P-07-233

Forsmark site investigation

Boremap mapping of core drilled borehole KFM06C

A comparative study of mapping in Oskarshamn and Forsmark

Jan Ehrenborg, Mírab Mineral Resurser AB

Peter Dahlin, Geosigma AB

December 2008

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co

Box 250, SE-101 24 Stockholm
Phone +46 8 459 84 00

ISSN 1651-4416
SKB P-07-233

Forsmark site investigation

Boremap mapping of core drilled borehole KFM06C

A comparative study of mapping in Oskarshamn and Forsmark

Jan Ehrenborg, Mírab Mineral Resurser AB

Peter Dahlin, Geosigma AB

December 2008

Keywords: KFM06C, Geology, Drill core mapping, Boremap, Fractures, BIPS, Forsmark.

Abstract

A comparative study has been accomplished for the Boremap mapping at the Oskarshamn and Forsmark investigation sites. The mapping was carried out in accordance with the methodology used in mapping of deep cored boreholes.

This report covers the comparative mapping of KFM06C in Forsmark mapped by the mapping team from Oskarshamn investigation site, Jan Ehrenborg (Mírab Mineral Resurser AB) and Peter Dahlin (Geosigma). The mapping interval was between 176.54 m and 335.5 m.

Sammanfattning

En jämförande studie har genomförts för Boremapkarteringen vid platsundersökningarna i Oskarshamn och Forsmark. Karteringen genomfördes i enlighet med den metodologi som används vid kartering av djupa kärnborrhål.

Föreliggande rapport redovisar den jämförande karteringen av KFM06C i Forsmark som karterats av karteringslaget från Oskarshamn, Jan Ehrenborg (Mírab Mineral Resurser AB) och Peter Dahlin (Geosigma). Det karterade intervallet sträcker sig från 176,54 m och ner till 335,5 m.

Contents

1 Introduction

This document reports data gained by Boremap mapping of borehole KFM06C within the site investigation at Forsmark (Figure 1-1). The work was carried out in accordance with activity plan AP PS 400-05-084 and AP PF 400-05-086 respectively. In Table 1-1 controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB´s internal controlling documents.

Table 1-1. Controlling documents for the performance of the activity.

Activity plan	Number	Version
Jämförande Boremapkartering på del av teleskopborrhål KFM06C och KLX07B	AP PS 400-05-084	1.0
	AP PF 400-05-086	1.0
Method descriptions	**Number**	**Version**
Nomenklatur vid Boremapkartering	SKB MD 143.008	1.0
Metodbeskrivning för Boremap-kartering	SKB MD 143.006	2.0
Mätsystembeskrivning för Boremap, Boremap v 3.0	SKB MD 146.005	1.0

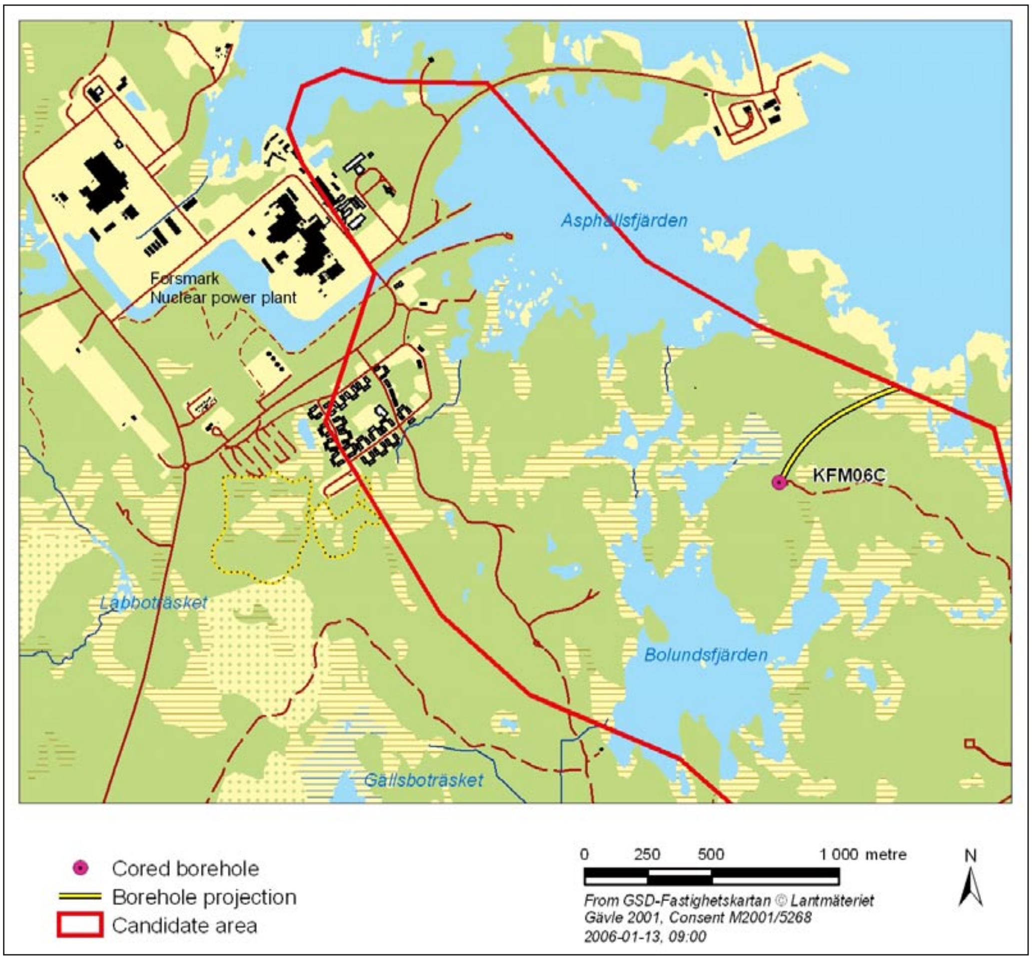


Figure 1-1. Location of the core drilled borehole KFM06C.

