	mörkt grå	6
	svart	13
2	**Orientering - terminologi** (gäller alla typer av strukturer i berg) **Strykning/stupning** (eng strike/dip) har använts för plana strukturer **Bäring/fältstupning** (eng bearing/plunge) har använts för linjära strukturer	

Table 5-1. Cont. Mapped geological parameters and coding of the data tables (in Swedish)

3	**Sprickans fysikaliska egenkaper**	
	Sprickspårslängd sprickans synliga längd	
	Sprickavslut	**kod**
	Sprickan iakttas så att stupningen är åt höger. Sprickavslut A är då bakåt, och sprickavslut B framåt. Vid helt vertikal eller horisontell stupning, definieras sprickavslut B i norra kompasshalvan (271-90 grader).	
	Sprickavslut utanför häll (under jord, vatten, växtlighet)	o
	Sprickavslut på häll, men ej mot annan spricka	p
	Sprickavslut mot annan spricka	t
	Sprickan delar sig i y-form (en eller flera gånger)	y
	Sprickavslut mot bergartsgräns. Bergartskod anges i respektive kolumn för bergartsavslut	x
	Sprickans relation till bergartsgränser (utom sprickavslut - se ovan)	**kod**
	Sprickan korsar ingen bergartsgräns	a
	Sprickan korsar en bergartsgräns	b
	Sprickan korsar flera bergartsgränser	c
	Sprickan går i en bergartsgräns. Denna anges i kolumnen "kommentar"	d
	Sprickans vidd	**kod**
	Sprickan bedöms vara öppen	o
	Sprickan bedöms vara sluten	s
	Sprickans form	**kod**
	Sprickan är trappstegsformad med "hack" upp till ca 1 cm (om mer registreras varje sprickdel för sig)	t
	Sprickan är undulerande (vågformig)	u
	Sprickan är plan	p
	Sprickans strävhet (råhet)	**kod**
	Sprickytanan är rå (ojämnheter som sandpapper nr 2 eller grövre)	r
	Sprickan är slät (jämnare än sandpapper nr 2)	s
	Sprickan företer glidyta (harneskyta, slickensides)	h
	Rörelseindikation	**kod**
	Indikation finns på att rörelse ej förekommit längs sprickan (t.ex. bergartsgräns i samma läge på ömse sidor om sprickan)	0
	Sinistral (moturs) rörelse	s
	Dextral (medurs) rörelse	d
	Indikation på att rörelse ser ut att ha förekommit men med okänd riktning	ja
	Ingen av ovanstående rörelseindikationer har kunnat observeras	-

Table5-1. Cont. Mapped geological parameters and coding of the data tables (in Swedish)

4	**Sprickmineralogi och sprickkemi**	
	Sprickfyllnadsmineral	**kod**
	kalcit	30
	klorit	33
	kvarts	36
	zeolit (förmodad)	106
	jaspis (röd, kryptokristallin kiseldioxid, "röd kvarts")	104
	annan eller oidentifierad fyllning, jfr kommentar	45
	sprickfyllnad saknas eller är för tunn för att kunna observeras med lupp.	-
	Omvandling av sidoberg	**kod**
	Berget intill sprickan är rödfärgat <1 cm på varje sida, om ej annat anges under "kommentar"	r
	Berget intill sprickan är starkt rödfärgat <1 cm på varje sida, om ej annat anges under "kommentar"	rr
	Sidoberget är inte omvandlat (motsvarar ISRM** vittringsklass I)	0
	Sidoberget är missfärgat, dock ej rödfärgat (ISRM vittringsklass II)	1
	Sidoberget är omvandlat m.a.p. mineralhårdhet, dock utan sönderfall (ISRM vittringsklass II***)	2
	Omvandling har ej kunnat observeras på grund av missfärgad bergyta	-
	**ISRM = International Society for Rock Mechanics	
	***omvandlingsgrader motsvarande ISRM vittringsklass III - VI förekommer inte i det undersökta området	

