P-05-103

Forsmark site investigation

Boremap mapping of percussion boreholes HFM20, HFM21 and HFM22

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November 2005

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ISSN 1651-4416
SKB P-05-103

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Part 1

Boremap mapping

Johan Berglund

Part 2

Boremap mapping of HFM21 and HFM22

Christin Döse

Keywords: Geology, Fractures, BIPS, Boremap, Percussion drilling, Generalised geophysical logs, Comparative study, AP PF 400-04-106.

Abstract

This report presents the Boremap mapping of three percussion drilled boreholes: HFM020, HFM021 and HFM022. The activity is one of many within the site investigation program at Forsmark.

The drilling of these three boreholes was completed in the autumn, 2004. HFM21 and HFM22 were drilled to supply drill sites 7 and 8 with flushing water during the core drilling and to investigate the character at depth of two lineaments that trend ca north-south. HFM20 was drilled vertically and is together with HFM21 and HFM22 forming an array that permits a detailed, cross-hole hydraulic investigation of the superficial part of the bedrock in this part of the investigation area.

The Boremap mapping includes interpretations of BIPS-images, supported by generalised geophysical logs as well as drilling penetration rate. The drill-cuttings from the percussion drilled boreholes are generally available in the form of a 1 dm^3 large sample taken every metre of penetration. The drill cuttings were only inspected when needed, primarily to aid the interpretation of rock type when a change in the lithology was indicated in the BIPS-image.

The report is divided in two parts. Part 1 reports the Boremap mapping made by SwedPower AB. Part 2 reports an independent mapping of the section 90–201.7 m in HFM21 made by Geosigma AB, including a comparison between the two borehole interpretations, as well as an alternative mapping of HFM22, also by Geosigma AB.

All three percussion drilled boreholes are dominated by a medium grained metagranite to metagranodiorite (rock code 101057). Both amphibolite and pegmatite are common rock occurrences in all three boreholes. In HFM20 more than 7% of the borehole length is intersecting amphibolites, the longest borehole section being over 11 m.

A few, narrow (< 1 dm) sections with crushed bedrock have been mapped in HFM20, HFM21 and HFM22. In HFM20 and HFM21 they are all concentrated to a 5 m long section in each borehole, at 20–25 m in HFM20 and at 95–100 m in HFM21. In HFM22 they are more separated; the first is observed at 62.2 m and the second at 85.2 m borehole length.

There are no significant differences in the classification and distribution of the rock types between the two interpretations. The difference between the two interpretations is mainly concerning the number of recorded fractures and the judgement whether narrow fractures are open or not. The comparison clearly shows not only the difficulty of interpreting features that are so small that they cannot be clearly observed in the BIPS-image, but also that a methodology for mapping uncertain fractures in percussion drilled borehole with this method is needed.

Sammanfattning

Denna rapport presenterar Boremapkartering av de tre hammarborrade hålen HFM020, HFM021 och HFM022. Aktiviteten är en av många som utförs inom ramen för platsundersökningar i Forsmark. Borrningarna genomfördes hösten 2004. Syftet med HFM21 och HFM22 var att förse borrplatserna 7 och 8 med spolvatten till borrningarna av de teleskopborrade kärnborrhålen. Ett annat syfte var att undersöka karaktären på djupet hos två nord-sydliga lineament. Tillsammans med det vertikalt borrade HFM20 skapar de tre borrhålen en möjlighet att genomföra en ytnära hydraulisk undersökning mellan borrhålen.

Karteringen innefattade tolkning av BIPS-bilderna från TV-loggningarna med stöd av generaliserade geofysikloggar och borrsjunkning. Borrkax finns normalt tillgänglig som 1 dm^3 stora prover tagna varje meter av borrhålspenetration. Borrkax från borrningen undersöktes dock endast i undantagsfall för att få en hjälp vid bergartsbestämning då förändringar av bergartstyp indikerades i BIPS-bilden.

Rapporten är uppdelad i två delar. Del 1 rapporterar Boremap-karteringen utförd av SwedPower AB. Del 2 rapporterar en oberoende kartering av sektion 90–201,7 meter i borrhål HFM21 av Geosigma AB och inkluderar en jämförelse mellan de två tolkningarna av borrhålet, samt en alternativ kartering av HFM22, även denna utförd av Geosigma AB.

Alla tre hammarborrhål domineras av en medelkornig metagranit till metagranodiorit (bergartskod 101057). Både amfibolit och pegmatit är vanliga inslag i alla tre borrhålen. I HFM20 består mer än 7 % av borrhålslängden av amfibolit och den längsta enhetliga sammanhängande sektionen amfibolit överstiger 11 meter.

Några få, smala (< 1 dm) sektioner med krossat berg har karterats i HFM20, HFM21 och HFM22. I HFM20 och HFM21 är de alla lokaliserade till en fem meter lång sektion i respektive borrhål, mellan 20–25 meter i HFM20 och mellan 95 och 100 meter i HFM21. I HFM22 är de mer åtskiljda: den första påträffas på 62,2 m och den senare på 85,2 m borrhålslängd.

Det förekommer inga betydande skillnader i klassificering och fördelning av bergarter mellan de två tolkningarna. Skillnaden mellan de två tolkningarna består främst i antalet noterade sprickor och bedömningen huruvida sprickorna är öppna eller slutna. Jämförelsen visar tydligt inte bara svårigheten att tolka små objekt som inte kan ses tydligt i BIPS, utan även behovet av att utarbeta en metod för att kartera osäkra sprickor i BIPS-filmade hammarborrhål.

Contents

Part 1

Boremap mapping of HFM20, HFM21 and HFM22 by SwedPower

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April 2005

Contents Part 1

1 Introduction

This document reports the results gained from the Boremap mapping of percussion boreholes HFM20, HFM21 and HFM22, one of the activities performed within the site investigation at Forsmark (Figure 1-1). The work was carried out in accordance with activity plan SKB AP PF 400-04-106. In Table 1-1 controlling documents for performing this activity are listed. All activity plans and method descriptions are SKB internal controlling documents.

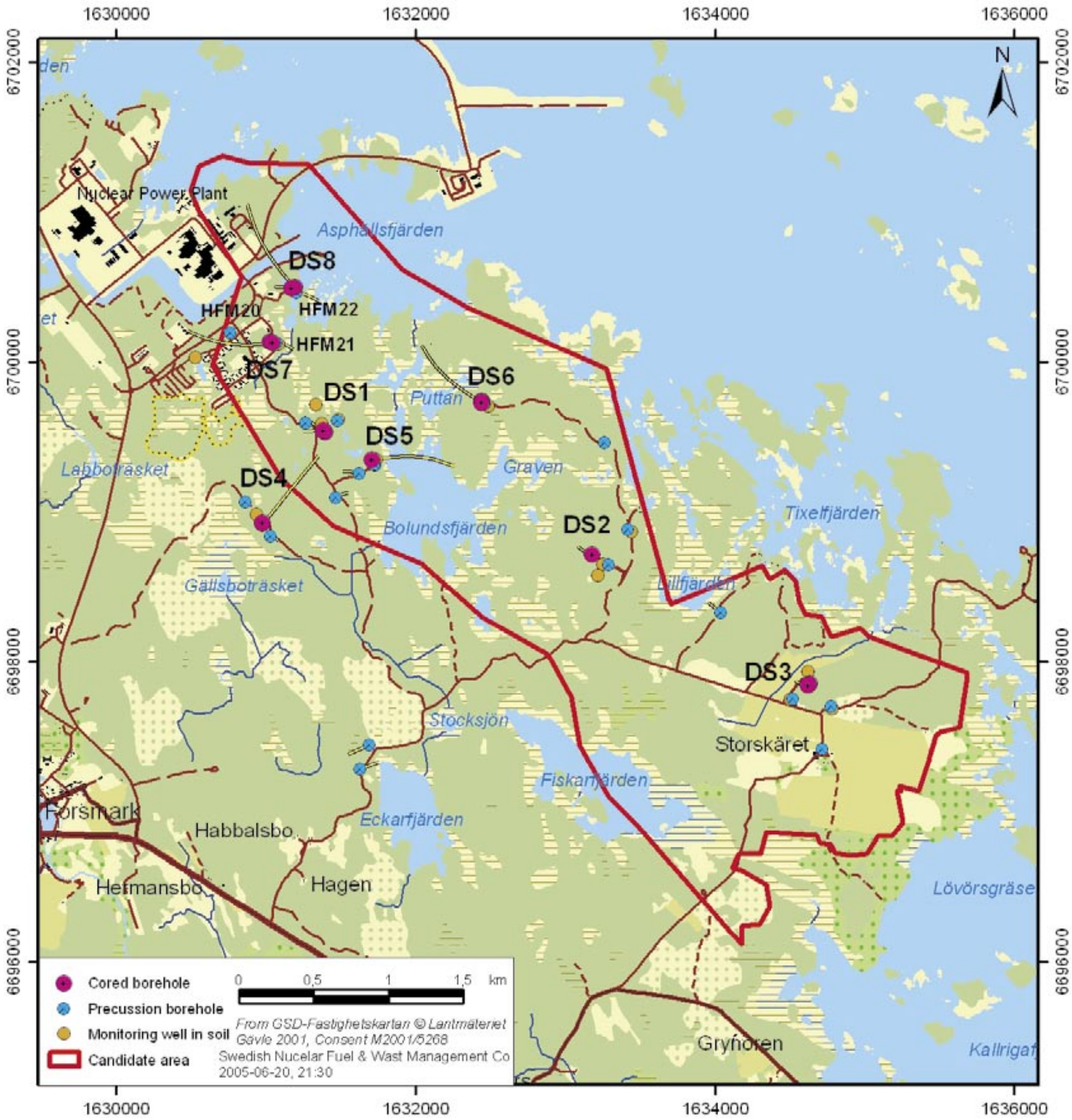

***Figure 1-1**. General overview over Drill Sites (DS) end borehole location Forsmark site investigation area. Borehole HFM20 and HFM21 is located close to drill site 7, while borehole 22 is located close to drill site 8.*

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

Activity plan	Number	Version
Name	AP PF 400-04-106	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för Boremapkartering	SKB MD 143.006	1.0
Mätsystembeskrivning för Boremapsystemet	SKB MD 143.005	01

The drilling of these three boreholes was completed in the autumn, 2004. HFM21 and HFM22 were drilled to supply drill sites 7 and 8 with flushing water during the core drilling and to investigate the character at depth of two lineaments that trend ca north-south. HFM20 was drilled vertically and together with HFM21 and HFM22 the boreholes form an array that permits a detailed, cross-hole hydraulic investigation of the superficial part of the bedrock in this part of the investigation area.

After completion, the boreholes were investigated by means of several logging methods, e.g. conventional geophysical logging, borehole radar and BIPS (SKB internal controlling document MD 222.006). The mapping of percussion drilled boreholes according to the Boremap system is based on the use of BIPS-images of the borehole wall. The mapping is supported by interpretations of generalised geophysical borehole logging data (Appendix 10), samples from drill cuttings and the drilling penetration rate.

It should be noted that the interpretation of rock types and rock occurrences is not straight-forward. It may be biased e.g. by variations in colour of the image, by geology that is not orthogonal to the borehole and by the resolution of geophysical logs.

Also the identification of fractures is often ambiguous. The width of the fractures or the alteration surrounding the fracture must be wide enough to be positively identified in the image. Thin fractures may be mistaken for narrow occurrences or even foliation planes.

Different geologists are likely to make slightly different decisions when fractures are mapped, and when rock types and alterations are identified in this type of Boremap mapping. In order to test the differences in the result from two different geologists a sub-activity was performed, where a second geologist first remapped a part of HFM21 and made a comparative study between the to Boremap mappings and then remapped the whole HFM22 (see Part 2 in this report).

As a comment to the difficulties in Boremap mapping of the percussion drilled boreholes with the current methodology at Forsmark, it is suggested that a more inflexible method instruction is made. This should state in more detail what kind of objective images in the BIPS that correspond to the separate lithologies found at Forsmark. It should also state what kind of objective images in the BIPS that should be regarded as a fracture and when the fractures should be regarded as having an aperture or not. Furthermore it should state in more detail how to use the generalised geophysical logs and the drilling penetration rate.

2 Objective and scope

The aim of this activity was to document lithologies, ductile structures and the occurrence and character of fractures and fracture zones in the bedrock penetrated by the three percussion drilled boreholes HFM20, HFM21 and HFM22. Data were collected in order to obtain a foundation for a preliminary assessment of the bedrock conditions adjacent to nearby telescopic drilled boreholes (KFM07A and KFM08A, respectively) to study the character at depth of two lineaments (code XFM0157A0 and XFM0431A0) that trend north-south and that possibly represent minor deformation zones.

Other data obtained from the percussion drilled boreholes, such as thickness of soil cover, soil stratigraphy, groundwater level and groundwater flow, will not be treated in this paper.

3 Equipment

3.1 Description of equipment/interpretation tools

Mapping of BIPS-images was performed with the software Boremap v. 3.4.5.2.
The Boremap software calculates actual directions (strike and dip) of planar structures penetrated by the borehole (foliations, fractures, contacts, etc). Data on inclination, bearing and diameter of the borehole are used as in-data for the calculations (Appendices 7 and 8). The BIPS-image lengths were calibrated as described in Chapter 4.2. The Boremap software is loaded with the bedrock and mineral standard used for surface mapping at the Forsmark investigation site, to enable correlation with the surface geology. Stereographic projections were plotted in stereographic diagrams using the software GeoPlot, while schematic presentations of the boreholes were presented in WellCad.

3.2 BIPS-image quality

The BIPS-image quality is generally good, although in the lower part of the boreholes HFM21 and HFM22, only part of the borehole walls is clearly visible.

4 Execution

4.1 General

Boremap mapping of the percussion drilled boreholes HFM20, HFM21 and HFM22 was performed and documented according to activity plan AP PF 400-04-106. Generalised geophysical logs of the boreholes, as well as drilling percussion rate, were available and used as an aid during the mapping. The Boremap mapping was performed in accordance with the SKB method description for Boremap mapping (SKB MD 143.006, v. 1.0, SKB internal controlling document).

4.2 Preparations

The lengths of the boreholes are listed in Table 4-1. Length corrections of the BIPS-images were made for all the boreholes in a general way, empirically based on an extension of the wire of 0.5 m per 100 m.

Background data collected from SICADA prior to the Boremap mapping included:

- Borehole diameter (Appendix 7).
- Borehole length (Appendix 7).
- Borehole deviation data (Appendix 8).
- Drilling penetration rate (Appendix 9).

Generalised geophysical logs from Geovista AB were used as supporting data for the boreholes HFM20–22 (Appendix 10).

Measurements of borehole directions were refined using deviation data from the SKB SICADA database.

Geometric data for boreholes HFM20–22 are given in Table 4-1.

Table 4-1. Geometric information of percussion-drilled boreholes.

IDCODE	Length (m)	Diameter (mm)	Lenght BIPS-image in rock (not adjusted) (m)	Soil cover (m)
HFM20	301.0	139	287.754 (12.046–299.800)	3.0
HFM21	202.0	139	188.807 (12.052–200.859)	3.1
HFM22	222.0	140	202.764 (12.036–214.800)	3.9

4.3 Execution of measurements

Available geological information is more limited for Boremap mapping of percussion-drilled boreholes than for core-drilled boreholes, where the drill core can be directly compared with BIPS-images of the borehole wall. During mapping of percussion drilled boreholes, fractures and rock types can only be observed in the BIPS-images. As solid rock samples are not at hand, certain assumptions and simplifications have to be made during mapping. These are described below.

4.3.1 Fractures

As fractures could only be studied in the BIPS-image, several parameters were not mapped in Boremap. For broken fractures neither “Roughness”, “Surface”, “Alteration”, “Joint Alteration” nor “Visible in BIPS” were documented, for obvious reasons. For Unbroken fractures neither “Alteration”, nor “Visible in BIPS” were documented.

The location of fractures and judgement of aperture is based on the BIPS-image, but the generalised geophysical logs (Appendix 10) also indicate the location of open fractures and fracture frequency.

Regarding the fracture infilling, it is not possible to classify the mineralogy with an acceptable degree of confidence. In the BIPS-image it is the colour of the individual pixels in the image that are studied and the relation between these. During mapping a fracture was identified in the image by a narrow array of pixels with anomalous colour, lying in a sinusoidal shape across the image. When these pixel arrays only had a width of 1 pixel (~ 0.5 mm), the fracture was mapped without infilling mineral. When the width exceeded 1 pixel, i.e. when an infilling was clearly visible, it was mapped as unknown mineral, regardless of its colour. If a bleach or a reddish zone was identified in a sinusoidal shape across the image, with or without a central more distinct plane, this was mapped as “Oxidized walls”.

The classification of fractures into those with and without aperture, respectively, is based on the occurrence of 100% black pixels. Single such pixels were ignored and not judged as an aperture, not a few aligned such pixels either. However, when several black pixels are aligned a few millimetres or more, or the width of aligned black pixels exceeds 1 pixel, an aperture has been assigned to the fracture. The width of the aperture was measured in the image and an average of the measured width along the observed aperture was estimated.

The width of thin fracture fillings and apertures (< 1 mm) were difficult to measure accurately and were therefore, as a rule, interpreted as 0.5 mm thick.

4.3.2 Rock type and occurrences

The separation of rock types in the percussion drilled boreholes is based on the observations of colour and texture in the BIBS-image, with the aid of generalised geophysical logs and samples from the drill cuttings.

The generalised geophysical logs used are silicate density, natural gamma radiation and magnetic susceptibility. The interpretation from generalised geophysical logs are standardized (SKB 221.003 v. 2.0, SKB internal controlling document).

The sampling of drill cuttings is done when the drill head passes the sample depth, during approximately 20 cm penetration. Normally a sample is taken every metre and the rest of the rock in the borehole is not sampled. It is assumed that the sample is contaminated with material from other parts of the borehole and that this effect increase with increasing depth, however, no detailed study is done to verify these assumptions. The drill cutting fractions vary. In the upper part of a borehole it is coarser. When the cuttings are studied, it is first sieved with water and in the upper part of the boreholes it is much easier to decide what rock the cutting is derived from. In the lower (major) part of the borehole the cuttings is much finer grained due to grinding, and most (often all) material is washed away when sieved. The cuttings from deeper sections are of little help to define rock type.

As a general rule, only occurrences wider than ca 30 cm have been mapped. Very distinct occurrences (e.g. amphibolites in granites), or occurrences that are steep in relation to the borehole have, however, also been mapped.

Irregular boundaries have been approximated with a single plane.

4.3.3 Alteration

Suspected altered parts observed in BIPS that are not confined to an observed fracture, has been mapped as alteration. Oxidation is the most common type of alteration. Only the colour observed in the BIPS-image was used as indicator of alteration. As for the boundaries between rocks, the boundaries between altered and non-altered sections in the borehole are approximated with a plane.

4.4 Data handling/post processing

The Boremap mapping of HFM20, HFM21 and HFM22 was performed on a local computer, with backup on diskettes made whenever a longer brake in the mapping was done. After completion of mapping and quality control the access database was sent to SKB for storage in SICADA.

4.5 Nonconformities

A lower limit of ca 0.3 m borehole length was used for registration of rock occurrences. Fractures with an estimated width of less than 1 mm was mapped although the resolution in the BIPS-image do not justify this according to the activity plan. This was done when the fractures was identified with a high level confidence (certain). However, fractures judged as uncertain were not mapped.

5 Results

The Boremap mapping of HFM20, HFM21 and HFM22 are stored in the SICADA database and are traceable by the activity plan number. All data used for further interpretations and modelling should be ordered from there. It is important that the interpreter read this report and is aware of the methods of mapping and related biases.

The results from the Boremap mapping are briefly described in sections 5.1–5.3 below as well as stereographic projection of structural data (fractures and foliations; equal-area, lower hemisphere). Other graphical presentations of the data (WellCad and BIPS-images) are presented in Appendices 1–6.

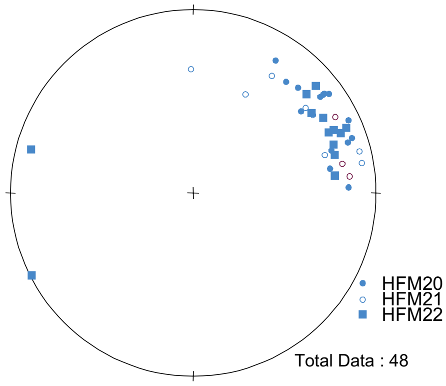

***Figure 5-1.** Foliations in HFM20, HFM21 and HFM22. Lilac, open circles represent shear zones in HFM21.*

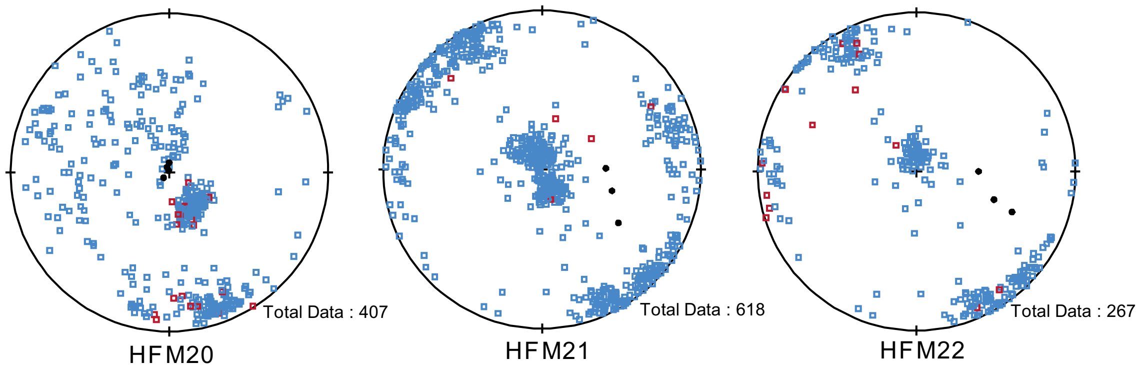

***Figure 5-2.** Fracture orientations in HFM20, HFM21 and HFM22, respectively. Blue symbols represent fractures mapped with no aperture and red symbols fractures with aperture. Black dots represent borehole orientation at every 100 m.*

5.1 HFM20

Lithologies

The dominant rock type in HFM20 is a medium grained, foliated, reddish grey metagranite to metagranodiorite (101057), making up 93.1% of the borehole. The other 6.9% is amphibolite (102017).

Rock occurrences, mapped as unspecified or dikes, is composed of 1.8% pegmatite and 1.0% amphibolite.

The general orientation of the foliation in the borehole is N-S to NW-SE, with a steep dip to the east (Figure 5-1).

Fractures

Only a minor part of the fractures have been mapped as having an aperture. These do not seem to have any separate orientations from the general fracture orientation pattern. A major part of the mapped fractures have oxidized walls.

Between 20 and 25 m three narrow (< 1 dm), gently dipping sections with crushed bedrock occur. The section is indicated to have a fracture frequency of more than 10 fractures per metre in the interpreted geophysical logging data (Appendix 10).

5.2 HFM21

Lithologies

The dominant rock type in HFM20 is a medium grained, foliated, reddish grey to grey metagranite to metagranodiorite (101057), making up 96.8% of the borehole. In the lower ca 21 m of the borehole the granitoid has a grey colour that may reflect a more granodioritic composition, a general lower component of feldspars, however it may also reflect some unspecified alteration.

Rock occurrences, mapped as unspecified or dikes, is composed of 2.7% pegmatite, 2.8% amphibolite, 2.4% granitoid (101057) and 0.5% of the younger granitoid (101051).

The general orientation of the foliation in the borehole is N-S to NW-SE, with a steep dip to the east (Figure 5-1). One suspected ductile and a few suspected brittle-ductile shear zones have been mapped, the widest is ca 1.5 m and is related to the occurrence of two narrow amphiboles. It is located at a borehole length of 95.414–96.971 m and has a crush zone in its centre. The orientations of the ductile and two of the brittle-ductile zones are plotted in Figure 5-1.

Fractures

Only a minor part of the fractures have been mapped as having an aperture. These do not seem to have any separate orientations from the general fracture orientation pattern. A major part of the mapped fractures have oxidized walls.

Between 95 and 100 m three narrow (< 1 dm), gently dipping sections with crushed bedrock occur.

5.3 HFM22

Lithologies

The dominant rock type in HFM20 is a medium grained, foliated, reddish grey metagranite to metagranodiorite (101057), making up 93.6% of the borehole.

Rock occurrences, mapped as unspecified or dikes, is composed of 2.7% pegmatite, 0.7% amphibolite, 1.9% granitoid (101057), 0.1% of the younger granitoid (101051) and finally 0.4% of the younger aplitic granite, the so-called Klubbudden type (101058).

The general orientation of the foliation in the borehole is N-S to NW-SE, with a steep dip to the east (Figure 5-1). One narrow brittle-ductile shear zone is mapped just above 159 m in the borehole.

Fractures

Only a minor part of the fractures have been mapped as having an aperture. These do not seem to have any separate orientations from the general fracture orientation pattern. A major part of the mapped fractures have oxidized walls.

No sections with crushed bedrock were mapped in this borehole.

Part 2

Boremap mapping of HFM21 and HFM22 by Geosigma

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Geosigma AB

June 2005

Contents Part 2

1 Introduction

SKB uses the software Boremap and BIPS-images in order to map both core drilled and percussion drilled boreholes. Final data for both mapping types seems to be equivalent, and therefore interpreters using the result may believe that the quality of the two drilling methods is equivalent.

Geological interpretation of percussion drilled boreholes is based on BIPS-images and generalised geophysical logs. Occasionally, drilling penetration rate and drill cuttings are also used for the geological interpretation. The quality of the BIPS-image is of crucial importance to the quality of the mapping. Other crucial factors are: 1) the interpreter's knowledge of how different structures look like in BIPS, 2) the interpreter's knowledge of the geology in the area and 3) within which limits the interpreter ranks the observation as too uncertain to be documented.

Since a drill core is absent, key answers for the mapping of percussion drilled boreholes are lacking. There is no SKB controlling document that in detail describes how different fractures or other structures shall be mapped in percussion drilled boreholes. For example, which fractures shall be mapped as possibly open and which fractures shall be interpreted as too uncertain to be documented in the mapping. As a result of these factors, diverse interpretations made by different persons are expected.

This document reports the data gained by Boremap mapping of percussion drilled boreholes HFM21 (section 90–201.7 m) and HFM22 drilled within the site investigation at Forsmark. The boreholes have been mapped earlier by another interpreter (see Part 1 in this report). The Boremap mapping of HFM21 and HFM22 in this report is performed with two different approaches. HFM21, section 90–201.7 m, was mapped in order to compare the mapping with the one performed earlier, while HFM22 was mapped in order to receive an alternative interpretation of the geology in the borehole.

The work – apart from the comparison – was carried out in accordance with activity plan SKB PF 400-04-106. In Table 1-1 controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB's internal controlling documents. The Boremap mappings in this report were performed independently from the previous mappings of HFM21.

All necessary background data of HFM21 and HFM22 are to be found in the report of the previous mappings of the boreholes, Part 1 in this report.

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

Activity plan	Number	Version
Boremapkartering av hammarborrhålen HFM20, HFM21,HFM22	AP PF-400-04-106	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för Boremap-kartering	SKB MD 143.006	1.6

2 Objective and scope

The aim of the mapping of HFM21 is to compare the mapping of percussion drilled boreholes, performed by two different persons. The aim of the mapping of HFM22 is to receive an alternative interpretation of the geology in the borehole.

3 Boremap mapping of HFM21 – a comparative study

3.1 Methods

In this commission the section 90.0–201.7 m adjusted length (or 89.669–200.737 m recorded BIPS-length) in HFM21 was mapped with the Boremap method (Boremap, v. 3.6) in accordance with the activity plan SKB PF 400-14-106 and the method description MD 143.006, v. 1.0 (SKB, internal controlling document). Generalised geophysical logs, as well as drilling penetration rate were used as a complement to the mapping. The mapping was performed independent from previously made Boremap mapping of HFM21. Some minor deviations from the activity plan occur. Deviation data from the borehole are not collected automatically from SICADA, since there was no access to SICADA. Deviation data for each 12th meter are therefore manually recorded in the software Boremap.

The mapping in this study (mapping A) was compared with the earlier performed mapping (mapping B) of HFM21, mainly with respect to fractures, but also with respect to lithology and other structures. The comparison of fractures was performed in Excel, where mapping data from both mappings were sorted and compared. The comparisons of less frequently occurring features were performed in Boremap with the application "view feature".

In mapping A possibly open fractures are mapped with a 0.7 mm possible aperture, probably open fractures are mapped with a 0.7 mm probable aperture, while other open fractures are mapped with a 0.7 mm certain aperture or with an aperture greater than 0.7 mm. In this comparison the corresponding fractures in mapping B are interpreted as follows: open fractures mapped with 0 or 0.5 mm possible aperture as possibly open fractures, 0.5 mm probable aperture as probably open fractures and > 0.5 mm aperture as open fractures.

Since the mappings have different length adjustments all length values in this report are given as the recorded BIPS-image length if nothing else is mentioned, so that all length values in both mappings are possible to correlate.

3.1.1 Differences in in-data between the mappings

Borehole deviation data

Mapping B imported deviation data from SICADA, while deviation data in mapping A was manually recorded in Boremap (a value for each 12th metre), since there was no access to SICADA.

Length adjustments

In mapping B the BIPS-image was length adjusted, so that the end of the BIPS-image was 201.905 m, while the end length of the BIPS-image of mapping A was adjusted to 201.7 m. The end length of mapping A is based on the fact that the total length of the borehole is 202.00 m according to information in SICADA, and that the BIPS-camera cannot record the last 30 cm in a borehole.

Borehole diameter

The stated borehole diameter in Boremap of mapping B is the same as the stated drill bit diameter when the drilling started (139 mm). In mapping B a mean value has been used (138 mm), since the drill bit wears during drilling and had a diameter of 137 mm when the drilling was completed.

3.2 Results

The dominating rock type is metagranite-granodiorite (SKB code 101057). Smaller occurrences of amphibolite (102017), fine-grained granite (101058 and 111058), and felsic to intermediate metavolcanic rock (103076) has been observed. In the end of borehole HFM21 the metagranite-granodiorite changes character (169.5 m recorded depth) and becomes darker and more fine-grained (Figure 3-1). In the BIPS-image foliation is visible, but sometimes no clear structure is discernible. The generalised geophysical logs indicate that the rock type is granitic in composition. The mapping of rock types have not been studied in detail in this work.

In mapping A, all observable rock occurrences have been mapped, while it seems that only rock occurrences with a width exceeding ca 20 cm have been documented in mapping B (Table 3-2). No observations of fine-grained granites have been made in mapping B. Furthermore, there are more rock type observations in mapping A than in mapping B. The reason for this is probably that differences in character of the metagranite-granodiorite has been documented as a new observation in mapping A. See Table 3-2 for comparisons between mapping A and B.

