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Boremap mapping of core drilled borehole KFM25, KFM26 and KFM27

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Boremap mapping of core drilled borehole KFM25, KFM26 and KFM27

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Summary

This report presents the geological mapping of the core drilled boreholes KFM25, KFM26 and KFM27, drilled in the area of Forsmark nuclear power station. Each borehole is approximately 100 m long with a subvertical inclination. The main purpose of the boreholes is to measure and monitor the changes in water pressure during the construction of the repository access, but the mapping will also gain information to the current geological understanding.

The boreholes were mapped by the mapping Boremap system, which integrates information from the drill core with an OPTV-image to calculates the position and orientation of mapped structures.

The dominating rock type in all three boreholes is fine- to medium-grained metagranite (rock code 101057). The metagranite in KFM25 and KFM26 has a reddish grey color while the metagranite in KFM27 is whiteish grey with parts of more pale appearance and grain-size reduction due to albitization.

Subordinated rock types are pegmatite to pegmatitic granite (rock code 101061) and amphibolite (rock code 102017).

In addition, rock occurrences (rock types < 1 m in borehole length) of pegmatite (rock code 101061), amphibolite (rock code 102017), metagranite (rock code 101057), metagranitoid (rock code 101051), granite (rock code 111058), quartz-dominated hydrothermal veins (rock code 8021) and aplites (rock code (1062) occur sporadically in all three boreholes.

In KFM25 and KFM26 there are minor occurrences of chloritization and albitization of rock contacts in association with amphibolite and some additional short intervals of oxidation. In KFM27 albitization is the only alteration and is affecting the whole borehole length.

The foliation in the three boreholes strikes in an SSE direction dipping steeply towards the west.

Fracture frequencies for open and sealed fractures in KFM25 are 1.9 and 2.1 fractures/m, 2.2 and 3.3 fractures/m for KFM26 and 4.2 and 5.9 fractures/m for KFM27.

The most frequent fracture fillings in both open and sealed fractures for all three boreholes, but in different proportions, are calcite, chlorite, oxidized walls and fractures with no detectable mineral.

The orientation of both open and sealed fractures in KFM25, KFM26 and KFM27 show a pronounced set of horizontal to gently dipping fractures.

A total of 9 crush zones are registered in the three boreholes. The most extensive crush zone is found in KFM27 at 66.44–67.03 m with infillings of chlorite, clay minerals and hematite.

Sammanfattning

Denna rapport presenterar resultatet från Boremap-karteringen av kärnborrhålen KFM25, KFM26 och KFM27 som borrats i området för Forsmark kärnkraftverk. Borrhålen är ca 100 m långa vardera med subvertikal inklination.

Det huvudsakliga syftet med borrhålen är att mäta och övervaka förändringar i vattentrycket under byggtiden för slutförvaret, men karteringen av borrhålen bidrar även med information till den geologiska platsförståelsen.

Borrhålen karterades med Boremap-systemet, som integrerar information från borrkärnan med OPTVbilden för att beräkna läge och orientering för karterade strukturer.

Den dominerande bergarten i alla tre borrhålen, KFM25, KFM26 och KFM27, är fin- till medelkornig metagranit (bergartskod 101057). Metagraniten i KFM25 och KFM26 har en röd-grå färg medans metagraniten i KFM27 är vit-grå med ställvis blekt utseende och kornstorleksförminskning pga albitisering.

Underordnade bergarter är pegmatit till pegmatitisk granit (bergartskod 101061) and amfibolit (bergartskod 102017).

Dessutom förekommer mindre bergartsförekomster (bergarter < 1 m i borrhålslängd) av pegmatit (bergartskod 101061), amfibolit (bergartskod 102017), metagranit (bergartskod 101057), metagranitoid (bergartskod 101051), granit (bergartskod 111058), kvartsdominerade hydrotermala ådror (bergartskod 8021) och apliter (bergartskod 1062) sporadiskt i alla tre borrhålen.

I KFM25 och KFM26 förekommer kortare intervall med kloritomvandling och albitisering i samband med amfibolit samt ett par korta intervall med oxidation. Albitisering är den enda förekommande omvandlingen i KFM27 men påverkar hela borrhålslängden.

Foliationen i de tre borrhålen stryker i en SSO-riktning och stupar brant mot väster.

Sprickfrekvensen för öppna och läkta sprickor i KFM25 är 1,9 respektive 2,1 sprickor/m, 2,2 respektive 3,3 sprickor/m för KFM26 och 4,2 respektive 5,9 sprickor/m för KFM27.

De vanligaste sprickmineralen i både öppna och läkta sprickor är i alla tre borrhålen, men i olika förhållanden, kalcit, klorit, oxiderade väggar och sprickor utan detekterbart mineral.

Orienteringen av både öppna och läkta sprickor i KFM25, KFM26 och KFM27 visar en tydlig gruppering av horisontella till svagt stupande sprickor.

Totalt 9 krosszoner har registrerats i de tre borrhålen. Den mest omfattande krosszonen finns i KFM27 vid 66,44–67,03 m med klorit, lermineral och hematit.

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1 Introduction

This report presents the result from mapping of the core drilled boreholes KFM25, KFM26 and KFM27, drilled in the area of Forsmarks nuclear power station, Figure 1-1.

The main purpose for the three boreholes KFM25, KFM26 and KFM27, which are approximately 100 m long each with a subvertical inclination, is to measure and monitor the changes in water pressure but will in addition also gain information to the current geological understanding.

The boreholes were drilled during the period of August to October 2019 and was after completion logged by Optical Televiewer (OPTV).

The boreholes were mapped in the period October to November 2019 with the Boremap system, which integrates information from the drill core with the OPTV-image to calculate the position and orientation of mapped structures.



Figure 1-1. Location of the three boreholes KFM25, KFM26 and KFM27.

Table 1-1 presents some technical information about the three boreholes.

KFM25	
Northing (m)	6698868.99 (SWEREF 99 18 00)
Easting (m)	159804.37 (SWEREF 99 18 00)
Elevation at top of casing (m)	2.66 (RH2000)
Bearing (°)	140
Inclination (°)	-84
Diameter (mm)	76
Length, core drilled part (m)	100.72
KFM26	
Northing (m)	6698941.42 (SWEREF 99 18 00)
Easting (m)	159726.47 (SWEREF 99 18 00)
Elevation at top of casing (m)	3.00 (RH200)
Bearing (°)	17–40
Inclination (°)	-86
Diameter (mm)	76
Length, core drilled part (m)	100.74
KFM27	
Northing (m)	6698854.47 (SWEREF 99 18 00)
Easting (m)	159597.05 (SWEREF 99 18 00)
Elevation at top of casing (m)	2.54 (RH2000)
Bearing (°)	323–328
Inclination (°)	-74
Diameter (mm)	76
Length, core drilled part (m)	100.64

2 Objective and scope

The purpose of the geological mapping of KFM25, KFM26 and KFM27 is to document all structures and lithologies in the drill cores for future integration with the hydrological characteristics of these boreholes.