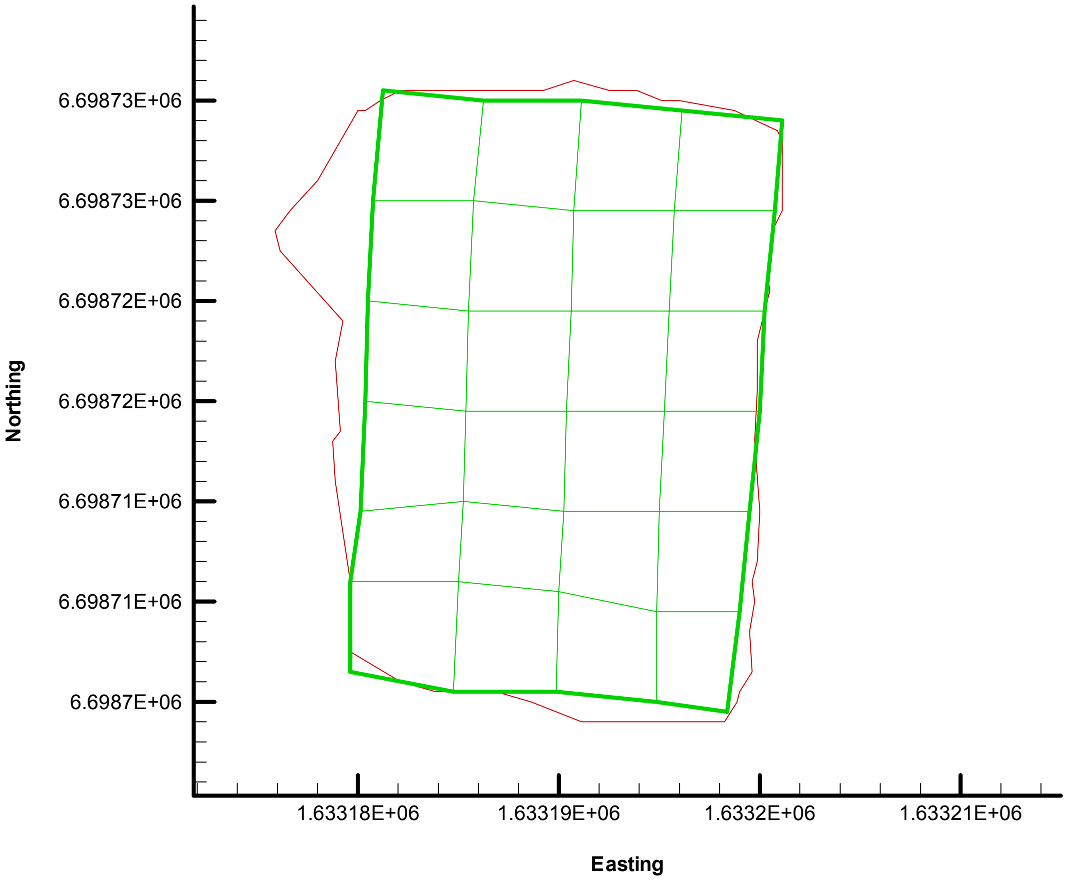

Figure 5-1. *The pattern of plastic bands on the AFM000053 outcrop. The thin line shows the boundary of the outcrop.*

Figure 5-2. *Fracture trace maps of the AFM000053 (left) and AFM000054 outcrops (right)***.**

6 References

/1/ **SKB, 2003.** Bedrock mapping – Forsmark. Stage 1 (2002) – Outcrop data including fracture data. SKB P-03-09.

Appendix

Detailed bedrock mapping at the KFM02 and KFM03 drill sites

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Geological Survey of Sweden
April 2003