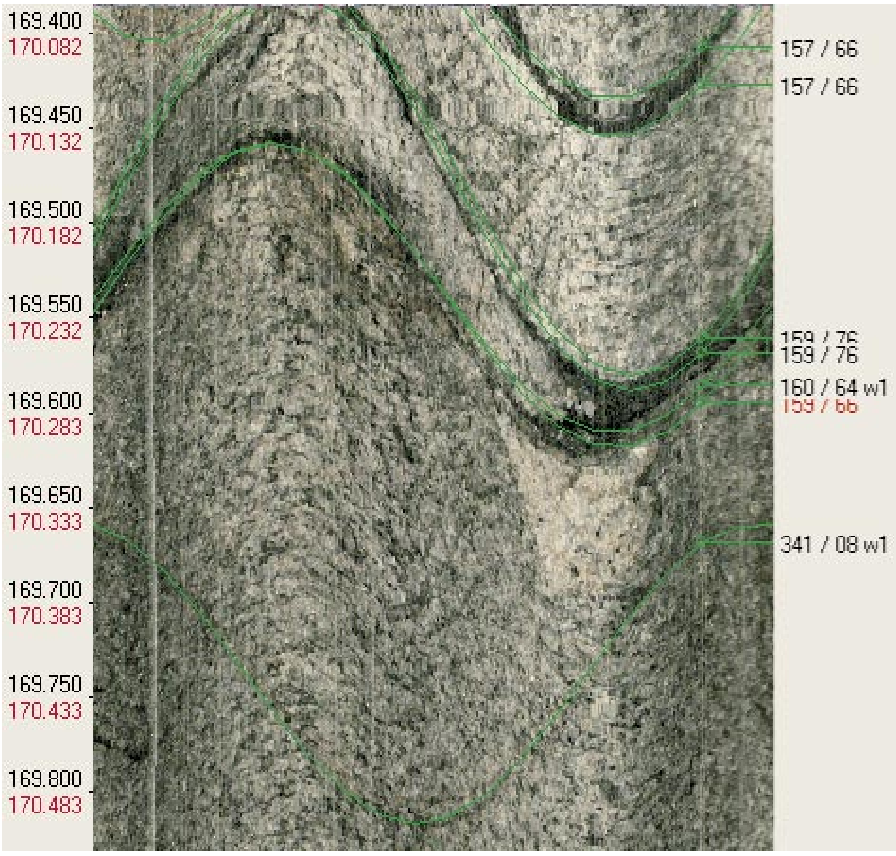


Figure 3-1. Changes in the character of the metagranite-granodiorite at approximately 169.5 m, mapping A.

3.2.1 Structures

There are some differences in the interpretation of structures in the two mappings (Table 3-1). In mapping B, sealed fracture network is mapped in the following sections: 116.54–116.83 m and 146.47–146.66 m. In mapping A, the former section has been interpreted as a few sealed fractures together with drill induced fractures (irregular fracture shape), while every single fracture has been mapped separately (as possibly open fractures with oxidized walls) in the latter section.

In mapping A, a sealed fracture network has been mapped at 148.86–149.24 m (Figure 3-2) In mapping B, this section (148.81–149.44 m) is mapped as a rock occurrence with the structure brittle-ductile shear zone. In mapping B there are several similar occurrences, while such standpoints have not been made in mapping A, since the resolution of the BIPS-image is not considered good enough for such standpoints. A possible reason why this decision was taken is that the drill cuttings may have indicated a brittle-ductile shear zone.

In mapping B a ductile shear zone has been documented at 186.41 m. In mapping A this zone is interpreted as an occurrence of a felsic intermediate volcanic rock (Figure 3-3).

In mapping B a brittle-ductile shear zone has been documented at 149.20 m and 150.42 m (Figure 3-5). In mapping A the first is interpreted as a part of a sealed fracture network, while the latter is interpreted as a granitic vein.

A mylonitic occurrence is observed at 119.01 m in mapping B (Figure 3-4). This has been mapped as an oxidized zone with fractures having oxidized walls in mapping A.

In mapping A the structural observations are exclusively foliations and lineations. One undefined structure (Figure 3-6) has been mapped as a strong foliation, but it is possible that this is a ductile shear zone or a mylonite**.**

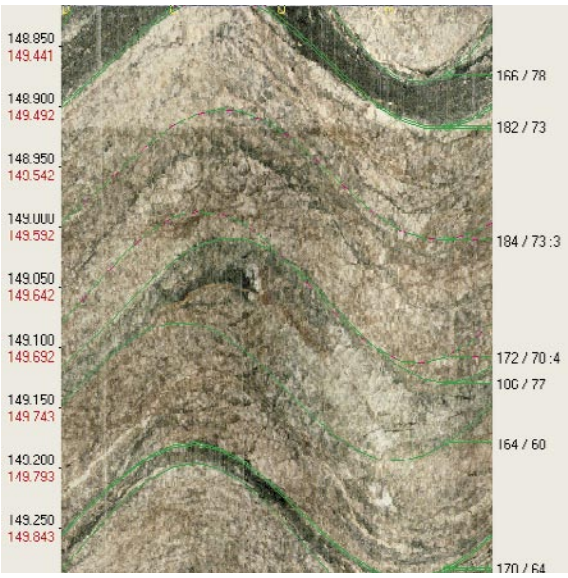


Figure 3-2. *Sealed fracture network at 148.86–149.24 m, mapping A.*

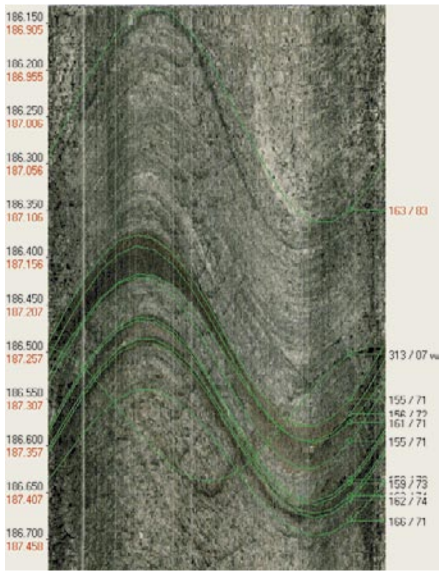


Figure 3-3. *Felsic intermediate volcanic rock, mapping A.*

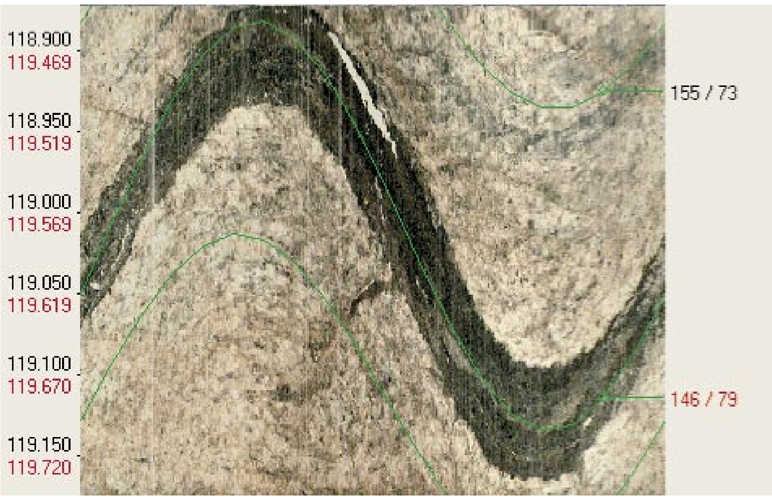


Figure 3-4. *Possible mylonite at 119.01 m, mapping B.*

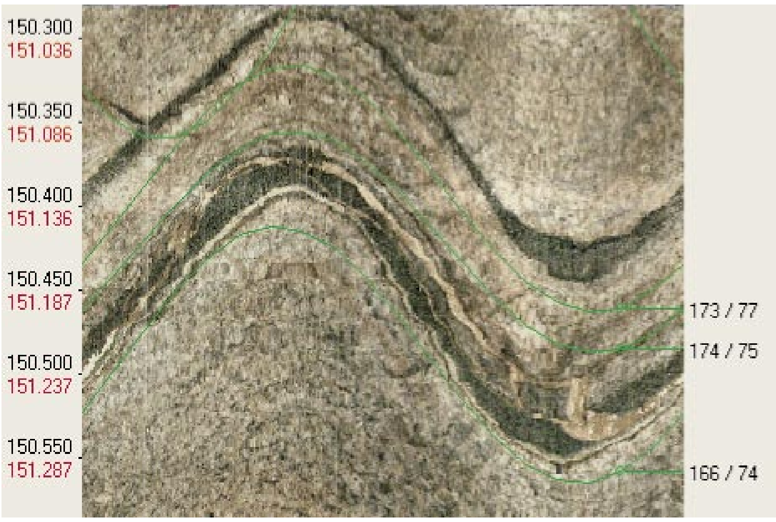


Figure 3-5. *Possible brittle-ductile shear zone at 150.42 m, mapping B.*

Figure 3-6. *Undefined structure at 162.08 m, mapping A.*

3.2.2 Alteration

Sericitization has been observed at 192.99–193.32 m in mapping B (Figure 3-7). In mapping A this is interpreted as oxidation, but the interpreter has observed that the section looks strange. The alteration type is most likely interpreted on the basis of the drill cuttings in mapping B.

Table 3-1. Differences in interpretation between mapping A and B.

Borehole length (m)	Mapping A	Mapping B
95.98–96.43	Crush zone (more narrow)	Crush zone
98.63–99.10	Fractures and dissolved amphibolite	Crush zone
119.01	Oxidised section with fractures	Mylonite
116.53–116.83	Separate fractures	Sealed fracture network
146.47–146.66	Separate fractures	Sealed fracture network
148.81–149.44	Sealed fracture network, narrow	Brittle-ductile shear zone
149.20	Part of sealed fracture network	Brittle-ductile shear zone
150.42	Granitic rock occurrence	Brittle-ductile shear zone
186.41	Felsic to intermediate volcanic rock	Ductile shear zone
192.99–193.32	Strange, oxidized section?	Sericitization

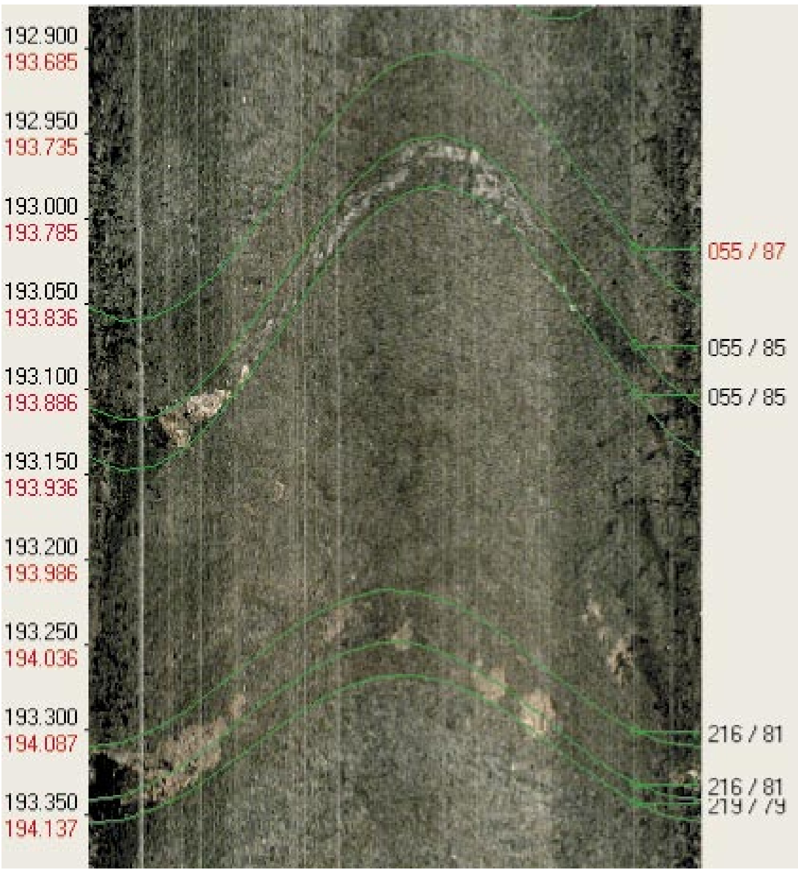


Figure 3-7. Sericitization at 192.99–193.32 m, mapping B.

3.2.3 Crush

In mapping B two crushed sections have been documented at 95.98–96.43 m (Figure 3-8) and 98.63–99.10 m (Figure 3-9). The first has also been mapped as a crushed section in mapping A, but it is interpreted to be narrower. The latter has not been mapped as a crushed section in mapping A, but as individual fractures and an amphibolite occurrence with the comment “partly dissolved”. It is possible that also this occurrence is a crushed section. It should be noted that both these interpreted crushed sections do not appear in the BIPS-image as certain crushed sections, i.e. no fragments can clearly be observed.

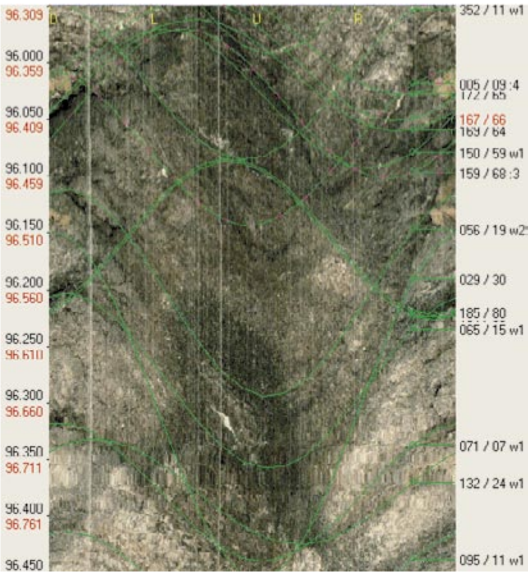


__Figure 3-8 a.__ Crushed section at 96.00–96.15 m, mapping A.

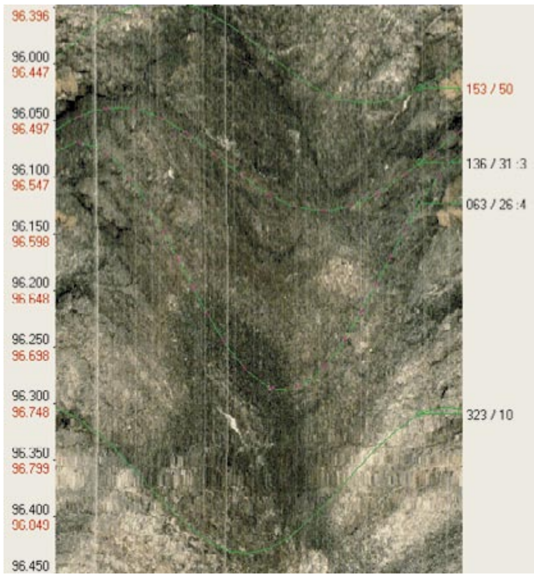


__Figure 3-8 b.__ Crushed section at 95.98–96.43 m, mapping B.

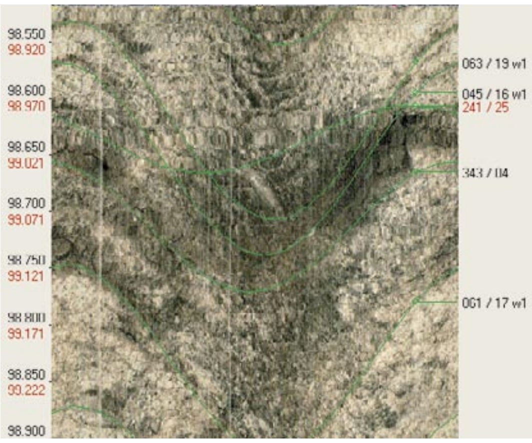


__Figure 3-9 a.__ Interpreted amphibolite, partly dissolved at 98.63–98.71 m, mapping A

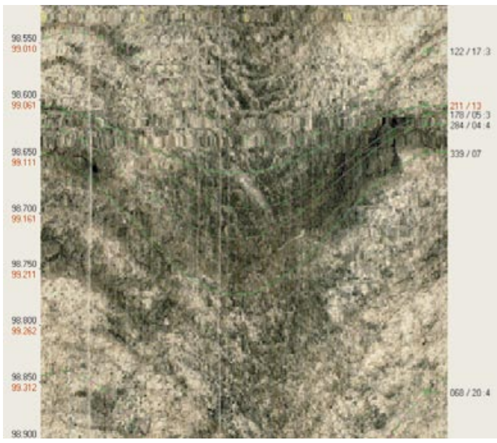


__Figure 3-9 b.__ Crushed section at 98.63–99.10 m, mapping B.

Table 3-2. Comparison between observations in mapping A and B.

Type of observation (89.67–200.74 m rec. depth in BIPS)	Mapping A	Mapping B
Rock occurrences > 1 m	11	4
Rock occurrences < 1 m	138	18
Open fractures	127	2
Sealed fractures	316	250
Alteration	29	3
Structural observation	19	11
Crush zone	1	2
Sealed fracture network	1	3
Total amount of observations	642	293

3.2.4 Fractures

The major difference between mapping A and B is the amount of documented fractures (Table 3-2). In mapping B, only 2 open fractures have been documented in the compared section, while 127 open fractures have been documented in mapping A. Of these fractures the interpreter has considered 18 as certain observations, 34 as probably open fractures and 75 as possibly open fractures (Table 3-3). In mapping B one open fracture is certain while one has a possible aperture.

The amount of mapped sealed fractures differs also. In mapping A 316 sealed fractures have been observed, while the corresponding amount for mapping B is 250. Of the mapped sealed fractures in mapping A, 89 is considered having an aperture, while none of the sealed fractures in mapping B is considered having any aperture.

Since the amount of observed fractures differs remarkably, and especially the amount of open fractures, a comparison between all mapped fractures has been done. In order to see how many fractures are observed in both mappings, this comparison has been performed regardless whether they are open or sealed (Table 3-4). It shows that 224 fractures (open or sealed) have been documented in both mappings. This means that 28 fractures in mapping B has not been documented in mapping A, while as many as 219 fractures in mapping A were not registered in mapping B. Of the common fractures 61 have been mapped as certainly/probably/possibly open in mapping A. Of these 13 are mapped as certainly open, 22 as probably open and 26 as possibly open fractures.

Of the common fractures, 0 fractures are mapped as open in both mapping A and B (Table 3-5), while 161 are mapped as sealed in both mapping A and B. 61 of the common fractures are mapped as open in mapping A, but as sealed in mapping B. 2 of the common fractures are mapped as open in mapping B, but as sealed in mapping A. In this comparison the sealed fractures mapped with aperture are considered as sealed.

Table 3-3. Fracture observations in mapping A and B – amount and type of fracture.

Type of fracture observation (89.67–200.74m rec. depth in BIPS)	Mapping A	Mapping B
Possibly open fractures	75	1
Probably open fractures	34	0
Other open fractures	18	1
Total amount of mapped open fractures	127	2
Sealed fractures with aperture	89	0
Other sealed fractures	227	250
Total amount of mapped sealed fractures	316	250
Total amount of mapped fractures	443	252

Table 3-4. Mapping of fractures – possibility to reproduce mappings by different interpreters.

Reproducibility, fracture mapping (two interpreters)	Mapping A	Mapping B
Fractures observed in mapping A		224
Fractures observed in mapping B	224	
Fractures **not** observed in mapping A		28
Fractures **not** observed in mapping B	219	
Of which:		
Fractures in sealed network in mapping A		0
Fractures in sealed network in mapping B	7	
Fractures in crush zones in mapping A		0
Fractures in crush zones in mapping B	3	

Table 3-5. Mapping of fractures – open versus sealed.

Common fractures	Amount
Fractures interpreted as open in both mapping A and B	0
Fractures interpreted as sealed in both mapping A and B	161
Fractures interpreted as open in mapping A but sealed in mapping B	61
Fractures interpreted as open in mapping B but sealed in mapping A	2
Fractures observed in both mapping A and B	224

3.2.5 Comparison with possible deformation zones from the geological single-hole interpretation of HFM21

In the recently performed geological single-hole interpretation of HFM21, two possible deformation zones have been interpreted on the basis of mapping B and generalised geophysical logs. These possible deformation zones are at 94–102 m and 160–177 m. The first interpreted deformation zone is indicated by geophysics and by crushed sections and a higher frequency of sealed fractures in mapping B. However, in mapping B there are no indications of other deformation zones and hence the latter deformation zone was only indicated by geophysics. Mapping A, on the other hand, also indicates the latter deformation zone by increased frequency of open fractures. See comparison of observations between mapping A and B in these sections in Figure 3-12 and Figure 3-13.

Preferred fracture orientations in the interpreted deformation zones (Figure 3-10 and Figure 3-11) resemble the ones for the whole borehole (Figure 3-14). The mapped open fractures are mostly sub-horizontal, but in section 160–177 m also some fractures with the orientation ca 050/75 occur. The mapped sealed fractures in section 94–102 m are mostly sub-horizontal, while the ones in section 160–177 m are mostly vertical (ca 050/90).

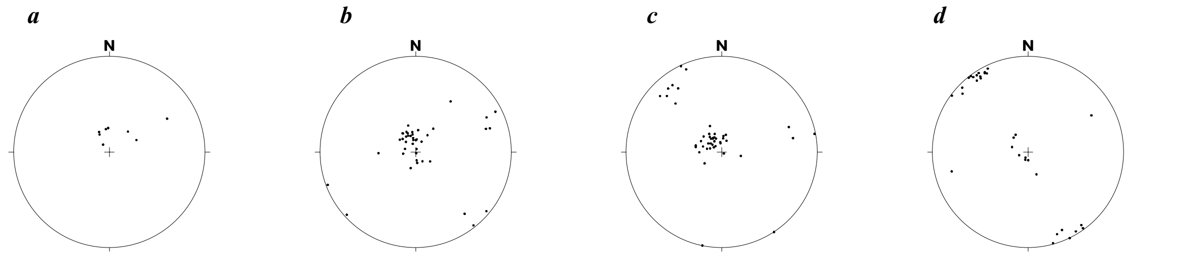


Figure 3-10. *Mapping A. Lower hemisphere, equal-area stereographic projections showing the poles to fractures in interpreted deformation zones in HFM21. a) open fractures (n=8) in 94–102 m; b) sealed fractures (n=42) in 94–102 m; c) open fractures (n=45) in 160–177 m; d) sealed fractures (n=35) in 160–177 m. All lengths are adjusted lengths.*

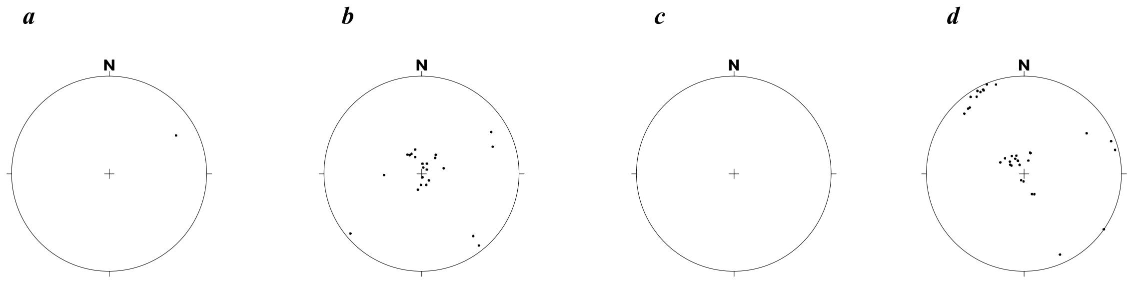


Figure 3-11. *Mapping B. Lower hemisphere, equal-area stereographic projections showing the poles to fractures in interpreted deformation zones in HFM21. a) open fractures (n=1) in 94–102 m; b) sealed fractures (n=23) in 94–102 m; c) open fractures (n=0) in 160–177 m; d) sealed fractures (n=34) in 160–177 m. All lengths are adjusted lengths.*