This report describes the data obtained from the Boremap mapping of the three drill cores, which was performed and documented in accordance with the controlling documents listed in Table 2-1.

Documents	Number	Version
Boremapkartering 300 m borkärna	AP SFK-19-020	1.0
Mätsystembeskrivning för Boremap	SKB MD 146.005	2.0
Metodbeskrivning för Boremapkartering	SKB MD 143.006	3.0
Nomenklatur vid Boremapkartering	SKB MD 143.008	1.0
Instruktion: Regler för bergarters benämningar vid platsundersökningen i Forsmark	SKB MD 132.005	1.0

3 Equipment

3.1 Description of equipment and interpretation tools

The core logging was performed with the mapping software Boremap v. 7.0.0.1. The bedrock and mineral standard used for surface mapping at the Forsmark investigation site is used to enable correlation with the surface geology. Measurements of orientation of planar structures (fractures, foliations, lithological contacts etc) are made on the linked OPTV-image of the borehole wall, and orientations of the structures are calculated by the Boremap system. Azimuth and inclination of the borehole and the borehole diameter are used as in-data for the orientation calculations.

Equipment used to facilitate the core mapping are folding rule, 10 % hydrochloric acid, hand lens, paint brush and water.

3.2 OPTV-image

Optical televiewer (OPTV) makes a digital scan of the borehole and provides a highly resolved and oriented image of the borehole wall in one plane (360°).

The horizontal resolution of the OPTV-images is 720 pixels/circle. The vertical resolution depends on the logging speed, but when exporting the images in the OPTV software to the file format used in Boremap, the resolution becomes 1 mm.

For KFM26 and KFM27 the OPTV-files are too dark for thin fractures to be visible. Therefore, lightadjusted jpg-images generated by the OPTV-software, was simultaneously studied to be able to see all fractures. The jpg-images also have the original vertical resolution generated during logging, ranging between 0.5 to 0.6 mm.

The borehole images of KFM25, KFM26 and KFM27 are presented in Appendix 1 and information about the used OPTV-files are listed in Table 3-1.

KFM25						
OPTV-file	KFM25 ner 190926_H_LGX.HED					
Logging date	2019-09-26					
From, recorded lenght (m)	1.55					
To, recorded lenght (m)	100.44					
KFM26						
OPTV-file	KFM26 Ner 191022_H_LGX_HED					
Logging date	2019-10-22					
From, recorded lenght (m)	1.55					
To, recorded lenght (m)	100.91					
KFM27						
OPTV-file	KFM27 Ner 191022_H_LGX.HED					
Logging date	2019-10-22					
From, recorded lenght (m)	1.56					
To, recorded lenght (m)	100.85					

Table 3-1. Information about the used OPTV-files.

4 Execution

4.1 General

Boremap mapping of the core drilled boreholes KFM25, KFM26 and KFM27 was performed and documented according to activity plan AP SFK-19-020 at SKB's core mapping facility in Forsmark.

Core mapping with the Boremap system is based on the use of OPTV-image of the borehole wall and the simultaneously study of the drill core. Orientations of fractures and structures, as well as apertures and widths wider than 0.5 mm, are measured in the OPTV-image.

4.2 Preparations

The drill cores are disposed in their entire length on roller tables in the core mapping facility in Forsmark.

The length adjustment of the OPTV-image is based on clearly identifiable geological reference features as fractures and rock contacts, which are identified both in the OPTV-image and the core, Table 4-1. KFM25 is logged with another shorter winch compared to KFM26 and KFM 27. This explains the more significant length adjustments for KFM25.

Background data necessary for calculations of structure orientations in Boremap include diameter and orientation of the boreholes. When starting a new mapping the id-code, azimuth and inclination of the borehole are directly imported from SICADA and the borehole diameter is manually entered in Boremap.

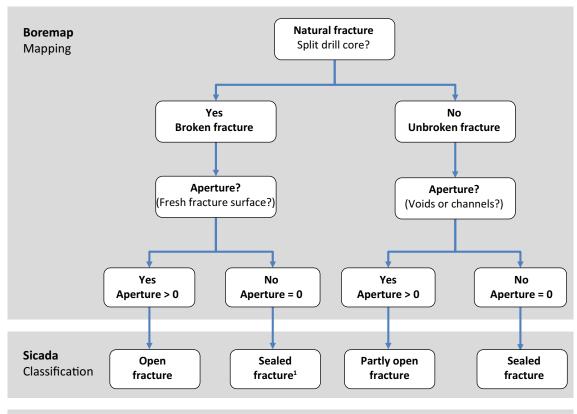
 Table 4-1. Depth positions of geological objects and applied length adjustments in KFM25, KFM26

 and KFM27.

Borehole	Recorded length (m)	Adjusted length (m)	Difference (m)
KFM27	9.17	9.03	0.14
	9.69	9.55	0.14
	15.072	14.935	0.14
	21.134	21.015	0.12
	28.093	27.97	0.12
	40.157	40.045	0.11
	45.3	45.18	0.12
	54.067	53.925	0.14
	60.13	59.99	0.14
	71.08	70.935	0.14
	76.143	75.99	0.15
	80.02	79.85	0.17
	91.09	90.905	0.19
	94.27	94.095	0.17
	100.635	100.46	0.18

4.3 Fracture definitions

Two types of fractures, broken and unbroken, are registered in Boremap depending on whether the core is split through the core axis or not. In the SICADA database fractures with apertures > 0 mm are registered as open, and fractures with apertures = 0 mm are registered as sealed, Figure 4-1.



¹Sealed (broken) fracture is not separated from sealed (unbroken) by Sicada, but can be found through a conditional search

Figure 4-1. Connection between fracture concepts in Boremap and SICADA.

All fractures are described with their fracture minerals, width, aperture, roughness and alteration. To decide whether a fracture was open, partly open or sealed prior to drilling, the aperture confidence is expressed as "certain", "probable" or "possible". The confidence level depends on weathering of fracture surfaces, fit of the core pieces or if the fracture has a visible aperture in the OPTV-image.

Sealed networks are mapped in intervals with abundant sealed fractures that makes it difficult to discern individual fractures, or if they are too many to map individually within a reasonable time. The sealed networks are mapped with main fracture orientations, the most common minerals, alteration and the average fracture distance.

Crush zones are accumulations of open fractures where the drill core cannot be reconstructed or has such a high fracture frequency that detailed mapping is not possible. Crush zones are mapped with main fracture orientations, most common minerals, roughness and alteration of the fracture with the lowest strength in the crush zone and the average length of the core pieces.

4.4 Data handling

The mapping of KFM25, KFM26 and KFM27 is performed with automatic synchronization with SKB's database SICADA. When the mapping is completed it is quality checked by the operator, the "Check mapping" routine in Boremap and a reviewer.

The Data from the reported activity are stored in SKB's database SICADA and are also traceable by the Activity Plan number (AP SFK-19-020). Only data in the SICADA database are accepted for further interpretation and modelling. The data may be revised, if needed, but such revisions will not necessarily result in a revision of the P-report. However, the normal procedure is that major data revisions entail a revision of the P-report. Minor data revisions are normally presented as supplements, available at www.skb.se.