Detailed bedrock mapping of stripped outcrops was performed at the drill sites for telescopic drilled borehole KFM02 (AFM000053, ca 600 m^2) and KFM03 (AFM000054, ca 500 m^2). The mapping was carried out at the scale 1:50 allowing documentation of objects ≥ 0.5 m. The aim of the activity was to obtain detailed information on lithologies, contact relations and ductile deformational structures at outcrops subsequently used for detailed fracture mapping. The bedrock mapping was performed according to the methodology described in the method description for bedrock mapping, SKB MD 132.001 (SKB internal controlling document). The areal distribution of lithologies was measured with a theodolite (see section 3.1 in main text). The outcrop data for the two outcrops, AFM000053 and AFM000054, were incorporated into the database created within the project "Bedrock mapping at Forsmark" (an activity carried out within the site investigation programme at Forsmark) and archived in the SKB SICADA database under the field note Forsmark 22. The geometrical data on lithological occurrences and the detailed geological maps are archived as GIS shape-files under the field note Forsmark 49. The GIS data from AFM000053 (KFM02) is stored with the identities: SDEADM.SKB_FO_GEO_1329 (area information) and SDEADM.SKB_FO_GEO_1330 (point information). The GIS data from AFM000054 (KFM03) is stored with the identities: SDEADM.SKB_FO_GEO_1337 (area information) and SDEADM.SKB_FO_GEO_1339 (point information).

Bedrock geology at AFM000053 – Drill site 2

The outcrop is dominated (> 85%) by a greyish red, medium-grained metagranite (Figure A-1). This rock is typically found in surrounding outcrops and is part of a meta-plutonic complex that constitutes the principal lithological unit in the central part of the candidate area at Forsmark (see P-report from Bedrock mapping in Forsmark 2002 /1/).

The metagranite has a distinct penetrative mineral lineation defined by the preferred orientation of biotite and elongate aggregates of quartz and feldspar. The lineation trends approximately 135–140 (SE) and plunges shallowly between 30–35° (to the SE). A mineral foliation defined by biotite and flattened aggregates of quartz and feldspar is locally developed, mainly along contacts to other rocks in the outcrop (see below). A small scale folding is observed in places. The fold axis of these folds is subparallel to the mineral lineation in the metagranite (Figure A-1).

Other rock units in the outcrop are inclusions of fine-grained reddish grey granitoid (about 5%), different generations of pegmatite (< 8%) and amphibolite (< 2%).

The fine-grained granitoid occurs as a larger coherent body in the northern part of the outcrop. A few dm^2 large isolated bodies were also observed along the outer margin of the mapped area (Figure A-2). The fine-grained metagranitoid is typically banded with cm-wide leucocratic, light reddish veins. In places, it is folded (Z-asymmetri), and it is commonly spatially associated with pegmatite (Figure A-1). The fine-grained metagranitoid inclusions also have a high magnetic susceptibility (Table A-1).

Amphibolite occurs as 1x10 cm large schlieren or 10x50 cm large lenses, as drawn out and folded ca 10 cm wide bands, or as 1.5–0.5 m wide lenses spatially associated with white, plagioclase-rich pegmatite. Some bands of amphibolite can be traced across the outcrop, indicating an apparent folding. In places, this type of folded amphibolite has fractured contacts. In the southwestern corner of the outcrop, the occurrence of amphibolite is spatially associated with an apparent bleaching of the metagranite. The magnetic susceptibility is similar in all amphibolite occurrences (Table A-1).

Based on structural relationships, up to three generations of pegmatite can be distinguished in the outcrop. The structurally oldest pegmatite occurs as diffuse, fine- to medium-grained irregular patches or schlieren in the metagranite, in places assembled along the axial surface of folds. This type of pegmatite also commonly occurs in areas of the outcrop with larger lenses of amphibolite, for example in the northwestern and southeastern corners of the outcrop (Figure A-1).

A second type of pegmatite occurs as penetratively deformed NW-striking, commonly ca 2 dm wide, medium- to coarse-grained irregular dykes (Figure A-1), typically with a fairly high amount of biotite. The metagranite has commonly developed a distinct high-temperature ductile foliation along the contacts to this type of pegmatite.

The structurally youngest generation of pegmatite occurs as NNE-striking, subvertical to steeply dipping distinct dykes that cross cut all other rock units observed in the outcrop (Figure A-2). They vary in thickness from a couple of dm to a couple of cm. These thin dykes can be continuously traced along strike across the outcrop.

Table A-1. Magnetic susceptibility (SI-units*10^{-5}) of principal lithologies at AFM000053.