Figure 3-12. *Deformation zone 1 in geological single-hole interpretation.*

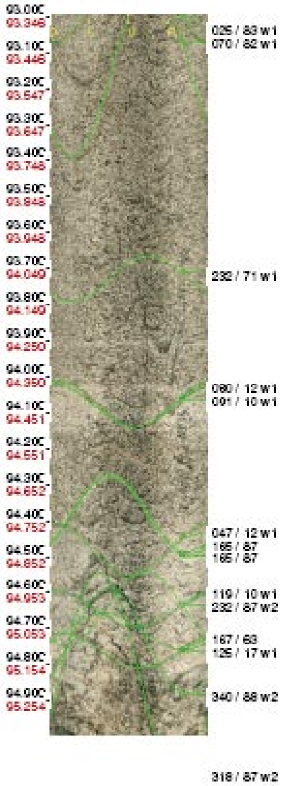


Figure 3-12 a: *93-95 m, mapping A*

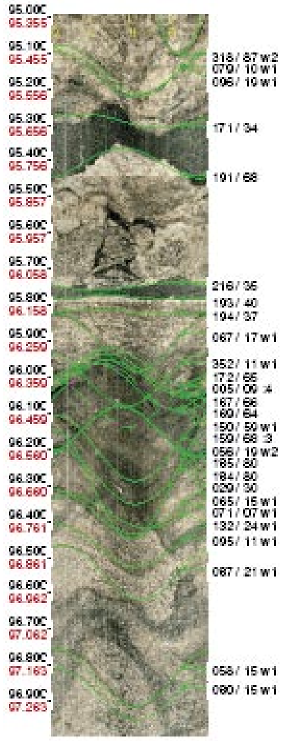


Figure 3-12 b: *95-97 m, mapping A*

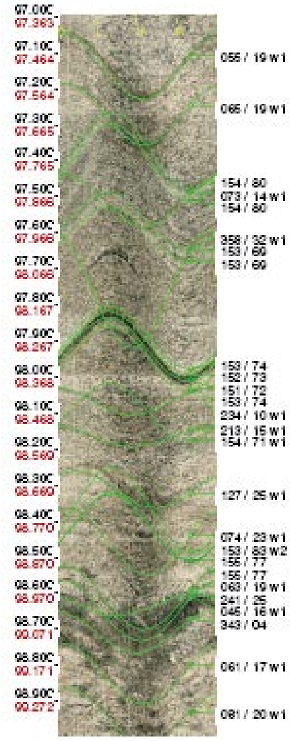


Figure 3-12 c: *97-99 m, mapping A*

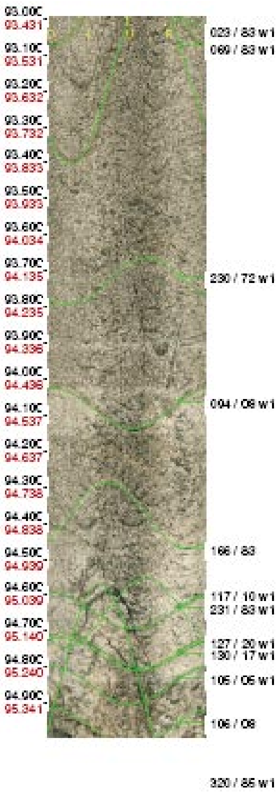


Figure 3-12 d: *93-95 m, mapping B*

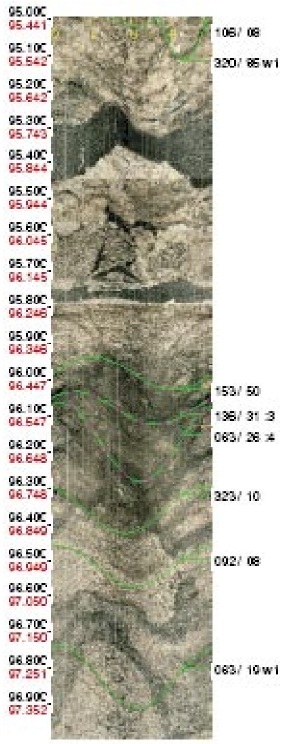


Figure 3-12 e: *95-97 m, mapping B*

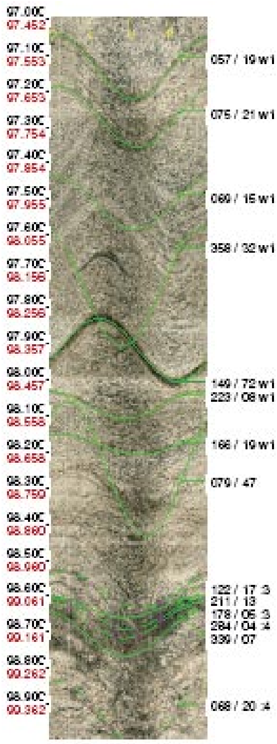


Figure 3-12 f: *97-99 m, mapping B*

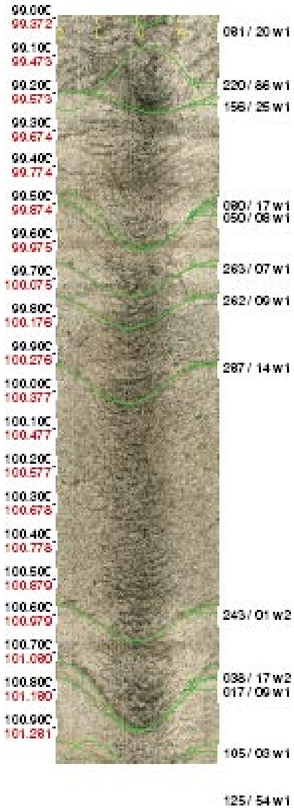


Figure 3-12 g: *99-101 m, mapping A*

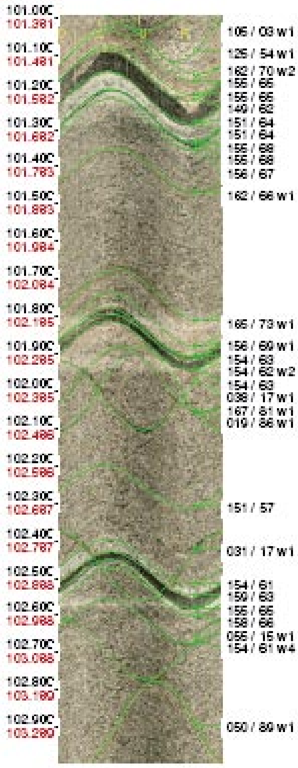


Figure 3-12 h: *101-103 m, mapping A*

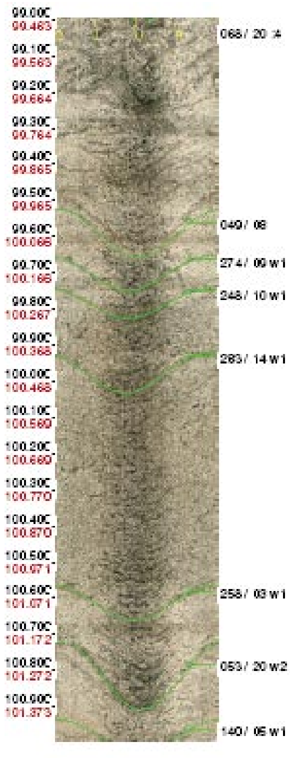


Figure 3-12 i : *99-101 m, mapping B*

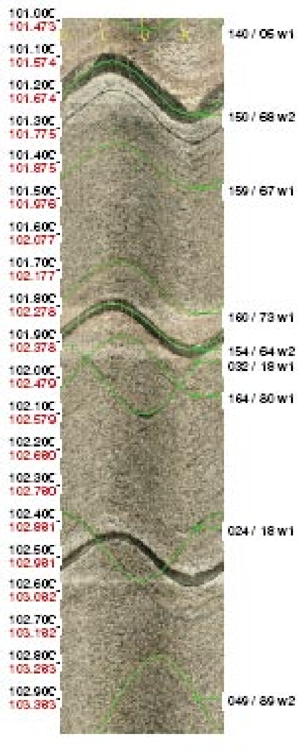


Figure 3-12 j: *101-103 m, mapping B*

Figure 3-13. *Deformation zone 2 in geological single-hole interpretation.*

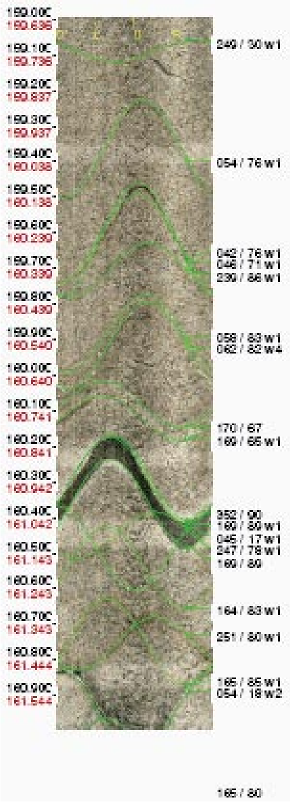


Figure 3-13 a: *159-161 m, mapping A*

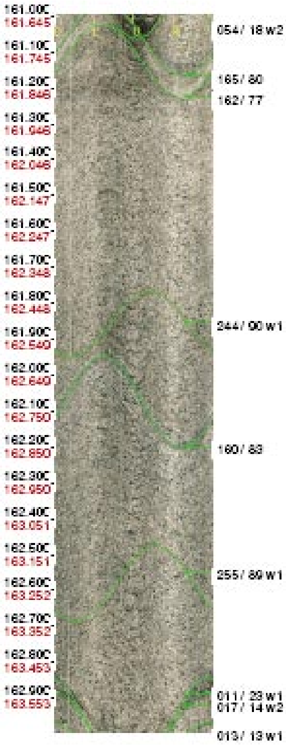


Figure 3-13 b: *161-163 m, mapping A*

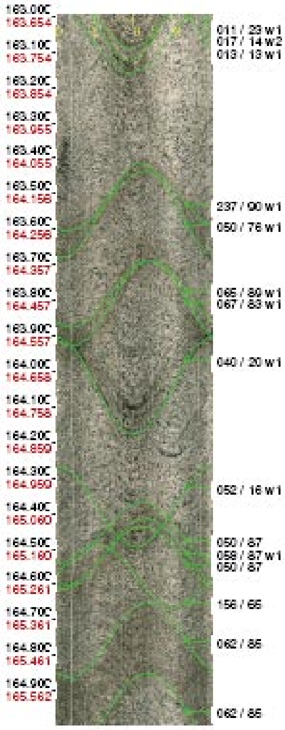


Figure 3-13 c: *163-165 m, mapping A*

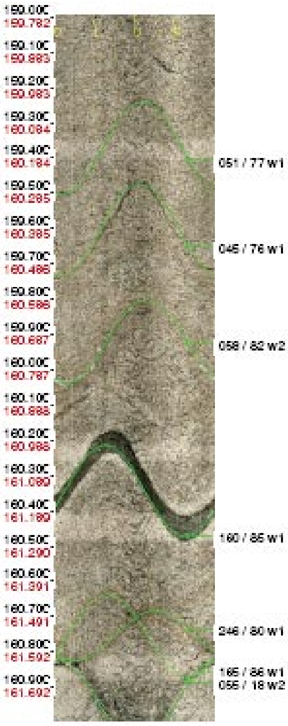


Figure 3-13 d: *159-161 m, mapping B*

Figure 3-13 e: *161-163 m, mapping B*

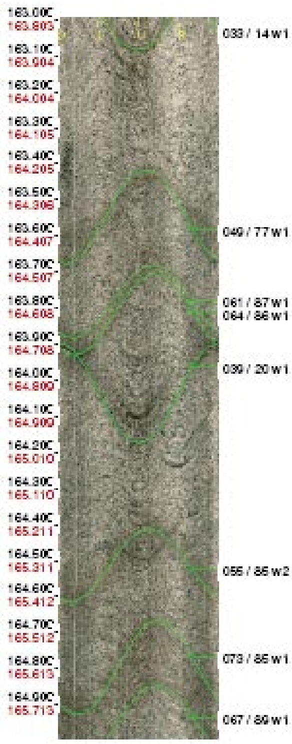


Figure 3-13 f: *163-165 m, mapping B*

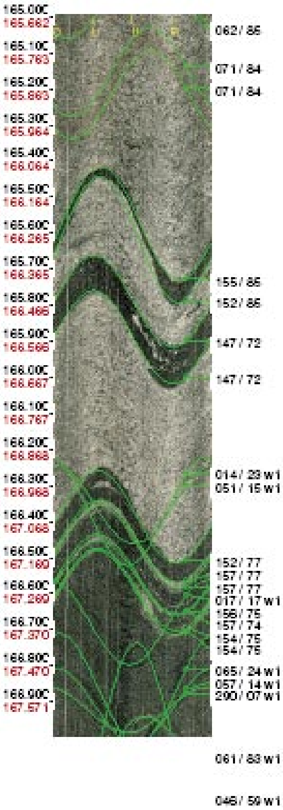


Figure 3-13 g: *165-167 m, mapping A*

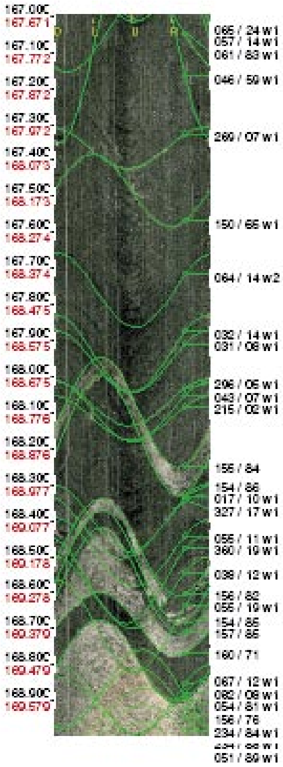


Figure 3-13 h: *167-169 m, mapping A*

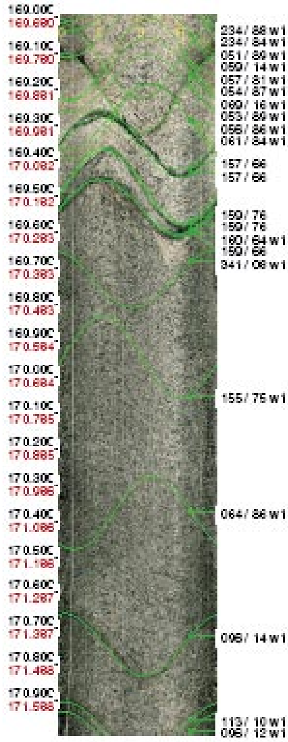


Figure 3-13 i: *169-171 m, mapping A*

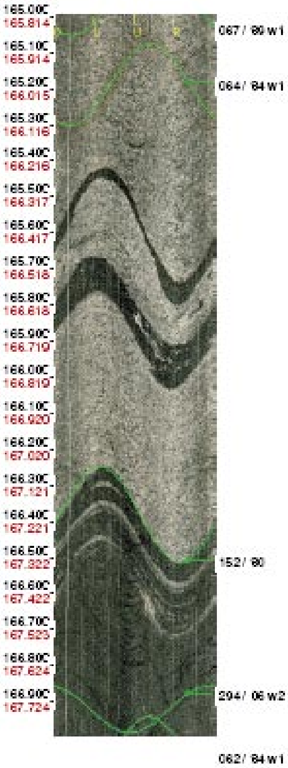


Figure 3-13 j: *165-167 m, mapping B*

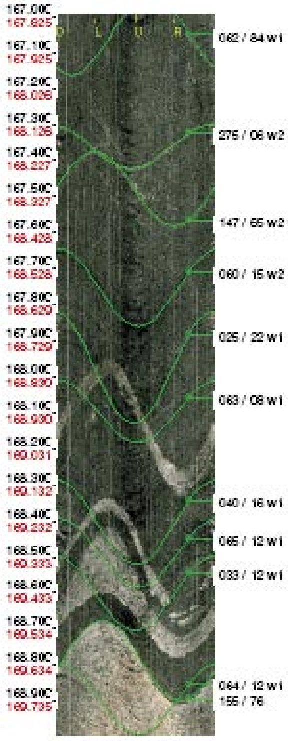


Figure 3-13 k: *167-169 m, mapping B*

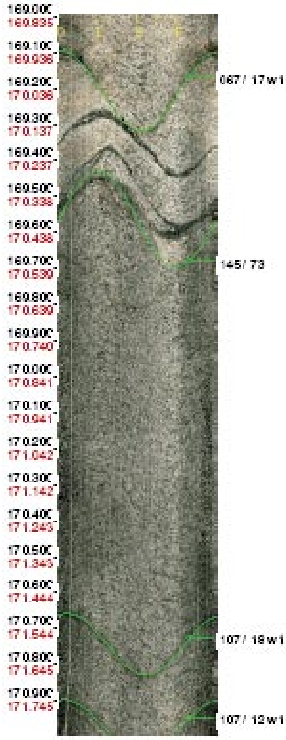


Figure 3-13 l: *169-171 m, mapping B*

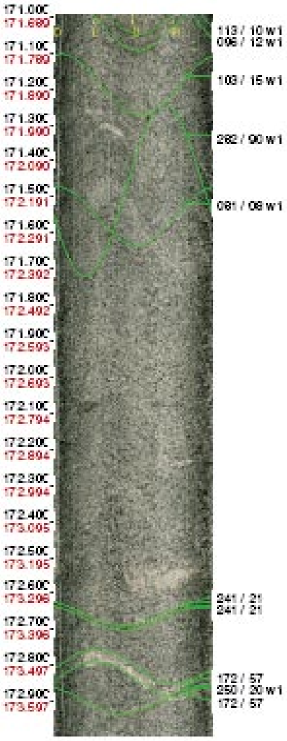


Figure 3-13 m: *171-173 m, mapping A*

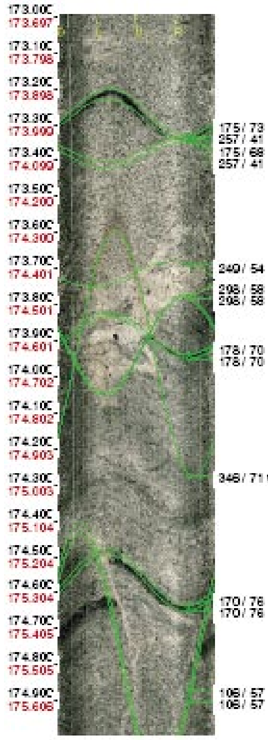


Figure 3-13 n: *173-175 m, mapping A*

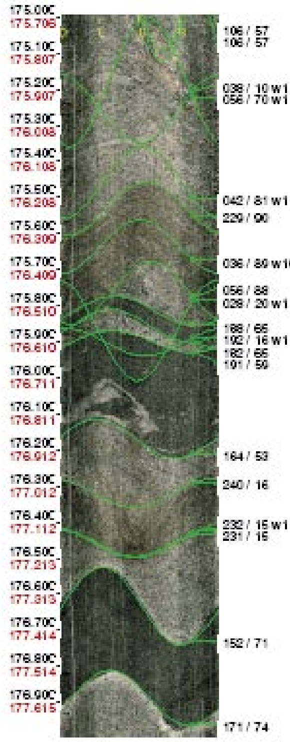


Figure 3-13 o: *175-177 m, mapping A*

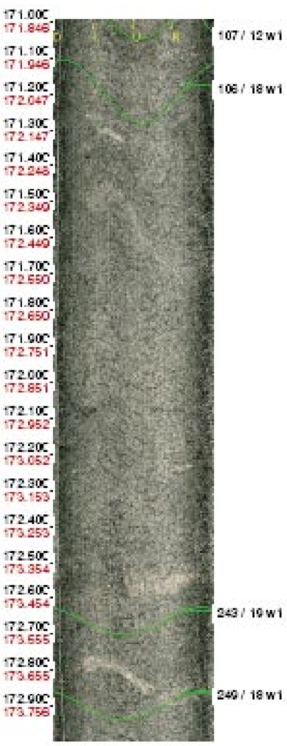


Figure 3-13 p: *171-173 m, mapping B*

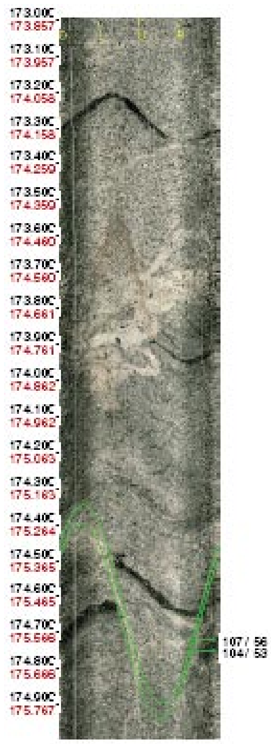


Figure 3-13 q: *173-175 m, mapping B*

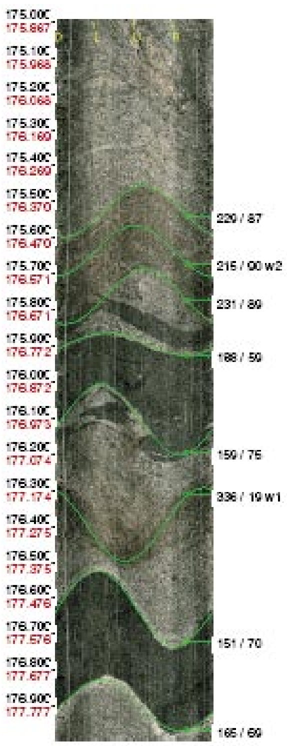


Figure 3-13 r: *175-177 m, mapping B*

3.2.6 Results from the fracture mapping A, HFM21, 90–201.7 m

HFM21 (90–201.7 m, adjusted length) has a fracture frequency of 3.97 fractures/m. The frequency of interpreted open fractures is 1.14 fractures/m while the frequency of sealed fractures is 2.83 fractures/m. One section with a high amount of open fractures (10.3 fractures/m) is observed at 168.4–169.9 m (adjusted length). The dominating orientation of open fractures is 045/10 (Figure 3-14 a). Two other preferred orientations are 060/90 and 160/70.

Five sealed fracture sets have been noted (Figure 3-14 b): 240/10, 055/15, 055/90, 165/75 and 025/85.

The horizontal to sub-horizontal fractures are overrepresented in the borehole because of the borehole orientation (azimuth 88.8, dip –54.5), while fractures parallel to sub-parallel with the borehole are underrepresented. All orientation data are given according to the right hand rule.

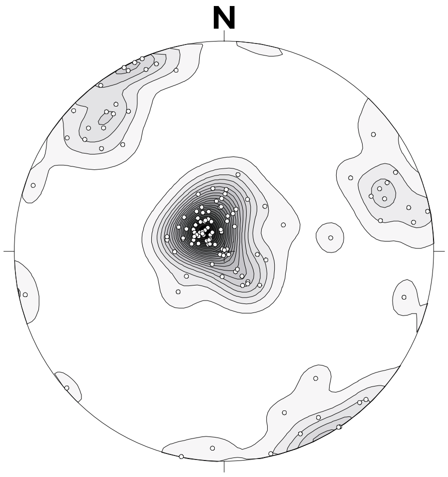


Figure 3-14 a. *Lower hemisphere, equal-area stereographic projections showing the poles to all open fractures HFM21, 90–201.7 m (n=127).*

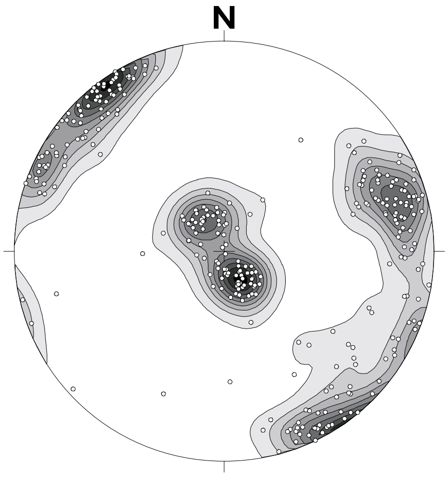


Figure 3-14 b. *Lower hemisphere, equal-area stereographic projections showing the poles to all sealed fractures, HFM21, 90–201.7 m (n= 316.)*

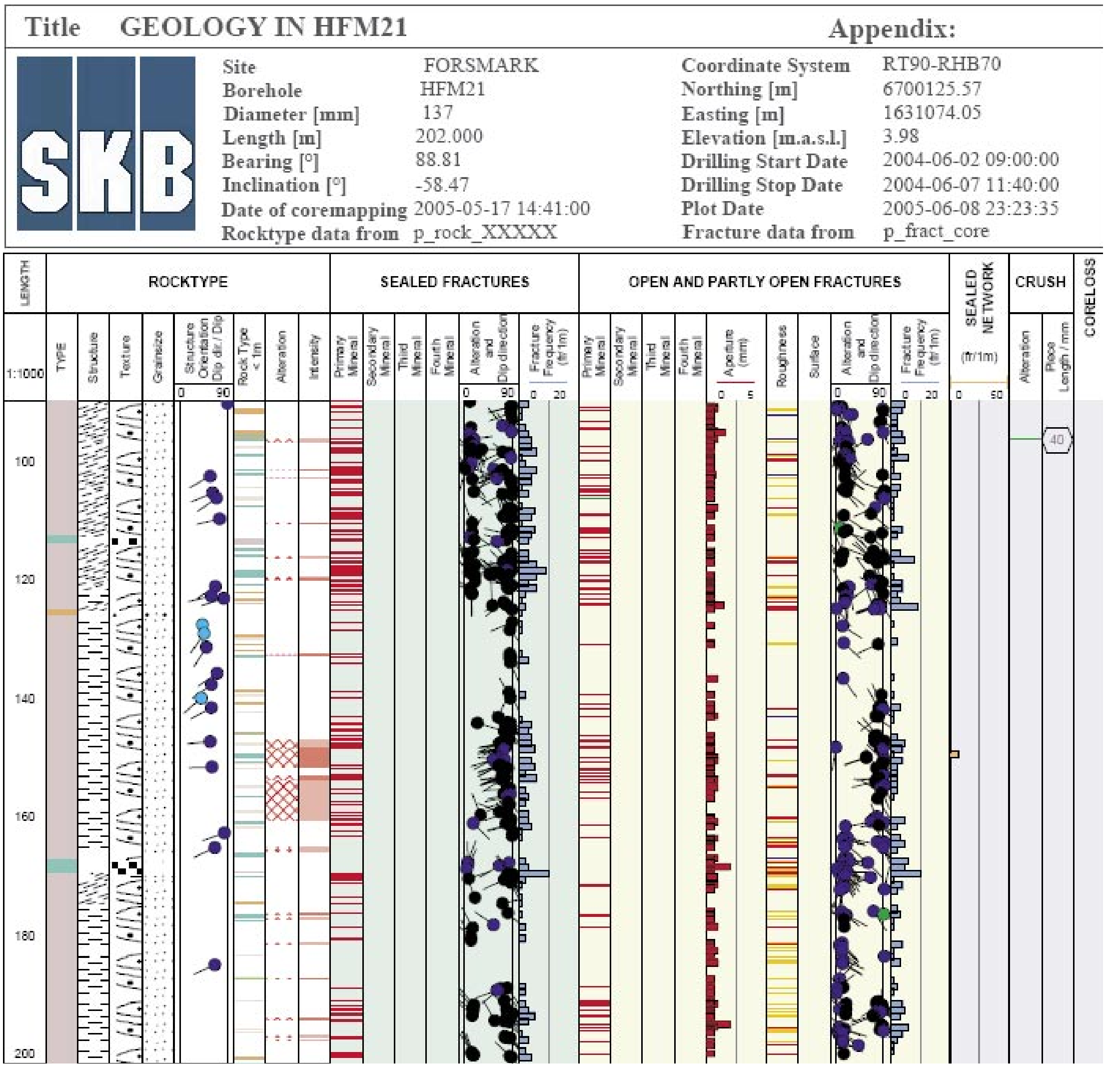


Figure 3-15 a. *WellCad-diagram of mapping A (in-data from SICADA).*

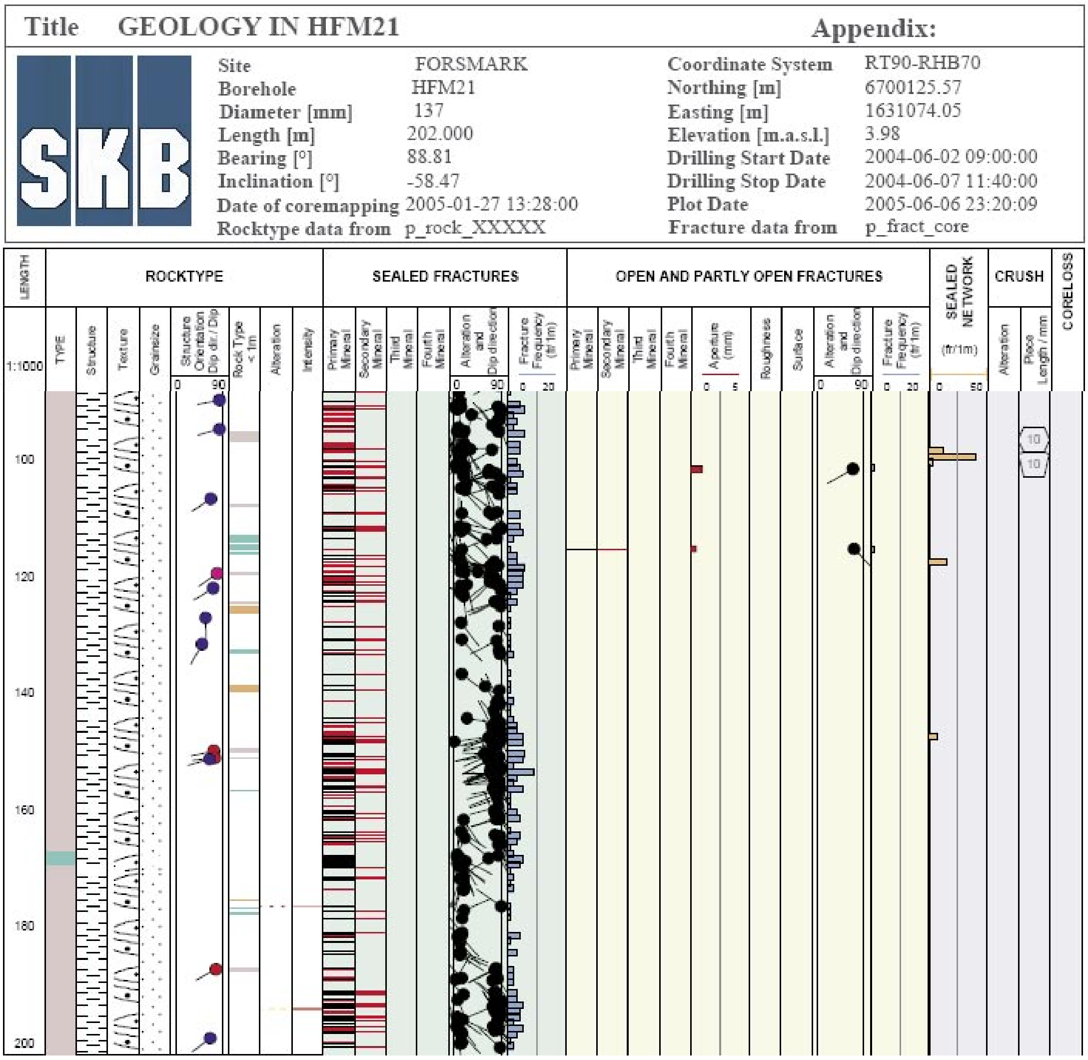


Figure 3-15 b. WellCad-diagram of mapping B (in-data from SICADA).

4 Boremap mapping of HFM22 – an alternative interpretation

4.1 Methods

HFM22 was mapped with the Boremap method (Boremap, version 3.6) in accordance with the activity plan SKB PF 400-04-106 and the method description MD 143.006, version 1 (SKB, internal controlling document), with three exceptions. Borehole deviation data in this work has not been automatically collected from SICADA, since there was no access to 1) SICADA. Instead, a value for bearing and inclination for each 12th metre has been manually recorded in Boremap. As requested by the client no fracture mineral was recorded 2). The third deviation from the activity plan is that drill cuttings from HFM22 have not been studied. 3)

Generalised geophysical logs, as well as drilling penetration rate were used as a complement to the mapping. The mapping was performed independent from the previously performed Boremap mapping of HFM22.

4.1.1 Length adjustment

Length adjustments have been performed as follows. Recorded length in BIPS-image at the end of casing was 12.03 m. According to SICADA the casing length is 12.03 and hence the BIPS-image length is correct in the beginning of the borehole. The end length of the BIPS-image is 214.8 m, and this was corrected to 215.87 m. The correction was made since it is known that the registered length in the BIPS-images in general deviates with approximately 0.5 m per 100 m from the true length.

4.1.2 Interpretations in the mapping

0.7 mm is the recorded minimum width and minimum aperture (if not = 0) of fractures and not 0.5 mm as in core drilled boreholes. This higher minimum width is set because one pixel in the BIPS-image of percussion drilled boreholes represent 1.22 mm^2 of the borehole wall, while one pixel in BIPS-images of core drilled boreholes represent 0.66 mm^2 of the borehole wall.

Fractures with a width ≤ 1 mm are not measured in the BIPS-image, but by ocular estimation. This is because such small fracture width is very difficult to measure with the tool in Boremap.

Very narrow fractures that are impossible to determine whether they are open or sealed are mapped as open fractures with a possible aperture of 0.7 mm. To this group belong fractures with a shadowed fracture trace.

Fractures that seem to be open and have clear apertures in the extremes, but no clear aperture in the inflection point of the fracture trace (only darker fracture trace) are mapped as open fractures with a probable aperture of 0.7 mm.

Most sealed fractures with oxidized walls are mapped with a width of 0.7 mm. Some may actually be wider, but it is rather difficult to observe the fracture width in the oxidized section if the fracture filling mineral have the same colour. Therefore there might be some misinterpretations of fracture widths.

Interpretations and assumptions of rock colour, oxidation, lithology and foliation versus lineation are in line with the ones in earlier Boremap mapping of percussion drilled boreholes in Forsmark/4/.

4.2 Results

4.2.1 Lithologies

The dominant rock type of HFM22 is a medium-grained, lineated to foliated, light pinkish grey to greyish red (if oxidized) metagranite-granodiorite. The orientation of the foliation is ca 150/70, while the lineation is ca 235/45 (Figure 4-1 and 4-2). This is cut by several minor rock occurrences of pegmatite, fine-grained granite, fine-grained granite-granodiorite-tonalite, fine-grained amphibolite and foliated metagranodiorite (Table 4-1 and Figure 4-7).

The generalised geophysical logs imply varying composition of the metagranite-granodiorite, but no contacts were clearly observable in the BIPS-image. Only one occurrence of foliated metagranodiorite was hence documented at 72.5–73.0 m adjusted length. This occurrence is clearly more deformed than the surrounding metagranite-granodiorite.

Six observations of age relationships between different rock types are made, where ca 150/80 striking aplitic granite occurrences are cut by narrow ca 055/50 striking pegmatites.

In some cases very narrow occurences of pegmatite and aplitic granite were difficult to separate in the mapping, and there may therefore be some misinterpretations in these cases.

Some occurrences of biotite rich bands are observed in the metagranite-granodiorite. They are most common in the section 103–111 m, but a few observations are also made lower down in the borehole. The orientation of these is ca 000/75 in the section 103–111 (10 observations) and 199–200 m (2 observations). In the section 140–155 m the orientation of the biotite rich bands is ca 160/65–90 (3 observations), i.e. they are parallel to sub-parallel with the foliation (Figure 4-6).

4.2.2 Deformation

The observed plastic deformations in HFM22 are lineation and foliation, while the observed brittle deformations are open and sealed fractures, two sealed fracture networks and two crushed sections.

Table 4-1. Documented rock types in HFM22.

Rock type	SKB code	%
Granite to granodiorite, metamorphic, medium grained	101057	83.1
Pegmatite, pegmatitic granite	101061	6.7
Granite, metamorphic, aplitic	101058	6.3
Granite, granodiorite and tonalite, metamorphic, fine- to medium grained	101051	3.3
Amphibolite	102017	0.6
Granodiorite, metamorphic	101056	0.2

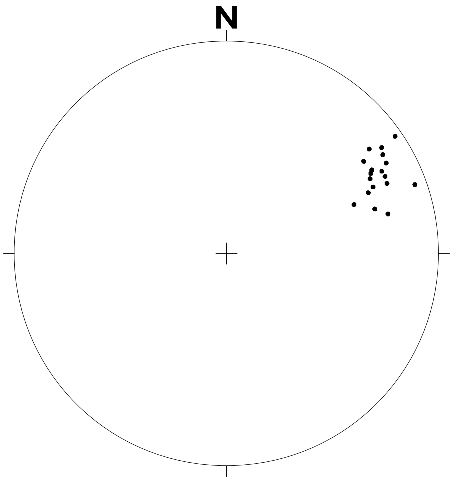


Figure 4-1. Lower hemisphere, equal-area stereographic projections showing the poles to the foliation in HFM22 (n=18).

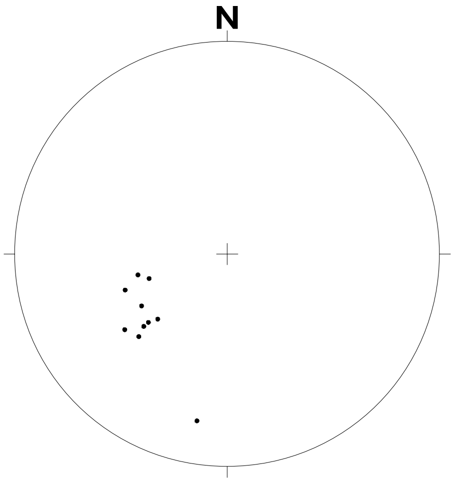


Figure 4-2. Lower hemisphere, equal-area stereographic projections showing the lineation in HFM22 (n=10).

4.2.3 Fractures

HFM22 has a fracture frequency of 1.8 fractures/m. The frequency of interpreted open fractures is 0.7 fractures/m while the frequency of sealed fractures is 1.1 fractures/m (of which partly open fractures are 0.3 fractures/m). The dominating orientations of interpreted open fractures are 060/70, 075/10 and 000/80 (Figure 4-3). The preferred orientation of interpreted sealed fractures show the same pattern: 075/10, 225/85 and 000/90 (Figure 4-4).

One section with increased fracture frequency (4.6 fractures/m) and oxidation is observed at 109.0–136.5 m (Figure 4-5). Interpreted frequency of open fractures for the whole section is 1.7 fractures/m and of sealed fractures 2.9 fractures/m. Some of the mapped sealed fractures in this section are mapped with an aperture, but it is suspected that the possible aperture may be a black fracture mineral instead.

