P-03-115

Forsmark site investigation

Detailed fracture mapping of the outcrops Klubbudden, AFM001098 and Drill Site 4, AFM001097

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December 2003

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Contents

1 Introduction

SKB performs site investigations for localisation of a deep repository for high level nuclear waste. The site investigations are performed at two sites; Forsmark, located some 120 km to the North of Stockholm and Simpevarp, located near the town of Oskarshamn, and 225 km to the South-Southwest of Stockholm. This document reports the data gained during detail fracture mapping of the outcrops Drill Site 4, AFM001097 and Klubbudden, AFM001098, being one of the activities performed within the site investigations at Forsmark during May and June 2003. The bedrock mapping of the sites is presented in Appendix 1.

The detail mapping campaign was conducted according to Activity Plan AP PF 400-03-37 (SKB internal controlling document).

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 is expected to indicate the geometric properties for fractures in the trace length interval between 0.5 m to 10 m at the sites. It should be noticed, that the term fracture is used as a wide concept, comprising old, sealed or closed fractures, so called joints, as well as open fractures. 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 sites.

The location of the two investigated outcrops can be seen in Figure 2-1. Outcrop Klubbudden, AFM001098 is a natural outcrop, Drill Site 4, AFM001097 has been reamed from soil cover, prior to mapping. The outcrops are approximately 325 and 525 m^2, respectively.

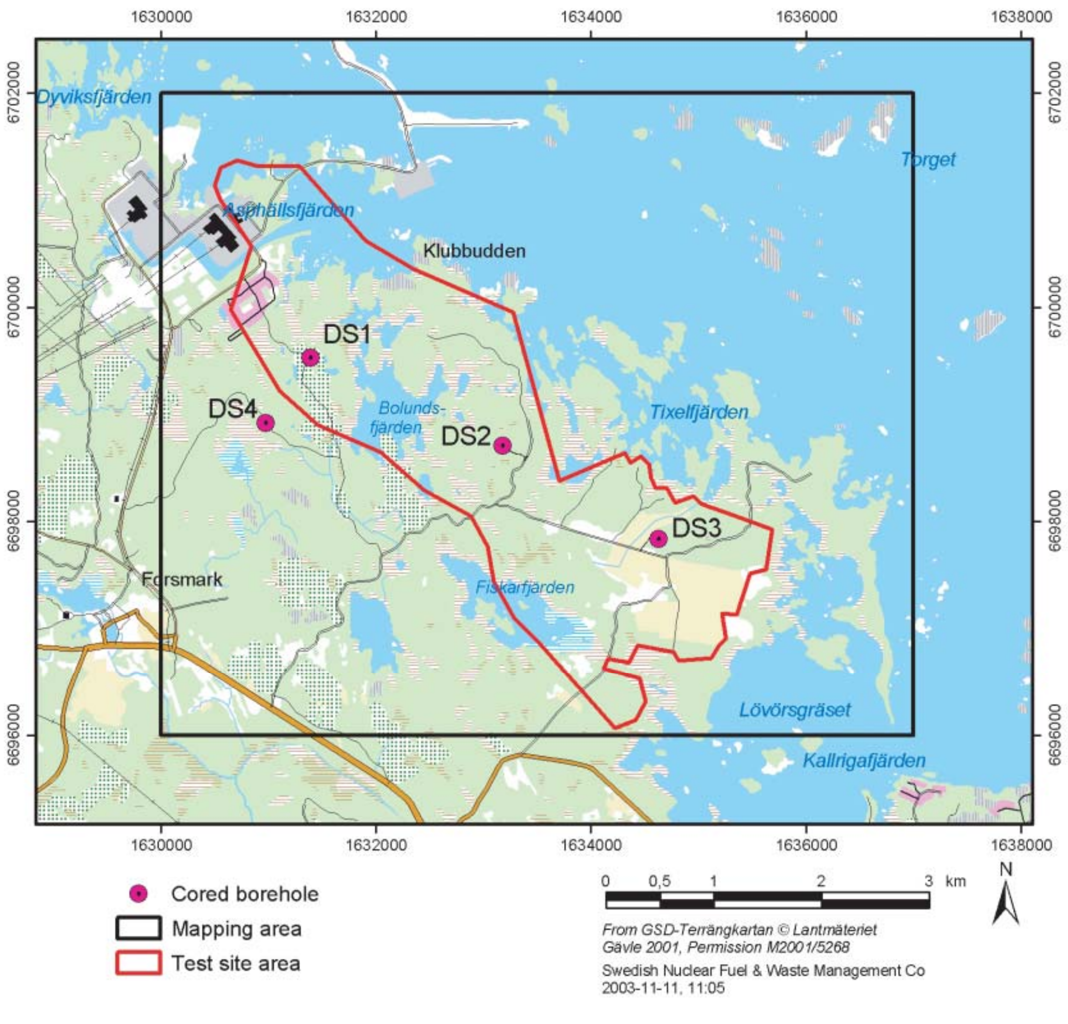

Figure 2-1. *Locations of outcrops AFM001098 Klubbudden, and AFM001097 Drill Site 4, (DS4) in the Forsmark area.*

3 Equipment and methods

The fracture trace geometry was measured with a Geodimeter 640S Total Station. In theory, the survey instrument 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 error is often 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 is based on the survey results 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 from two, up to several points 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 tend to slow down the survey substantially. The work was performed in a way, that there was a balance between mapping speed and degree of detail of the mapped fracture traces.

When the position of each point along a fracture trace was recorded, orientation and all other fracture parameters were mapped by hand, using a standard protocol, 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

At Drill Site 4, the survey instrument was positioned outside the outcrop and was calibrated against three fix points on the outcrop, and to a fix point in the regional coordinate system, positioned by the SKB Survey Team. This provided the coordinate translation to our local outcrop systems. The survey instrument 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 survey results were converted to the RT90 system after each completed survey.

At Klubbudden, no regional survey point existed. The Golder Team established four fix points, with preliminary Numbers 101, 102, 103, and 104, to which the fracture survey was related. Later these four points were surveyed, and related to the regional point system by the SKB Survey Team.

4.2 Execution of tests/survey

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 grid of plastic tape was applied over the outcrop as a help to divide the outcrop in sub domains during the mapping campaign. These squares have no imprint on the collected data. Figure 5-1 and Figure 5-2 show the grids and the mapped areas.