Since 2002, SKB investigates two potential sites for a deep repository of nuclear waste in the Swedish Precambrian basement at approximately 500 m depth. These sites are Forsmark in northern Uppland and Simpevarp in eastern Småland. In order to make a preliminary evaluation of the rock mass down to a depth of about 1 km at these sites, SKB has initiated a drilling program using core drilled boreholes.

Detailed mapping of the drill cores is essential for a three dimensional understanding of the geology at depth. The mapping is based on the use of so called BIPS-images of the borehole wall and by the study of the drill core itself. The BIPS-images enable the study of orientations, since the Boremap software calculates strike and dip of planar structures such as foliations, rock contacts and fractures. Also the fracture apertures in the rock can be estimated.

2 Objective and scope

For the comparative study two boreholes KFM06C in Forsmark and KLX07B in Oskarshamn were used. One interval of each borehole were selected for Boremap mapping by each mapping team.

The mapping started at 176.54 m and ended at 335.5 m. It was decided by SKB that a comparative study of the drill core mapping with the Boremap method should be executed by the ordinary mapping teams from Forsmark and Oskarshamn. Each team mapped 4 x 8 hours on their ordinary locality and then changed and mapped the same interval as the crew in the other locality. The principal purpose was to detect systematical differences in the mapping process between the two investigation sites.

The results from the investigations that are carried out at the Oskarshamn and Forsmark investigation sites will be compared before the choice of the site for the deep repository in Sweden is performed. It is important that the investigations at the two sites are performed in the same way and follow the same methodology. That is why method descriptions exist, but despite all controlling documents different persons make different judgements, especially in uncertain cases. It has therefore been decided that a comparison between the two mapping teams from Forsmark and Oskarshamn should be conducted. The comparison is not covered in this report but will be performed by SKB´s analysis group.

The lithology is not crucial for the comparison since the invited mapping team lack experience from the bedrock in the local area. This is also true to some extent for the specific fracture mineralogy at each locality.

This report covers the comparative mapping of KFM06C at Forsmark as mapped by the ordinary mapping team from Oskarshamn site investigation, Jan Ehrenborg (Mírab Mineral Resurser AB) and Peter Dahlin (Geosigma).

3 Equipment

3.1 Description of software

The mapping was performed with Boremap v. 3.6, with bedrock and mineral standards of SKB. The final data presentation was made using StereoNet, WellCad v.4, and BIPS Image Print.

Boremap is the software that integrate orthodox core mapping with modern video mapping. The software deals with the mapping data as well as the internal communication between programs. Boremap shows the video image from BIPS (Borehole Image Processing System) and extracts the geometrical parameters: length, width, strike and dip from the image.

3.2 Other equipment

The following equipment was used to facilitate the core mapping: folding rule and pen, hydrochloric acid, knife, water-filled atomizer and hand lens.

3.3 BIPS-image video film sequences

The BIPS video film of KFM06C covers the interval 102.10–992.15 m.

3.4 BIPS-image video film: resolution, contrast and quality

The visibility of thin fractures in BIPS depends on image resolution, image contrast and image quality.

The BIPS-image resolution is perhaps the principal reason why very thin fractures as well as very thin apertures are not visible in the BIPS-image. The resolution depends on the BIPS video camera pixel size and illumination angle.

Thick fractures are always visible in both drill core and the BIPS-image. However, the visibility of thin fractures depends strongly on the colour contrast between the fracture and the wall rock.

A light fracture in a dark rock is clearly visible in the BIPS-image. A light coloured fracture in a light coloured rock might, however, be clearly visible in the drill core but not visible in the BIPS-image, especially if the fracture and wall rock have the same colour. The opposite is true for dark fractures.

In the rare case when the BIPS-image contrast between a very thin fracture and the wall rock is very strong the fracture might be visible in the BIPS-image even if it is not visible in the drill core.

The BIPS-image quality is sometimes limited by disturbances such as:

1) blackish coatings probably related to the drilling equipment,
2) vertical bleached bands from the clayey mixture of drill cuttings and water,
3) light and dark bands at right angle to the drill hole related to the automatic aperture of the video camera,
4) vertical enlargements of pixels due to stick-slip movement of the camera probe.

Problems related to the video camera aperture and the enlargement of pixels can be neglected. The main disturbances caused by the BIPS-image quality are the vertical bleached bands and the blackish coatings.

The image quality is classified into four classes; good, acceptable, bad and very bad. With good quality means a more or less clear image which is easy to interpret. Acceptable quality means that the image is not good, but that the mapping can be performed without any problems. An image of bad quality is somewhat difficult to interpret while an image of very bad quality cannot be interpreted except from very obvious and outstanding features. It should be remembered that even if only 10–20% of the image is visible, this is often enough for an acceptable interpretation. When the BIPS-image quality is so bad that fractures and structures can not be identified in the BIPS-image, they can still be oriented using the *guide-line method* (chapter 4.3.3). Better cleaning of the borehole could increase the mapping quality significantly.

4 Execution

4.1 General

The Boremap-mapping of the telescopic drilled borehole KFM06C was performed and documented according to activity plan AP PS 400-05-084 as well as AP-PF 400-05-086 (SKB, internal document) referring to the *Metodbeskrivning för Boremap-kartering* (SKB MD 143.006, v.2.0, SKB, internal controlling document).