4.5 Non conformities

There is one core loss in KFM25 at 62.63-62.73 m and one in KFM27 at 77.83-77.87 m.

Due to the reaction with hydrochloric acid, calcite is detected even in very small amounts, whereas other minerals in the same fracture as calcite run the risk of getting underestimated, relative to calcite.

5 Results

5.1 KFM25

5.1.1 Lithology

96 % of the logged core consists of medium-grained metagranite (rock code 101057). The rock is rather equigranular with elongated quartz and feldspar and thin streaks of biotite. The color is greyish-red with varying intensity of the red color.

A short interval of amphibolitic rock (rock code 102017) occur at 47.07–48.57 m. The amphibolite is fine-grained and equigranular with a dark greenish-gray color. The structure is massive or shows very weak signs of foliation.

One occurrence of pegmatite (rock code 101061) exceeds one meter in borehole length, at 39.28–40.37 m, and appears otherwise sparsely as veins and dykes throughout the borehole with widths rarely exceeding one decimeter. The pegmatitic occurrences are generally texturally heterogenous and medium- to coarse grained with no, or little signs of deformation.

Five minor occurrences of fine- to medium grained metagranitoid (rock code 101051), with a total borehole length of 1.24 m, located at 37–38 and 89–91 m. The rock is granitic to tonalitic in composition, with massive structure and equigranular texture.

Additionally occurrences are metagranite (rock code 101057), amphibolite (rock code 102017), aplites (rock code 1062) and quartz-dominated hydrothermal vein (rock code 8021).

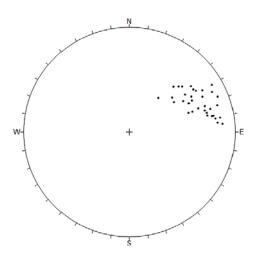
Rock occurrences, rock types < 1 m in borehole length, occupy 7.3 % of the logged drill core.

5.1.2 Alterations

Two short intervals of amphibolite are altered by chloritization and the adjacent metagranite contacts are weakly altered by albitization. In addition, there is a short interval in a core loss mapped as altered by chloritization based on the OPTV-image and a nearby fracture.

5.1.3 Ductile structures

The metagranite (rock code 101057) shows medium intensity foliation and lineation. As shown in the stereographic projection in Figure 5-1, the foliation in KFM25 strikes in an SSE direction and dipping steeply to the west. The foliation is measured in KFM25 on average every third meters.



Figur 5-1. Orientation of poles to foliation planes (n = 34) in KFM25, plotted on lower hemisphere equal area projection.

5.1.4 Fractures

The total number of open and sealed fractures in KFM25 are 178 and 206, respectively, and two fractures are partly open (sealed fractures with apertures > 0 mm). The resulting fracture frequency is 1.9 open fractures/m and 2.2 sealed fractures/m.

Intervals with increased fracture frequencies, > 9 fractures/m, are listed in Table 5-1.

Open	Interval (m)	Fracture/m	Sealed	Interval (m)	Fracture/m	Open + Sealed	Interval (m)	Fracture/m
	7–8	10		62–63	12		6–7	10
	8–9	10		98–99	12		7–8	14
							8–9	12
							16–17	10
							61–62	11
							62–63	14
							73–74	10
							90–91	11
							93–94	11
							98–99	15

Table 5-1. Intervals with increased fracture frequencies, > 9 fractures/m, in KFM25.

Figure 5-2a and b displays the orientation of the open and sealed fractures in stereographic projections. The open fractures show a well-defined group with near horizontal or gently dipping fractures. The sealed fractures show a lager orientation spread, but with a slight concentration of near horizontal fractures.

One small interval, 2 cm wide at borehole length 66.54 m, is mapped as crush in KFM25. The crush is moderately altered with chlorite and calcite, Figure 5-3.

No sealed networks or brecciated zones are registered in KFM25.

The different minerals detected in open and sealed fractures are presented in Table 5-2. The most common minerals in both types of fractures, but in different proportions, are calcite, chlorite and oxidized walls.

A large number of fractures are mapped without mineral filling with fresh surfaces. These fractures are visible in the OPTV-image and some of them also exhibit visible aperture. The orientation of these fractures is all horizontal to subhorizontal.

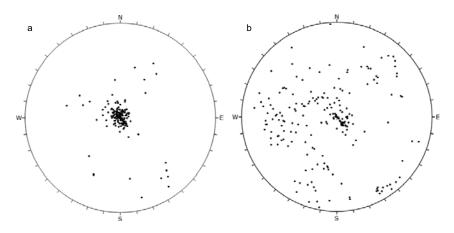


Figure 5-2. Orientation of poles to a) open (n = 178) and b) sealed fracture planes (n = 208) in KFM25, plotted on lower hemisphere equal area projection.



Figure 5-3. OPTV-image of the only crushed interval in KFM25 at 66.54 m.

Open	%	No	Mineral	Sealed	%	No	Mineral
	60.7	108	Calcite		62	128	Oxidized walls
	40.4	72	Chlorite		41.5	83	Calcite
	33.1	59	No detectable mineral		15.5	31	Chlorite
	11.2	20	Oxidized walls		14.6	30	No detectable mineral
	10.7	19	Polished walls		12.6	26	Adularia
	7.3	13	Pyrite		4.4	9	Quartz
	6.7	12	Quartz		1.5	3	Bleached walls
	1.7	3	Hematite		1.0	2	Hematite
	1.7	3	Bleached walls		1.0	2	Pyrite
	1.1	2	Adularia		0.5	1	Laumontite
	0.6	1	Unknown mineral		0.5	1	Biotite
	0.6	1	Clay mineral				
	0.6	1	Iron hydroxide				

Table 5-2. The different minerals and their representation in open and sealed fractures in KFM25.

The fracture with the widest aperture, 30 mm, in KFM25 is located just below the casing at 6.63 m, Figure 5-4.



Figure 5-4. The fracture with the widest aperture, 30 mm, at borehole length 6.63 m.

5.2 KFM26

5.2.1 Lithology

Medium-grained metagranite (rock code 101057) occupies 89 % of the logged interval and is relatively equigranular with quartz and feldspar and thin streaks of biotite. The color is reddish-gray with varying intensity of the red color due to intervals affected by weak to faint oxidation.

There are three intervals of amphibolite (rock code 102017) located in the lower part of KFM26, occupying 12 % of the mapped interval. The amphibolite at 54.22–60.06 m, have contacts and pronounced foliation parallel with the foliation in the adjacent metagranite. This interval has a large proportion of biotite which is altered into chlorite. The other two amphibolitic intervals are more fine-grained, equigranular and with no or faintly developed foliation.