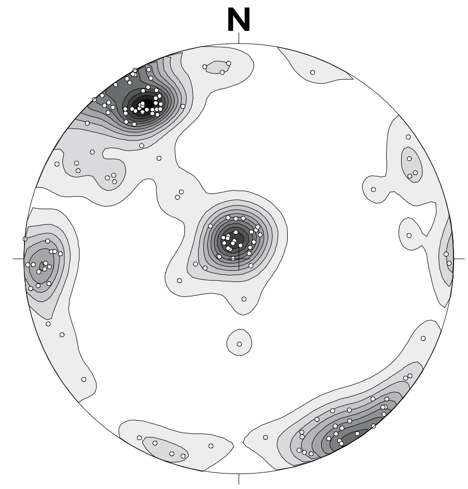


Figure 4-3. Lower hemisphere, equal-area stereographic projections showing the poles to all open fractures (n=144), HFM22.

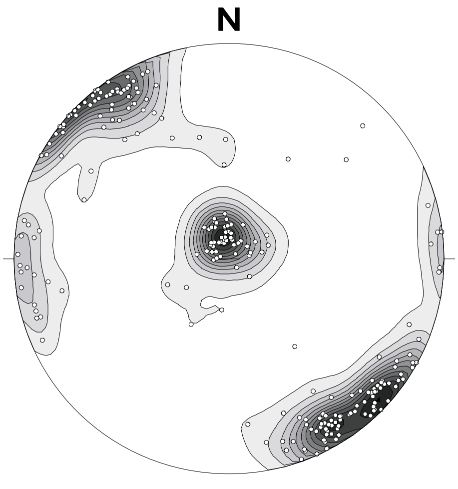


Figure 4-4. Lower hemisphere, equal-area stereographic projections showing the poles to all sealed fractures (n=230), HFM22.

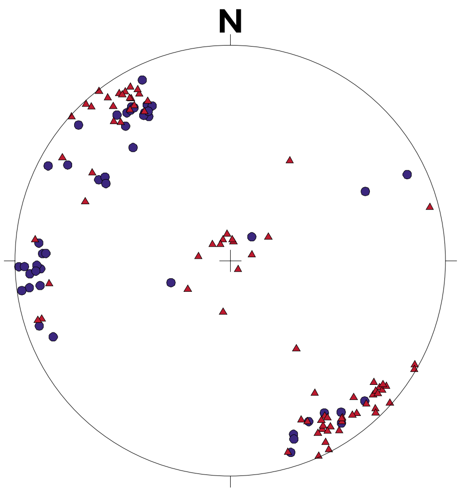


Figure 4-5. Lower hemisphere, equal-area stereographic projections showing all fractures in section 109.5-136.3 m, HFM22. Red triangles = sealed fractures (n=30), blue circles = open fractures (n=26).

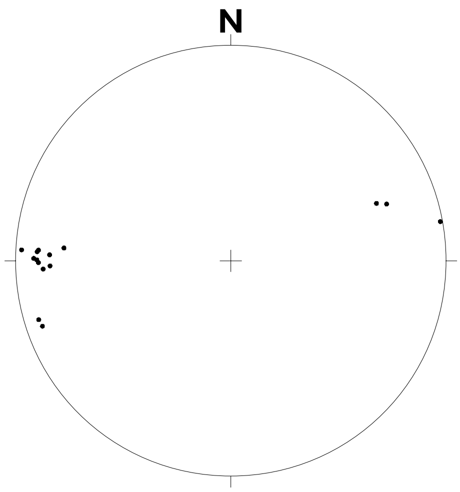


Figure 4-6. Lower hemisphere, equal-area stereographic projections showing the orientations of biotite rich bands (n=15), HFM22.

The upper part of this section is oxidized with several biotite rich bands and has a fracture frequency of 8.2 fractures/m (109.8–116.5 m). The frequency of interpreted open fractures is 3.7 fractures/m and of interpreted sealed fractures 4.5 fractures/m. Two preferred fracture orientations are observed: 355/80 with mostly interpreted open fractures and 240/75 with both interpreted open and sealed fractures. The first fracture set shows the same orientation as the biotite rich bands in the section 103–111 m and they may be correlated.

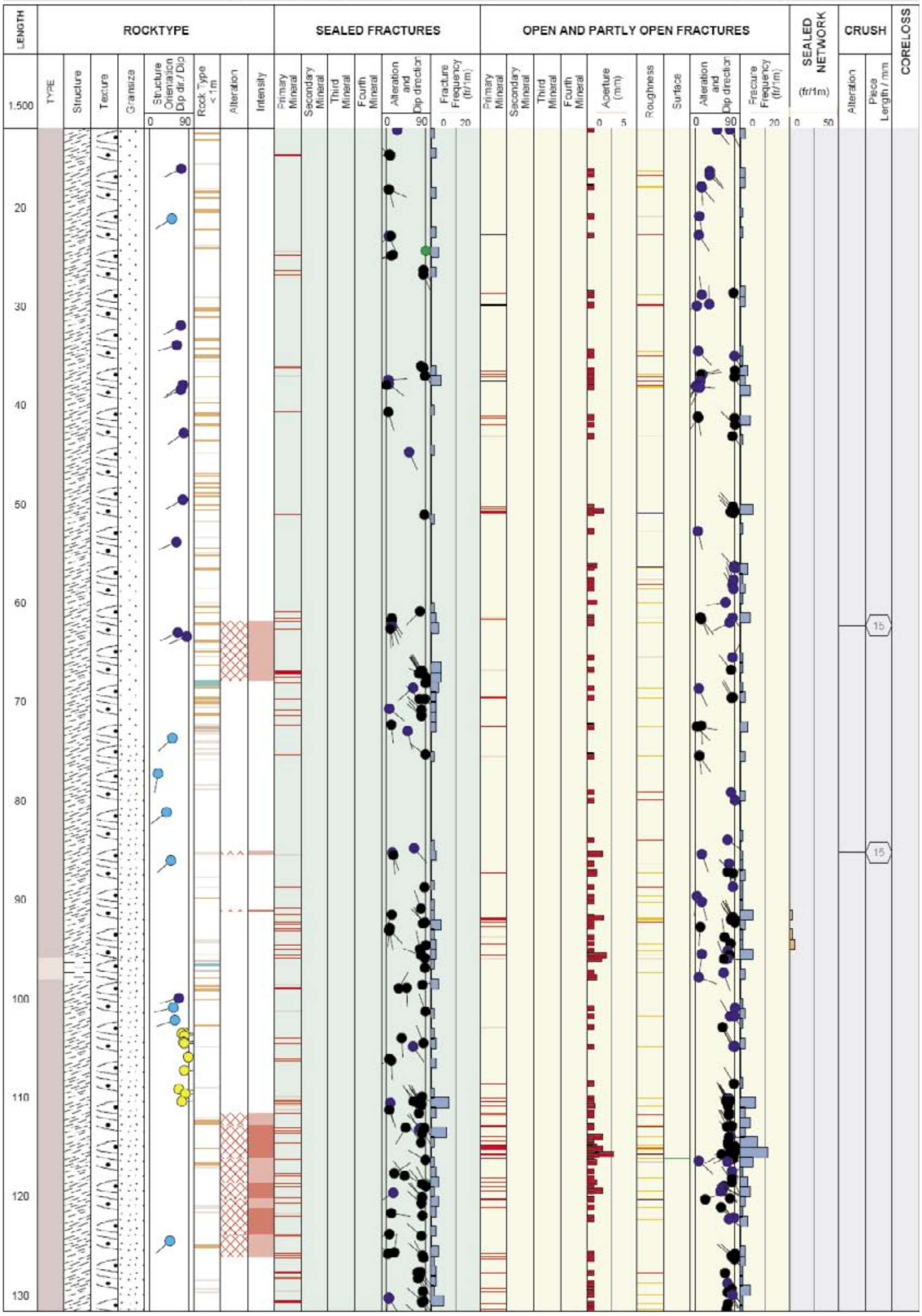
The lower part of this section (ca 115–136.5 m) is characterized by occasional oxidized fractures and some obviously open fractures, for example at 115.5–116.0 m, ca 119.0 m and 134.5–136.5 m. The orientation of open fractures are ca 060/70, while the orientation of sealed fractures are 060/80 and 220/80. Some sub-horizontal fractures are also observed.

4.2.4 Crush

Two crushed sections were observed at 62.2–62.3 m and 85.2 m (only 4 cm wide) adjusted length. The indicated orientation of these crushed sections are 055/15 and 055/10 respectively. A mapped thin amphibolite at 85.4 m might be a thin crushed section, but it was not possible from the BIPS-image to decide what this is.

Title **GEOLOGY IN HFM22** **Appendix:**

Site	FORSMARK	**Coordinate System**	RT90-RHB70
Borehole	HFM22	**Northing [m]**	6700456.18
Diameter [mm]	136	**Easting [m]**	1631217.64
Length [m]	222.000	**Elevation [m.a.s.l.]**	1.54
Bearing [°]	90.08	**Drilling Start Date**	2004-09-07 12:00:00
Inclination [°]	-58.84	**Drilling Stop Date**	2004-09-10 10:17:00
Date of coremapping	2005-06-09 13:24:00	**Plot Date**	2005-06-20 23:18:06
Rocktype data from	p_rock_XXXXX	**Fracture data from**	p_fract_core



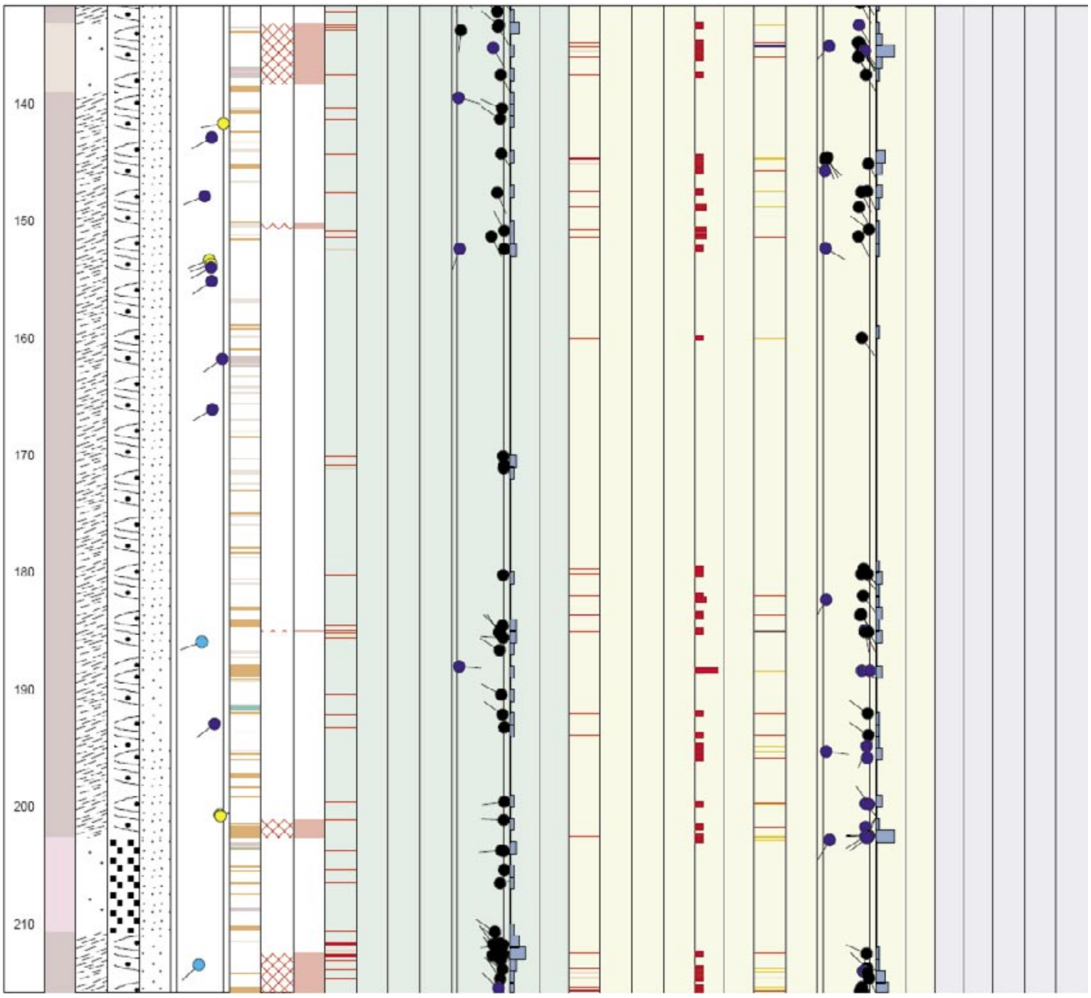


Figure 4-7. *WellCad diagram of HFM22.*

5 Discussion

BIPS-images have given remarkably better possibilities for mapping the rock type, structures and fractures in percussion drilled boreholes, compared to earlier methods. However, it is easy to believe that the results from the mappings of percussion drilled boreholes are of the same high quality as those from core drilled boreholes. The interpretation of BIPS-image, generalised geophysical logs and drill cuttings is less accurate than the interpretation of BIPS-image, drill core and generalised geophysical logs.

One reason for this is that the pixel resolution of the BIPS-image is making it impossible to see very small features in the borehole, for example elongated mineral grains, sheared crystals or whether very thin fractures are open or not. For example, in HFM18 water outflow was observed from fractures that seemed to be sealed in BIPS /5/. If these fractures had no visible outflow they would have been mapped as sealed. Another common reason for less amount of accurate interpretations are blurred BIPS-images. The blurring is caused by drill cuttings in suspension, resulting in few observations in the borehole (compare with HFM03 /1/). Good quality of the BIPS-images on the other hand is resulting in more accurate observations in the borehole. The BIPS-image quality is of crucial importance for mapping percussion drilled boreholes.

If it is intended that percussion boreholes will be drilled in order to investigate lineaments, one should also be aware that deformation in the rock is very difficult to interpret only on the basis of BIPS with the resolution we use today. The rock types of HFM09 and HFM10, which were drilled through the Eckarfjärden deformation zone, were very fine-grained and in places the deformation in these was very difficult to interpret in BIPS /3/. However, deformation might be observed in the drill cuttings. It is normally not possible to correlate drill cutting mapping with certain features in the BIPS-image without a risk for over-interpretation.

It has earlier been suggested that the BIPS-images of percussion drilled boreholes should be logged with a higher resolution, in order to be equivalent to the resolution of the BIPS-images from core drilled boreholes /2/. Even though a higher resolution is achieved, there will always be a great amount of fractures that cannot be classified with certainty, i.e. whether the fracture is open or sealed. Consequently, different interpreters will map these features differently.

It is recommended that a methodology is prepared for mapping uncertain fractures, since these dominate the observations.

6 References

/1/ **Nordman C, 2003.** Forsmark site investigation. Boremap mapping of percussion boreholes HFM01–03. SKB P-03-20. Svensk Kärnbränslehantering AB.

/2/ **Nordman C, 2004.** Oskarshamn site investigation. Boremap mapping of percussion boreholes HSH01–03. SKB P-04-02. Svensk Kärnbränslehantering AB.

/3/ **Nordman C, 2004.** Forsmark site investigation. Boremap mapping of percussion boreholes HFM09–12. SKB P-04-101. Svensk Kärnbränslehantering AB.

/4/ **Nordman C, Samuelsson E, 2004.** Forsmark site investigation. Boremap mapping of percussion boreholes HFM13–15 and HFM19. SKB P-04-112. Svensk Kärnbränslehantering AB.

/5/ **Nordman C, Samuelsson E, 2004.** Forsmark site investigation. Boremap mapping of percussion boreholes HFM16–18. SKB P-04-113. Svensk Kärnbränslehantering AB.

Appendix 1

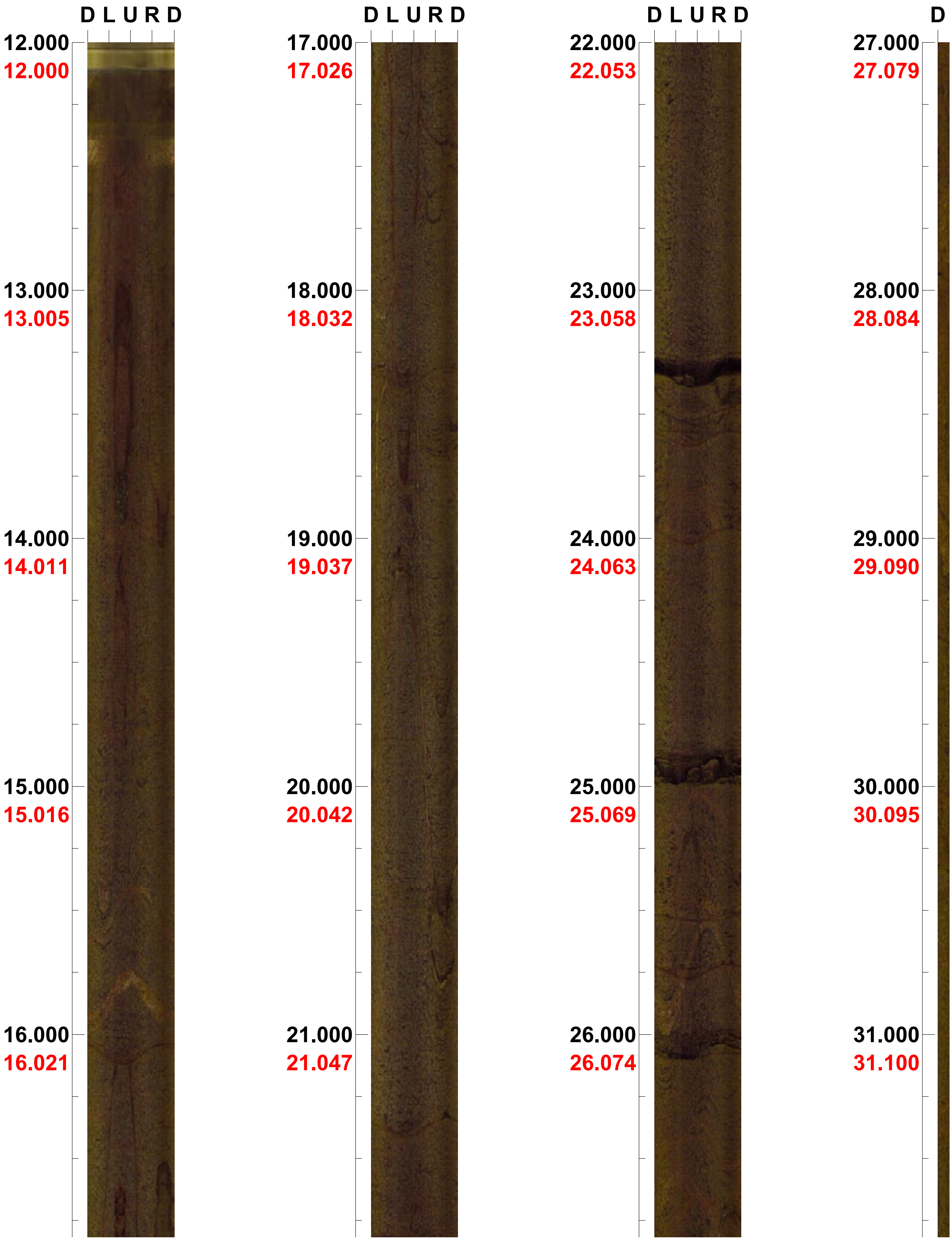
BIPS-images, HFM20

Project name: Forsmark

Image file	: hfm20_~1.bip
BDT file	: hfm20_~1.bdt
Locality	: FORSMARK
Bore hole number	: HFM20
Date	: 04/06/15
Time	: 10:50:00
Depth range	: 12.000 - 298.128 m
Azimuth	: 359
Inclination	: -85
Diameter	: 139.0 mm
Magnetic declination	: 0.0
Span	: 4
Scan interval	: 0.25
Scan direction	: To bottom
Scale	: 1/25
Aspect ratio	: 80 %
Pages	: 15
Color	: +0 +0 +0

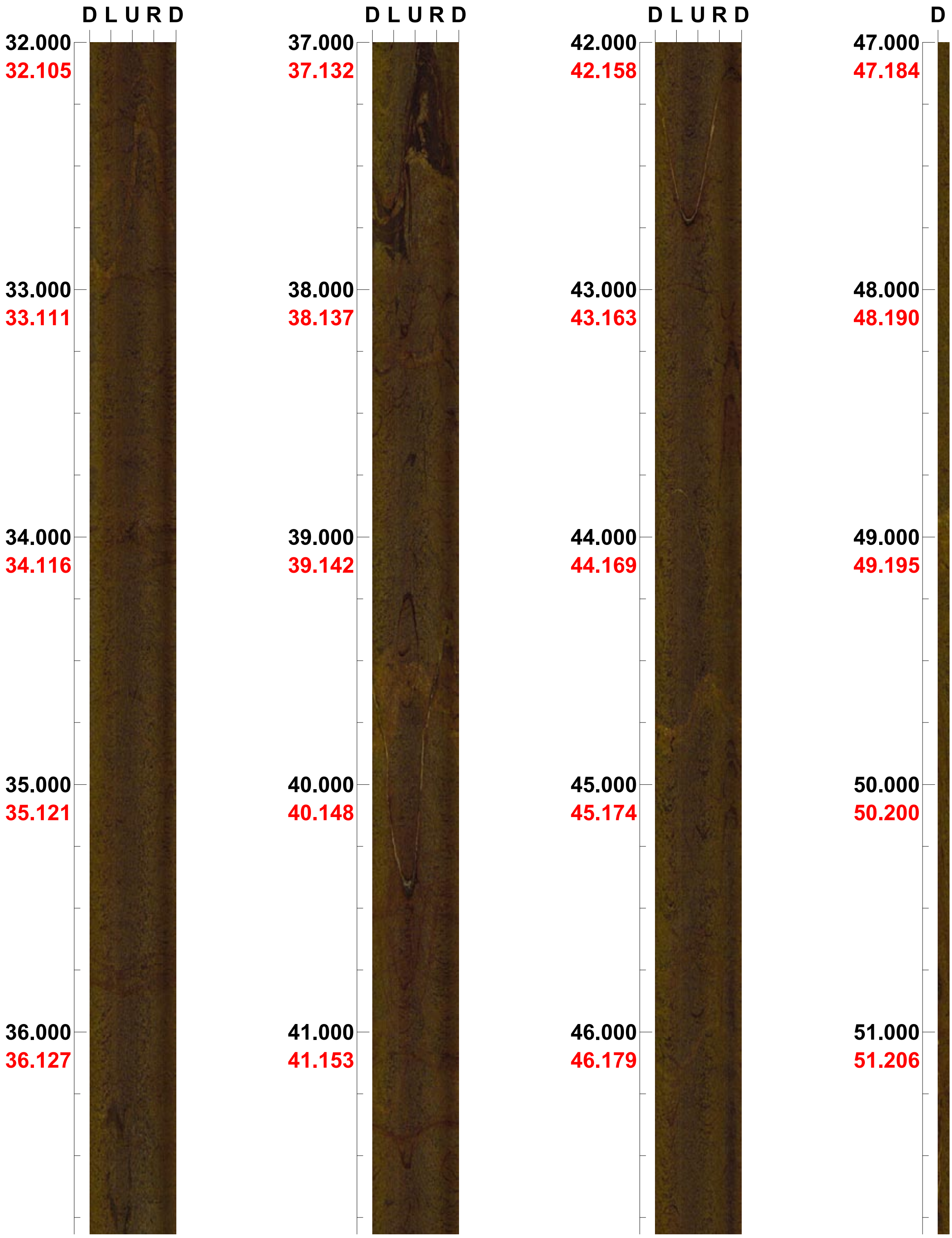
Project name: Forsmark
Bore hole No.: HFM20 **Azimuth: 359** **Inclina**

Depth range: 12.000 - 32.000 m



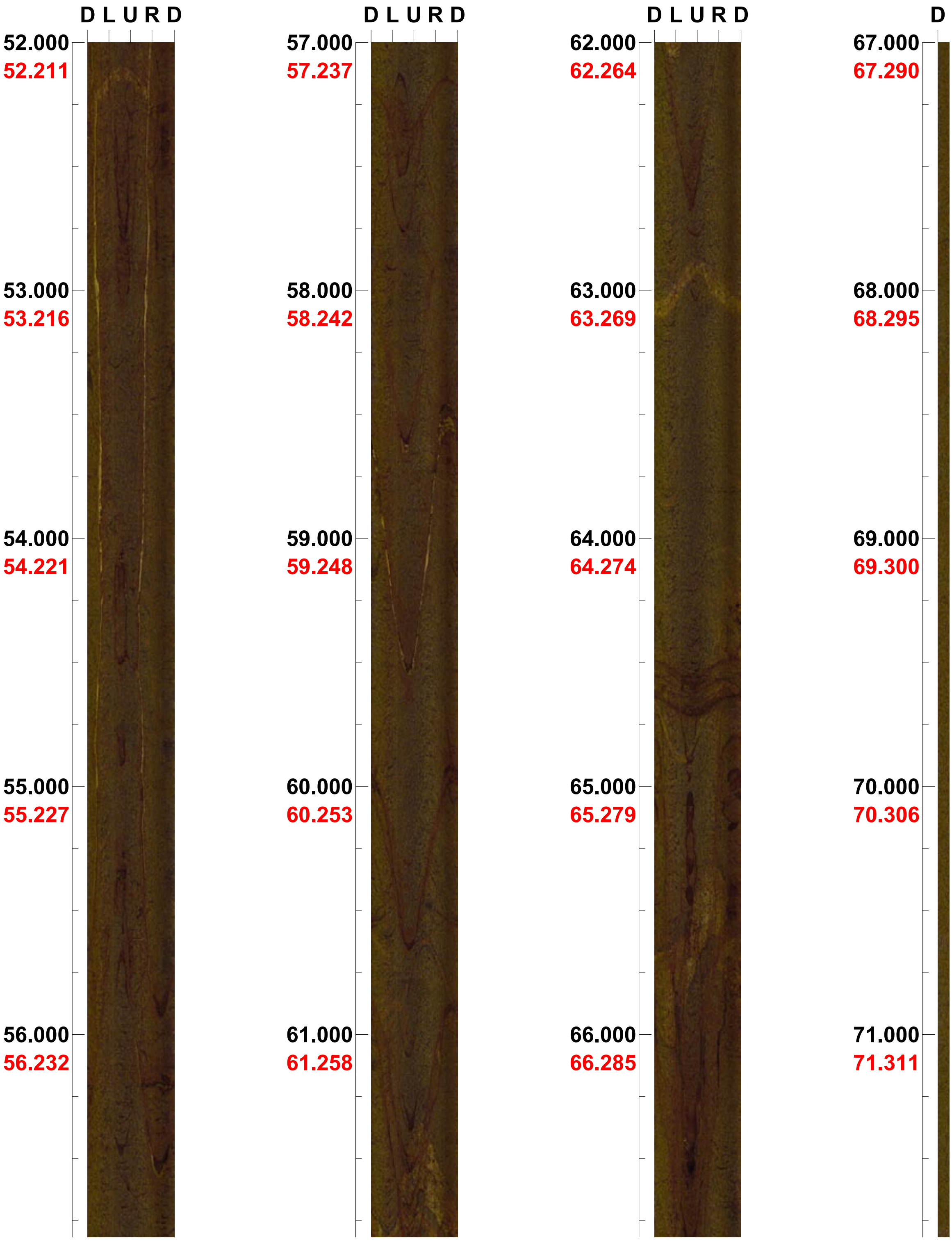
Project name: Forsmark
Bore hole No.: HFM20 Azimuth: 1 Inclina

Depth range: 32.000 - 52.000 m



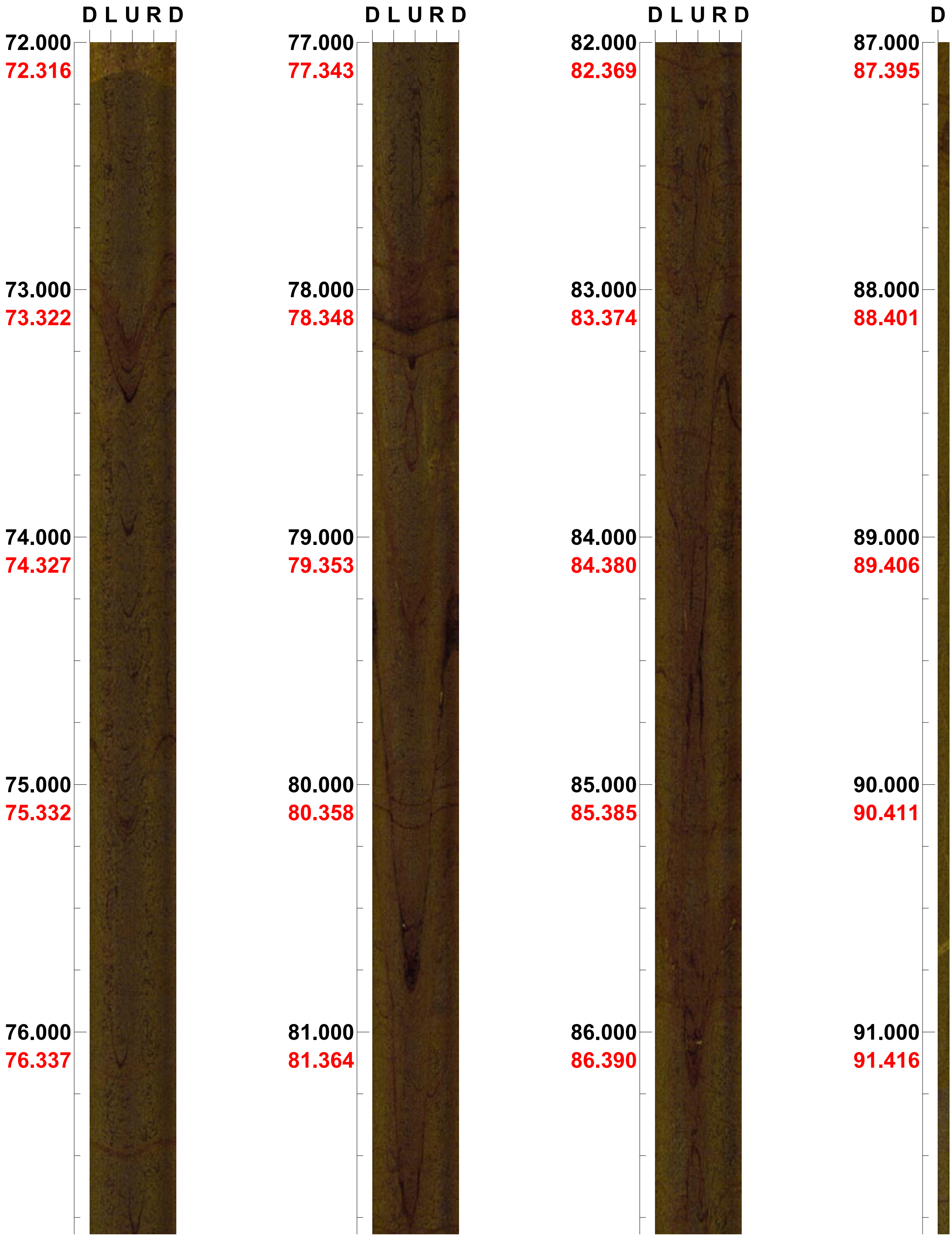
Project name: Forsmark
Bore hole No.: HFM20 Azimuth: 0 Inclina