2. The survey instrument was calibrated against fix points in the vicinity of the outcrop, as specified in Section 4.1, above.

3. Each fracture trace was labelled at its start (A) and end (B) points on the outcrop, in order to keep track of surveyed fractures. The used truncation for fracture trace length for fracture mapping was 0.5 m.

4. Each fracture location and length was surveyed with two or more points with the survey instrument. The number of points on each fracture was controlled by its complexity. Special attention was given to the ends of certain fractures, in order to determine the fracture termination mode.

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 Tables 5-1, 5-2, and 5-3.

6. Scan line measurements were performed along two 10 m long, approximately orthogonal scan lines. Scan line traces are shown in Figure 5-1 and Figure 5-2.

7. Fracture locations were measured along the scan line. The used truncation for fracture trace length for scan line mapping 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 labels.

10. Digital conversion of survey instrument data to RT90-RHB70 coordinate data

11. Conversion to an AutoCAD DWG 14 file of fracture traces, square pattern and outcrop boundary.

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

13. Report production.

4.3 Data handling

The deliverables to SKB for fracture mapping of Drill Site 4, AFM001097 and Klubbudden, AFM001098 (SICADA Field note: Forsmark 173) include:

1. Geological parameters for the areal mapping of the outcrops:
   Files: Ytkartering_klubb_kfm4.xls

2. Geological parameters for the scan line mapping of the outcrops.
   Files: Linjekartering_klubb_kfm4.xls

3. Coordinate points of each survey result of the fracture traces.
   Files: Sprickor_KFM04_Kod.PXY, Sprickor_KLUBBUDDEN_KOD.PXY

4. AutoCAD DWG R14 files for the outcrop boundary and fracture traces. The DWG trace map file has one fracture trace on each layer.
   Files: KONTUR_KFM04.dwg, SPRICKOR_KFM04_KOD.dwg, KONTUR_KLUBBUDDEN.dwg, SPRICKOR_KLUBBUDDEN_KOD.dwg

5. Digital photos and description from the outcrops.
   Files: Leverans_Photo_Borrpl4_Klubb.xls (contains filenames and captions for all photos in.zip files), Foto_Borrpl4.zip, Foto_Klubbudden.zip

6. Controlling document for metadata for GIS archiving.
   Files: AFM001097_TRACES.xls, AFM001098_TRACES.xls

7. Report (this).
   Filename: Rapport_Klubbudd_mfl_V1.02.doc

5 Results

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

- Area fracture mapping.
- Scan line fracture mapping.

However, in addition to the method described in the activity plan, fractures have been surveyed directly by using survey results on several locations along each fracture trace, and not mapped by hand on a drawing 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 digital values are obtained immediately, while digital conversion of hand drawn data is time consuming.

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 of 0.5 m) in each square metre of the outcrop. Drill Site 4, AFM001097 featured 2.3 fractures per square metre and Klubbudden, AFM001098 3.2 fractures per square metre.

The scan line mapping was performed along two approximately perpendicular 10 m lines at each outcrop, one trending North-East and one trending North-West. The truncation length for fracture traces in the scan line survey was 0.2 m. The fracture frequency along the North-East trending lines is 2.9 fractures per metre for Drill Site 4, and 5.4 for Klubbudden. Along the North-West trending lines, the figures are 1.7 fractures per metre and 3.0 fractures per metre, respectively.

Table 5-1, Table 5-1, and Table 5-3 present the mapped geological parameters on the fracture traces. The parameters have been coded according to a specified system, which is appropriate for retrieving from SICADA, the SKB data base for the site investigations.

Figure 5-1 shows an example of an outcrop mapping grid (Drill Site 4). Figure 5-3 and Figure 5-4 demonstrate the actual fracture trace maps of Drill Site 4 and Klubbudden, respectively.

Table 5-1. Bedrock codes and description. SKB code system has been used to describe rock, structure, grain size and colour.

code	**Rock type** (two first digits relate to the Forsmark site)
111058	Granite, fine- to medium-grained
101061	Pegmatite, pegmatitic granite
111051	Granitoid, metamorphic *(COMMENT: A general rock name which refers to all metamorphosed, quartz-rich, felsic intrusive rocks)*
101051	Granite, granodiorite and tonalite, metamorphic, fine- to medium-grained
101058	Granite, metamorphic, aplitic
101057	Granite to granodiorite, metamorphic, medium-grained
101056	Granodiorite, metamorphic
101054	Tonalite to granodiorite, metamorphic
101033	Diorite, quartz diorite and gabbro, metamorphic
101004	Ultramafic rock, metamorphic
102017	Amphibolite
108019	Calc-silicate rock (skarn)
109014	Magnetite mineralization associated with calc-silicate rock (skarn)
109010	Sulphide mineralization
103076	Felsic to intermediate volcanic rock, metamorphic
103066	Mafic volcanic rock, metamorphic
106000	Sedimentary rock, metamorphic
code	**structure**
45	lineation
20	gneissic
98	metamorphic, unspecified
12	discordance
52	veined
53	banded
code	**appearance**
31	vein
code	**grain-size of matrix**
2	fine grained
3	fine to medium grained
9	medium grained
4	coarse grained
code	**colour**
11	light red
10	red
19	greyish red
18	reddish grey
4	greyish red
6	dark grey
13	black
	Orientation (terminology applied on all structures in bedrock)
	Strike/dip (used for all planar structures)
	Bearing/plunge (used for all linear structures)

Table 5-2. Physical properties of fractures with codes.