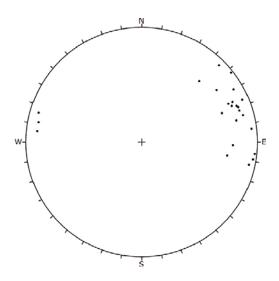
Rock occurrences (rock types < 1 m in borehole length) of veins, dykes and segregations of pegmatite (rock code 101061), metagranite (rock code 101057), aplite (rock code 1062), quartz-dominated hydro-thermal veins (rock code 8021), metagranitoid (rock code 101051), amphibolite (rock code 102017) and granite (rock code 111058) occur sporadically throughout the boreholes. These occurrences occupy 5.4 % of the logged drill core and have often a width less than 1 dm.

5.2.2 Alterations

Chloritization and locally also oxidation is affecting the amphibolite at 54.21–60.05 m. In addition, the metagranite is oxidized in a short interval just below the casing and have contacts to the amphibolites altered by albitization.

5.2.3 Ductile structures

The metagranite (rock code 101057) that dominates in KFM26 shows medium intensity foliation. As shown in the stereographic projection in Figure 5-5, the foliation in KFM26 strikes in an SSE direction and dipping steeply towards the west. The foliation is measured in KFM26 on average every fourth meters.



Figur 5-5. Orientation of poles to foliation planes (n = 24) in KFM26, plotted on lower hemisphere equal area projection.

5.2.4 Fractures

The total number of open and sealed fractures in KFM26 are 204 and 308, respectively, and five fractures are partly open (sealed fractures with apertures > 0 mm). The resulting fracture frequency is 2.2 open fractures/m and 3.3 sealed fractures/m.

Intervals with increased fracture frequencies, > 9 fractures/m, are listed in Table 5-3. The high frequency of sealed fractures at interval 73–74 m, consist of thin fractures with mainly oxidized walls in an amphibolitic rock.

Open	Interval (m)	Fracture/m	Sealed	Interval (m)	Fracture/m	Open + Sealed	Interval (m)	Fracture/m
	7–8	13		72–73	12		7–8	21
	8–9	11		73–74	33		8–9	15
				75–76	14		16–17	11
				84–86	18		22–23	13
				85–86	12		53–54	12
							54–55	10
							55–56	12
							72–73	12
							73–74	37
							74–75	10
							75–76	16
							80–81	10
							83–84	10
							84–85	22
							85–86	13
							87–88	14

Figure 5-6a and b displays the orientation of the open and sealed fractures in stereographic projections. The orientation of the sealed fractures is more scattered, but both open and sealed fractures show a pronounced set of horizontal to gently dipping fractures.

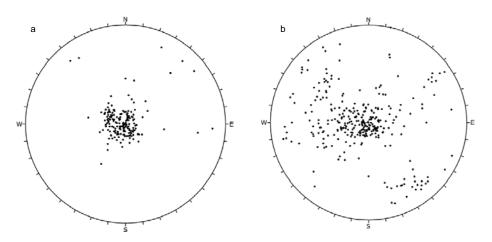


Figure 5-6. Orientation of poles to a) open (n = 204) and b) sealed fracture (n = 313) planes in KFM26, plotted on lower hemisphere equal area projection.

Three short intervals of crush are registered in KFM26, Table 5-4. The OPTV-image of the three crushed zones are shown in Figure 5-7.

Table 5-4.	Crushed	intervals	in	KFM26.
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Interval (m)	Minerals	Alteration
35.16–35.21	Chlorite, clay minerals, calcite, asphalt	Highly altered
97.46–97.61	Calcite, chlorite, oxidized walls	Moderately altered
98.71–98.79	Chlorite, calcite, Iron hydroxide, hematite	Moderately altered

The different minerals detected in open and sealed fractures are presented in Table 5-5. The most common minerals in both types of fractures, but in different proportions, are calcite, chlorite and oxidized walls.

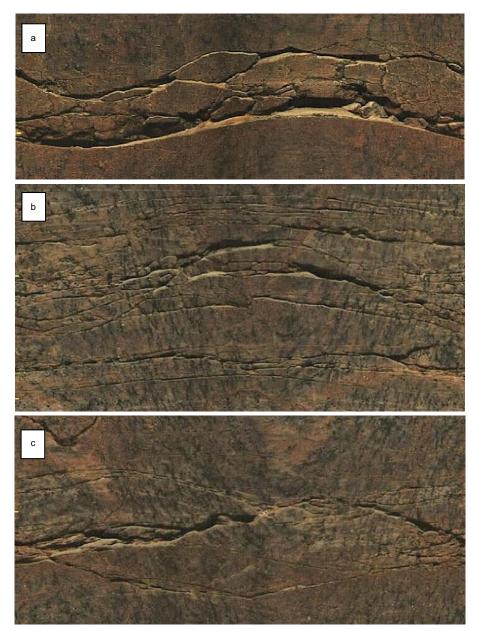


Figure 5-7. OPTV-images of the three crushed intervals in KFM26, a) 35.16–35.21 m b) 97.46–97.61 m and c) 98.71–98.79 m.

Both red feldspar and adularia are mapped in KFM26. Adularia is mapped when the mineral is colored by hematite and red feldspar where the red color is inferred to be the feldspar's own inherent color.

A large number of fractures are mapped without mineral filling with fresh surfaces. These fractures are visible in the OPTV-image and some of them also with a visible aperture. The orientation of these fractures is predominantly horizontal to gently dipping.

Open	%	No	Mineral	Sealed	%	No	Mineral
	60.3	123	Calcite		71.1	219	Oxidized walls
	38.7	79	Chlorite		26.3	81	Calcite
	32.4	66	No detectable mineral		18.5	57	Chlorite
	16.2	33	Oxidized walls		11.4	35	No detectable mineral
	13.2	27	Polished walls		6.5	20	Quartz
	4.4	9	Pyrite		5.9	18	Adularia
	3.9	8	Red feldspar		2.9	9	Bleached walls
	2.5	5	Quartz		0.7	2	Pyrite
	2.0	4	Hematite		0.3	1	Prehnite
	1.0	2	Laumontite				
	0.5	1	Asphalt				
	0.5	1	Iron hydroxide				
	0.5	1	Clay minerals				

Table 5-5. The different minerals and their representation in open and sealed fractures in KFM26.

The two fractures with the widest apertures are located just below the casing, as in KFM25, at depths 6.31 and 6.56 m. The apertures are 44 and 55 mm, respectively, Figure 5-8.

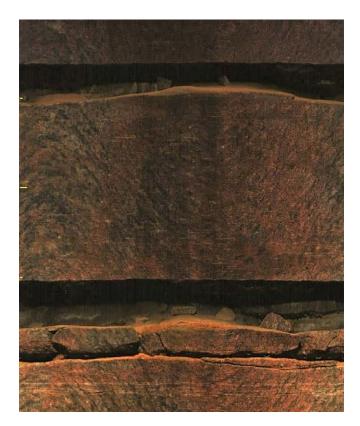


Figure 5-8. The two fractures in KFM26 with widest apertures, 44 and 55 mm, at borehole length 6.31 and 6.56 m, respectively.