The drill cores were displayed on inclined roller tables and mapped in their entire length with the Boremap system at Simpevarp. The core mapping was carried out without any detailed geological knowledge of the area but with access to geophysical logs and rock samples.

In the first stage each mapping team mapped 4 x 8 hours on their ordinary locality. Thereafter the mapping teams switched boreholes and site and began mapping the same section on respective drill core and worked 4 x 8 hours. The principal purpose was to detect systematic differences in the mapping process between the two investigation sites. Each mapping team mapped in the same way as during the ordinary mapping in accordance with the *Metodbeskrivning för Boremap-kartering, SKB MD 143.006 v.2.0* and *Mätsystembeskrivning för Boremap, Boremap v.3.0, SKB MD 146.005 v.1.0*. Software Boremap v.3.6 was used for the mapping, SKB internal documents.

The lithology was not crucial for the comparison since the invited mapping team lacked experience from the local bedrock in the area. This is also true to some extent for the specific fracture mineralogy at each locality.

The mapped section of KFM06C covers the interval 176.54–335.5 m.

The mapping was performed by Jan Ehrenborg (Mírab Mineral Resurser AB) and Peter Dahlin (GEOSIGMA).

4.2 Preparations

Any depth registered in the BIPS-image deviates from the true depth in the borehole, a deviation which increases with depth. This problem is generally eliminated by adjusting the depth according to reference slots cut into the borehole every fiftieth metre. The level for each slot was measured in the BIPS-image and then adjusted to the correct level using the correct depth value from the Sicada database.

The different orientations of the observations were adjusted to true space. Data necessary for this adjustment were borehole diameter and deviation; both collected from the Sicada database.

This process had been accomplished by the ordinary mapping team in Forsmark before the mapping team from Oskarshamn arrived. Recorded depth values were used during the comparative mapping.

4.3 Execution of measurements

Nomenclature and definitions used during the core mapping, are defined in this chapter.

4.3.1 Fracture definitions

Definitions of different fracture types, also crush and sealed fracture network, are found in *Nomenklatur vid Boremapkartering, SKB MD 143.008 v.1.0* (SKB internal document). Apertures for broken fractures have been mapped in accordance with the definitions in this document.

In the mapping phase, fractures that split the core are mapped as BROKEN and fractures that have not parted the core are mapped as UNBROKEN. All fractures are described with their fracture minerals and other characteristics, e.g. width, aperture and roughness. Visible apertures are measured down to 1 mm in the BIPS-image. Smaller apertures, which are impossible to detect in the BIPS-image, are denoted a value of 0.5 mm. If the core pieces don't fit well, the aperture is considered "probable". If the core pieces do fit well, but the fracture surfaces are dull or altered, the aperture is considered "possible".

All fractures that possess apertures > 0 mm, are in the Sicada database interpreted as OPEN. Only few BROKEN fractures are given the aperture = 0 mm. UNBROKEN fractures usually have apertures = 0 mm. If UNBROKEN fractures possess apertures > 0 mm, they are interpreted as partly open and included in the OPEN-category. OPEN and SEALED fractures are finally frequency calculated and shown in Appendices 1 and 4.

4.3.2 Fracture alteration and joint alteration number

The joint alteration number is principally related to the thickness of, and the clay content in a fracture. Thick fractures rich in clay minerals are given a joint alteration number between 2 and 3. The majority of the broken fractures are very thin to extremely thin and seldom contain clay minerals and receive a joint alteration number between 1 and 2.

A subdivision of fractures with joint alteration numbers between 1 and 2 was introduced to facilitate both the evaluation process for fracture alterations and the possibility to compare the alterations between different fractures in the boreholes. The subdivision is based on fracture mineralogy as follows:

a) fracture wall alterations

b) fracture mineral fillings assumed to have been deposited from circulating water-rich solutions

c) fracture mineral fillings most likely resulting from altered wall rock material

Joint alteration number equal to 1: Fractures with or without wall rock alteration, e.g. oxidation or epidotization, and without mineral fillings is considered as fresh. The joint alteration number is thus set to 1.

The minerals calcite, quartz, fluorite, zeolites, such as laumontite and sulphides are regarded as deposited by circulating water- rich solutions in broken fractures and not as true fracture alteration minerals. The joint alteration number is thus set to 1 also for these minerals.

Joint alteration number equal to 1.5: Minerals as epidote, prehnite, hematite, chlorite and/or clay minerals are regarded as fracture minerals most likely resulting from altered wall rock material. A weak alteration is thus assumed and the joint alteration number was set to 1.5. Extra considerations have been given to clay minerals since the occurrence of these minerals often resulted in a higher joint alteration number.

Joint alteration numbers higher than 1.5: When the mineral fillings is thick and contain a few mm of clay minerals, often together with minerals like epidote and chlorite, the joint alteration number is set to 2. In rare cases, when a fracture contains 5–10 mm thick clayey bands, together with chlorite, the joint alteration number is set to 3.

When the alteration of a fracture is too thick (and/or intense) to give the fracture the joint alteration number 1.5 and too thin and/or weak to give it a 2, 1.7 and 1.8 are used.

4.3.3 Mapping of fractures not visible in the BIPS-image

Not all fractures are visible in the BIPS-images. These fractures are orientated by using the *guide-line method*, based on the following data:

- Absolute depth.
- Amplitude (measured along the drill core). The amplitude is the interval between fracture extremes along the drill core.
- The relation between the orientations of the fracture trace, measured on the drill core and a well defined structure visible in the BIPS-image.