	Fracture trace = Visible length of the fracture in metres
code	**Fracture Termination**
	Right-hand rule. Fracture termination A is starting point and B ending point. At vertical dip, the strike (B-direction) is against the northern hemisphere (271–90 degrees). Horizontal fractures are defined with strike=0
o	Termination outside outcrop (under soil cover, water or vegetation)
p	Termination within outcrop, not against any other fracture
t	Termination against another fracture
y	Fracture terminates in a y-shape (one or several times)
x	Fracture terminates against a rock boundary. Rock code is given in column for rock termination, respectively
code	**Fracture relation to rock boundary** (except termination against code o–y, see above)
a	Fracture crosses no rock boundary
b	Fracture crosses one rock boundary
c	Fracture crosses several rock boundaries
d	Fracture is oriented in a rock boundary (rock types given in "comment" column)
code	**Fracture aperture**
o	Fracture appears to be open
s	Fracture appears to be closed
code	**Fracture shape**
t	Fracture is stepped up to approximately 1 cm (if the distance is greater, each part is mapped separately)
u	Fracture is undulating
p	Fracture is planar
code	**Fracture roughness**
r	Fracture surface is rough
s	Fracture surface is smooth
h	Fracture surface indicate movement (e.g. slickenside)
code	**Indication of movement**
0	There is an indication that movement have not occurred along the fracture (e.g. no displacement along a crossing rock boundary)
s	Sinistral
d	Dextral
1	Indication of movement with unknown direction
	None of above indications has been observed

Table 5-3. Fracture mineralogy and chemistry with codes.

code	Fracture minerals
30	calcite
33	Chlorite
36	quartz
106	zeolite (assumed)
104	jasper (red chalcedony)
45	other or unidentified fill
code	**Alteration of side-rock**
r	The rock in the vicinity of the fracture is red coloured < 1 cm on each side, unless otherwise indicated
rr	The rock in the vicinity of the fracture is deep red coloured < 1 cm on each side, , unless otherwise indicated
0	No alteration (equivalent to ISRM** weathering class I)
1	County rock is discoloured, not red (ISRM weathering class II)
2	Weathering due to mineral hardness with no disintegration (ISRM weathering class III)

** International Society for Rock Mechanics Classification System

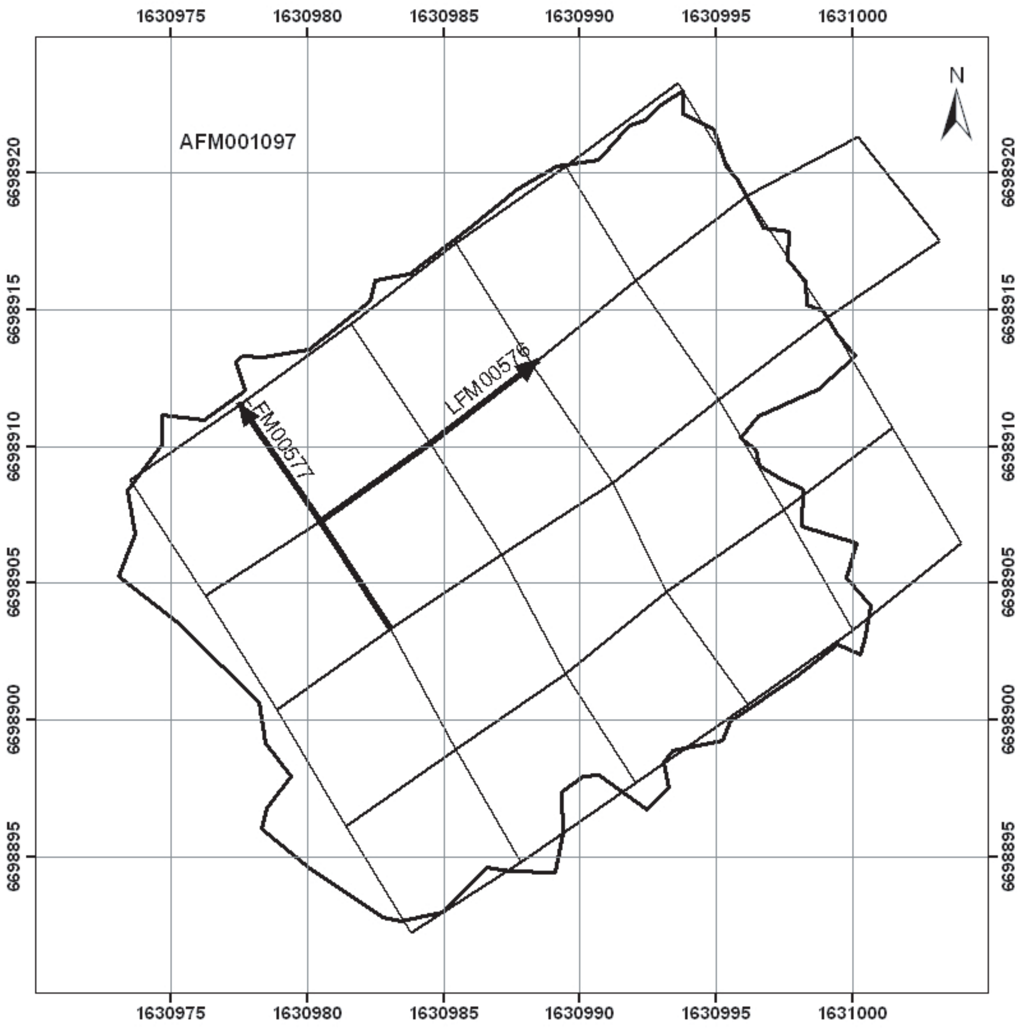

Figure 5-1. Mapping grid and mapped area at Drill Site 4, AFM001097 outcrop also showing the scan lines LFM00576 and LFM00577.