5.3 KFM27

5.3.1 Lithology

Metagranite (rock code 101057) occupies 77 % of the logged interval. The rock type is generally finely-medium grained and have due to albitization a whiteish grey color, partly with a pale appearance and reduction of grain-size and obliterated or diffuse texture. Intervals with bleached feldspars occur, mainly associated with fractures but also in a scattered appearance in the rock mass.

Pegmatite to pegmatitic granite (rock code 101061) is found in several intervals throughout the borehole and occupies 23 % of the logged interval. The pegmatitic occurrences are generally texturally heterogenous and medium- to coarse grained with no or little signs of deformation. Coarse hematite grains, up to 2 cm in diameter, is found in some of the pegmatites.

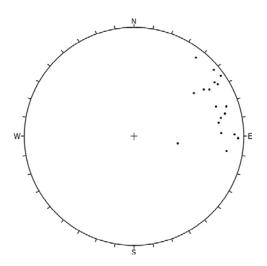
Rock occurrences (rock types < 1 m in borehole length) with metagranite (rock code 101057), pegmatite (rock code 101061), granite (111058) and aplite (rock code 1062) occupy 3.7 % of KFM27.

5.3.2 Alterations

The only alteration in KFM27 is faint to weak albitization and is affecting the entire borehole length.

5.3.3 Ductile structures

The metagranite (rock code 101057) that dominates in KFM27 shows medium intensity foliation. As shown in the stereographic projection in Figure 5-9, the foliation strikes in an SE-SSE direction and dipping steeply towards the west. The foliation is measured in KFM27 on average every fifth meters.



Figur 5-9. Orientation of poles to foliation planes (n = 19) in KFM27, plotted on lower hemisphere equal area projection.

5.3.4 Fractures

The total number of open and sealed fractures in KFM27 are 380 and 517, respectively, and 20 fractures are partly open (sealed fractures with apertures > 0 mm). The resulting fracture frequency is 4.2 open fractures/m and 5.9 sealed fractures/m, which is markedly higher compared to fracture frequencies in KFM25 and KFM26.

Intervals with increased fracture frequencies, > 9 fractures/m, are listed in Table 5-6.

Open	Interval (m)	Fracture/m	Sealed	Interval (m)	Fracture/m	Open + Sealed	Interval (m)	Fracture/m
	52–53	13		17–18	12		10–11	10
	55–56	11		30–31	10		17–18	15
	87–88	15		31–32	15		18–19	10
				32–33	16		28–29	12
				35–36	12		30–31	14
				45–46	10		31–32	17
				49–50	10		32–33	24
				51–52	10		33–34	17
				55–56	12		34–35	13
				61–62	11		35–36	15
				70–71	12		36–37	12
				77–78	10		38–39	12
				80–81	17		40–41	13
				81–82	12		41–42	12
				82–83	17		45–46	13
							47–48	11
							48–49	10
							49–50	13
							51–52	15
							52–53	21
							53–54	13
							54–55	11
							55–56	24
							56–57	10
							58–59	12
							60–61	11
							61–62	15
							62–63	10
							63–64	10
							69–70	11
							70–71	15
							73–74	16
							76–77	16
							77–78	17
							80–81	20
							81–82	15
							82–83	21

Tabell 5-6. Intervals in KFM27 with fracture frequencies > 9 fractures/m.

Open	Interval (m)	Fracture/m	Sealed	Interval (m)	Fracture/m	Open + Sealed	Interval (m)	Fracture/m
							85–86	10
							86–87	12
							87–88	23
							88–89	15
							90–91	10
							91–92	10
							95–96	12
							97–98	12

Tabell 5-6, continuation. Intervals in KFM27 with fracture frequencies > 9 fractures/m.

Figure 5-10a and b displays the orientation of the open and sealed fractures in KFM27 in stereographic projections. Both the open and sealed fractures show some orientation scattering, but both types of fractures have a pronounced set of horizontal to gently dipping fractures.

Five crush zones are registered in KFM27, Table 5-7 and Figure 5-11. The widest occur at 66.44–67.03 m but looks more extensive in the core than indicated in the OPTV-image. The most fractured part of this crush is in the interval 66.79–66.89 m, with several apertures up to 7 mm and mineral filling with chlorite, clay minerals and hematite.

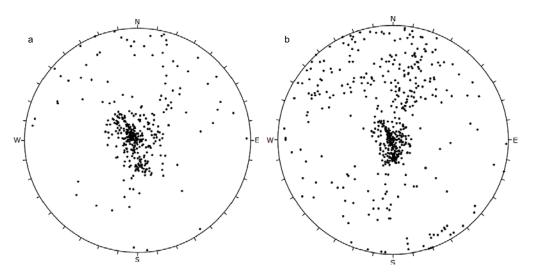


Figure 5-10. Orientation of poles to a) open (n = 380) and b) sealed fracture (n = 537) planes in KFM27, plotted on lower hemisphere equal area projection.

Interval (m)	Minerals	Alteration
19.53–19.56	Calcite	Slightly altered
66.44–67.03	Chlorite, clay minerals, hematite, calcite	Highly altered
86.70-86.74	Calcite	Slightly altered
87.85–87.92	Quartz, Iron hydroxide, chlorite, oxidized walls	Slightly altered
88.32-88.36	Clay minerals, Iron hydroxide, oxidized walls	Highly altered

Table 5-7. Crush intervals in KFM27.

The widest apertures in KFM27 is found in the crush zones, with the single widest ca 8 mm in the crush at 86.70–86.74 m.

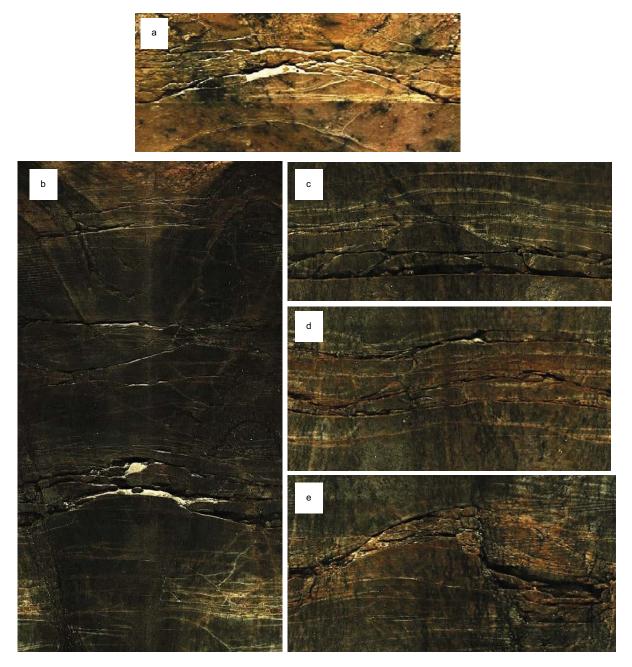


Figure 5-11. OPTV-images of the five crushed intervals in KFM27, a)19.53–19.56 *m, b*) 66.44–67.03 *m, c*) 86.70–86.74 *m d*) 87.85–87.92 *m and e*) 88.32–88.36 *m.*

The different minerals detected in open and sealed fractures are presented in Table 5-8. The most common minerals in both types of fractures, but in different proportions, are calcite, chlorite and oxidized walls.