The error of orientating fractures using the *guide-line method* is not known but experience and an estimation using stereographic plots indicated that the error is most likely insignificant. Anyhow, the *guide-line method* is so far considered better than only marking fractures that are non-visible in the BIPS-images as planes perpendicular to the borehole. The fractures in question are mapped as "non-visible in BIPS" and can therefore be separated from fractures visible in BIPS which probably have a more accurate orientation.

When using the *guide-line method* the difference between the 50 mm drill core diameter and the 76 mm borehole diameter must be considered. This difference result in displacements of the structures seen in the drill core compared with the structures seen in the BIPS-image which represents the borehole walls. This displacement is zero for structures that cut the drill core at right angle and successively becomes larger as the orientation of the structure approximates the direction of the drill core axis. This displacement always has to be corrected for, since displacements of up to a few cm are common even if they seldom reach 10 cm.

Orientation of fractures and other structures with the *guide-line method* is done in the following way: The first step in the guide-line method is to calculate the amplitude of the fracture trace in the BIPS-image (with 76 mm diameter) from the fracture amplitude in the drill core (with 50 mm diameter). The second step is the correction of strike and dip. This is done by rotating the fracture trace in the BIPS-image relative to a feature with known orientation. The fracture trace is then put at the correct depth according to the depth measured on the drill core.

The *guide-line method* can be used to orientate any feature that is not visible in the BIPS-image. It is also a valuable tool to control that the personnel working with the drill core is observing the same feature as the personnel delineating the fracture trace in the BIPS-image, especially in intervals rich in fractures.

4.3.4 Definition of veins and dikes

Chiefly two different rock occurrences are mapped: veins and dikes. These two are differentiated by their respectively length in the core; veins are set to 0–20 cm and dikes are set to 20–100 cm. Rock occurrences that covers more than 100 cm of the drill core are mapped under the feature *rock type.*

4.3.5 Mineral codes

In the case where properties and/or minerals are not represented in the mineral list, following mineral codes have been used:

X5 whitish, bleached feldspar.

X6 the drill core is broken at a right angle and the broken surfaces have a polished appearance. This may indicate a sealed fracture that has been broken up during drilling. The two drill core parts have rotated against each other and worn down the mineral fillings.

X7 fracture with no detectable mineral fill.

4.4 Data handling

The mapping is performed on-line on the SKB network, in order to obtain the best possible data security. Before every break (> 15 minutes) a back-up is saved on the local disk.

As a regular quality check every working day a summary report and a WellCad plot are printed in order to find possible misprints. The mapping is also quality checked by a routine in Boremap before it is exported to and archived in Sicada database. Personnel from SKB also perform spot test controls and regular quality revisions.

All primary data from KFM06C is stored in SKB´s database Sicada and only these quality-checked data are to be used for further interpretation and modelling.

4.5 Geological summary table, general description

An overview of the geological parameters mapped with the Boremap system is collected in the Geological Summary table (Appendix 1). It also facilitates comparisons between Boremap information collected from different boreholes and is more objective than a pure descriptive borehole summary.

The Geological Summary table is the result of cooperation between Jan Ehrenborg from the mapping personnel at Simpevarp and Pär Kinnbom from PO (site investigation, Simpevarp). The aim was to make a standard form in handy A4-size, where all information is taken directly from the Sicada database using simple and well defined search paths for each geological parameter (Appendix 2).

The search paths are, however, yet not automatic and the geological information therefore has to be extracted from the Boremap database before it is reworked on separate Excel-files and finally presented in the Geological Summary table. At the moment it is only possible to extract the Rock Type and Alteration parameters directly from the Boremap database.

The main reason why the information in the Sicada database cannot be extracted automatically is the lack of a mathematical formula for calculation of frequencies for different parameters.

The Geological summary table is made up of 23 columns, each one representing a specific geological parameter. The geological parameters are presented as either intervals or frequencies. Intervals are calculated for parameters with a width ≥ 1 m and frequencies for parameters with a width < 1 m. Frequency information is treated as if it does not have any extension along the borehole axis. They are treated as point observations. It should be noted that parameters with a thickness of only 1 mm therefore has the same “value” as a similar parameter with a thickness of 999 mm since both are treated as point observations and used for frequency calculations.

Parameters are sometimes related in such a way that the mapping of one parameter cause a decrease in the frequency of another parameter. This type of intimate relationship between parameters has been noted for the following cases;

- There is a decrease in the frequency of *unbroken fractures* with oxidized walls and without mineral fillings in intervals mapped with *Alteration – oxidation.*
- No *unbroken fractures* are mapped in intervals of *sealed fracture network*.
- No *broken fractures* are mapped in intervals with *crush.*
- Composite dikes generally include a large amount of fine to medium grained granite veins. These veins are not mapped and the frequency presented for veins + dikes in column 6 (Appendix 1) are lower than the true frequency in composite dike intervals.

4.5.1 Columns in the geological summary table

The Geological summary table includes the following 23 columns:

Column 1: *Rock Type/Lithology*, interval column. Only lithologies longer than 1 m are presented here. Shorter lithologies are presented in column 6. This column is identical with the ordinary WellCad presentation.

Column 2: *Rock Type/Grain size*, interval column. Interval limits follows column 1. This column is identical with the ordinary WellCad presentation.

Column 3: *Rock Type/Texture*, interval column. Interval limits follows column 1. This column is identical with the ordinary WellCad presentation.

Column 4: *Alteration/Oxidation*, interval column. No frequency column is presented for alteration/oxidation. The alteration/oxidation column is identical with the ordinary WellCad presentation.