Depth range: 52.000 - 72.000 m



Project name: Forsmark
Bore hole No.: HFM20 **Azimuth: 348** **Inclina**

Depth range: 72.000 - 92.000 m



Project name: Forsmark

Bore hole No.: HFM20 **Azimuth: 344** **Inclina**

Depth range: 92.000 - 112.000 m

Project name: Forsmark

Bore hole No.: HFM20 **Azimuth: 324** **Inclina**

Depth range: 112.000 - 132.000 m

Project name: Forsmark
Bore hole No.: HFM20 **Azimuth: 255** **Inclina**

Depth range: 132.000 - 152.000 m

Project name: Forsmark

Bore hole No.: HFM20 **Azimuth: 245** **Inclina**

Depth range: 152.000 - 172.000 m

Project name: Forsmark
Bore hole No.: HFM20 **Azimuth: 239** **Inclina**

Depth range: 172.000 - 192.000 m

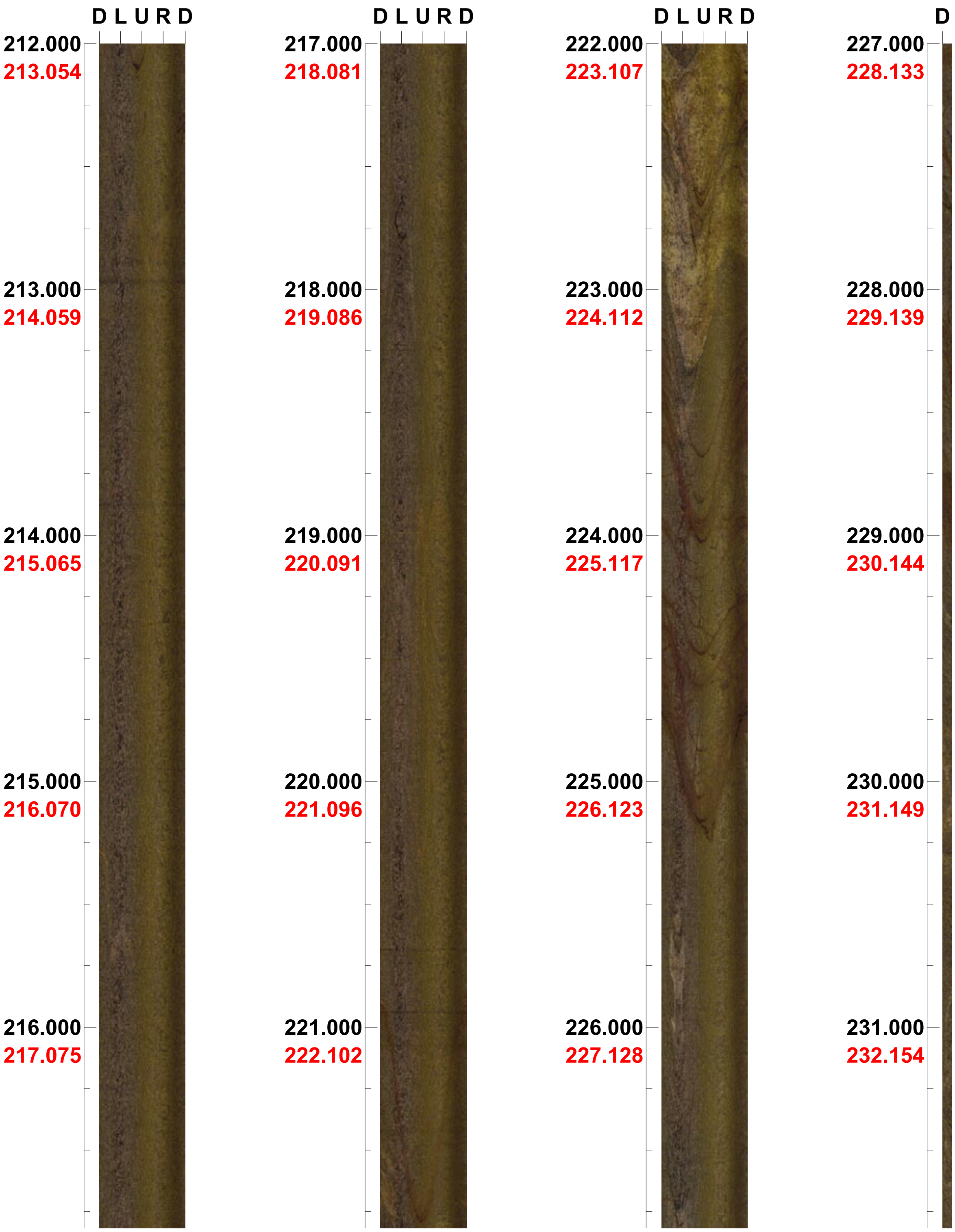
Project name: Forsmark
Bore hole No.: HFM20 **Azimuth: 238** **Inclina**

Depth range: 192.000 - 212.000 m

Project name: Forsmark

Bore hole No.: HFM20 **Azimuth: 236** **Inclina**

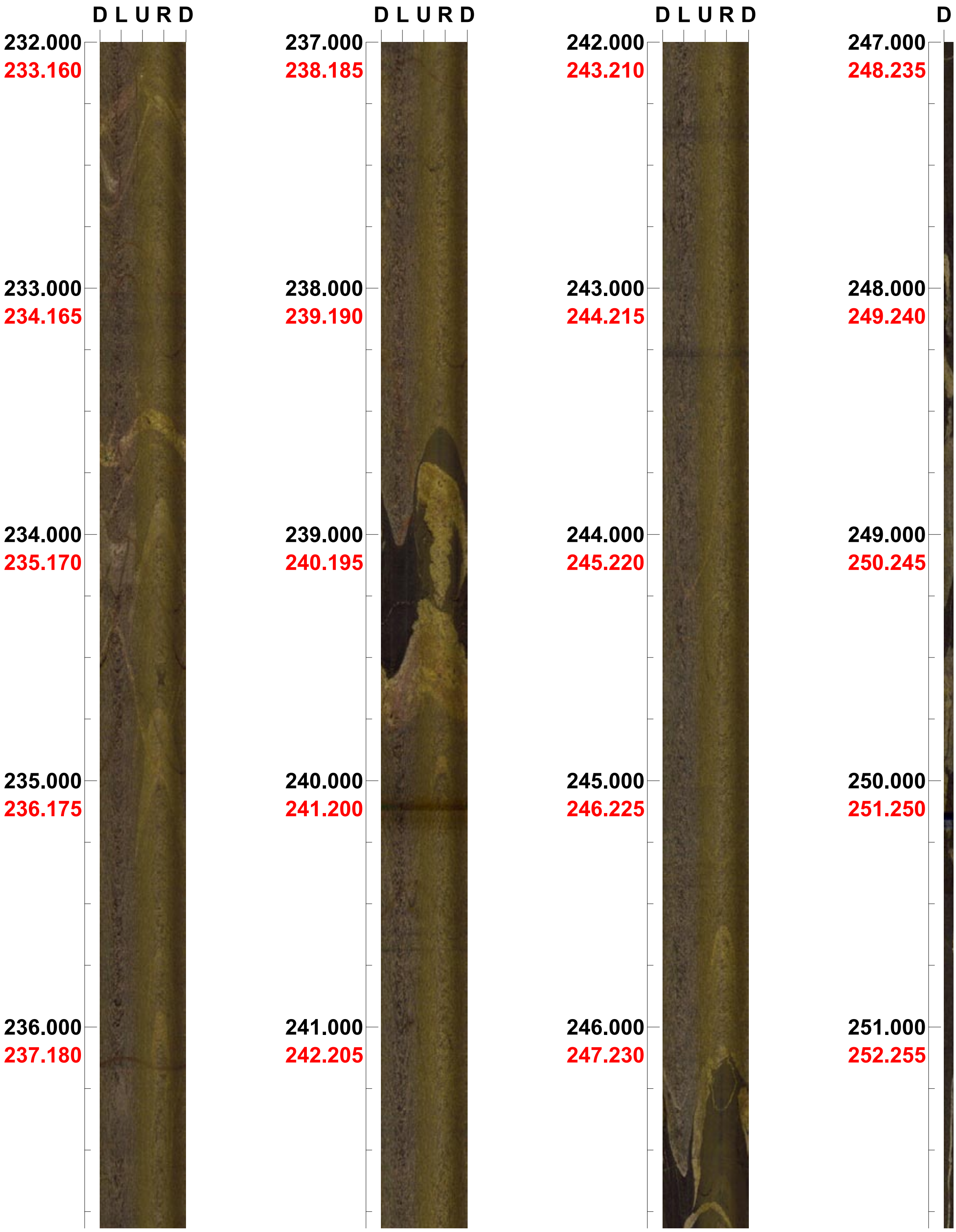
Depth range: 212.000 - 232.000 m



Project name: Forsmark

Bore hole No.: HFM20 **Azimuth: 236** **Inclina**

Depth range: 232.000 - 252.000 m



Project name: Forsmark
Bore hole No.: HFM20 **Azimuth: 229** **Inclina**

Depth range: 252.000 - 272.000 m

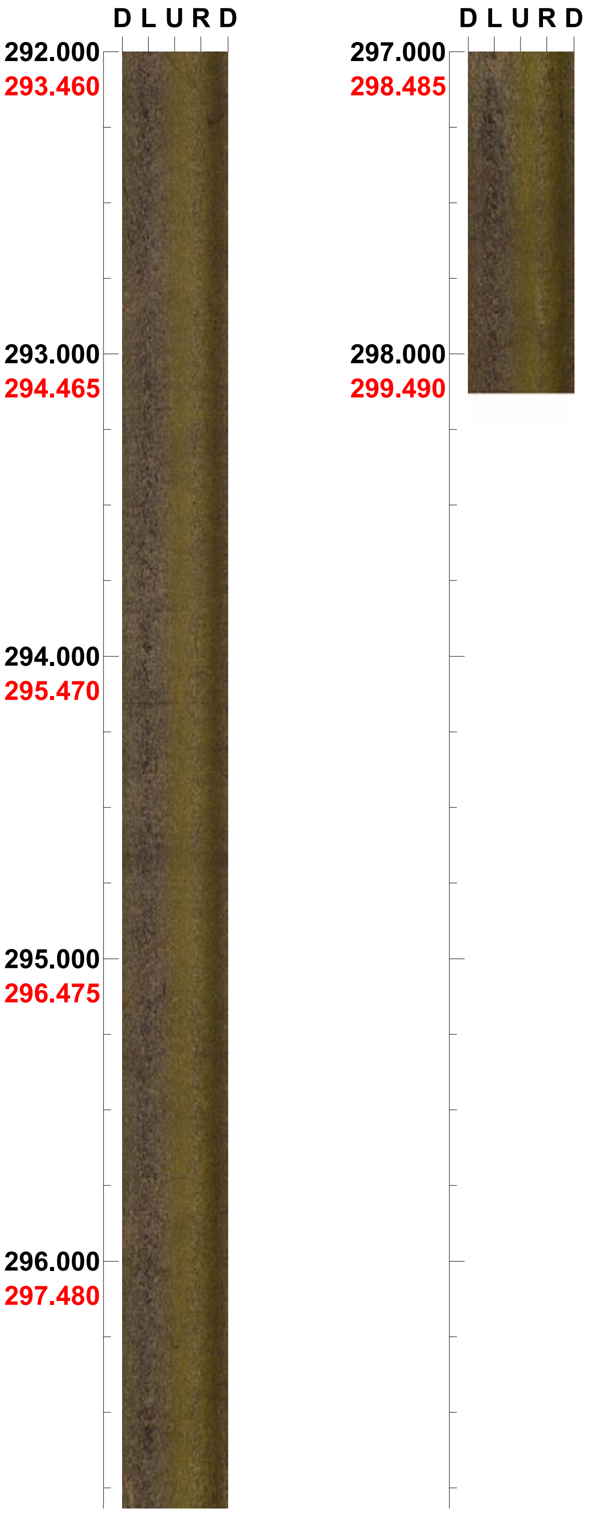
Project name: Forsmark
Bore hole No.: HFM20 Azimuth: 229 Inclina

Depth range: 272.000 - 292.000 m

Project name: Forsmark

Bore hole No.: HFM20 **Azimuth: 227** **Inclina**

Depth range: 292.000 - 298.128 m



Appendix 2

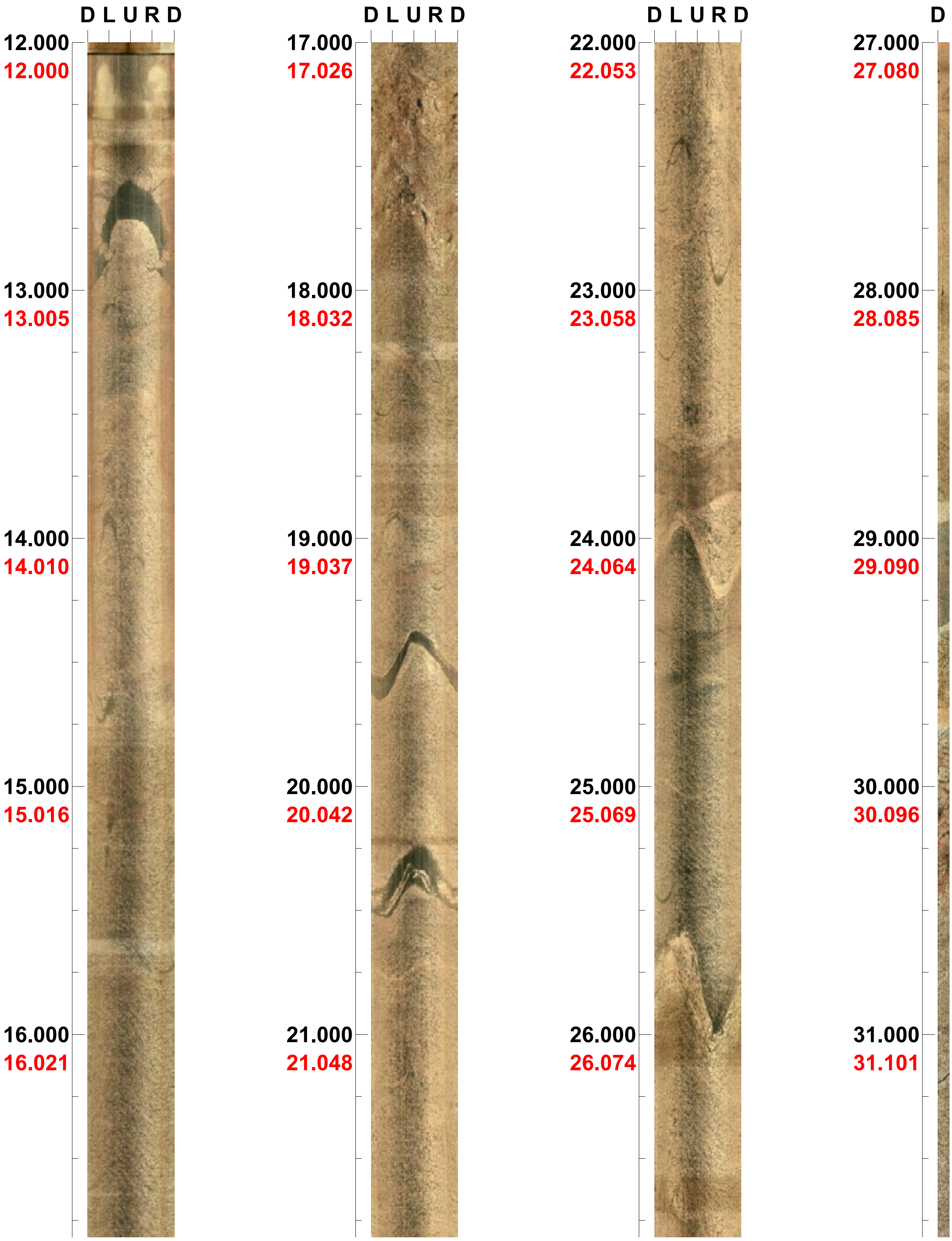
BIPS-images, HFM21

Project name: Forsmark

Image file	: hfm21_~1.bip
BDT file	: hfm21_~1.bdt
Locality	: FORSMARK
Bore hole number	: HFM21
Date	: 05/01/18
Time	: 11:10:00
Depth range	: 12.000 - 200.926 m
Azimuth	: 88
Inclination	: -57
Diameter	: 139.0 mm
Magnetic declination	: 0.0
Span	: 4
Scan interval	: 0.25
Scan direction	: To bottom
Scale	: 1/25
Aspect ratio	: 80 %
Pages	: 10
Color	: +0 +0 +0

Project name: Forsmark
Bore hole No.: HFM21 **Azimuth: 88** **Inclina**

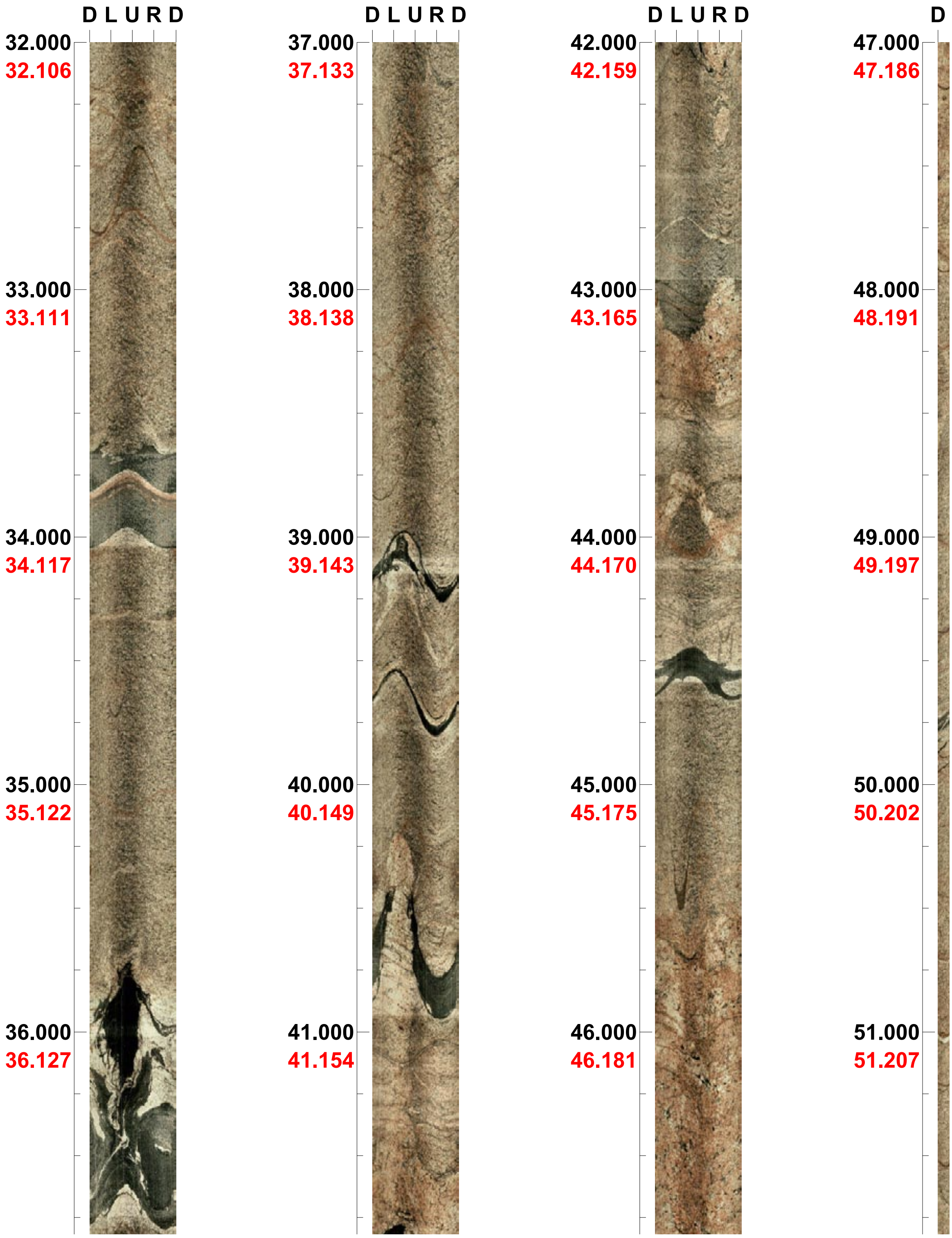
Depth range: 12.000 - 32.000 m



Project name: Forsmark

Bore hole No.: HFM21 **Azimuth: 88** **Inclina**

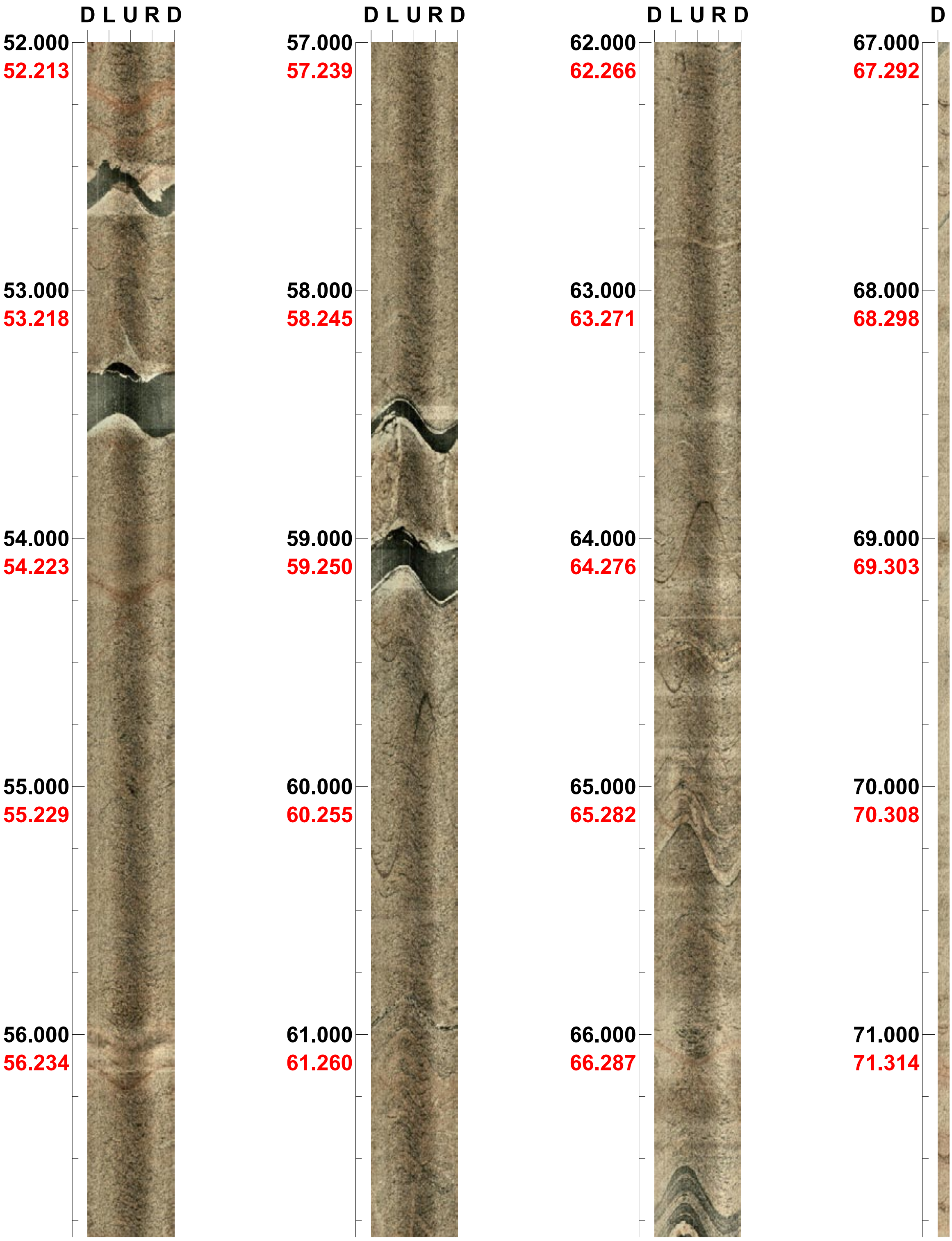
Depth range: 32.000 - 52.000 m



Project name: Forsmark

Bore hole No.: HFM21 **Azimuth: 94** **Inclina**

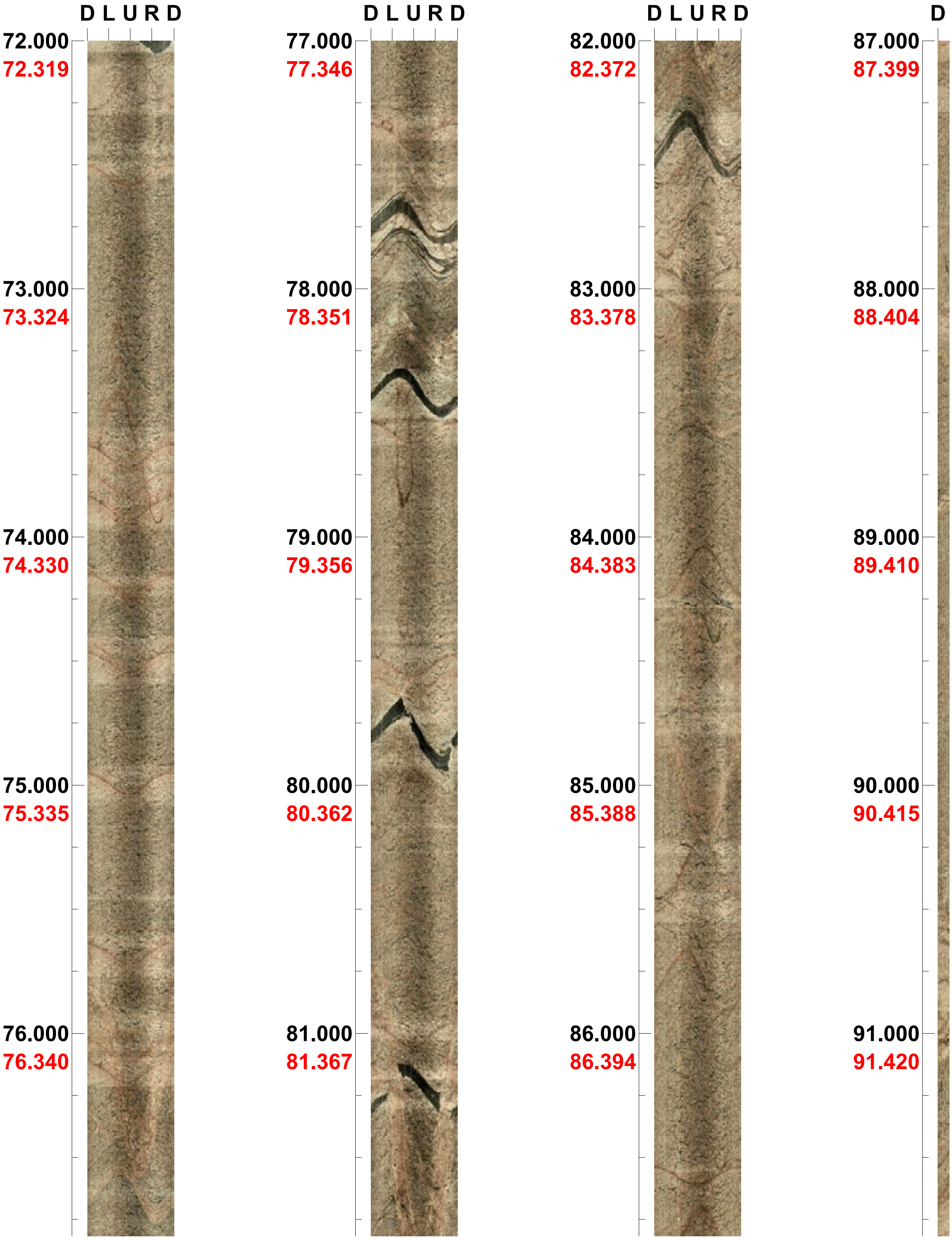
Depth range: 52.000 - 72.000 m



Project name: Forsmark

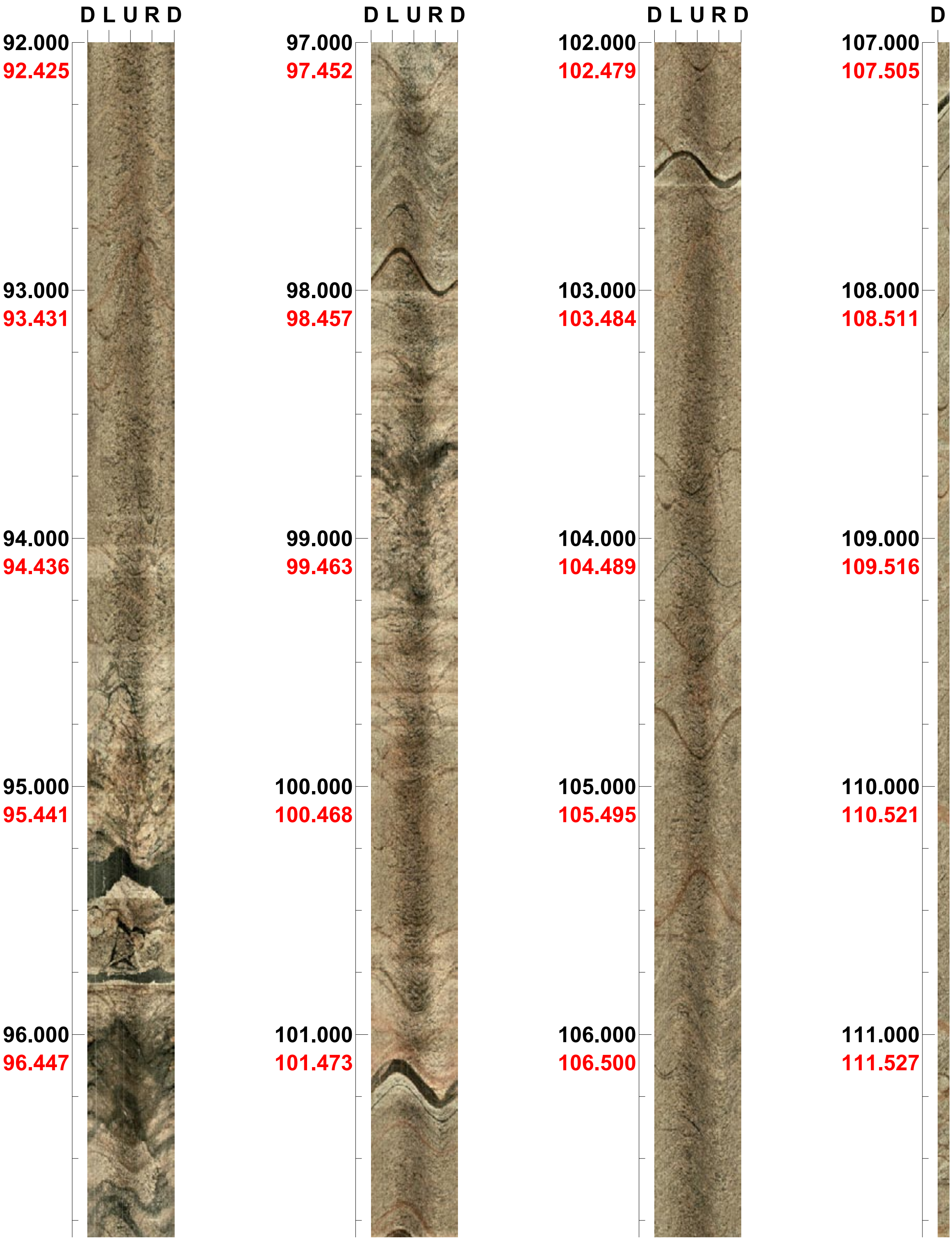
Bore hole No.: HFM21 Azimuth: 101 Inclina