Just like in KFM25 and KFM26 there is a large number of fresh fractures with no detected mineral and with a near horizontal orientation.

Open	%	No	Mineral	Sealed	%	No	Mineral
	66.3	252	Calcite		40.6	210	Oxidized walls
	41.6	158	Chlorite		29.2	151	Calcite
	22.9	87	Oxidized walls		24.2	125	Chlorite
	19.7	75	No detectable mineral		23.0	119	No detectable mineral
	7.9	30	Polished walls		17.8	92	Bleached walls
	6.8	26	Pyrite		4.8	25	Laumontite
	3.9	15	Asphalt		2.7	14	Quartz
	3.2	12	Bleached walls		2.3	12	Adularia
	2.9	11	Quartz		0.4	2	Biotite
	2.6	10	Laumontite		0.2	1	Hematite
	1.6	6	Iron hydroxide				
	0.8	3	Clay minerals				
	0.3	1	Fluorite				
	0.3	1	Adularia				
	0.3	1	Hematite				
	0.3	1	Biotite				

Table 5-8. The different minerals and their representation in open and sealed fractures in KFM27.

Six intervals of sealed networks, Table 5-9, is registered in KFM27.

Table 5-9. Intervals with sealed networks in KFM27.

Interval (m)	Minerals
55.96–56.21	Calcite
56.57-56.88	Chlorite, oxidized walls
57.71–57.78	Chlorite, oxidized walls
65.46-65.82	Chlorite, oxidized walls
66.94–68.24	Calcite, chlorite, oxidized walls
71.45–72.93	Calcite, bleached walls, oxidized walls

Appendix 1

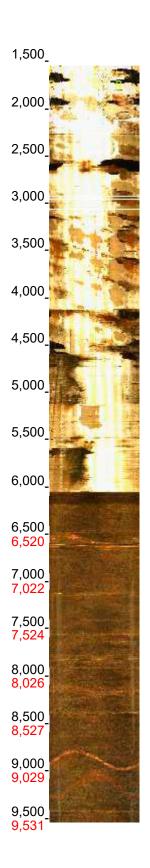
Borehole image report of KFM25

Borehole Name:	KFM25
Mapping Name:	KFM25
Mapping Range:	6,040 - 100,720 m
Diameter:	76,0 mm
Printed Range:	1,550 - 100,439
Pages:	5

Image File Information:

File: Date/Time: Start Depth:	M:\Documents\Boremap-7.0\KFM25\LGX\Kfm25ner 190926_H_LGX.HED 2019-09-26 1.550 m
End Depth:	100,439 m
Resolution:	1,00 mm/pixel (depth)
Orientation:	Gravimetric
Image height:	98890 pixels
Image width:	720 pixels
Intrinsic angle:	180 degrees
LGX Version:	101
Locality:	
Wellname:	
Scan Direction:	Down

Depth range: 1,550 - 33,550 m Azimuth: 140,1 Inclination: -84,6





17,500_ <mark>17,560</mark>	
18,000_ 18,062	
18,500_ 18,564	
19,000_ 19,066	
19,500_ 19,568	
20,000 20,069	
20,500_ 20,571	
21,000_ 21,073	1.3.4.5
21,500_ 21,575	
22,000_ 22,077	
22,500_ 22,579	
23,000_ 23,080	
23,500_ 23,582	
24,000_ 24,084	
24,500_ 24,586	
25,000_ <mark>25,088</mark>	A.S.
25,500_ <mark>25,590</mark>	

25,500_ 25,590	
26,000_ 26,091	
26,500_ 26,593	
27,000 27,095	
27,500_ 27,597	
28,000_ 28,099	高州
28,500_ 28,600	Red
29,000_ 29,102	
29,500_ 29,604	
30,000_ 30,106	
30,500_ 30,608	
31,000_ <mark>31,110</mark>	
31,500_ <mark>31,613</mark>	
32,000_ <mark>32,116</mark>	
32,500_ <mark>32,619</mark>	E.
33,000_ <mark>33,122</mark>	
33,500_ <mark>33,625</mark>	

Depth range: 33,550 - 65,550 m Azimuth: 142,4 Inclination: -84,8

33,500_ <mark>33,625</mark>	D L U R
34,000_ <mark>34,128</mark>	
34,500_ 34,632	
35,000_ <mark>35,135</mark>	
35,500_ <mark>35,638</mark>	
36,000_ 36,141	
36,500_ <mark>36,644</mark>	
37,000_ 37,147	Tage Alton
37,500_ <mark>37,651</mark>	
38,000_ 38,154	
38,500_ 38,657	
39,000_ 39,160	
39,500_ <mark>39,663</mark>	
40,000_ 40,167	
40,500_ 40,670	
41,000_ 41,173	
41,500_ <mark>41,676</mark>	

41,500_ <mark>41,676</mark>	D L. U.R
42,000_ 42,179	
42,500_ <mark>42,682</mark>	
43,000_ <mark>43,186</mark>	
43,500_ <mark>43,689</mark>	
44,000_ 44,192	
44,500_ 44,695	
45,000_ 45,198	
45,500_ 45,701	
46,000 46,205	
46,500 46,708	
47,000_ 47,211	
47,500_ 47,714	~
48,000_ 48,217	
48,500_ 48,720	
49,000_ 49,223	
49,500_ 49,726	

49,500_ 49,726	
50,000_ 50,229	
50,500_ 50,732	
51,000_ 51,235	
51,500_ 51,738	
52,000_ 52,241	
52,500_ 52,744	
53,000_ 53,247	
53,500_ 53,750	
54,000_ 54,253	
54,500_ 54,756	
55,000_ 55,259	
55,500_ 55,762	
56,000_ 56,265	
56,500_ <mark>56,768</mark>	
57,000_ 57,271	
57,500_ 57,774	

57,500_ 57,774	
58,000_ 58,277	
58,500_ 58,780	
59,000_ 59,283	Phone State
59,500_ 59,786	
60,000_ 60,289	
60,500 60,792	
61,000_ 61,295	
61,500_ <mark>61,798</mark>	
62,000_ <mark>62,301</mark>	
62,500_ <mark>62,804</mark>	
63,000 <mark>63,307</mark>	
63,500_ <mark>63,810</mark>	
64,000_ <mark>64,313</mark>	
64,500_ <mark>64,816</mark>	
65,000_ <mark>65,319</mark>	
65,500_ 65,822	

Depth range: 65,550 - 97,550 m Azimuth: 140,3 Inclination: -84,8



73,500_ <mark>73,877</mark>	
74,000_ 74,381	
74,500_ 74,884	
75,000_ <mark>75,388</mark>	
75,500_ <mark>75,892</mark>	
76,000_ <mark>76,396</mark>	
76,500_ <mark>76,899</mark>	
77,000_ 77,403	
77,500_ 77,907	
78,000_ <mark>78,411</mark>	
78,500_ <mark>78,914</mark>	
79,000_ <mark>79,418</mark> _	
79,500_ <mark>79,922</mark>	
80,000_ <mark>80,426</mark>	
80,500_ <mark>80,929</mark>	
81,000_ <mark>81,433</mark>	
81,500_ <mark>81,937</mark>	a stanger