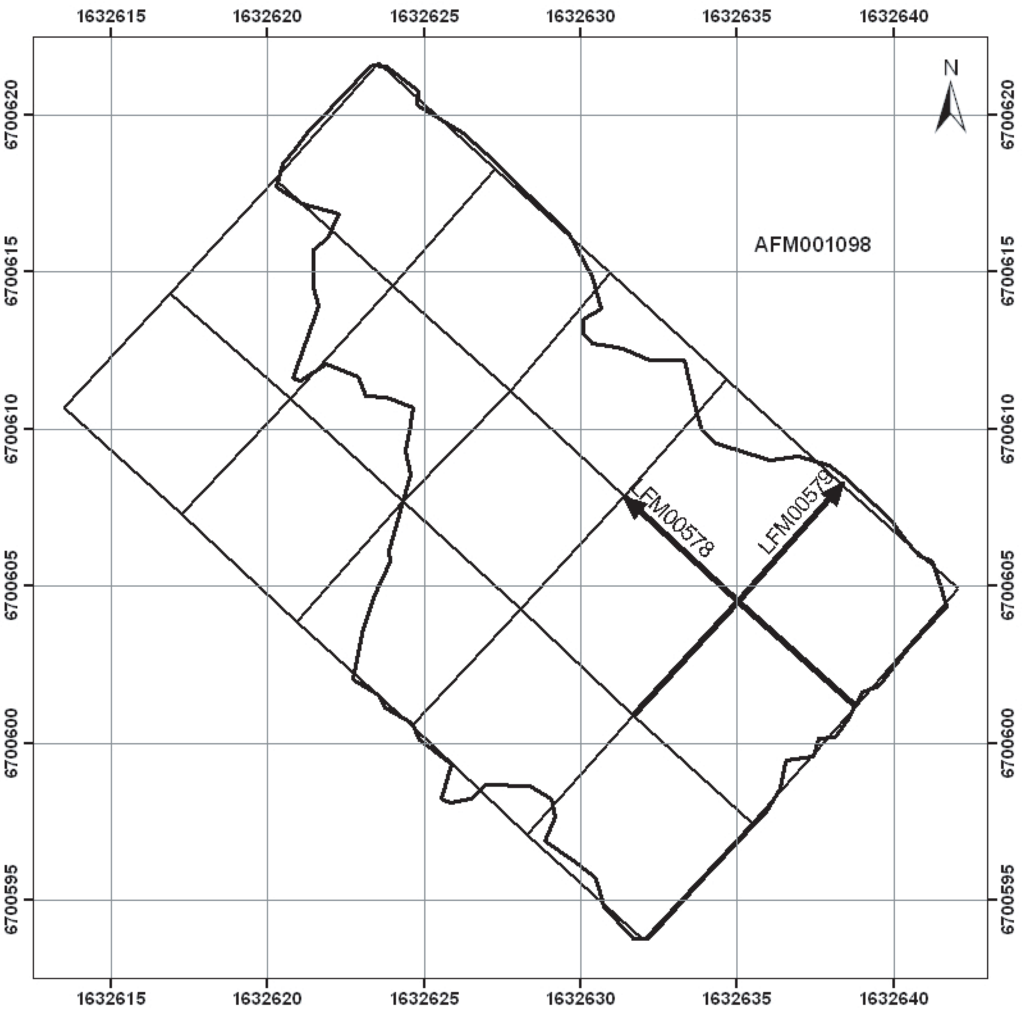

Figure 5-2. Mapping grid and mapped area at Klubbudden, AFM001098 outcrop also showing the scan lines LFM00578 and LFM00579.

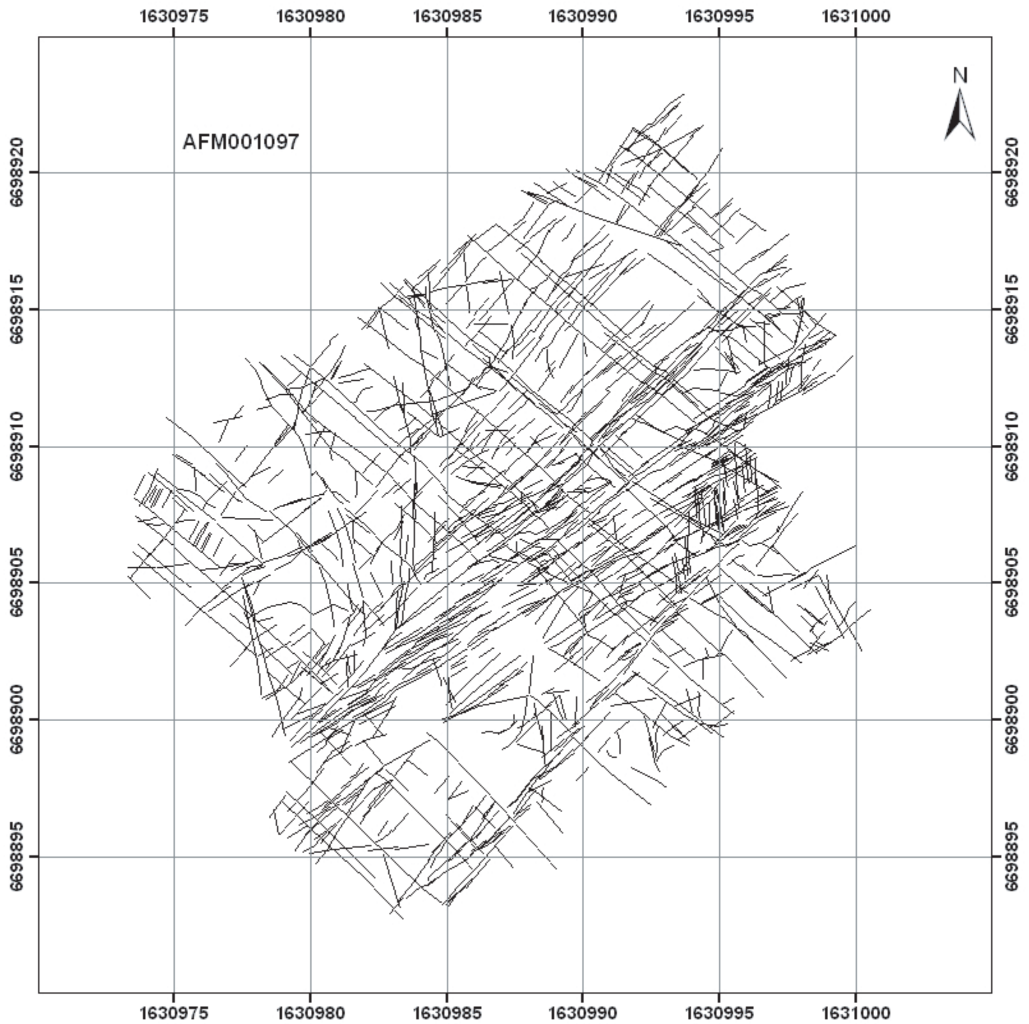

Figure 5-3. Fracture trace map of Drill Site 4, AFM001097 outcrop. The north-eastern band of fractures that crosses the site is a part of a fault zone (see Appendix 1). The dip of the fault is estimated to 85° towards north-west, judging from the dip of the majority of the fractures that constitute the fault zone.