Depth range: 72.000 - 92.000 m



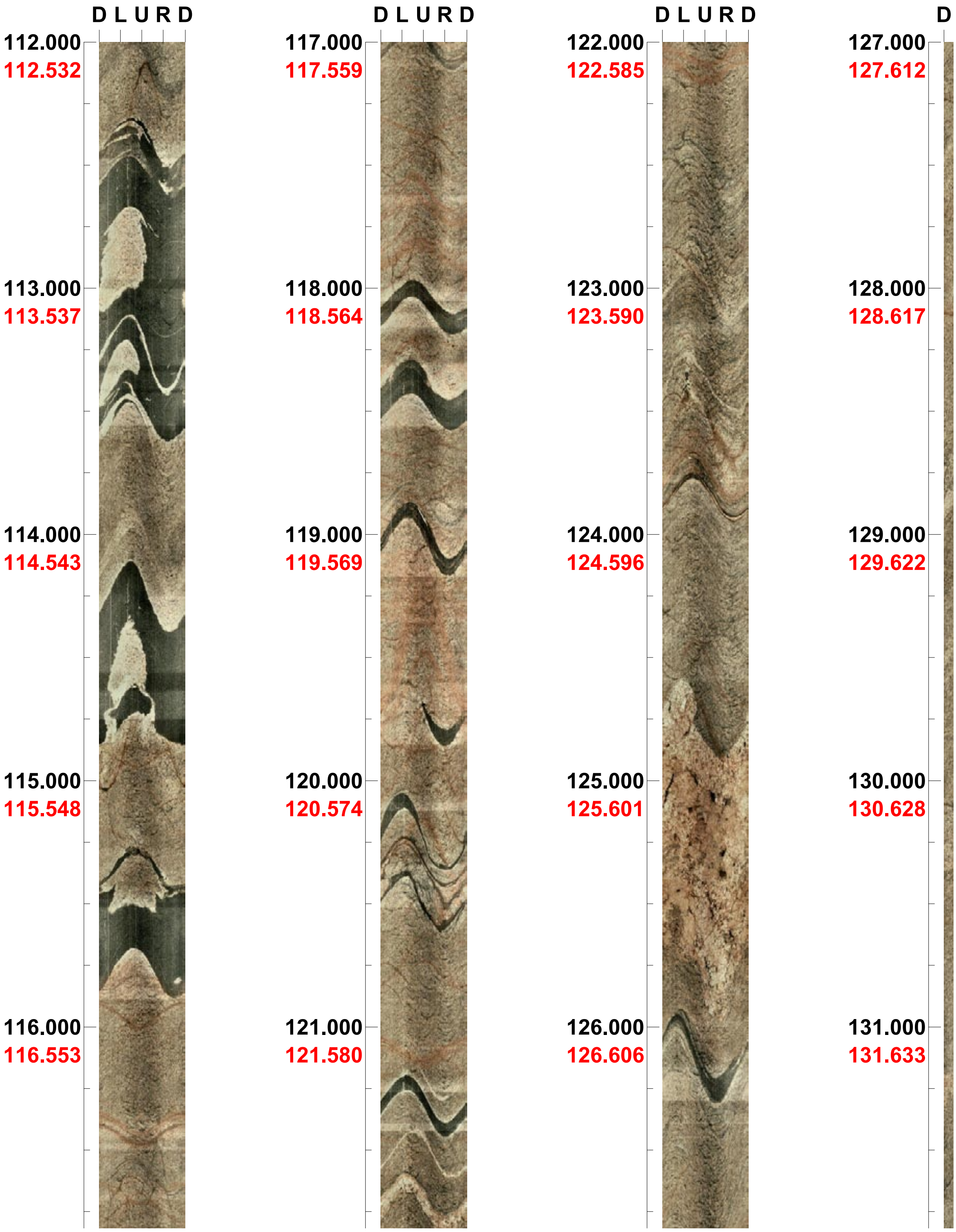
Project name: Forsmark
Bore hole No.: HFM21 **Azimuth: 103** **Inclina**

Depth range: 92.000 - 112.000 m



Project name: Forsmark
Bore hole No.: HFM21 **Azimuth: 110** **Inclina**

Depth range: 112.000 - 132.000 m

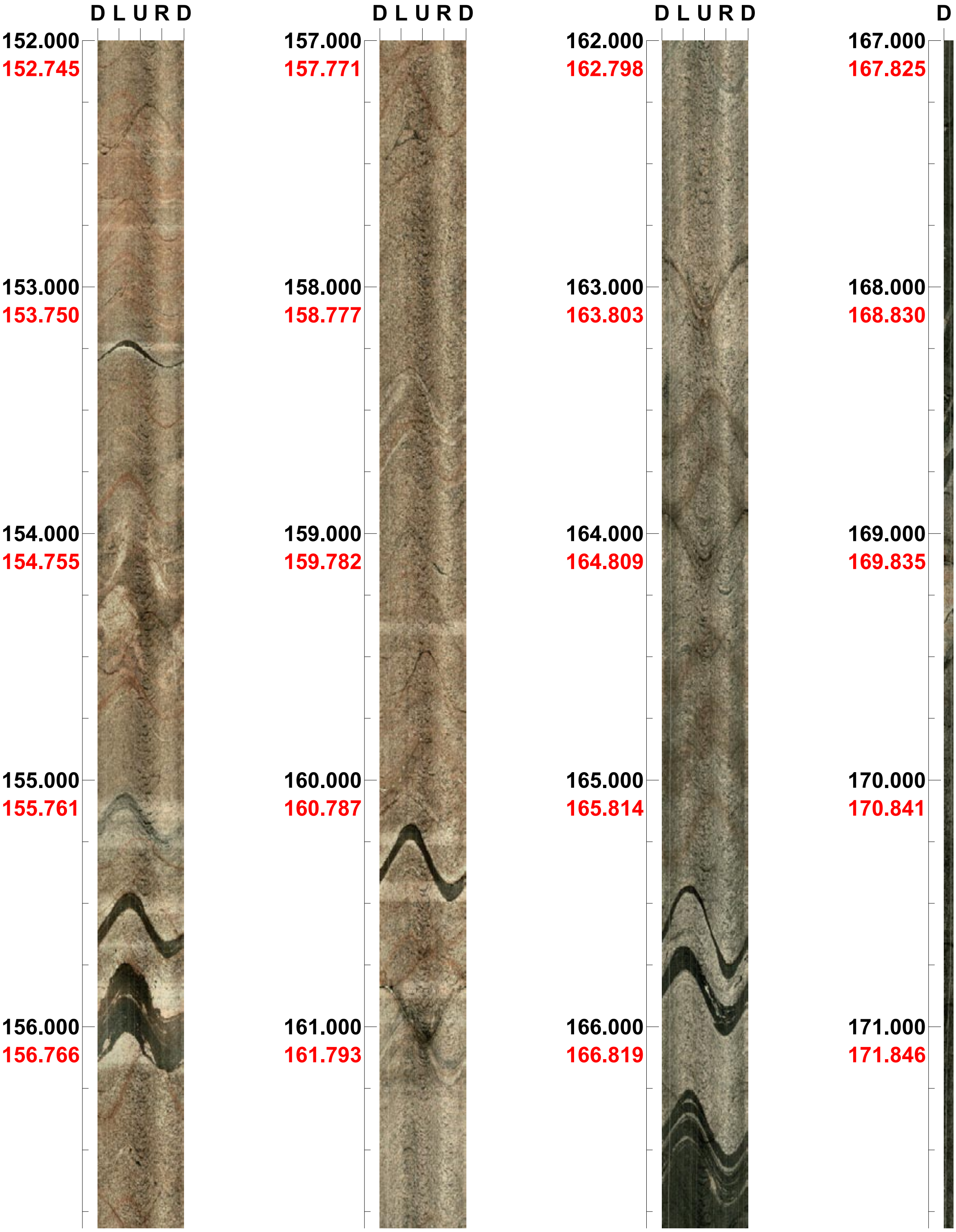


Project name: Forsmark
Bore hole No.: HFM21 **Azimuth: 117** **Inclina**

Depth range: 132.000 - 152.000 m

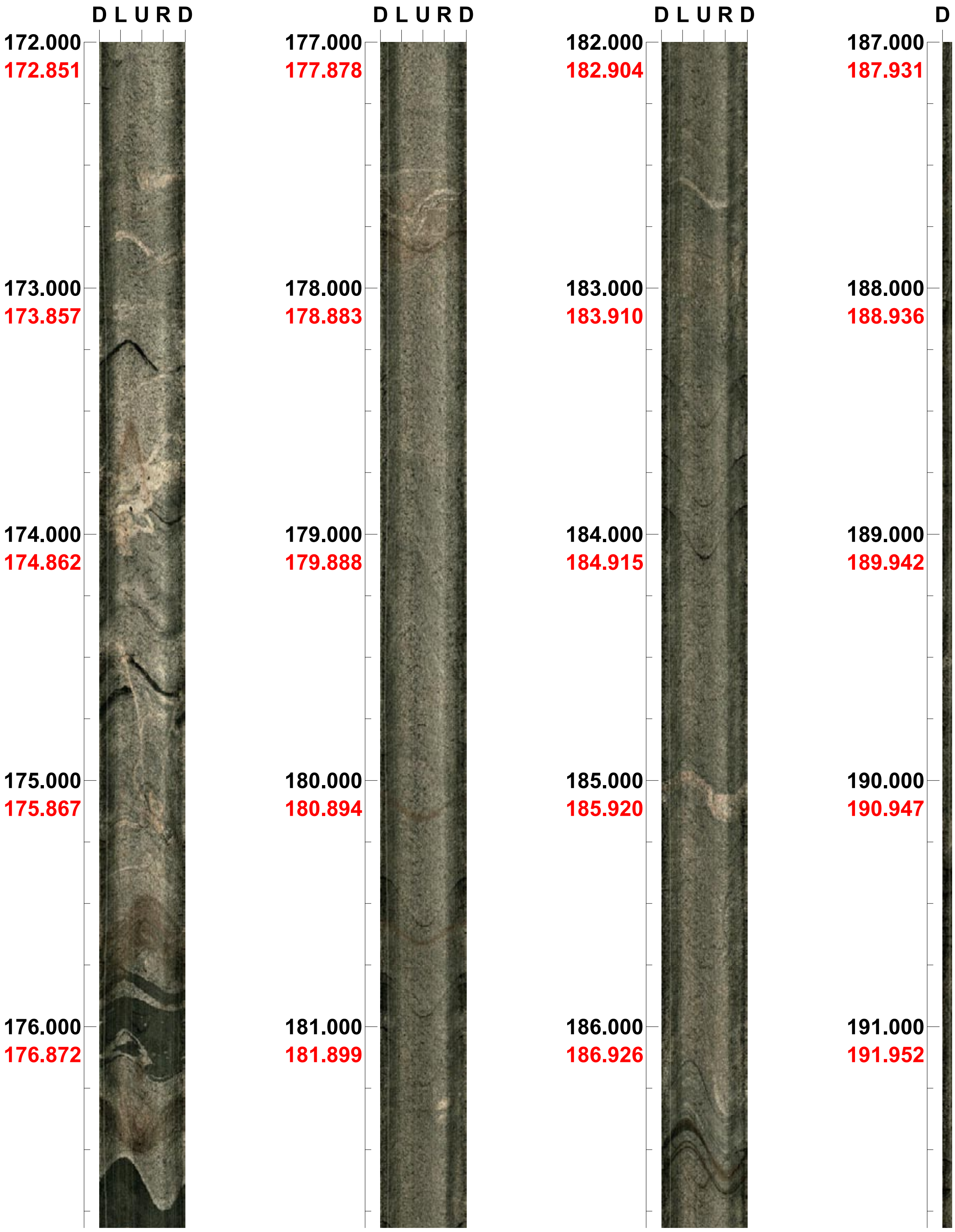
Project name: Forsmark
Bore hole No.: HFM21 **Azimuth: 119** **Inclina**

Depth range: 152.000 - 172.000 m



Project name: Forsmark
Bore hole No.: HFM21 **Azimuth: 123** **Inclina**

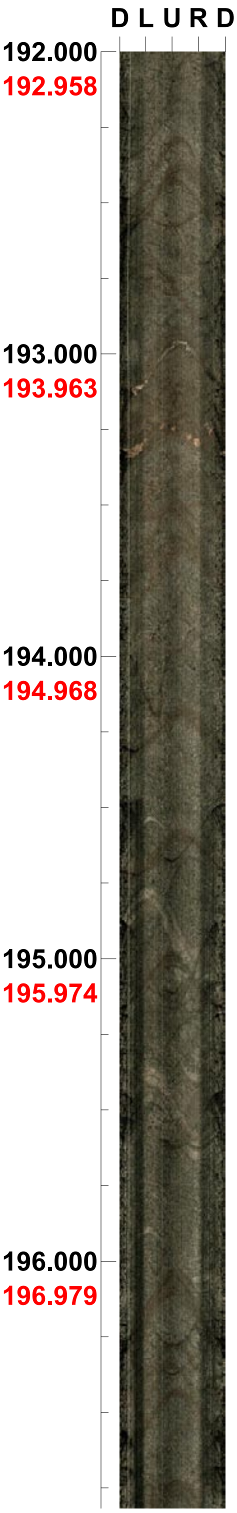
Depth range: 172.000 - 192.000 m



Project name: Forsmark

Bore hole No.: HFM21 **Azimuth: 124** **Inclina**

Depth range: 192.000 - 200.926 m



BIPS-images, HFM22

Project name: Forsmark

Image file	: hfm22_~1.bip
BDT file	: hfm22_~1.bdt
Locality	: FORSMARK
Bore hole number	: HFM22
Date	: 04/11/05
Time	: 11:09:00
Depth range	: 11.000 - 215.113 m
Azimuth	: 93
Inclination	: -57
Diameter	: 136.0 mm
Magnetic declination	: 0.0
Span	: 4
Scan interval	: 0.25
Scan direction	: To bottom
Scale	: 1/25
Aspect ratio	: 90 %
Pages	: 11
Color	: +0 +0 +0

Project name: Forsmark
Bore hole No.: HFM22 Azimuth: 93 Inclination: -57

Depth range: 11.000 - 31.000 m

D L U R D

11.000 / 11.000
12.000 / 12.000
13.000 / 13.005
14.000 / 14.011
15.000 / 15.016
16.000 / 16.021

D L U R D

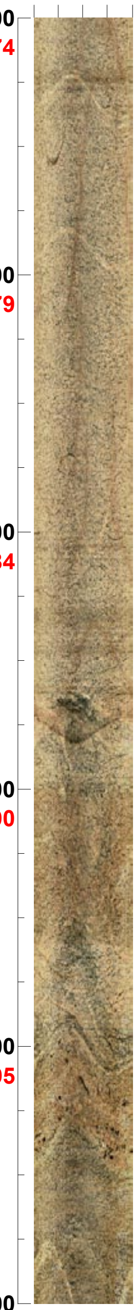
16.000 / 16.021
17.000 / 17.026
18.000 / 18.032
19.000 / 19.037
20.000 / 20.042
21.000 / 21.047

D L U R D

21.000 / 21.047
22.000 / 22.053
23.000 / 23.058
24.000 / 24.063
25.000 / 25.069
26.000 / 26.074

D L U R D

26.000 / 26.074
27.000 / 27.079
28.000 / 28.084
29.000 / 29.090
30.000 / 30.095
31.000 / 31.100



(1 / 11) Scale: 1/25 Aspect ratio: 90 %

Project name: Forsmark

Bore hole No.: HFM22 **Azimuth: 96** **Inclination: -56**

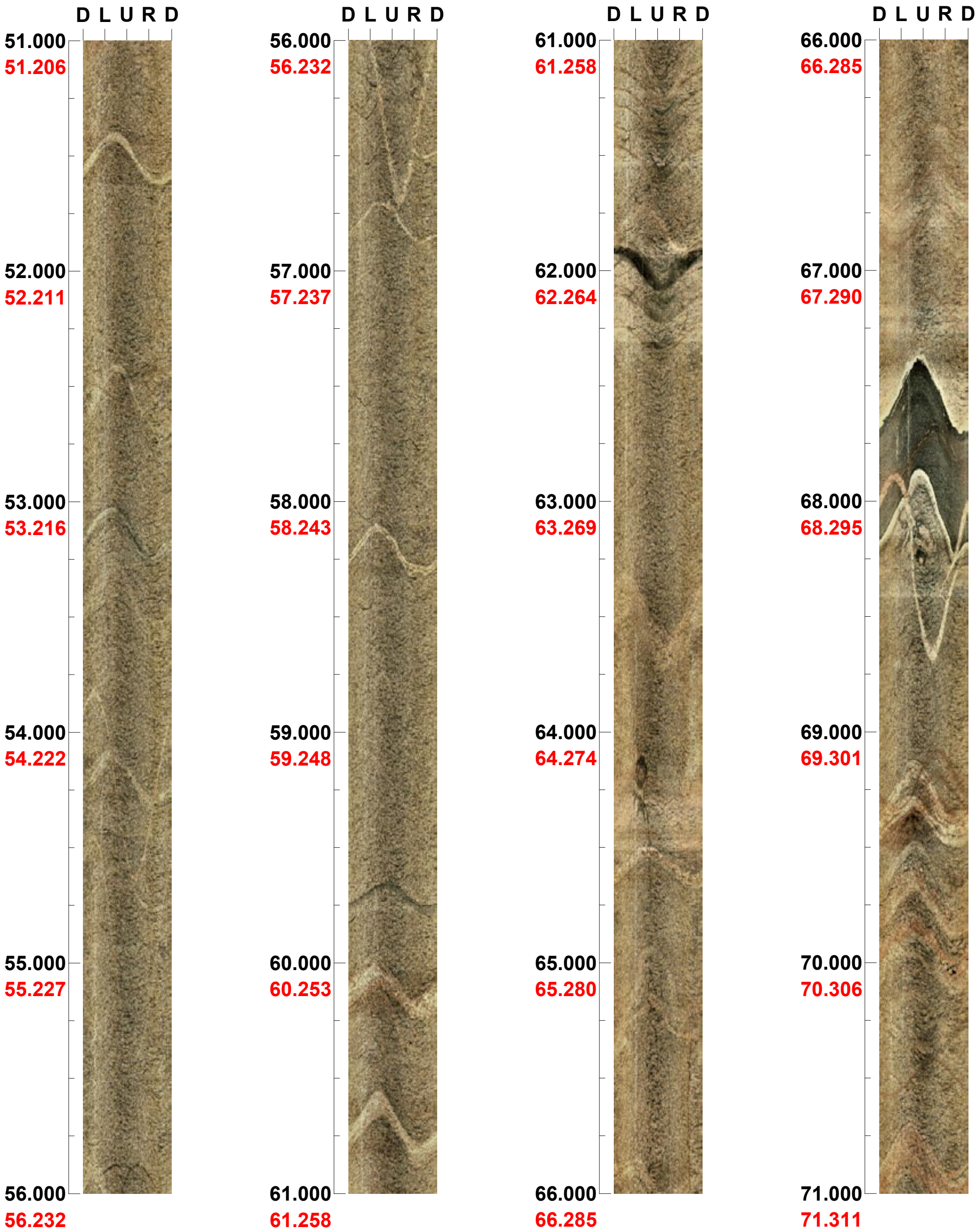
Depth range: 31.000 - 51.000 m

(2 / 11) **Scale: 1/25** **Aspect ratio: 90 %**

Project name: Forsmark

Bore hole No.: HFM22 Azimuth: 102 Inclination: -53

Depth range: 51.000 - 71.000 m



(3 / 11) Scale: 1/25 Aspect ratio: 90 %

Project name: Forsmark
Bore hole No.: HFM22 **Azimuth: 107** **Inclination: -51**

Depth range: 71.000 - 91.000 m

(4 / 11) **Scale: 1/25** **Aspect ratio: 90 %**

Project name: Forsmark
Bore hole No.: HFM22 **Azimuth: 111** **Inclination: -47**

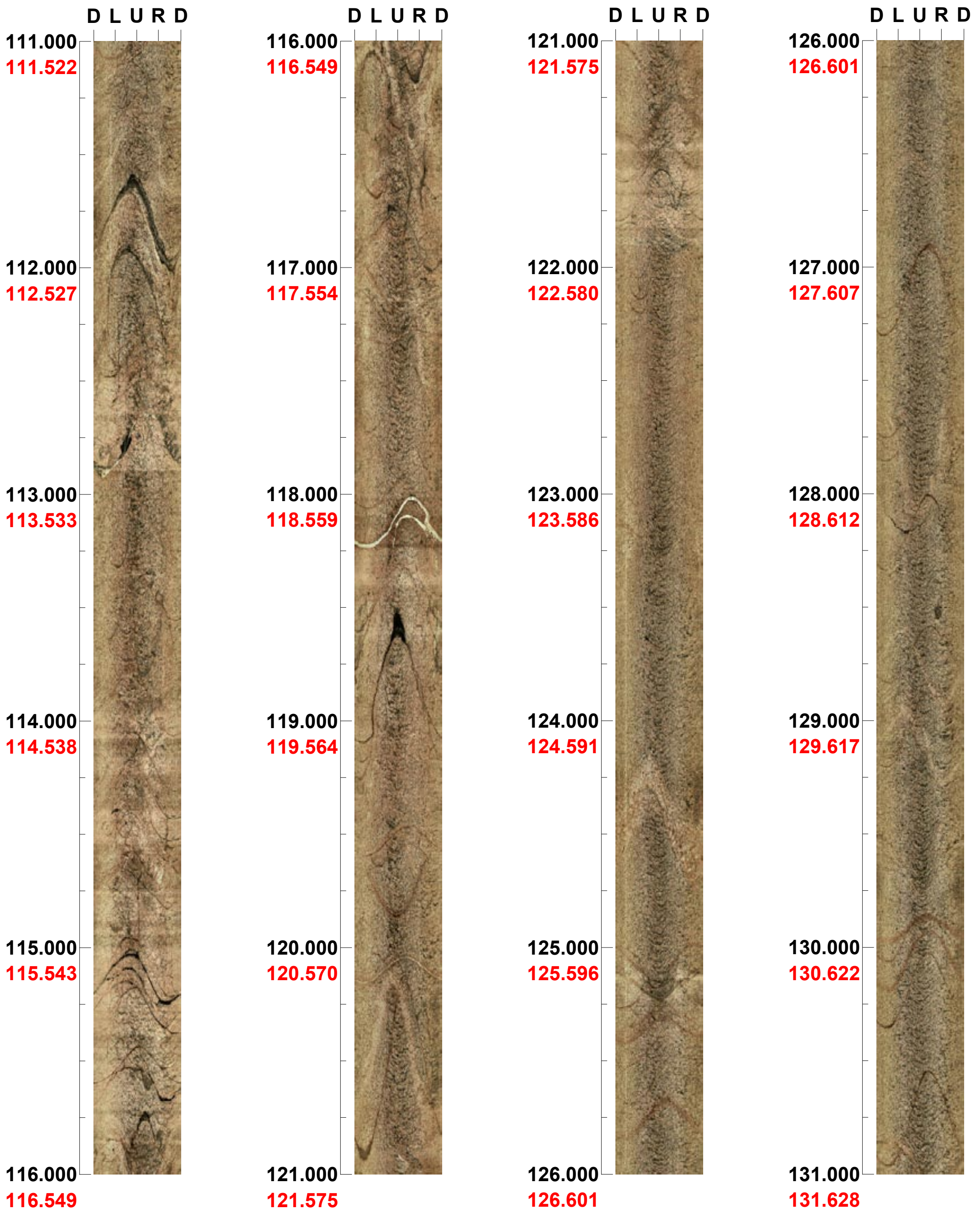
Depth range: 91.000 - 111.000 m

(5 / 11) **Scale: 1/25** **Aspect ratio: 90 %**

Project name: Forsmark

Bore hole No.: HFM22 Azimuth: 113 Inclination: -44

Depth range: 111.000 - 131.000 m



(6 / 11) Scale: 1/25 Aspect ratio: 90 %

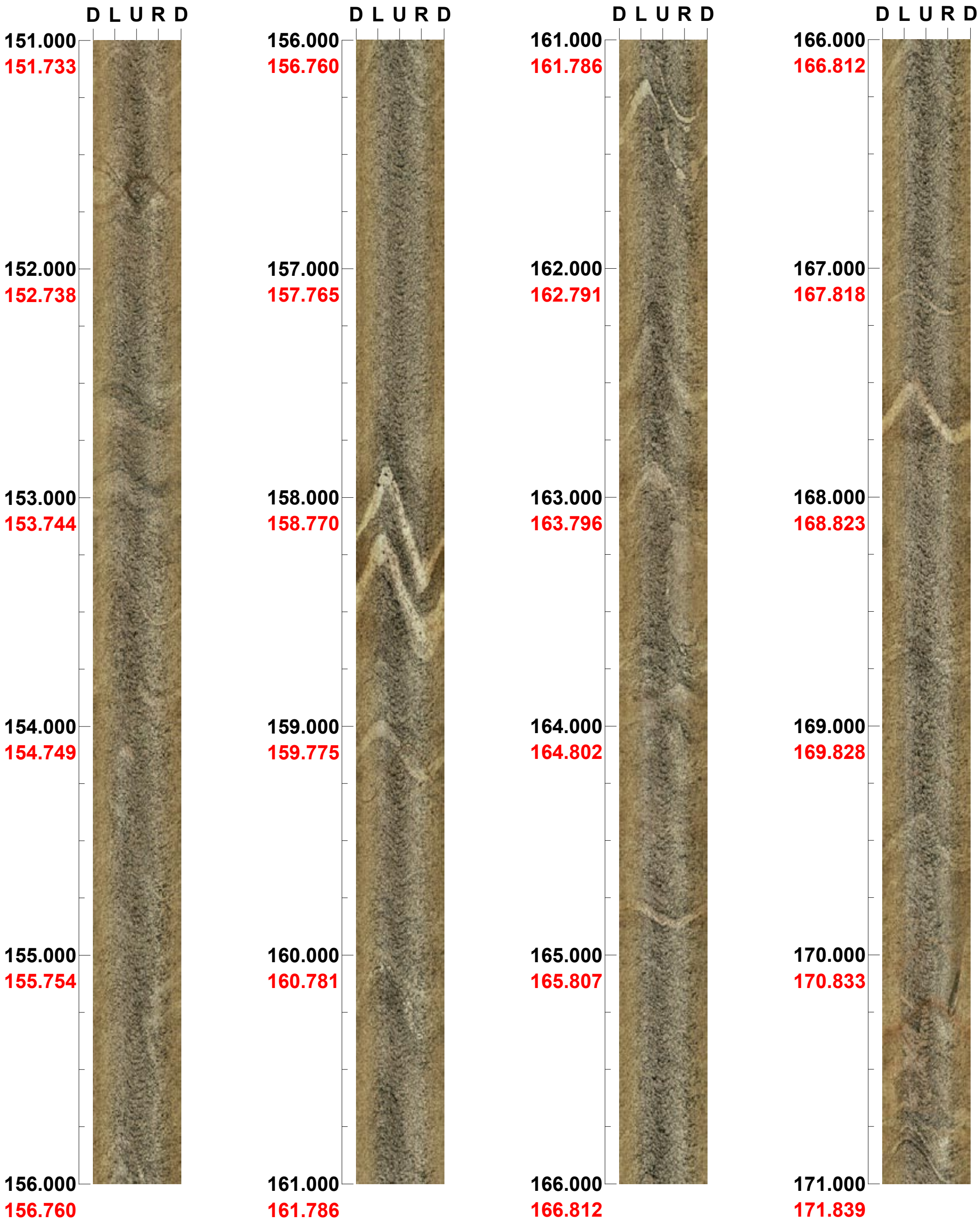
Project name: Forsmark
Bore hole No.: HFM22 **Azimuth: 115** **Inclination: -42**

Depth range: 131.000 - 151.000 m

(7 / 11) **Scale: 1/25** **Aspect ratio: 90 %**

Project name: Forsmark
Bore hole No.: HFM22 **Azimuth: 114** **Inclination: -39**

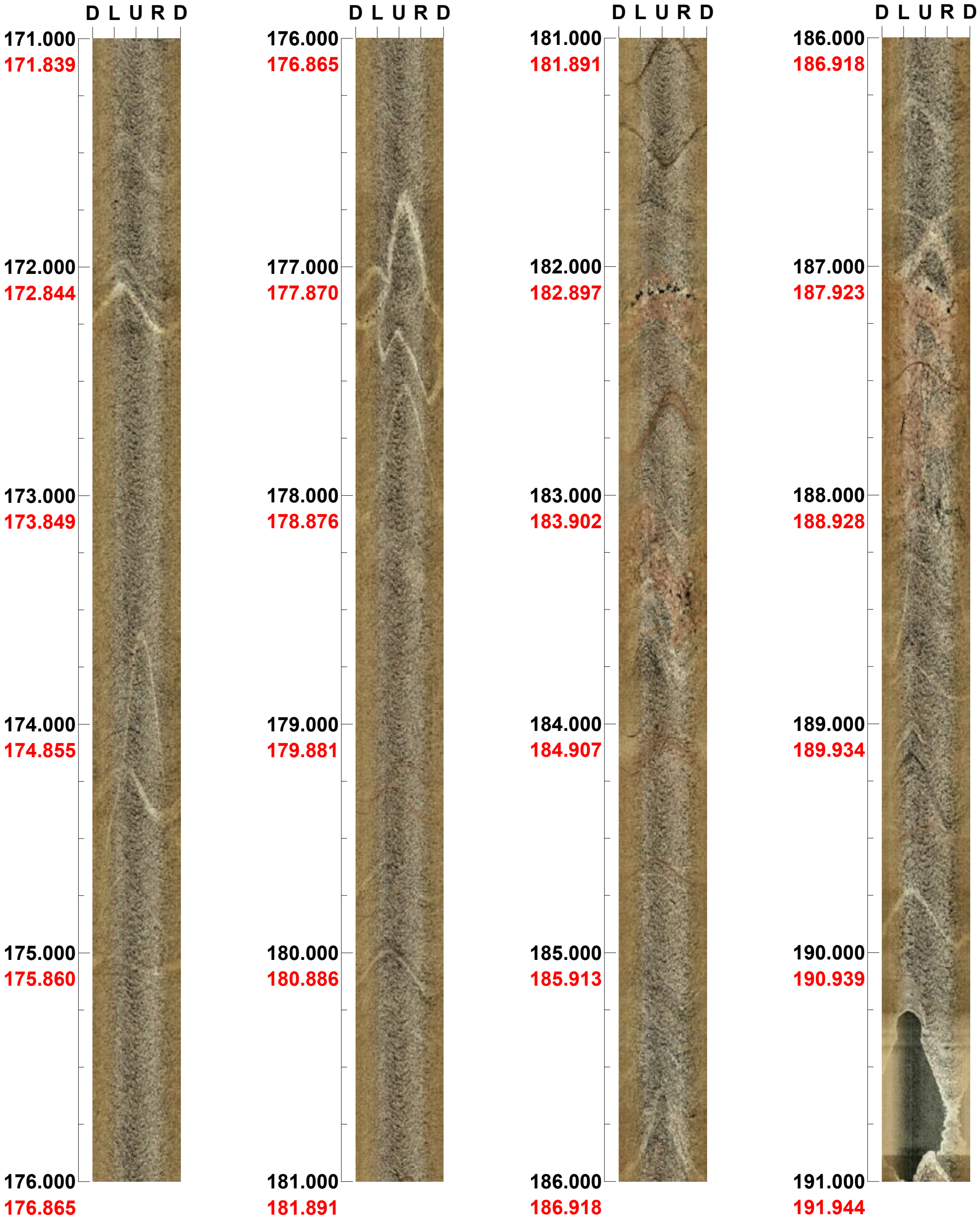
Depth range: 151.000 - 171.000 m



(8 / 11) **Scale: 1/25** **Aspect ratio: 90 %**

Project name: Forsmark
Bore hole No.: HFM22 Azimuth: 115 Inclination: -37

Depth range: 171.000 - 191.000 m



(9 / 11) Scale: 1/25 Aspect ratio: 90 %

Project name: Forsmark

Bore hole No.: HFM22 **Azimuth: 115** **Inclination: -35**

Depth range: 191.000 - 211.000 m

(10 / 11) **Scale: 1/25** **Aspect ratio: 90 %**

Project name: Forsmark
Bore hole No.: HFM22 **Azimuth: 115** **Inclination: -34**