Column 5: *Alteration/intensity*, interval column. This column is identical with the ordinary WellCad presentation.

Column 6: *Rock Occurrence/Veins + Dikes < 1 m wide*, frequency column. This rock type column can be seen as the frequency complement to the rock type/lithology interval column. Only rock type sections that are thinner than 1 m can be described as rock occurrences in Boremap. Thicker rock type sections are mapped as rock type.

Column 7: *Structure/Shear Zone < 1 m wide*, frequency column. This column includes ductile shear structures as well as brittle-ductile shear structures and these are mapped as rock occurrences in Boremap. Ductile sections in mm – cm scale are mapped as shear structures and in dm – m scale as sections with foliation.

Column 8: *Structure/Brecciated < 1 m wide*, frequency column. Breccias < 1 m wide are mapped as rock occurrence in Boremap. Very thin micro breccias along sealed/natural fracture planes are generally not considered.

Column 9: *Structure/Brecciated ≥ 1 m wide*, interval column. Breccias > 1 m wide are mapped as rock type/structure in Boremap.

Column 10: *Structure/Mylonite < 1 m wide*, frequency column. Mylonites < 1 m wide are mapped as rock occurrence/structure in Boremap.

Column 11: *Structure/Mylonite ≥ 1 m wide* is an interval column. Mylonites > 1 m wide are mapped as rock type/structure in Boremap.

Column 12: *Structure/Foliation < 1 m wide* is a frequency column. Sections with foliation < 1 m wide are mapped as rock occurrence/structure in Boremap. Very thin sections with foliation are called ductile shear structures and presented in column 7.

Column 13: *Structure/Foliation ≥ 1 m wide* is an interval column. Sections with foliation > 1 m wide are mapped as rock type/structure in Boremap.

Column 14: *Sealed fractures/All*, frequency column. This column includes all fractures mapped as unbroken in the Boremap system and this includes unbroken fractures where the drill core is not broken as well as unbroken fractures interpreted to have broken up artificially during/after drilling.

Column 15: *Sealed fractures/Broken fractures with aperture = 0*, frequency column. This column includes unbroken fractures interpreted to have broken up artificially during/after drilling.

Column 16: *Sealed fractures/Sealed Fracture Network < 1 m wide*, frequency column. The sealed fracture network parameter is the only parameter that is generally evaluated directly from observations of the drill core. These types of sealed fractures can only in rare cases be observed in the BIPS-image.

Column 17: *Sealed fractures/Sealed Fracture Network ≥ 1 m wide*, interval column.

Column 18: *Open fractures/All Apertures > 0*, frequency column. This column includes all broken fractures, both fractures that with certainty were open before drilling and fractures that probably or possibly were open before drilling.

Column 19: *Open fractures/Uncertain, Aperture = 0.5 probable + 0.5 possible*, frequency column. This column includes fractures that probably or possibly were open before drilling.

Column 20: *Open fractures/Certain Aperture = 0.5 certain and > 0.5*, frequency column. This column includes fractures that with certainty were open before drilling.

Column 21: *Open fractures/Joint alteration > 1.5*, frequency column. This column show fractures with stronger joint alteration than normal. This parameter is generally correlated with the location of lithologies with a more weathered appearance.

Column 22: *Open fractures/Crush < 1 m wide*, frequency column. This column includes shorter sections with crush.

Column 23: *Open fractures/Crush ≥ 1 m wide*, interval column. This column includes longer sections with crush.

5 Results

The result of the mapping of KFM06C is principally found in the appendices. The information in the Boremap database has been compressed to the size of an A4-sheet in the Geological Summary table, Appendix 1. The search paths for the Geological Summary table are presented in Appendix 2. Stereographic projection of the orientation of broken fractures are presented in Appendix 3. The WellCad diagram for the mapped interval is presented in Appendix 4.

5.1 Geological summary table for KFM06C

The Geological Summary table for the section 176.54–335.5 m in KFM06C is presented in Appendix 1.

All length information in this chapter is taken from the Geological Summary table (Appendix 1) and therefore may have an error of 5–10 m.

Rock types for the mapped section 176.54–335.5 m in KFM06C are shown in Table 5-1.

Granite to granodiorite, (101057) dominates the lithology in the interval 176.54–335.5 m of KFM06C with 78%. Minor lithologies are diorite to gabbro, (101033) with 10%, granite (111058) with 11% and felsic to intermediate metavolcanite (103076) with only 1%. The granite to granodiorite (101057) and diorite-gabbro (101033) show rather intense lineation but the lineation in the diorite-gabbro (101033) is occasionally weaker.

Oxidation occurs sparsely in short (0.5–9 m), faintly to weakly oxidized intervals. The interval 223.5–262 m lack oxidation, while short oxidized intervals are quite common in the interval 262–310 m.

Veins and dykes show a rather even distribution, with only minor frequency peaks in the mapped interval.

A few decimetre long sections where the foliation is stronger than the lineation, occur in the interval 178–261 m.

Sealed fractures (interpreted) show minor frequency maxima at 208 m, 228 m, 248 m and 294–306 m. Short sealed fracture network occur sparsely throughout the mapped section.

Open fractures (interpreted) are not frequent but minor frequency maxima occur at 206-210 m, 222–226 m and 286–298 m.

Table 5-1. Rock types for section 176.54–335.5 m in KFM06C.

%	Rock Type
78	Granite to granodiorite, metamorphic (101057)
11	Granite, fine- to medium-grained (111058)
10	Diorite to gabbro, metamorphic, medium-grained (101033)
1	Felsic to intermediate metavolcanite fine-grained (103076)

It is somewhat difficult to subdivide KFM06C in sections since the mapped geological parameters generally do not show strong variations in the mapped interval. However, an attempt is made to subdivide the mapped interval of KFM06C in five sections using lithology, oxidation, foliation and open fractures (interpreted).