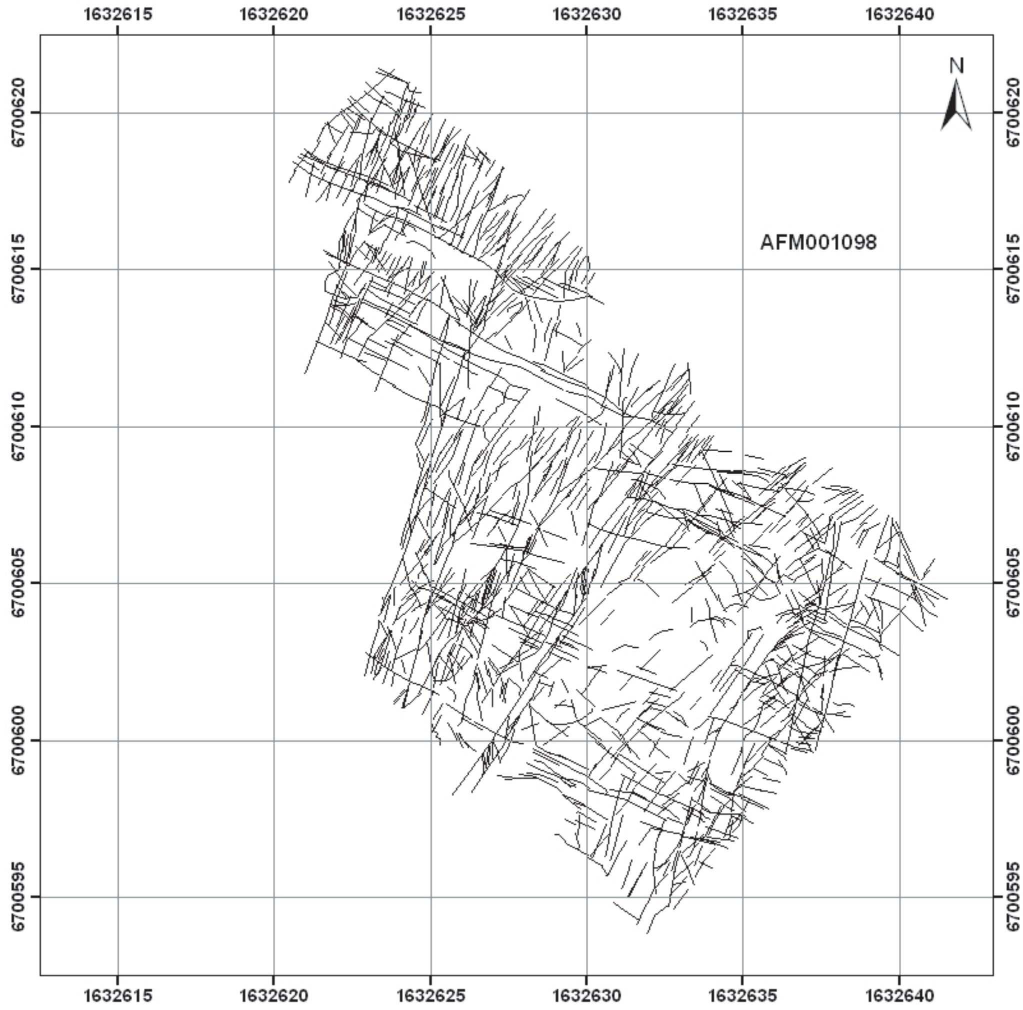

Figure 5-4. *Fracture trace map of Klubbudden, AFM001098 outcrop.*

Appendix 1

Detailed bedrock mapping of a shoreline outcrop at Klubbudden (AFM001098) and at Drill site 4 (AFM001097).

Katarina Persson Nilsson
Geological Survey of Sweden

October 2003, revised April 2004

Detailed bedrock mapping has been carried out at two localities. The first locality is a shoreline outcrop along the coastal area referred to as Klubbudden (AFM001098, c. 375m^2) and the second locality is a stripped outcrop at Drill site 4 (AFM001097, c. 525m^2). Both areas were mapped at the scale 1:50 and show objects ≥ 0.1 m in width. The mapping focused on rock type, contact relations and ductile deformational structures. The bedrock maps were subsequently used for the detailed mapping of fractures.

The bedrock mapping was carried out according to the method description for bedrock mapping, SKB MD 132.001, (SKB internal controlling document). The areal distribution of the different rock types was measured with a Geodimeter 640S Total Station (see chapter "Equipment and methods"). The data for both outcrops are presented in a separate database with the same format as that used in connection with the project "Bedrock mapping at Forsmark". The outcrop data are archived in the SKB SICADA database under the field note Forsmark 22. The detailed geological maps are archived as GIS shape-files under the field note Forsmark 196.

Klubbudden (AFM001098)

Five rock types are present in the mapped area at Klubbudden – aplitic metagranite (dominant), pegmatite, amphibolite, finely medium-grained metagranitoid (granite, granodiorite and tonalite, metamorphic, fine- to medium-grained on map) and a medium-grained metagranite-metagranodiorite. These rocks belong to a bedrock unit that can be traced along the coast, northeast of the candidate area.

The *aplitic metagranite* (pale brown on Figure A-1) displays a recrystallized mineral fabric and shows a distinctive banded structure (Figure A-2) with leucocratic white to greyish-red bands. Elongate aggregates of quartz and feldspar as well as a preferred orientation of biotite define a strong mineral lineation and a penetrative foliation. The foliation dips moderately to steeply (55°-90°) with a strike of approximately 107°. In some parts, the aplitic metagranite has "darker spots" on horizontal surfaces consisting of larger oriented aggregates of biotite (and to some extent hornblende) that display a predominantly linear mineral fabric (L-tectonite). The lineation plunges 30°-40° to the ESE (c. 110°). The areas where the aplitic metagranite is richer in biotite aggregates are limited and marked with dashed lines on Figure A-1.