Depth range: 211.000 - 215.113 m

(11 / 11) **Scale: 1/25** **Aspect ratio: 90 %**

Appendix 4

WellCad diagram, HFM20

Title LEGEND FOR FORSMARK HFM20

SKB

Site FORSMARK
Borehole HFM20
Plot Date 2005-04-27 23:08:01

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

ROCK ALTERATION

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

MINERAL

- Unknown
- 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

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

ROCK ALTERATION INTENSITY

- No intensity
- Faint
- Weak
- Medium
- Strong

ROUGHNESS

- Planar
- Undulating
- Stepped
- Irregular

SURFACE

- Rough
- Smooth
- Slickensided

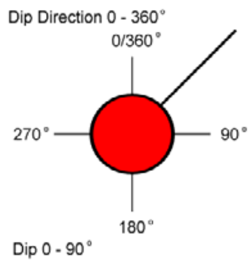
CRUSH ALTERATION

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

FRACTURE ALTERATION

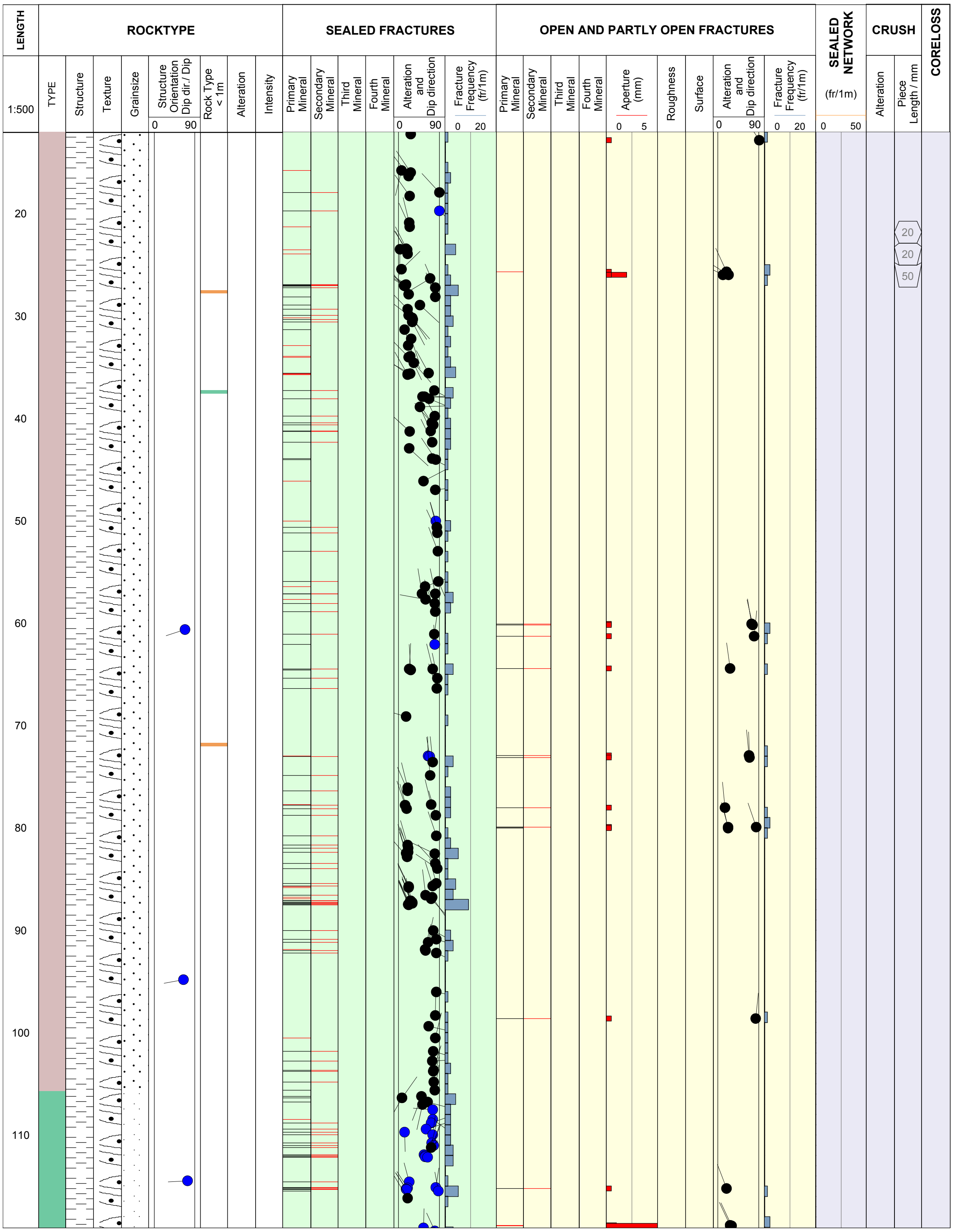
- Fresh
- Gouge
- Completely Altered
- Highly Altered
- Moderately Altered
- Slightly Altered

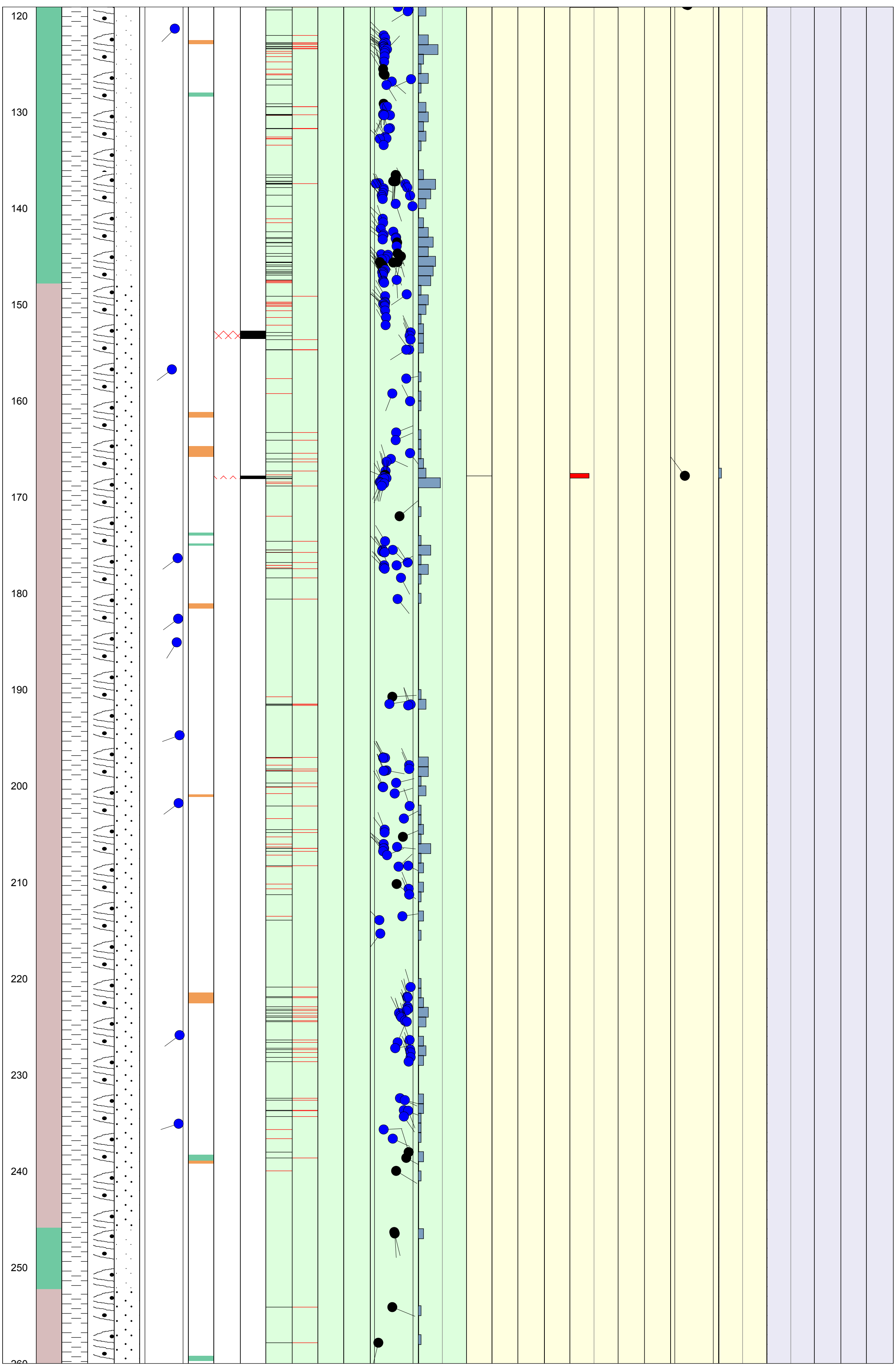
FRACTURE DIRECTION
STRUKTURE ORIENTATION

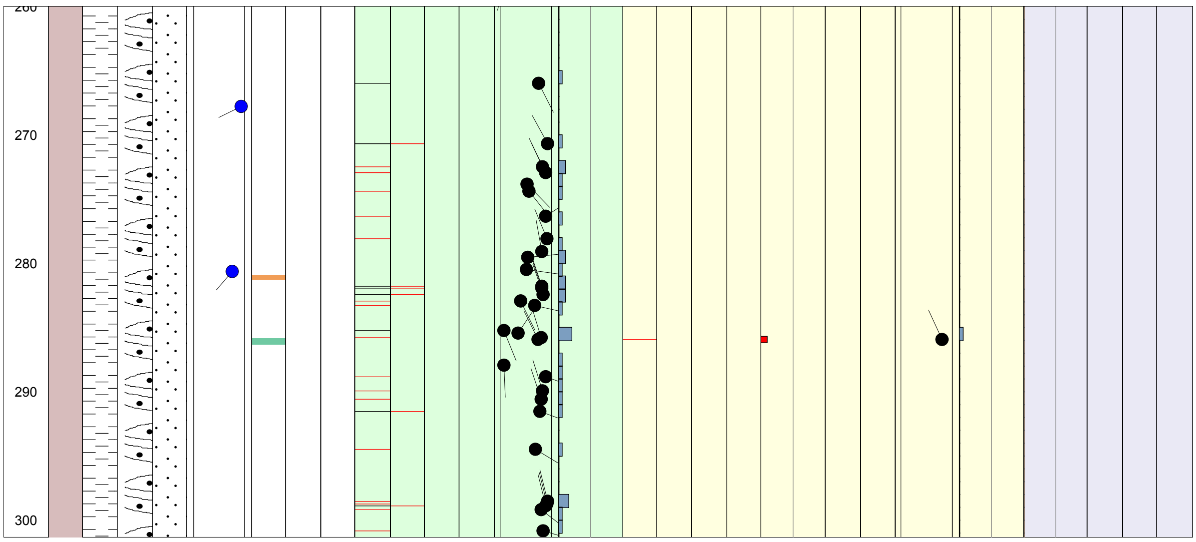


Title **GEOLOGY IN HFM20** **Appendix:**

Site	FORSMARK	**Coordinate System**	RT90-RHB70
Borehole	HFM20	**Northing [m]**	6700187.50
Diameter [mm]	135	**Easting [m]**	1630776.68
Length [m]	301.000	**Elevation [m.a.s.l.]**	2.97
Bearing [°]	354.41	**Drilling Start Date**	2004-05-18 15:20:00
Inclination [°]	-85.44	**Drilling Stop Date**	2004-06-01 20:00:00
Date of coremapping	2005-01-24 14:46:00	**Plot Date**	2005-04-24 22:32:03
Rocktype data from	p_rock_XXXXX	**Fracture data from**	p_fract_core




120
130
140
150
160
170
180
190
200
210
220
230
240
250
260


260
270
280
290
300

Appendix 5

WellCad diagram, HFM21

Title LEGEND FOR FORSMARK HFM21

SKB

Site FORSMARK
Borehole HFM21
Plot Date 2005-04-27 23:08:01

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

ROCK ALTERATION

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

MINERAL

- Unknown

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

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

ROCK ALTERATION INTENSITY

- No intensity
- Faint
- Weak
- Medium
- Strong

ROUGHNESS

- Planar
- Undulating
- Stepped
- Irregular

SURFACE

- Rough
- Smooth
- Slickensided

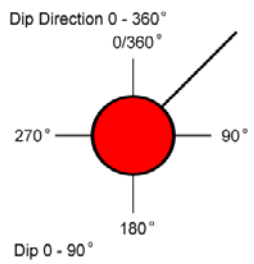
CRUSH ALTERATION

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

FRACTURE ALTERATION

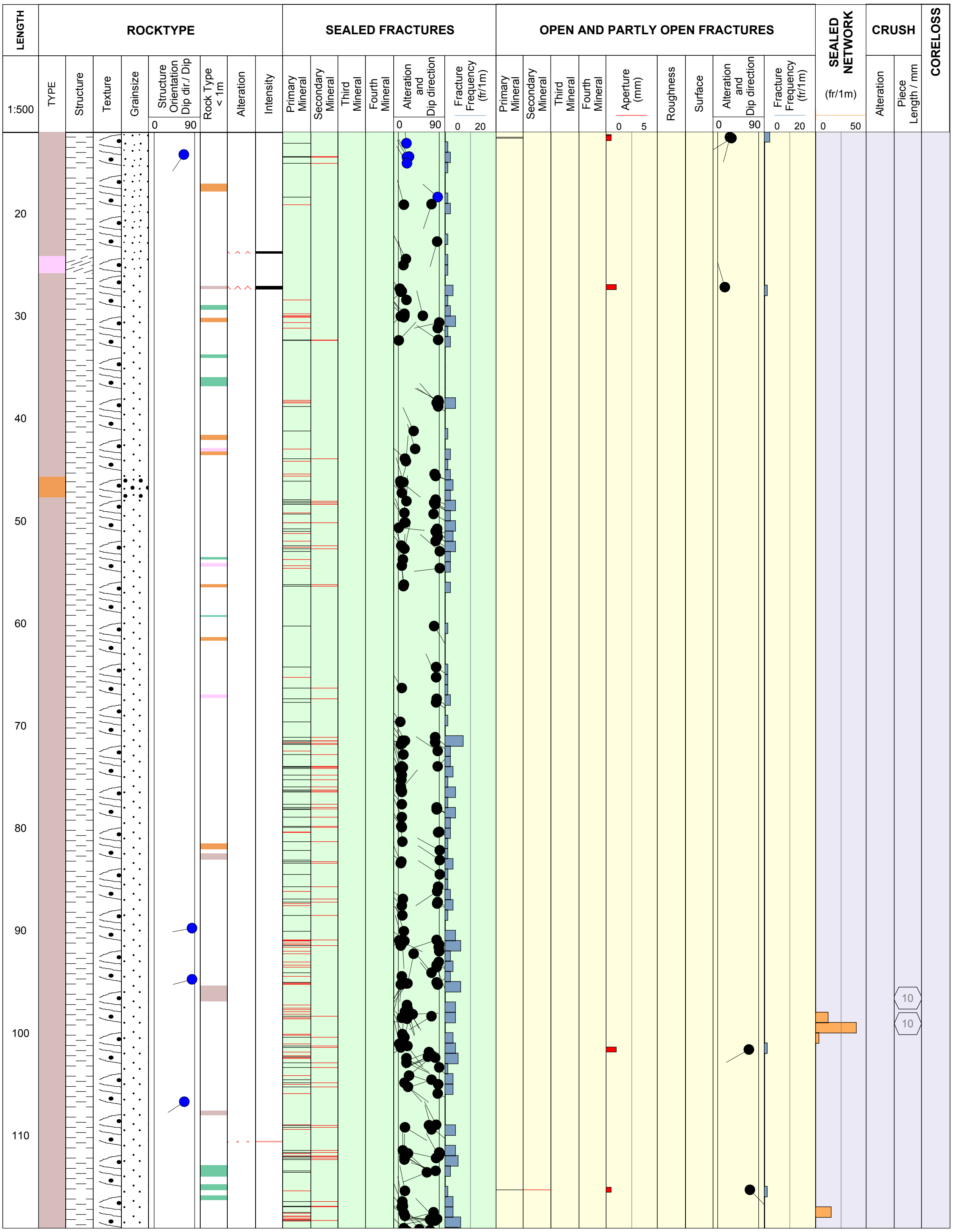
- Fresh
- Gouge
- Completely Altered
- Highly Altered
- Moderately Altered
- Slightly Altered

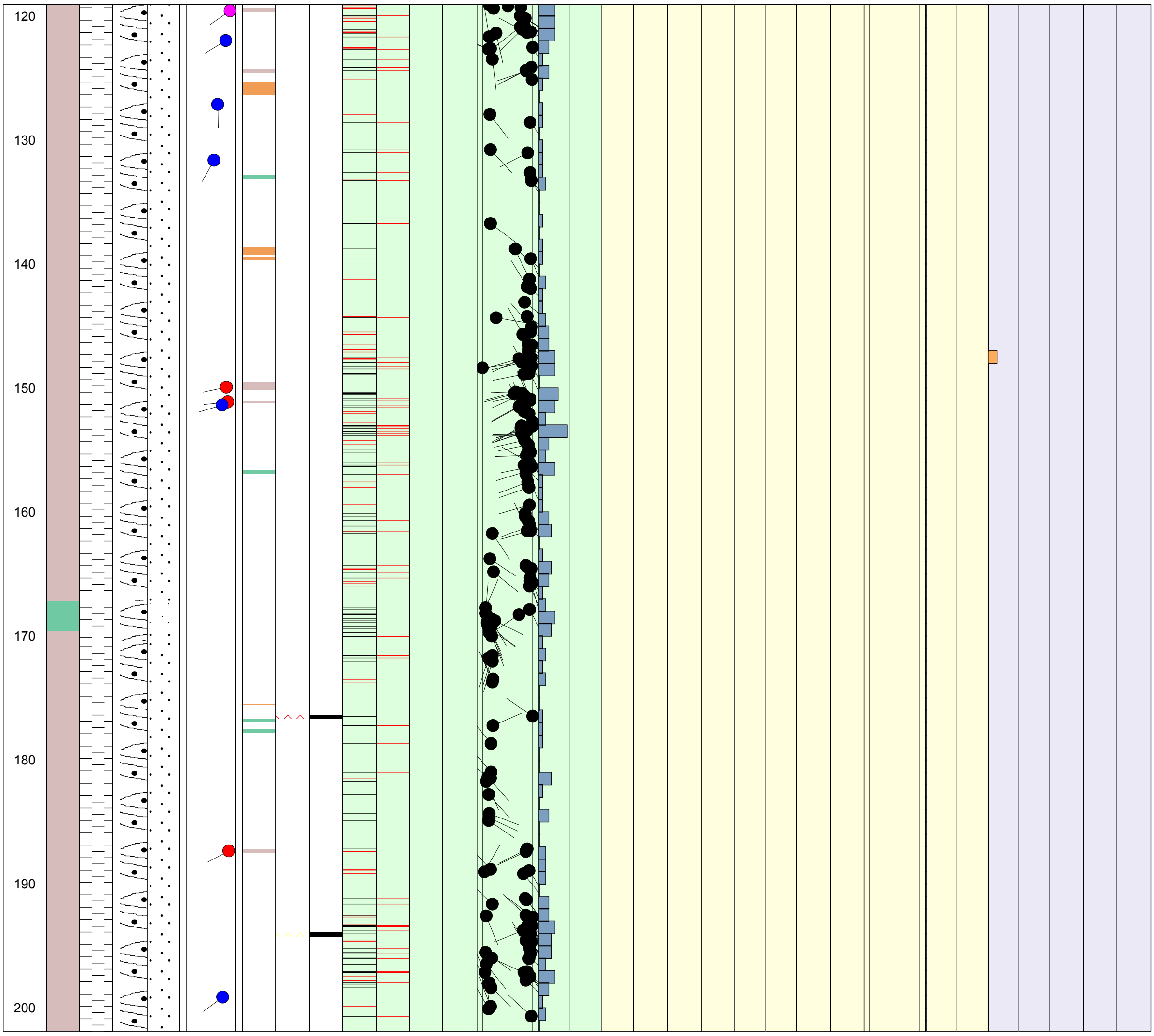
FRACTURE DIRECTION
STRUKTURE ORIENTATION



Title **GEOLOGY IN HFM21** **Appendix:**

Site	FORSMARK	**Coordinate System**	RT90-RHB70
Borehole	HFM21	**Northing [m]**	6700125.57
Diameter [mm]	137	**Easting [m]**	1631074.05
Length [m]	202.000	**Elevation [m.a.s.l.]**	3.98
Bearing [°]	88.81	**Drilling Start Date**	2004-06-02 09:00:00
Inclination [°]	-58.47	**Drilling Stop Date**	2004-06-07 11:40:00
Date of coremapping	2005-01-27 13:28:00	**Plot Date**	2005-04-24 22:32:03
Rocktype data from	p_rock_XXXXX	**Fracture data from**	p_fract_core




120
130
140
150
160
170
180
190
200

Appendix 6

WellCad diagram, HFM22

Title LEGEND FOR FORSMARK HFM22

Site	FORSMARK
Borehole	HFM22
Plot Date	2005-04-27 23:08:01

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

ROCK ALTERATION

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

MINERAL

- Unknown

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

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

ROCK ALTERATION INTENSITY

- No intensity
- Faint
- Weak
- Medium
- Strong

ROUGHNESS

- Planar
- Undulating
- Stepped
- Irregular

SURFACE

- Rough
- Smooth
- Slickensided

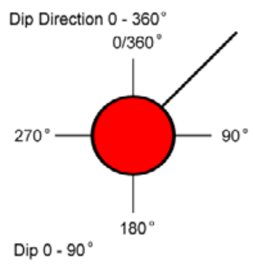
CRUSH ALTERATION

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

FRACTURE ALTERATION

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

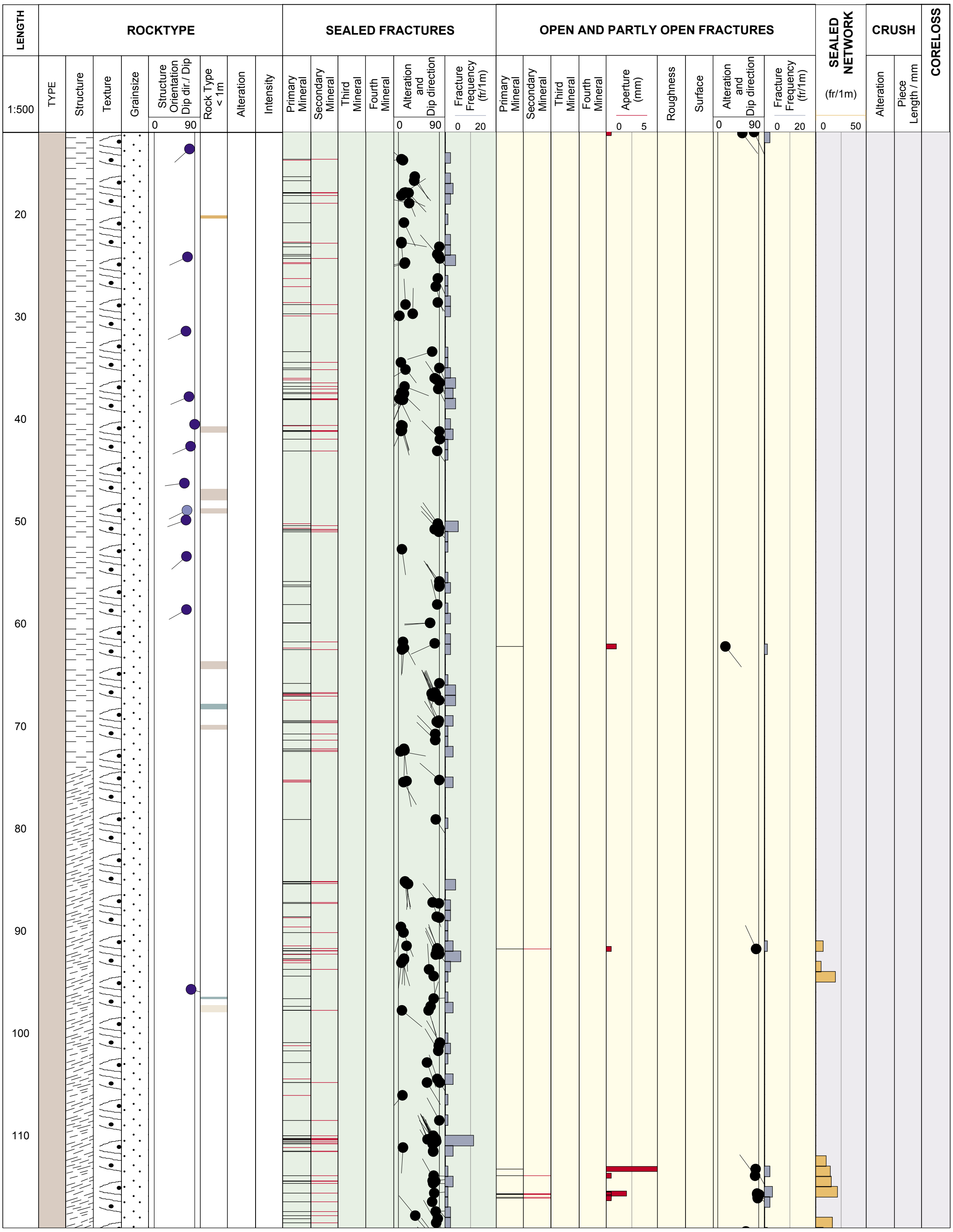
FRACTURE DIRECTION
STRUKTURE ORIENTATION

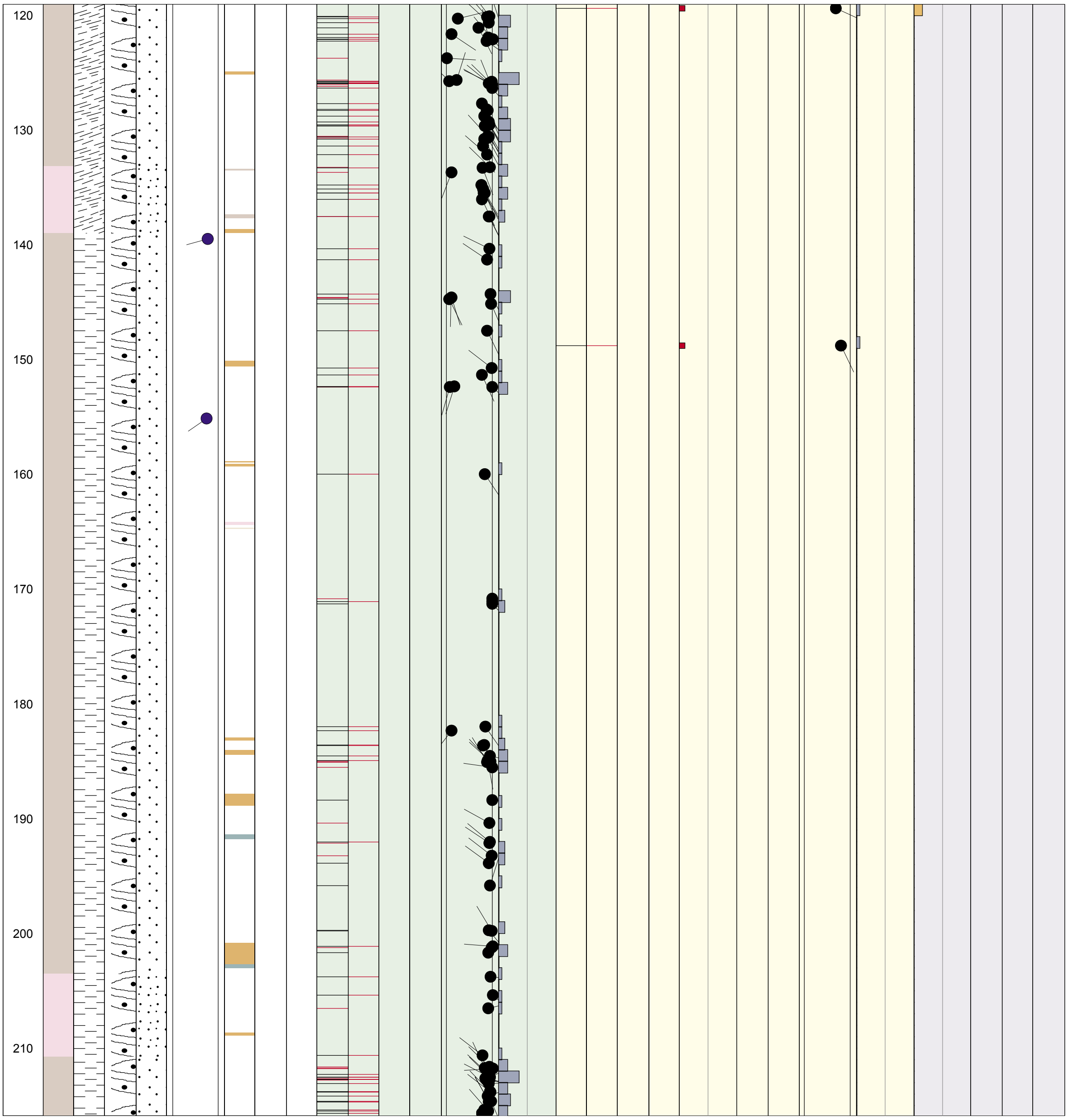


Title GEOLOGY IN HFM22

Appendix:

Site	FORSMARK	Coordinate System	RT90-RHB70
Borehole	HFM22	Northing [m]	6700456.18
Diameter [mm]	136	Easting [m]	1631217.64
Length [m]	222.000	Elevation [m.a.s.l.]	1.54
Bearing [°]	90.08	Drilling Start Date	2004-09-07 12:00:00
Inclination [°]	-58.84	Drilling Stop Date	2004-09-10 10:17:00
Date of coremapping	2004-11-25 10:11:00	Plot Date	2005-04-24 22:32:03
Rocktype data from	p_rock_XXXXX	Fracture data from	p_fract_core




120
130
140
150
160
170
180
190
200
210

Appendix 7

Borehole length and diameter; HFM20, HFM21 and HFM22

HFM20, 2004-05-18 15:20:00 – 2004-06-01 20:00:00 (0.000–301.000 m).