Metagranite	200, 350, 400, 400, 450, 450, 500, 650
Fine-grained metagranitoid	2000, 2000, 2500, 1000, 2500, 2500, 2500, 3000, 3000, 3000, 3500, 3500
Amphibolite (all)	60, 60, 70, 75, 80, 65, 65, 70, 75, 80
Diffuse pegmatite schlieren	5, 10, 10, 0, 20, 10, 10, 15, 0
Deformed pegmatite (NW-trending)	15, 0, 0, 150, 20, 20, 10, 10, 10, 25
Slightly deformed, discordant pegmatite dykes (NNE-trending)	10, 25, 40, 70, 40, 200, 100, 75, 1500, 25

Figure A-1. *Schematic geological map of stripped outcrop at drill site 2 (AFM000053).*

Figure A-2. *Photograph from the southwestern outer margin of the AFM000053 outcrop, showing a veined metagranitoid inclusion in strongly lineated metagranite (lower left) cross-cut by a deformed NW-striking irregular pegmatite dyke which, in turn, is cut by a NNE-striking slightly deformed pegmatite dyke.*

Bedrock geology at AFM000054 – Drill site 3

The outcrop is dominated by pegmatite (Figure A-3), mainly in the form of unequigranular metamorphosed pegmatitic granite (55% of outcrop). Pegmatitic granite is also common in surrounding natural outcrops and appears to be a common rock type in this part of the candidate area (see P-report from Bedrock mapping in Forsmark 2002 /1/).

Medium-grained, greyish red metagranite occurs as large (5–20 m^2) irregular domains (inclusions) in the pegmatitic granite. The metagranite has a distinct penetrative mineral lineation defined by the alignment of biotite and strung out aggregates of quartz-feldspar. In places, a less distinctive biotite-feldspar-quartz mineral lineation is observed also in the pegmatitic granite. The contacts between the pegmatitic granite and the metagranite are sometimes diffuse; in places the metagranite occurs as indistinct lenses or schlieren in the pegmatitic granite, indicating incipient assimilation. Sharp contacts are sometimes observed, but all contacts have been superimposed by subsequent ductile deformation. Field relations suggest that the metagranite was intruded and broken up by the pegmatitic granite.

Amphibolite (> 3%) occurs mainly as 0.5–5.0 m^2 large domains within the inclusions of metagranite (Figure A-3). Minor occurrences of amphibolite are observed also along contacts between the metagranite and the pegmatitic granite (Figure A-3). However, the predominance of amphibolite within inclusions of metagranite indicates that the amphibolite contacts, in general, did not act as zones of weakness during emplacement of the pegmatitic granite.

Minor occurrences of a fine-grained grey to reddish grey metagranitoid were observed in one of the inclusions of strongly lineated medium-grained metagranite in the southern part of the outcrop (Figure A-3). The fine-grained metagranitoid has a weak mineral lineation macroscopically defined by the alignment of biotite. Cross-cutting structural relations to the ductile deformation fabric in the side rock were not observed and it is unclear whether the fine-grained metagranitoid represents a younger intrusion or an inclusion of an older rock.

Distinct dykes, patches and lenses of pegmatite, commonly observed in surrounding outcrops, were difficult to distinguish within the pegmatitic granite, and have therefore not been mapped as distinct lithological units within this rock unit. Veins and patches of pegmatite are, however, clearly distinguishable within non-pegmatitic lithologies such as in metagranite, amphibolite and fine-grained metagranitoid (Figure A-3).

The structurally youngest rock is an approximately 5 cm wide discordant NNE-striking, subvertical to steeply dipping leucocratic granitic dyke. The dyke can be followed along strike through the outcrop and is seen to cross cut both ductile deformational structures and lithological contacts in the host rocks (Figure A-3).

Table A-2. Magnetic susceptibility (SI-units*10^{-5}) of principal lithologies at AFM000054.