Section I (176.54–202 m): granite to granodiorite (101057). Oxidation occurs in four thin, widely spaced bands. Decimetre-scale foliation zones are quite numerous. Both sealed fractures (interpreted) and open fractures (interpreted) are quite rare.

Section II (202–226 m): granite to granodiorite (101057), a thin band of granite (111058) and a thin band of felsic to intermediate metavolcanite, fine-grained (103076). Oxidation occurs in thin bands throughout the section. These bands are more frequent than in section I. Thin foliation zones show the same frequencies as in section I and are found throughout section II. In this section open fractures (interpreted) show the highest frequency maxima in the mapped interval and also a relatively high frequency of sealed fractures.

Section III (226–262 m): granite to granodiorite (101057), thin bands of diorite to gabbro (101033) and a thin band of granite (111058). No oxidation was mapped in this section. Decimetre-scale foliation zones still occur especially along the contacts between diorite to gabbro and granite to granodiorite but also within the diorite-gabbro bands. The frequency of open fractures (interpreted) is low in this section.

Section IV (262–310 m): granite to granodiorite (101057) and of thin bands of granite (111058). This section shows the strongest oxidation and has frequent bands of oxidation. Vein and dyke frequencies are somewhat lower than in other sections and thin foliation zones are much rarer than in sections I, II and III. The lower interval of section IV shows higher frequencies of open fractures (interpreted).

Section V (310–335.5 m): granite to granodiorite, metamorphic, medium-grained (101057). No oxidation, except for a 0.5 m thin faintly oxidized band was mapped in this section and no thin foliation zones occur. Sealed fractures (interpreted) as well as open fractures (interpreted) show very low frequency maxima.

5.2 Orientation of broken fractures

Broken fractures for the mapped interval in KFM06C are presented in the stereogram in Appendix 3. The stereographic information is from plane to pole plot data. Fracture orientation values are strike/dip values using the right hand rule.

The orientation of borehole KFM06C at ground level is 026/-60.

Broken fractures not visible in the BIPS-image were oriented according to the *guide-line method* (see chapter 4.3.3).

There is a general strong overrepresentation of broken fractures cutting the borehole at high angles compared to fractures cutting the borehole at low angles. This results in artificially high anomaly values for fractures cutting the borehole at high angles and in semi-circular distortion of anomaly shapes in the stereographic plots. These effects are stronger the longer the plotted depth interval. It is therefore not recommended to plot intervals longer than 100 m in the same stereogram.

Stereogram maxima for the mapped interval in KFM06C are few and scattered. The dominating maxima have the orientation 030/05 and 095/65.

5.3 Fracture mineralogies

Percentages of open fracture minerals are shown in Table 5-2 and percentages of sealed fracture minerals are shown in Table 5-3.

The total amount of open fractures is 273 (an average of 1.7 open fractures per metre). 75% of all fracture minerals detected in open fractures are chlorite, calcite and clay minerals. Minerals that constitute less than 0.5% have been excluded in Table 5-2.

The total amount of sealed fractures is 327 (an average of 2.1 sealed fractures per metre), see Table 5-3.

Table 5-2. Percentage of fracture minerals in open fractures, section 176.54–335.5 m in KFM06C.

%	Mineral
32	Calcite
31	Chlorite
12	Clay minerals
9	Pyrite
4	No detectable minerals
3	Quartz
3	Oxidized walls
~6	Sericite, Adularia, Hematite, Zeolite, Fluorite, Laumontite, Iron Hydroxide

Table 5-3. Percentage of mineral fillings in sealed fractures, section 176.54–335.5 m in KFM06C.

%	Mineral
28	Calcite
20	Chlorite
17	Oxidized walls
10	Quartz
9	Adularia
2	Pyrite
1	Hematite
1	Laumontite
0.5	Epidote

Geological summary table KFM06C

GEOLOGICAL SUMMARY KFM06C

APPENDIX: 1

Site	FORSMARK	Signed data		Company	Geosigma AB
Borehole	KFM06C	Activity ID	13130686		
Coordinate System	RT90-RHB70	Mapped by	Jan Ehrenborg	Peter Dahlin	
Date of mapping	2005-08-29 08:00:00	Activity type	GE052		

ROCK TYPE FORSMARK
- Granite, fine- to medium-grained
- Granite to granodiorite, metamorphic, medium-grained
- Diorite, quarts diorite and gabbro, metamorphic
- Felsic to intermediate volcanic rock, metamorphic