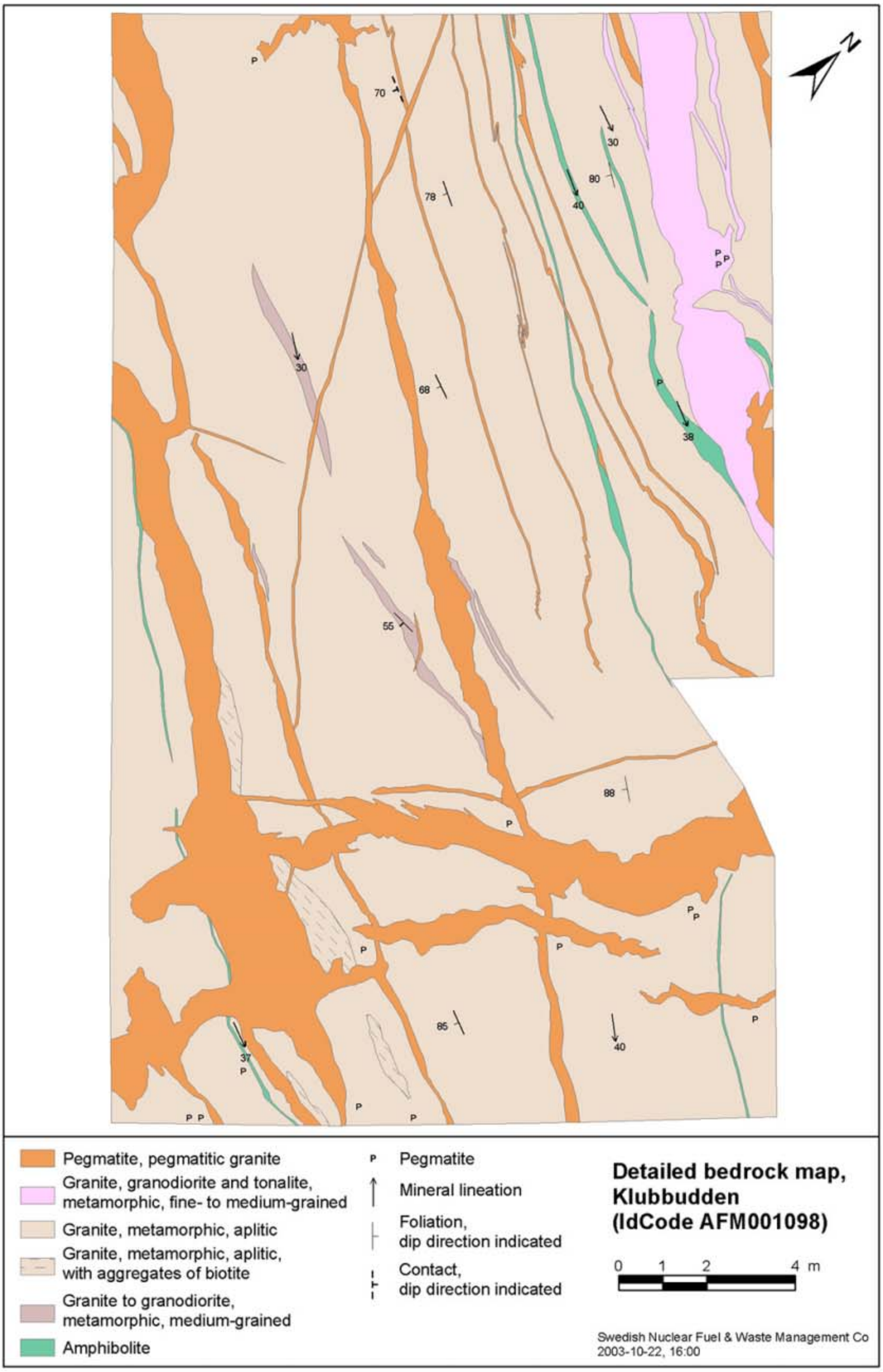

Figure A-1. *Geological map of Klubbudden (AFM001098).*

The aplitic metagranite is intruded by *pegmatites* and also affected by pegmatite schlieren in near vicinity to these pegmatites ("P" in Figure A-1). A clear distinction between two different generations of pegmatite has been made at only one locality in the mapped area (Figure A-3). The older pegmatites are affected more strongly by deformation than the younger pegmatites (Figure A-4). Ptygmatic folding of the older pegmatites also indicates a component of flattening perpendicular to the foliation within the aplitic metagranite. No precise measurements of fold axes were made but the approximate trend is sub-parallel to the mineral lineation in the aplitic metagranite.

The younger pegmatites are generally coarser-grained than the older generation. However, the grain-size is variable within the same pegmatite dyke. The grain-size ranges from medium- to coarse-grained, with a trend of smaller grain-sizes in minor, narrower dykes and coarser grains in larger, wider dykes. The younger pegmatites show complex cross-cutting relationships that indicate only minor age differences between the various dykes (see southern corner on Figure A-1). The younger pegmatites both follow the regional foliation as well as cross-cut the foliation. However, even the cross-cutting pegmatites are deformed and are commonly folded by ptygmatic folding or by buckle folding. Z-asymmetry of folds is observed in both the younger and older generation of pegmatites. The fine-grained aplitic metagranite is often "pinched in" at the necks of boudinaged larger pegmatites.

A finely medium-grained metagranitoid is exposed in the northern part of the mapped area (Figure A-1). This metagranitoid is younger and less deformed than the aplitic metagranite. The metagranitoid is grey and equigranular. Locally, pegmatite-schlieren with coarser grain-sizes and aggregates of biotite and megacrysts of magnetite are present. There is no obvious mineral lineation or foliation in this metagranitoid. It has a higher magnetic susceptibility than the aplitic metagranite (Table A-1).

Amphibolite occurs as boudinaged lenses or bands with a width that varies from <0.1 m up to 0.45 m. The amphibolites are fine-grained, dark grey, strongly foliated and display a strong lineation defined by a clear mineral orientation of hornblende. The same foliation is developed in both the amphibolites and the surrounding aplitic metagranite.

In the central part of the mapped area, there are lenses of *medium-grained, dark reddish-grey metagranite to metagranodiorite* within the aplitic metagranite (Figures A-1 and A-5). These lenses are also cross-cut by pegmatites. Aggregates or needles of biotite and hornblende define a strong mineral lineation and foliation in the metagranite-metagranodiorite. Minor mullion structures indicate a lower competence in the metagranite-metagranodiorite compared to that in the surrounding aplitic metagranite.