81,500_ <mark>81,937</mark>	L L L U R
82,000_ <mark>82,441</mark>	(Second
82,500_ <mark>82,944</mark>	
83,000_ <mark>83,448</mark>	
83,500_ <mark>83,952</mark>	A COLOR
84,000_ <mark>84,456</mark>	
84,500_ <mark>84,960</mark>	
85,000_ <mark>85,464</mark>	1000
85,500_ <mark>85,968</mark>	
86,000_ 86,472	Q.L
86,500_ <mark>86,976</mark>	
87,000 87,480	
87,500_ <mark>87,984</mark>	
88,000_ <mark>88,488</mark>	
88,500_ <mark>88,992</mark>	
89,000 <mark>89,497</mark>	ALC: N
89,500 <mark>90,001</mark>	

89,500_ 90,001	
90,000_ 90,505	D C + O R
90,500_ <mark>91,009</mark>	
91,000_ <mark>91,513</mark>	
91,500_ <mark>92,017</mark>	
92,000_ <mark>92,521</mark>	
92,500_ 93,025	
93,000_ <mark>93,529</mark>	
93,500_ 94,033	
54,000	
94,000 94,537	
94,000_	
94,000 94,537 94,500 95,041 95,000	
94,000 94,537 94,500 95,041	
94,000 94,537 94,500 95,041 95,000 95,545 95,500	
94,000 94,537 94,500 95,041 95,000 95,545 95,500 96,049 96,000	
94,000 94,537 95,000 95,041 95,000 95,545 95,500 96,049 96,000 96,553 96,500	

Depth range: 97,550 - 100,439 m Azimuth: 141,0 Inclination: -84,8

97,500 98,065 98,000 98,569	L U R
98,500_ 99,073	
99,000_ 99,577	
99,500_ 100,081	
100,000_ 100,585	
100,500_ 101,089	
101,000_ 101,593	
101,500_ 102,097	
102,000_ 102,601	
102,500_ 103,106	
103,000_ 103,610	
103,500_ 104,114	
104,000_ 104,618	
104,500_ 105,122	
105,000_ 105,626	
105,500_ <mark>106,130</mark>	

Borehole image report of KFM26

Borehole Name:	KFM26
Mapping Name:	KFM26
Mapping Range:	6,027 - 100,710 m
Diameter:	76,0 mm
Printed Range:	1,550 - 100,910
Pages:	5

Image File Information:

File: \\sv50-402\home\$\konsowi\Documents\Boremap-7.0\KFM26\LGX\KFM26 Ner 191022 _H_LGX.HED Date/Time: 2019-10-22 Start Depth: 1,550 m End Depth: 100,910 m Resolution: 1,00 mm/pixel (depth) Orientation: Gravimetric Image height: 99361 pixels Image width: 720 pixels Intrinsic angle: 180 degrees LGX Version: 101 Locality: Wellname: Scan Direction: Down

Depth range: 1,550 - 33,550 m Azimuth: 17,2 Inclination: -85,2



9,500_ 9,430	lili DLUR
10,000_ 9,930	
10,500_ 10,430	
11,000_ 10,929	
11,500_ <mark>11,428</mark>	
12,000_ 11,927	
12,500_ 12,426	
13,000_ 12,925	
13,500_ 13,425	
14,000_ 13,924	
14,500_ 14,424	
15,000_ 14,924	
15,500_ 15,423	
16,000_ 15,923	
16,500_ 16,423	
17,000_ 16,922	
17,500_ 17,422	

17,500_	25,500
17,422 DLUR	25,420
18,000	26,000
17,921	25,920
18,500	26,500
18,421	26,420
19,000_	27,000
18,921	26,920
19,500	27,500
19,420	27,419
20,000	28,000
19,920	27,918
20,500	28,500
20,420	28,417
21,000	29,000
20,920	28,917
21,500	29,500
21,420	29,416
22,000	30,000_
21,920	29,915
22,500	30,500_
22,420	30,414
23,000	31,000
22,920	30,913
23,500	31,500
23,420	31,412
24,000	32,000_
23,920	31,911
24,500	32,500_
24,420	32,411
25,000	33,000_
24,920	32,910
25,500	33,500_
25,420	33,411

Depth range: 33,550 - 65,550 m Azimuth: 30,1 Inclination: -85,7

33,500_	41,500	49,500_	57,500_
33,411	41,419	49,423	57,416
D L U R 34,000_ 33,911	D L U R 42,000 41,920	50,000 49,922	58,000 57,915
34,500_	42,500	50,500	58,500
34,411	42,421	50,422	58,415
35,000_	43,000	51,000	59,000
34,912	42,922	50,922	58,914
35,500	43,500	51,500	59,500_
35,412	43,422	51,421	<mark>59,413</mark>
36,000_	44,000	52,000-	60,000
35,913	43,923	51,921	59,913
36,500	44,500	52,500	60,500_
36,413	44,424	52,421	60,412
37,000_	45,000_	53,000_	61,000_
36,913	44,925	<mark>52,921</mark>	60,912
37,500	45,500	53,500	61,500_
37,414	45,425	53,420	<mark>61,411</mark>
38,000_	46,000_	54,000	62,000_
37,914	45,924	53,920	61,910
38,500_	46,500_	54,500_	62,500_
38,415	46,424	54,419	62,411
39,000	47,000	55,000	63,000
38,915	46,924	<mark>54,919</mark>	62,912
39,500_	47,500_	55,500	63,500_
<mark>39,416</mark>	47,424	55,418	63,413
40,000	48,000	56,000_	64,000_
<mark>39,917</mark>	47,923	55,918	63,914
40,500_	48,500	56,500	64,500
40,418	48,423	56,417	64,415
41,000	49,000	57,000	65,000_
40,918	48,923	<mark>56,916</mark>	<mark>64,916</mark>
41,500	49,500	57,500	65,500_
41,419	49,423	57,416	65,417

Depth range: 65,550 - 97,550 m Azimuth: 35,4 Inclination: -85,6

65,500_ 65,417	73,500_ 73,418	81,500_ 81,396	89,500_ 89,340 D L U R
66,000 65,918	D L U R 74,000 73,914	D L U R 82,000_ 81,894	D L Ü R 90,000 89,835
66,500	74,500	82,500_	90,500
66,419	74,410	82,391	90,333
67,000	75,000	83,000_	91,000
66,920	74,906	82,889	90,831
67,500	75,500_	83,500_	91,500
67,421	75,402	83,387	91,330
68,000	76,000	84,000	92,000
67,922	75,899	83,885	91,829
68,500	76,500	84,500_	92,500
68,423	76,395	84,383	92,327
69,000	77,000	85,000_	93,000
68,924	76,891	<mark>84,881</mark>	92,826
69,500	77,500_	85,500_	93,500
69,425	77,391	85,377	93,325
70,000	78,000	86,000	94,000
69,926	77,893	85,873	93,824
70,500	78,500	86,500_	94,500
70,427	<mark>78,394</mark>	86,368	94,322
71,000	79,000	87,000_	95,000
70,928	<mark>78,896</mark>	<mark>86,864</mark>	94,821
71,500	79,500-	87,500_	95,500
71,429	79,397	87,359	95,320
72,000	80,000	88,000_	96,000_
71,929	<mark>79,899</mark>	87,854	95,821
72,500	80,500	88,500_	96,500
72,425	80,400	88,350	96,323
73,000	81,000-	89,000	97,000
72,922	80,898-	88,845	96,824
73,500	81,500_	89,500_	97,500_
73,418	81,396	89,340	97,326