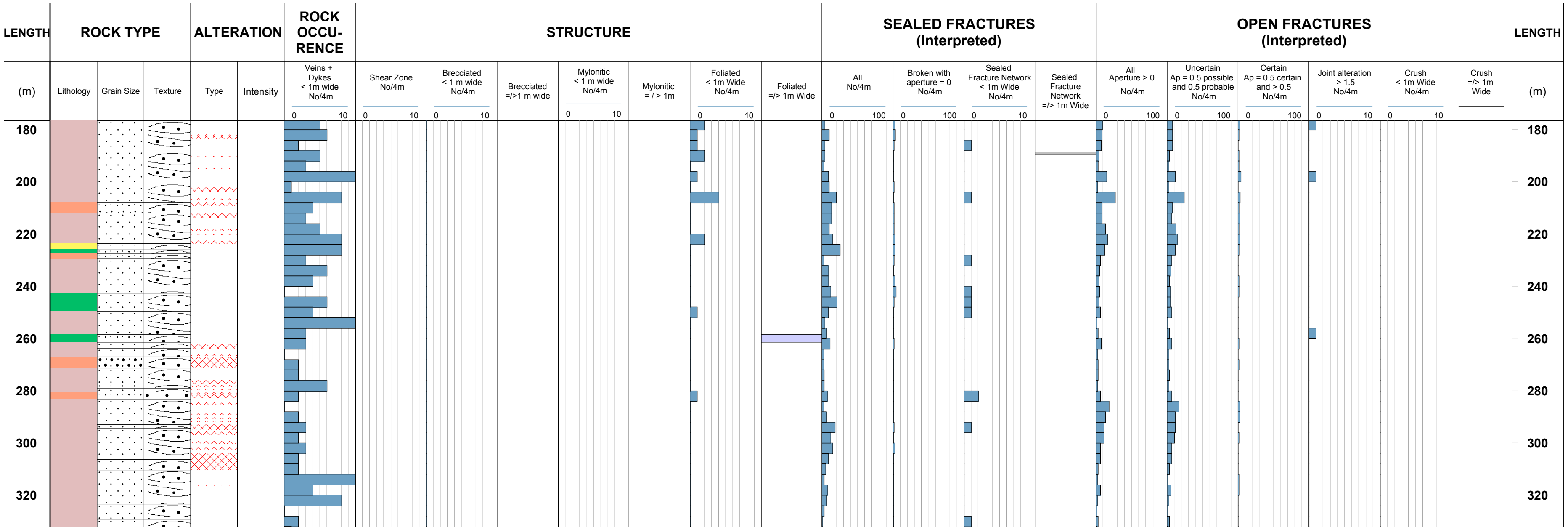
GRAINSIZE
- Fine-grained
- Fine to medium grained
- Medium to coarse grained
- Medium-grained