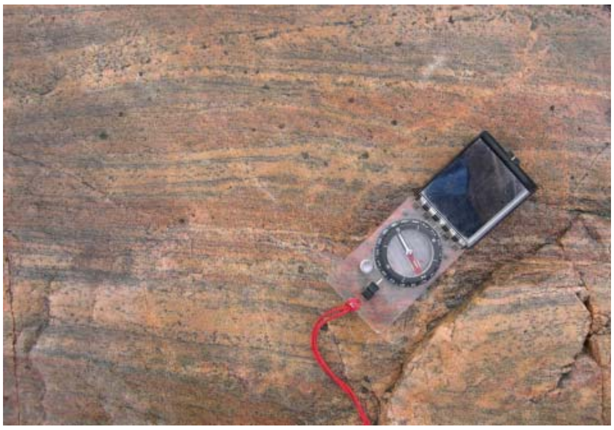

Figure A-2. *Banded, aplitic metagranite. Klubbudden, Forsmark. (photo: Katarina Persson Nilsson)*

Figure A-3. *Two generations of pegmatite outlined by yellow chalk. In this picture, older pegmatite is parallel to the general foliation whereas younger pegmatite cross-cuts the foliation and the older pegmatite. Klubbudden, Forsmark. (photo: Katarina Persson Nilsson)*

Figure A-4. *Intensely folded pegmatite that belongs to the older generation of pegmatites. Klubbudden, Forsmark. (photo: Katarina Persson Nilsson)*

Figure A-5. *A metagranite-metagranodiorite with white, leucocratic borders occurs as lenses within the banded, aplitic metagranite. Klubbudden, Forsmark. (photo: Katarina Persson Nilsson)*

Table A-1. *Magnetic susceptibility (SI-units * 10-5) of rock types at AFM001098.*

Metagranite (aplitic, leucocratic)	34, 2, 92, 12, 7, 46, 213, 266
Finely medium-grained metagranitoid	727, 387, 568, 352, 134, 556, 248, 290
Amphibolite	59, 56, 38, 38, 44, 57, 63, 40
Medium-grained metagranite-metagranodiorite	12, 9, 13, 10, 7, 9, 6, 5
Pegmatite	1, 17, 4, 18, 6, 6, 5, 2, 16, 14, 8, 7, 9, 3

Drill site 4 (AFM001097)

Six types of bedrock are exposed in the mapped area at Drill site 4 – felsic- to intermediate meta-volcanic rocks, metatonalite-metagranodiorite, pegmatitic granite, medium-grained metagranite, skarn and amphibolite (Figure A-6). The dominant rock units are the felsic- to intermediate meta-volcanic rocks and rocks ranging in composition from metatonalite to metagranodiorite (shown with yellow and brown colours, respectively, in Figure A-6). All rocks are intensely deformed and form a banded sequence. Only the pegmatitic granite is, in part, discordant to the banding. The banded sequence is, in turn, affected by faulting with a dextral component of displacement schematically visualized in Figure A-6. Fracture fillings along the fault zone consist of calcite (Figure A-7).