Depth range: 97,550 - 100,910 m Azimuth: 40,3 Inclination: -85,6



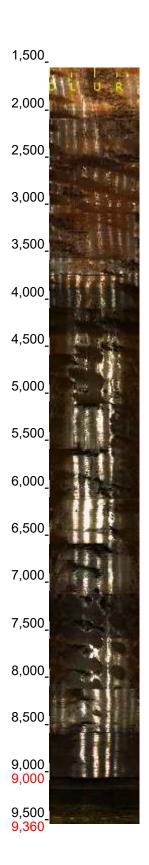
Borehole image report of KFM27

Borehole Name:	KFM27
Mapping Name:	KFM27
Mapping Range:	9,000 - 100,640 m
Diameter:	76,0 mm
Printed Range:	1,560 - 100,850
Pages:	5

Image File Information:

\\sv50-402\home\$\konsowi\Documents\Boremap-7.0\KFM27\LGX\KFM27 Ner 191022 File: _H_LGX.HED Date/Time: 2019-10-22 Start Depth: 1,560 m End Depth: 100,850 m Resolution: 1,00 mm/pixel (depth) Orientation: Gravimetric Image height: 99291 pixels Image width: 720 pixels Intrinsic angle: 180 degrees LGX Version: 101 Locality: Wellname: Scan Direction: Down

Depth range: 1,560 - 33,560 m Azimuth: 322,5 Inclination: -74,8





17,500_ <mark>17,370</mark>	
18,000_ 17,872	
18,500_ 18,373	
19,000_ 18,875	
19,500_ 19,376	
20,000_ 19,878	
20,500_ 20,379	
21,000_ 20,881	
21,500_ <mark>21,381</mark>	
22,000_ <mark>21,881</mark>	
22,500_ 22,380	
23,000_ 22,880	
23,500_ 23,380	
24,000_ 23,879	
24,500 24,379	
25,000_ 24,879	
25,500 25,378	



Depth range: 33,560 - 65,560 m Azimuth: 326,4 Inclination: -74,5

33,500_ <mark>33,382</mark>	DLUR
34,000_ 33,882	
34,500_ 34,383	
35,000_ <mark>34,883</mark>	
35,500_ <mark>35,384</mark>	
36,000_ <mark>35,884</mark>	
36,500_ <mark>36,385</mark>	
37,000_ <mark>36,885</mark>	
37,500_ <mark>37,386</mark>	
38,000_ 37,886	
38,500_ <mark>38,386</mark>	A
39,000_ <mark>38,887</mark>	
39,500_ <mark>39,387</mark>	
40,000_ 39,888	
40,500 40,387	and a first a
41,000_ 40,887	
41,500_ <mark>41,386</mark>	

41,500_ <mark>41,386</mark>	DLUR
42,000_ 41,885	
42,500_ <mark>42,384</mark>	
43,000_ 42,884	
43,500_ <mark>43,383</mark>	
44,000_ 43,882	
44,500_ 44,381	
45,000_ <mark>44,880</mark>	
45,500_ <mark>45,379</mark>	
46,000_ <mark>45,878</mark>	
46,500_ 46,377	
47,000_ <mark>46,876</mark>	
47,500_ 47,374	
48,000_ 47,873	
48,500_ 48,372	
49,000_ <mark>48,87</mark> 1	- Pa
49,500_ 49,369	

49,500_ 49,369	
50,000_ 49,868	
50,500_ 50,367	
51,000_ 50,866	and diver
51,500_ 51,364	and the second s
52,000_ <mark>51,863</mark>	
52,500_ <mark>52,362</mark>	
53,000_ <mark>52,861</mark>	
53,500_ 53,359	
54,000_ <mark>53,858</mark>	
54,500_ <mark>54,358</mark>	
55,000_ <mark>54,858</mark>	
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56,000_ 55,859	A A A A A A A A A A A A A A A A A A A
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60,500_ 60,360	
61,000_ <mark>60,860</mark>	
61,500_ <mark>61,359</mark>	
62,000_ <mark>61,859</mark>	
62,500_ 62,359	
63,000_ <mark>62,859</mark>	A start
63,500_ <mark>63,358</mark>	
64,000_ <mark>63,858</mark>	
64,500_ <mark>64,358</mark>	
65,000_ <mark>64,858</mark>	
65,500_ <mark>65,358</mark>	

Depth range: 65,560 - 97,560 m Azimuth: 326,5 Inclination: -74,2

65,500_	73,500_	81,500_	89,500_
65,358	73,351	81,328	89,317
66,000 65,857	74,000 73,850	D L U R 82,000 81,827	D L U R 90,000 89,816
66,500	74,500	82,500	90,500_
66,357	74,350	82,327	90,316
67,000	75,000	83,000	91,000_
66,857	74,849	82,826	90,815
67,500	75,500	83,500	91,500_
67,357	75,348	83,325	91,316
68,000	76,000	84,000	92,000
67,856	75,847	83,825	91,818
68,500	76,500	84,500	92,500
68,356	76,345	84,324	92,319
69,000	77,000	85,000	93,000
68,856	76,843	<mark>84,823</mark>	92,821
69,500	77,500	85,500	93,500
69,356	77,341	<mark>85,323</mark>	93,323
70,000	78,000	86,000	94,000
69,855	77,839	85,822	93,824
70,500	78,500	86,500	94,500
70,355	78,337	86,321	94,325
71,000	79,000	87,000	95,000_
70,855	78,834	<mark>86,821</mark>	94,825
71,500_	79,500	87,500	95,500
71,354	79,332	<mark>87,320</mark>	95,325
72,000_	80,000	88,000	96,000
71,854	79,830	87,819	95,825
72,500	80,500	88,500	96,500
72,353	80,329	88,319	96,325
73,000	81,000	89,000	97,000
72,852	80,829	<mark>88,818</mark>	96,825
73,500	81,500_	89,500	97,500
73,351	81,328	89,317	97,325

Depth range: 97,560 - 100,850 m Azimuth: 327,5 Inclination: -74,2

97,500_ 97,325
98,000 97,825
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105,000 104,825
105,500 105,325

SKB is responsible for managing spent nuclear fuel and radioactive waste produced by the Swedish nuclear power plants such that man and the environment are protected in the near and distant future.

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