TEXTURE
- Unequigranular
- Metamorphic

ALTERATION TYPE
- Oxidized

ALTRATION INTENSITY

STRUCTURE INTENSITY
- Weak



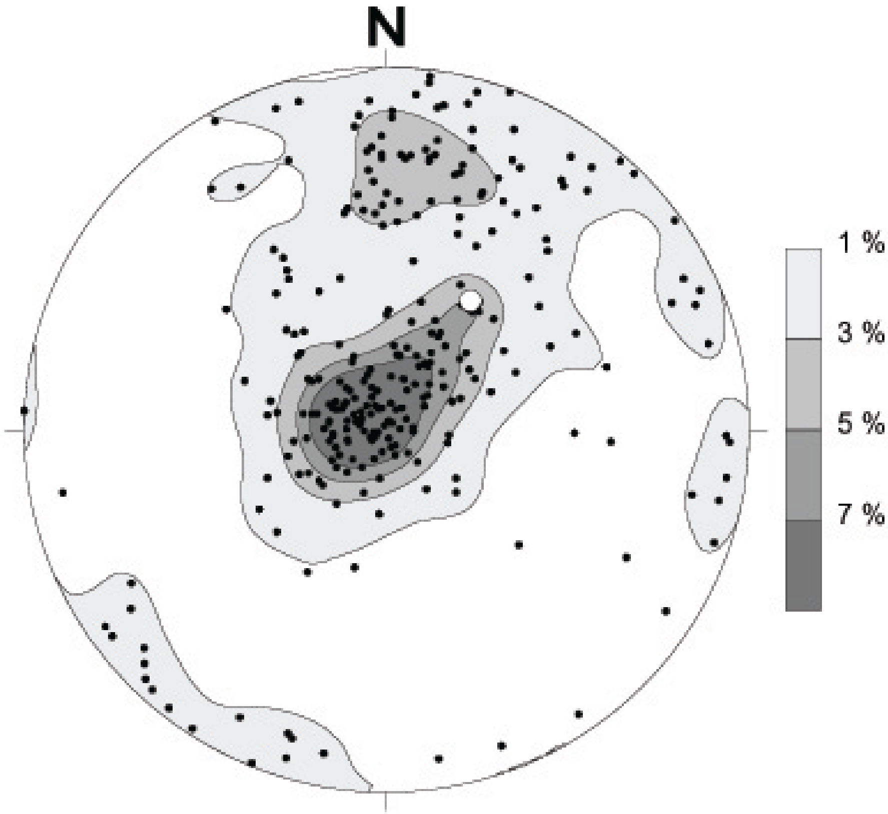
Appendix 2

Search paths for the geological summary table

TABLE HEAD LINES		INFORMATION SOURCE			PRESENTATION
Head lines	**Sub head lines**	**Varcode**	**First suborder**	**Second suborder**	**Interval / frequence**
Rock type	Lithology	5	Sub 1		Interval
	Grain size	5	Sub 5		Interval
	Texture	5	Sub 6		Interval
Alteration	Oxidation	7	Sub 1 = 700		Interval
	Oxidation intensity	7	Sub 1 = 700	Sub 2	Interval
Rock occurrence	Vein + dyke	31	Sub 1 = 2 and 18		Frequence
Structure	Shear zone	31	Sub 4 = 41 and 42		Frequence
	Brecciated, < 1m wide	31	Sub 4 = 7		Frequence
	Brecciated, >/= 1m wide	5 5	Sub 3 = 7 Sub 3 = 7	Sub 4; 101 and 102 = 102 Sub 4; 103 and 104 = 104	Interval
	Mylonite, < 1 m wide	31	Sub 4 = 34		Frequence
	Mylonite, >/= 1 m wide	5 5	Sub 3 = 34 Sub 3 = 34	Sub 4; 101 and 102 = 102 Sub 4; 103 and 104 = 104	Interval
	Foliation zone, < 1 m wide	31	Sub 4 = 81		Frequence
	Foliation zone, >/= 1 m wide	5 5	Sub 3 = 81 Sub 3 = 81	Sub 4; 101 and 102 = 102 Sub 4; 103 and 104 = 104	Interval
Sealed fracture	All unbroken fractures and broken fractures	3 2	 SNUM 11= 0		Frequence
	Broken fractures, Aperture = 0	2	SNum 11 = 0		Frequence
	Sealed fracture network < 1 m wide	32			Frequence
	Sealed fracture network>/= 1 m wide	32			Interval
Open fractures	All, Aperture > 0	2 and 3	SNum 11>0		Frequence
	Uncertain, Aperture = 0.5 possible and 0.5 probable	2 and 3 2 and 3	SNum 11>0 SNum 11>0	Sub 12 = 3 Sub 12 = 2	Frequence
	Certain, Aperture = 0.5 certain	2 and 3	SNum 11>0	Sub 12 = 1	Frequence
	Joint alteration > 1.5	2	SNum16 > 1.5		Frequence
	Crush < 1 m wide	4			Frequence
	Crush >/= 1 m wide	4			Interval

Stereographic projection of broken fractures KFM06C

Stereonet plots that show contoured poles to planes i.e. broken fractures in borehole KFM06C, Schmidt´s Net, lower hemisphere. The white cirkle marks the drill hole orientation.



(296 fractures)

Appendix 4

WellCad diagram of KFM06C

Title	LEGEND FOR FORSMARK	KFM06C

Site	FORSMARK
Borehole	KFM06C
Plot Date	2009-02-11 23:05:25
Signed data	

ROCKTYPE FORSMARK

- Granite, fine- to medium-grained
- Pegmatite, pegmatitic granite
- Granitoid, metamorphic
- Granite, granodiorite and tonalite, metamorphic, fine- to medium-grained
- Granite, metamorphic, aplitic
- Granite to granodiorite, metamorphic, medium-grained
- Granodiorite, metamorphic
- Tonalite to granodiorite, metamorphic
- Diorite, quarts diorite and gabbro, metamorphic
- Ultramafic rock, metamorphic
- Amphibolite
- Calc-silicate rock (skarn)
- Magnetite mineralization associated with calc-silicate rock (skarn)
- Sulphide mineralization
- Felsic to intermediate volcanic rock, metamorphic
- Mafic volcanic rock, metamorphic
- Sedimentary rock, metamorphic
- Cataclastic rock

ROCK ALTERATION TYPE

- Oxidized
- Chloritisized
- Epidotisized
- Weathered
- Tectonized
- Sericitisized
- Quartz dissolution
- Silicification
- Argillization
- Albitization
- Carbonatization
- Saussuritization
- Steatitization
- Uralitization
- Laumontitization
- Fract zone alteration

MINERAL

- Biotite
- Galena
- Epidote
- Flourite
- Hematite
- Calcite
- Chlorite
- Quartz
- Unknown
- Pyrite
- Clay Minerals
- Laumontite
- Zeolite
- Prehnite
- Asphalt
- Oxidized Walls

STRUCTURE

- Cataclastic
- Schistose
- Gneissic
- Mylonitic
- Ductile Shear Zone
- Brittle-Ductile Zone
- Veined
- Banded
- Massive
- Foliated
- Brecciated
- Lineated

TEXTURE

- Hornfelsed
- Porphyritic
- Ophitic
- Equigranular
- Augen-Bearing
- Unequigranular
- Metamorphic

GRAINSIZE

- Aphanitic
- Fine-grained
- Fine to medium grained
- Medium to coarse grained
- Coarse-grained
- Medium-grained

STRUCTURE ORIENTATION

- Cataclastic
- Brecciated
- Bedded
- Schistose
- Mylonitic
- Foliated
- Lineated
- Veined
- Ductile Shear Zone
- Banded
- Brittle-Ductile Shear Zone
- Gneissic

ROCK ALTERATION INTENSITY

- No intensity
- Faint
- Weak
- Medium
- Strong

ROUGHNESS

- Planar
- Undulating
- Stepped
- Irregular

SURFACE

- Rough
- Smooth
- Slickensided

CRUSH ALTERATION

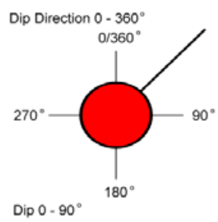
- Slightly Altered
- Moderately Altered
- Highly Altered
- Completley Altered
- Gouge
- Fresh

FRACTURE ALTERATION

- Highly Altered
- Completely Altered
- Gouge
- Fresh
- Slightly Altered
- Moderately Altered

FRACTURE DIRECTION

STRUKTURE ORIENTATION



Title **GEOLOGY IN KFM06C** **Appendix: 4**

Site	FORSMARK	**Coordinate System**	RT90-RHB70
Borehole	KFM06C	**Northing [m]**	6699740.96
Diameter [mm]	76	**Easting [m]**	1632437.03
Length [m]	1000.910	**Elevation [m.a.s.l.]**	4.09
Bearing [°]	26.07	**Drilling Start Date**	2005-04-26 14:30:00
Inclination [°]	-60.11	**Drilling Stop Date**	2006-06-05 00:00:00
Date of coremapping	2005-08-29 08:00:00	**Plot Date**	2009-02-11 23:05:25
Rocktype data from	p_rock	**Signed data**	
		Activity ID	13130686
		Mapped by	Jan Ehrenborg Peter Dahlin
		Company	Geosigma AB