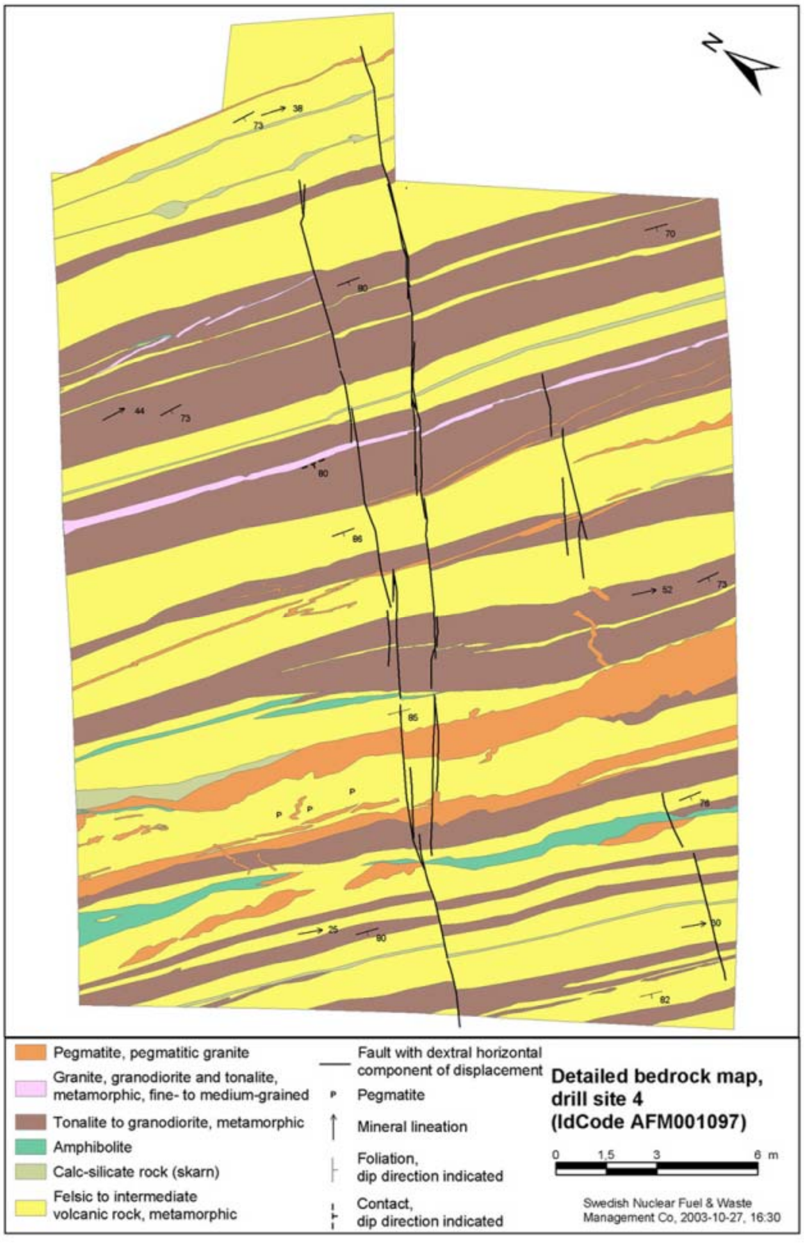

***Figure A-6**. Geological map of Drill site 4 (AFM001097).*

The *meta-volcanic rocks* are fine-grained, grey and range from felsic to intermediate in composition. Field assessment suggests a dominance of dacitic composition. In some places, the meta-volcanic rocks are strongly deformed (mylonitic-ultra mylonitic) and form bands usually less than 1 cm thick. In other places, the same rock is more homogeneous and appears less deformed, forming bands up to 1.5 m thick. All rock-units show a penetrative foliation parallel to the banding and a strong mineral lineation. The foliation is steep (70°-90°), with a strike of approximately 127°. No precise measurements of fold axes can be made in the area but the axes are approximately parallel to the mineral lineation. Tight or isoclinal folds display axial surfaces parallel to the foliation. Interlayered in the meta-volcanic units are bands and lenses of *skarn* (Figure A-8) and fine-grained *amphibolite.* The *amphibolites* are dark grey, strongly foliated and display a strong lineation defined by a clear mineral orientation of hornblende.

The grey *metatonalite-metagranodiorite* appears to be a coarser, medium-grained variety of the dacitic meta-volcanic rocks (Figure A-9). The primary relationship between these two rock types is unclear, but thin, finer-grained layers and lenses of the meta-volcanic rock exist within the coarser metatonalite-metagranodiorite and vice versa. Coarser feldspar grains in the metatonalite-metagranodiorite are affected by the deformation. The metatonalite-metagranodiorite also shows a penetrative foliation and a strong mineral lineation. Occasional pyrite megacrysts have also been observed within the metatonalite-metagranodiorite. There are no differences in magnetic susceptibility between the metatonalite-metagranodiorite and the felsic to intermediate meta-volcanic rocks (Table A-2).

In the central part of the mapped area and towards the northeast, there are thin dykes (≤3 dm) of a greyish red, *finely medium-grained metagranite* (granite, granodiorite and tonalite, metamorphic, fine- to medium-grained on map) within the metatonalite. The metagranite contains pegmatitic lenses or patches (Figure A-10). Compared to the younger pegmatitic granite, this metagranite is richer in biotite and has a clear foliation defined by the orientation of the biotite. The orientation of the metagranite dykes is also parallel or sub-parallel to the foliation/banding in the outcrop. The medium-grained parts of the metagranite show C' - structures indicating a dextral component of movement on horizontal surfaces (Figure A-11). The orientation of the meta-granitic dykes as well as the C' -structures indicate that the dyke intruded at a fairly early stage in the deformational history compared to the younger pegmatitic granites that show considerably less deformation.

The *pegmatitic granite* is fine- to medium-grained and, in part, pegmatitic with areas and slivers of coarser grain-size. The pegmatitic parts have a porphyritic appearance with rounded, larger feldspars. There are usually no sharp boundaries between the medium-grained and the pegmatitic parts. Pegmatites, that cross-cut all rock units and are oriented approximately perpendicular to the foliation, are considered to be the youngest rocks in the area. Even these pegmatites are deformed and show folding.

Several semi-ductile shear zones that deform the penetrative foliation and tectonic banding structure have been observed at Drill site 4. The semi-ductile shear zones predominantly display a dextral component of movement on the outcrop surface (shear direction c. 330°; Figure A-11) but conjugate sinistral shear zones also exist (shear direction c. 290°).

Figure A-7. *Fault zone with approximately NE strike and a white mineral along the fractures. The fault displaces the bedrock with a dextral component of displacement (cf. Figure A-6). View to the southwest. (photo: Katarina Persson Nilsson)*

Figure A-8*. Skarn lens (diopside) within felsic meta-volcanic rock. Metatonalite-metagranodiorite occurs in the upper part of the photo. (photo: Katarina Persson Nilsson)*

Figure A-9. *Medium-grained metatonalite-metagranodiorite. (photo: Katarina Persson Nilsson)*

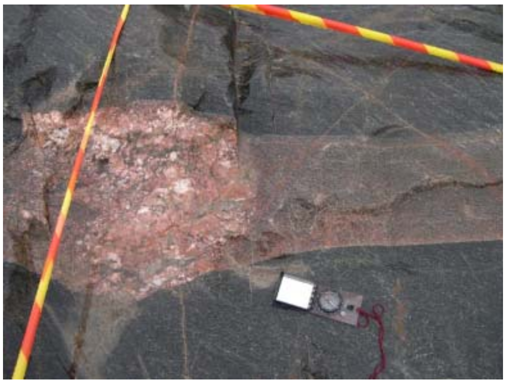

Figure A-10. *Meta-granitic dyke with irregular patches of pegmatite. (photo: Katarina Persson Nilsson)*

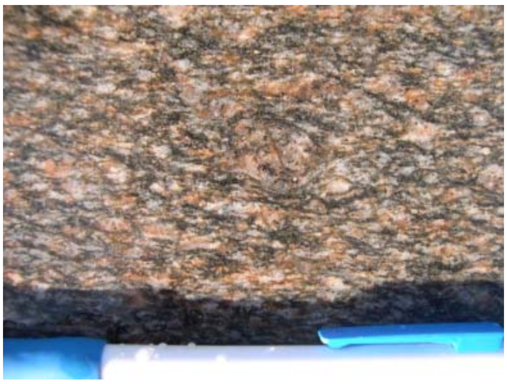

Figure A-11*. Dextral C'-structures in the metagranite. The foliation at this locality is 118/72 (right-hand-rule) and the C'-structures cut this foliation at an angle of c. 25˚. (photo: Katarina Persson Nilsson)*

Figure A-12*. Semi-ductile dextral shear zone with an apparent shear direction of 330˚. (photo: Katarina Persson Nilsson)*

*__Table A-2__. Magnetic susceptibility (SI-units * 10^{-5}) of rock types at AFM001097.*

Felsic- to intermediate meta-volcanic rocks	29, 32, 32, 31, 31, 41, 38, 44
Metatonalite-metagranodiorite	32, 36, 51, 20, 33, 32, 42, 30
Amphibolite	67, 58, 38, 52, 70, 62, 61, 56
Finely medium-grained metagranite	50, 203, 1220, 793, 425, 525, 283, 230
Pegmatite	48, 18, 67, 91, 64, 1, 291, 71, 45, 42