Pegmatitic granite	2000, 30, 40,100, 800, 200, 65, 100, 90
Medium-grained strongly lineated metagranite	450, 85, 750, 350, 250, 300, 600, 800
Amphibolite (all)	40, 60, 40, 40, 40, 50, 60, 60

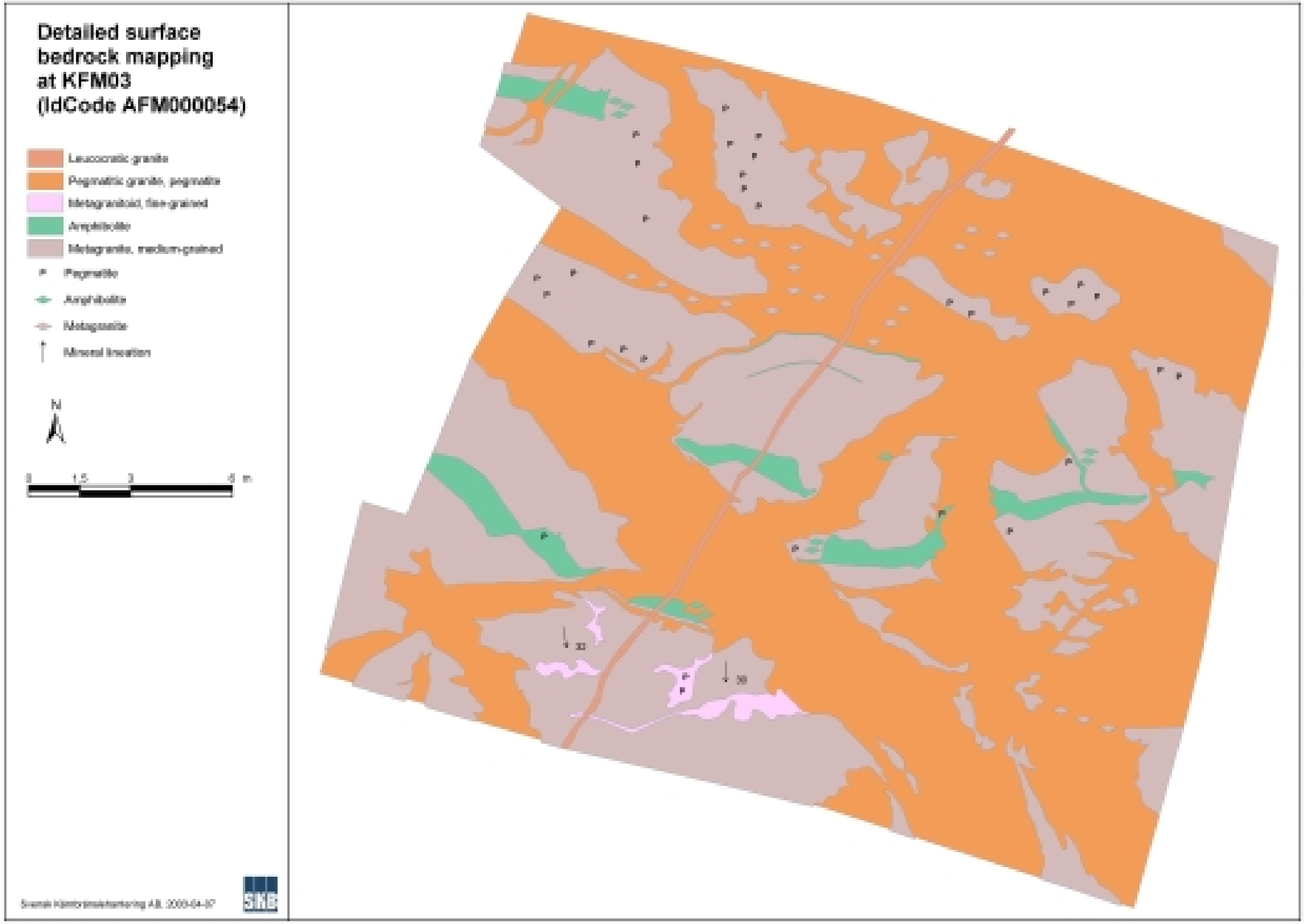

Figure A-3. *Schematic geological map of stripped outcrop at drill site 3 (AFM000054).*