Sub Secup (m)	Sub Seclow (m)	Hole Diam (m)	Comment
0.000	12.300	0.185	
12.300	112.700	0.139	
112.700	250.000	0.138	
250.000	301.000	0.135	

Printout from SICADA 2005-04-18 14:57:20.

HFM21, 2004-06-02 09:00:00 – 2004-06-07 11:40:00 (0.000–202.000 m).

Sub Secup (m)	Sub Seclow (m)	Hole Diam (m)	Comment
0.000	12.030	0.185	
12.030	148.000	0.139	
148.000	202.000	0.137	

Printout fromSICADA 2005-04-18 14:58:32.

HFM22, 2004-09-07 12:00:00 – 2004-09-10 10:17:00 (0.000–222.000 m).

Sub Secup (m)	Sub Seclow (m)	Hole Diam (m)	Comment
0.000	12.300	0.180	
12.030	222.000	0.136	

Printout fromSICADA 2005-04-18 14:59:24.

Appendix 8

Deviation data; HFM20, HFM21 and HFM22

HFM20, 2004-06-02 09:00:00 – 2004-06-02 11:00:00 (15.000–301.000 m).

Bhlen (m)	Magnetic Bearing (degrees)	Dip (degrees)	Northing (m)	Easting (m)	Elevation (m)	Local a (m)	Local b (m)	Local c (m)
15.00	359.4	–85.0						
18.00	1.1	–85.0						
21.00	4.0	–85.2						
24.00	5.7	–85.2						
27.00	4.9	–85.2						
30.00	1.2	–85.4						
33.00	359.8	–85.6						
36.00	358.6	–85.8						
39.00	357.7	–86.1						
42.00	356.0	–86.2						
45.00	356.9	–86.3						
48.00	0.4	–86.5						
51.00	0.0	–86.9						
54.00	0.5	–87.0						
57.00	359.0	–87.3						
60.00	355.6	–87.5						
63.00	353.3	–87.5						
66.00	352.3	–87.7						
69.00	350.9	–87.8						
72.00	348.2	–87.8						
75.00	345.2	–88.0						
78.00	343.4	–87.9						
81.00	346.0	–88.1						
84.00	342.9	–88.2						
87.00	345.0	–88.4						
90.00	344.0	–88.5						
93.00	343.7	–88.6						
96.00	342.3	–88.7						
99.00	338.9	–88.8						
102.00	335.7	–88.8						
105.00	331.4	–88.8						
108.00	330.8	–88.9						
111.00	324.0	–88.8						
114.00	315.0	–88.8						
117.00	290.2	–89.1						
120.00	272.5	–88.8						
123.00	266.1	–88.8						
126.00	260.7	–88.8						
129.00	256.1	–88.5						
132.00	255.7	–88.4						

Bhlen (m)	Magnetic Bearing (degrees)	Dip (degrees)	Northing (m)	Easting (m)	Elevation (m)	Local a (m)	Local b (m)	Local c (m)
135.00	250.7	–88.3						
138.00	250.5	–88.2						
141.00	248.6	–88.2						
144.00	248.8	–88.0						
147.00	244.1	–88.1						
150.00	245.8	–87.9						
153.00	243.3	–87.9						
156.00	241.8	–87.7						
159.00	243.6	–87.6						
162.00	241.2	–87.5						
165.00	240.7	–87.4						
168.00	240.2	–87.4						
171.00	239.2	–87.3						
174.00	238.5	–87.3						
177.00	239.1	–87.2						
180.00	237.3	–87.2						
183.00	237.7	–87.1						
186.00	239.8	–87.1						
189.00	237.7	–87.0						
192.00	238.0	–87.0						
195.00	236.8	–86.9						
198.00	236.9	–86.8						
201.00	237.2	–86.8						
204.00	237.2	–86.8						
207.00	236.4	–86.6						
210.00	236.7	–86.6						
213.00	236.5	–86.6						
216.00	236.8	–86.6						
219.00	235.7	–86.6						
222.00	236.6	–86.6						
225.00	235.6	–86.6						
228.00	235.3	–86.6						
231.00	236.1	–86.6						
234.00	234.1	–86.5						
237.00	233.8	–86.5						
240.00	234.5	–86.5						
243.00	233.5	–86.6						
246.00	233.0	–86.8						
249.00	232.2	–86.7						
252.00	229.9	–86.6						
255.00	232.1	–86.6						
258.00	231.2	–86.6						
261.00	231.4	–86.5						
264.00	231.8	–86.5						
267.00	230.1	–86.5						
270.00	229.8	–86.5						
273.00	230.4	–86.4						

Bhlen (m)	Magnetic Bearing (degrees)	Dip (degrees)	Northing (m)	Easting (m)	Elevation (m)	Local a (m)	Local b (m)	Local c (m)
276.00	230.6	–86.4						
279.00	229.8	–86.3						
282.00	229.5	–86.3						
285.00	228.1	–86.3						
288.00	229.4	–86.3						
291.00	227.6	–86.2						
294.00	227.7	–86.2						
297.00	227.4	–86.2						
300.00	227.0	–86.2						
301.00	226.6	–86.1						

Printout fromSICADA 2005-04-18 15:00:34.

HFM21, 2004-06-02 07:30:00 – 2004-06-02 09:00:00 (0.000–202.000 m).

Bhlen (m)	Magnetic Bearing (degrees)	Dip (degrees)	Northing m)	Easting (m)	Elevation (m)	Local a (m)	Local b (m)	Local c (m)
15.00	88.7	–57.4						
18.00	88.1	–57.3						
21.00	87.9	–57.2						
24.00	88.2	–57.0						
27.00	89.7	–57.0						
30.00	92.7	–56.9						
33.00	92.9	–56.9						
36.00	91.8	–57.2						
39.00	92.4	–56.6						
42.00	93.3	–56.6						
45.00	94.6	–56.2						
48.00	96.0	–56.2						
51.00	96.1	–55.8						
54.00	96.6	–55.7						
57.00	98.5	–55.2						
60.00	99.1	–55.0						
63.00	99.9	–54.8						
66.00	100.2	–54.8						
69.00	101.5	–54.6						
72.00	102.4	–54.3						
75.00	103.6	–54.2						
78.00	103.6	–54.2						
81.00	103.7	–54.1						
84.00	106.0	–53.8						
87.00	105.8	–53.7						
90.00	107.0	–53.5						
93.00	107.6	–53.5						
96.00	108.1	–53.1						
99.00	107.4	–52.4						
102.00	110.1	–52.5						

Bhlen (m)	Magnetic Bearing (degrees)	Dip (degrees)	Northing m)	Easting (m)	Elevation (m)	Local a (m)	Local b (m)	Local c (m)
105.00	110.6	–52.1						
108.00	112.9	–51.7						
111.00	112.8	–51.4						
114.00	113.8	–51.3						
117.00	113.8	–51.0						
120.00	114.3	–50.9						
123.00	115.2	–50.6						
126.00	116.0	–49.7						
129.00	117.9	–49.6						
132.00	119.5	–49.3						
135.00	117.8	–49.0						
138.00	118.7	–48.5						
141.00	119.2	–48.3						
144.00	121.4	–47.7						
147.00	121.5	–47.5						
150.00	121.6	–47.3						
153.00	123.3	–47.1						
156.00	122.7	–47.0						
159.00	123.7	–46.8						
162.00	124.5	–46.3						
165.00	123.0	–46.2						
168.00	123.3	–45.7						
171.00	123.8	–45.8						
174.00	124.3	–45.3						
177.00	124.0	–44.9						
180.00	124.4	–44.3						
183.00	124.3	–43.9						
186.00	124.7	–43.2						
189.00	124.8	–43.0						
192.00	124.9	–42.3						
195.00	124.5	–41.8						
198.00	125.0	–41.2						
201.00	125.0	–40.9						
202.00	125.0	–40.8						

Printout from SICADA 2005-04-18 15:01:34.

HFM22, 2004-09-30 12:15:00 – 2004-09-30 13:30:00 (0.000–222.000 m).

Bhlen (m)	Magnetic Bearing (degrees)	Dip (degrees)	Northing (m)	Easting (m)	Elevation (m)	Local a (m)	Local b m)	Local c (m)
15.00	91.0	–57.7						
18.00	91.2	–57.5						
21.00	92.2	–57.1						
24.00	92.5	–56.9						
27.00	94.1	–56.6						
30.00	93.8	–56.4						
33.00	94.7	–56.1						
36.00	95.3	–55.8						
39.00	97.7	–55.5						
42.00	98.0	–55.0						
45.00	99.0	–54.6						
48.00	98.2	–54.2						
51.00	100.3	–53.7						
54.00	101.4	–53.3						
57.00	102.2	–52.9						
60.00	103.6	–52.4						
63.00	104.5	–52.6						
66.00	105.4	–51.8						
69.00	105.2	–51.3						
72.00	105.2	–50.8						
75.00	107.2	–50.4						
78.00	106.5	–49.8						
81.00	108.1	–49.2						
84.00	108.7	–48.7						
87.00	109.2	–48.3						
90.00	109.4	–47.8						
93.00	109.8	–47.4						
96.00	109.4	–47.2						
99.00	110.2	–46.6						
102.00	110.5	–46.0						
105.00	110.7	–45.6						
108.00	111.0	–45.1						
111.00	111.3	–44.8						
114.00	111.6	–44.4						
117.00	112.0	–44.1						
120.00	111.8	–43.8						
123.00	112.9	–43.5						
126.00	112.5	–43.1						
129.00	113.2	–42.5						
132.00	114.2	–42.1						
135.00	114.1	–41.5						
138.00	114.5	–41.2						
141.00	114.2	–40.8						
144.00	113.9	–40.5						
147.00	115.1	–40.4						
150.00	112.3	–40.1						

153.00	113.5	–39.8
156.00	114.6	–39.6
159.00	113.0	–39.2
162.00	112.8	–38.9
165.00	113.2	–38.6
168.00	114.9	–38.2
171.00	113.4	–37.8
174.00	114.0	–37.5
177.00	114.3	–37.1
180.00	112.5	–36.7
183.00	114.8	–36.6
186.00	114.8	–36.2
189.00	113.4	–35.9
192.00	114.0	–35.8
195.00	113.6	–35.4
198.00	114.5	–35.2
201.00	113.0	–35.1
204.00	113.9	–34.8
207.00	113.0	–34.6
210.00	113.2	–34.4
213.00	114.1	–34.2
216.00	114.0	–34.3
219.00	113.3	–33.9
222.00	113.8	–34.0

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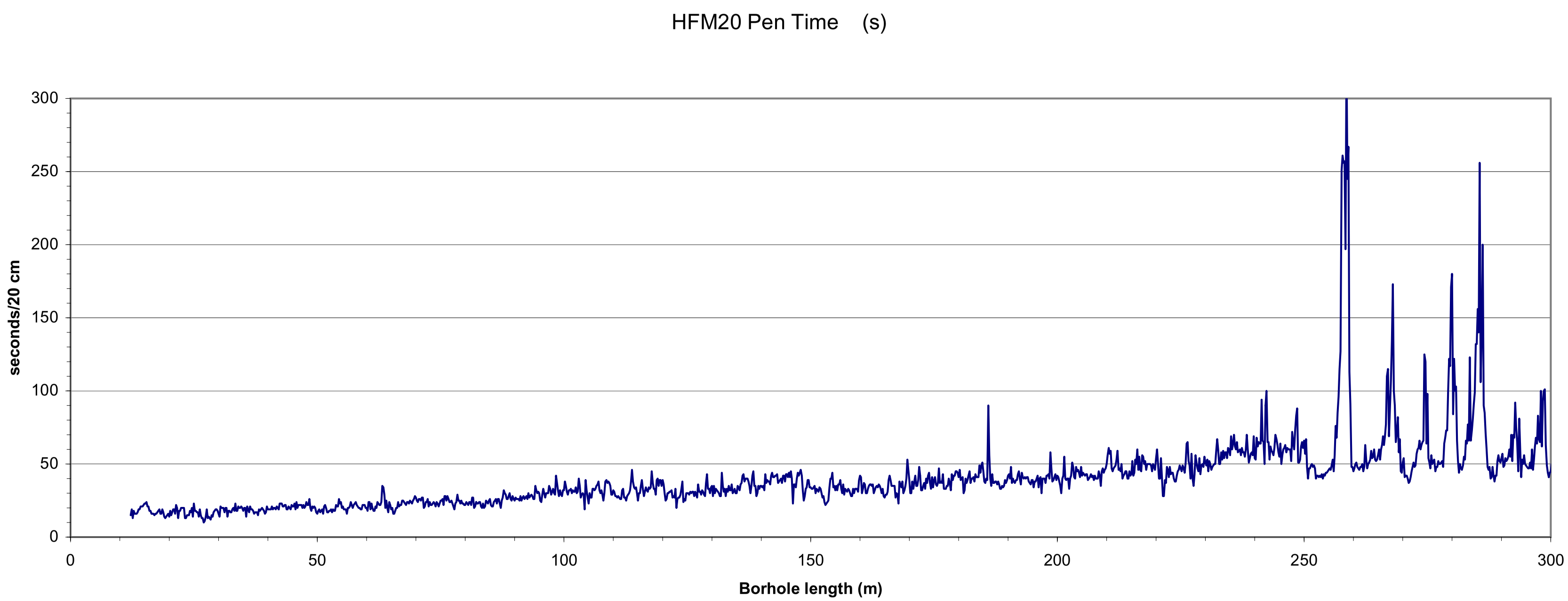
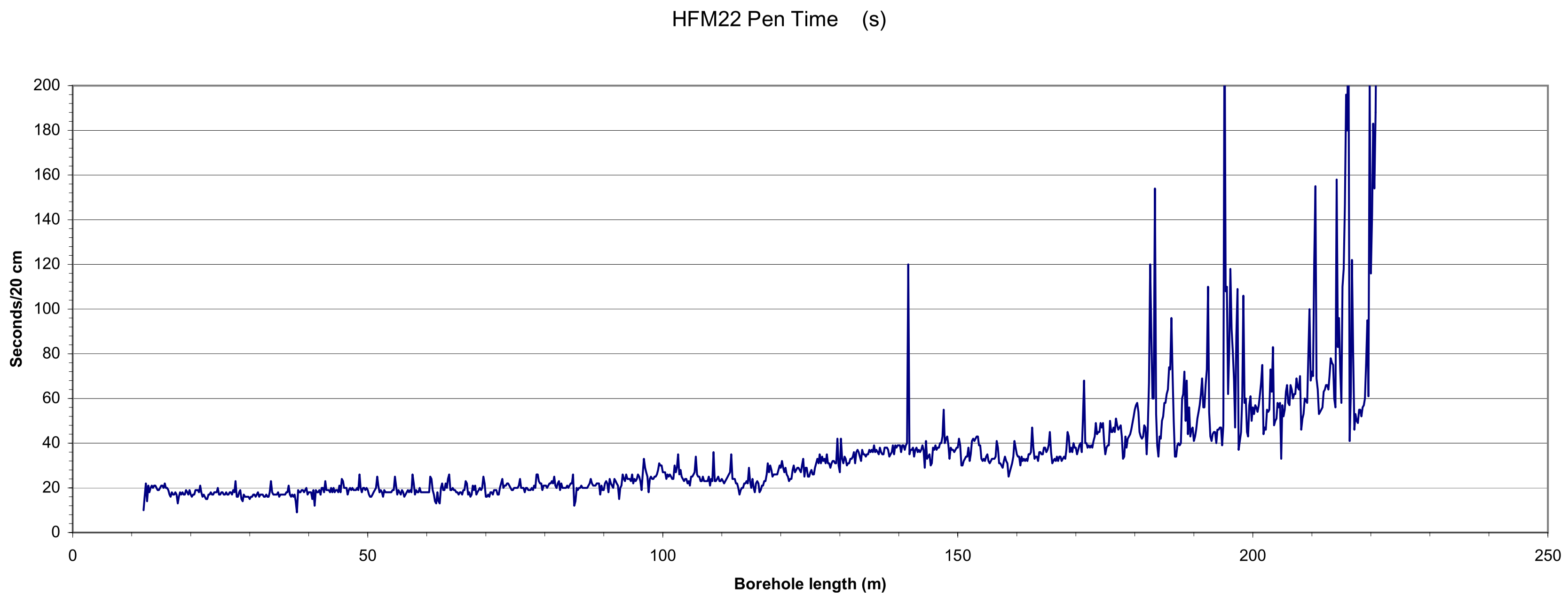
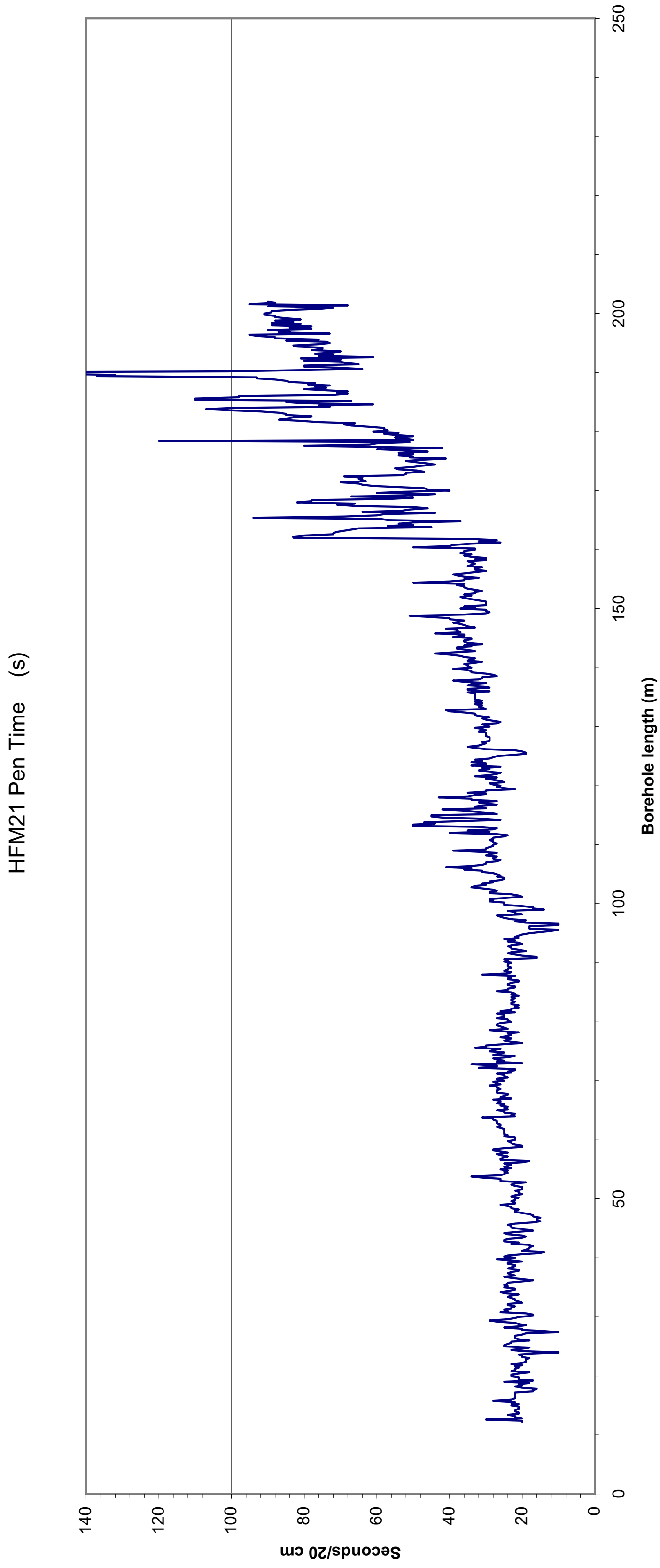
Appendix 9

Drilling penetration rate; HFM20, HFM21 and HFM22

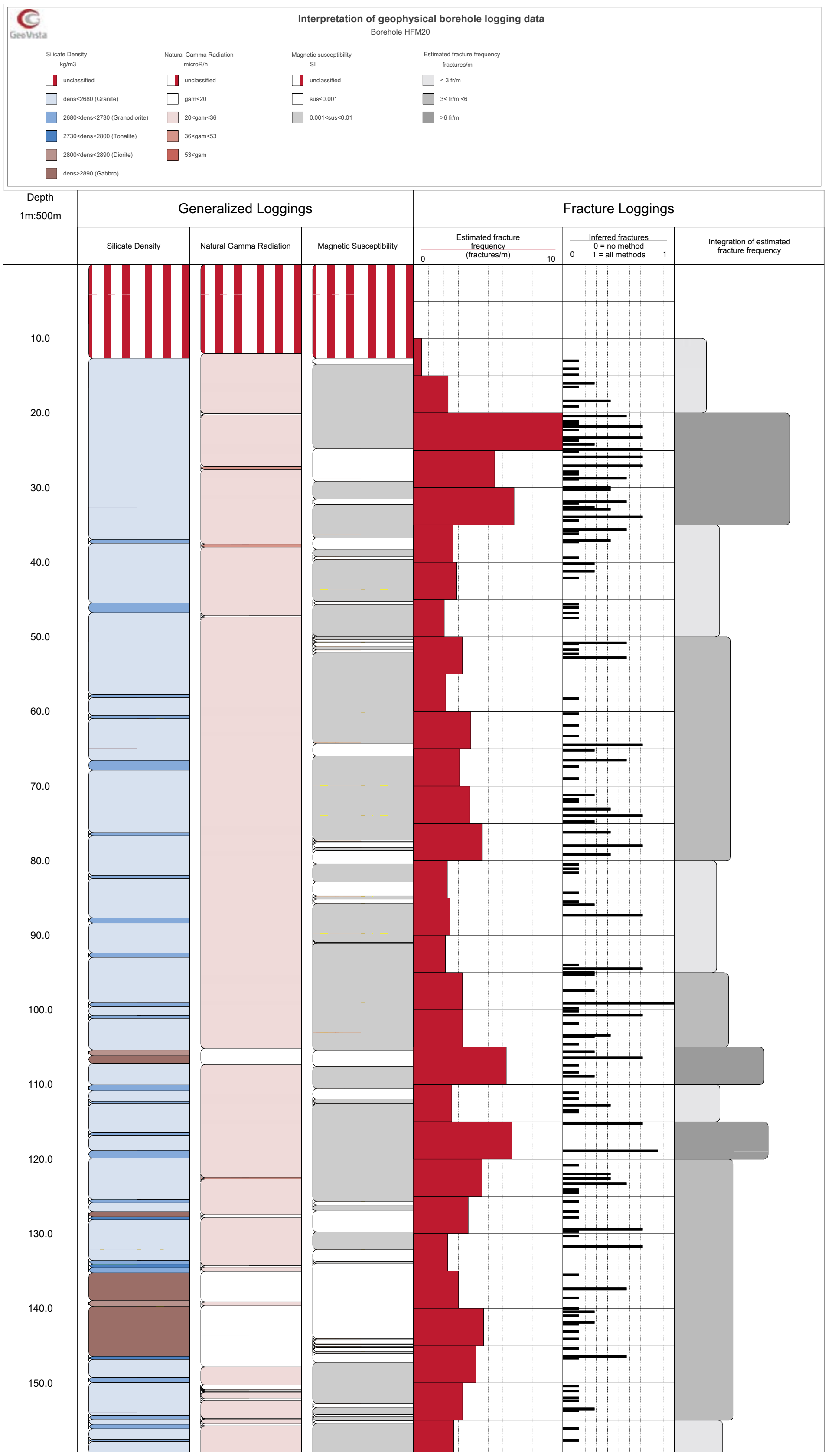


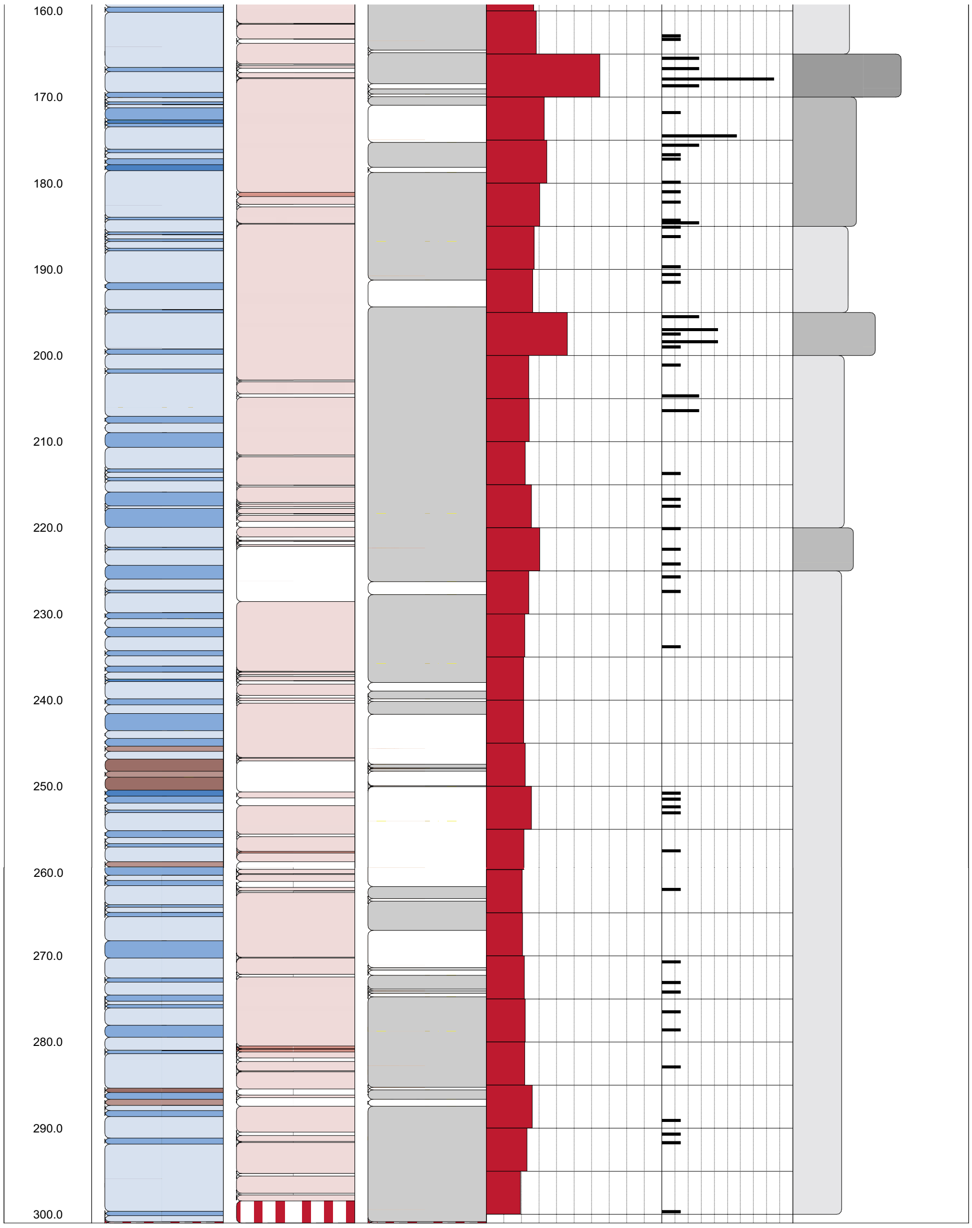

HFM22 Pen Time (s)
Seconds/20 cm
200
180
160
140
120
100
80
60
40
20
0
0
50
100
150
200
250
Borehole length (m)

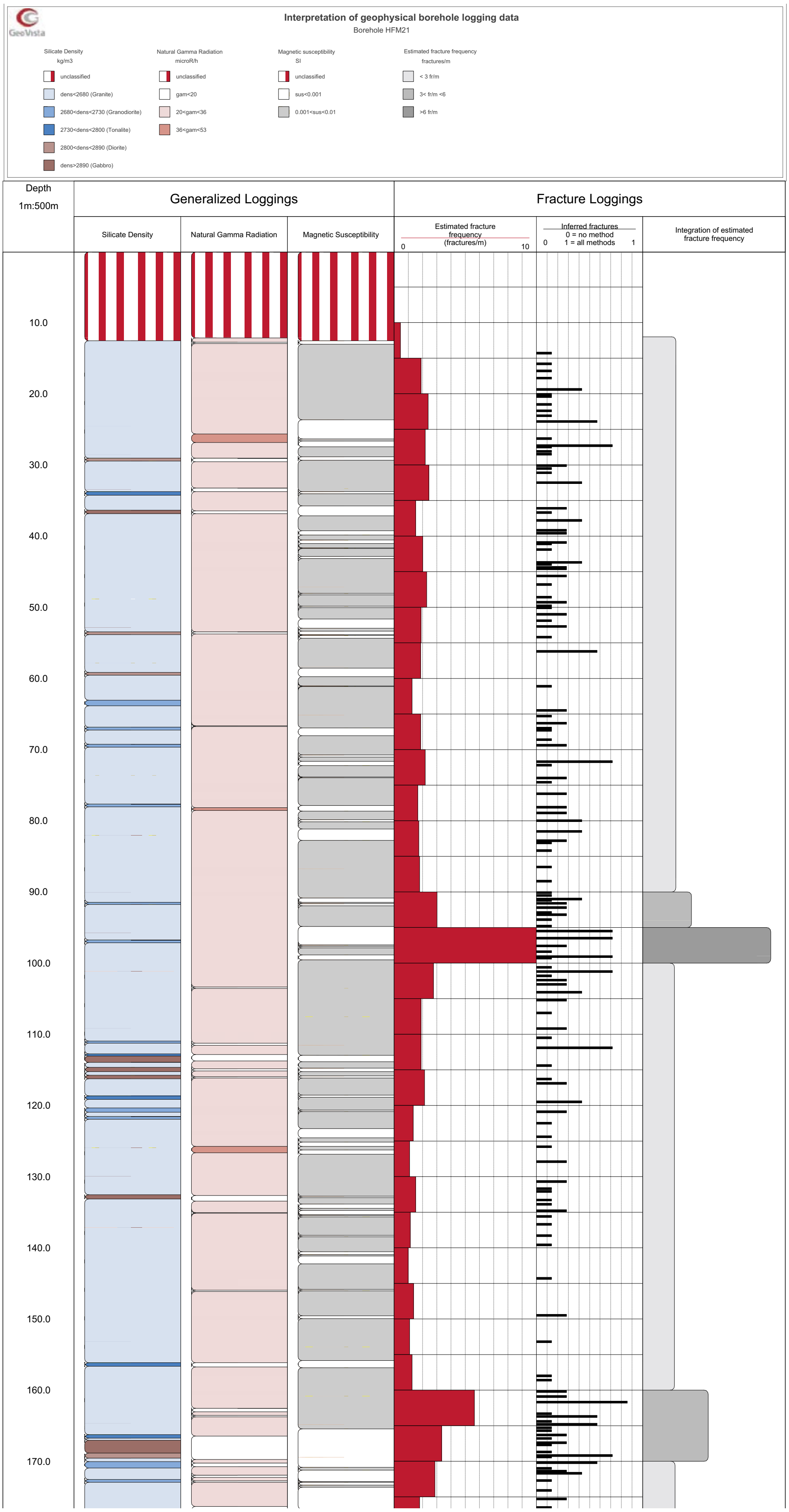

HFM21 Pen Time (s)
Seconds/20 cm
Borehole length (m)
0
20
40
60
80
100
120
140
0
50
100
150
200
250

Appendix 10

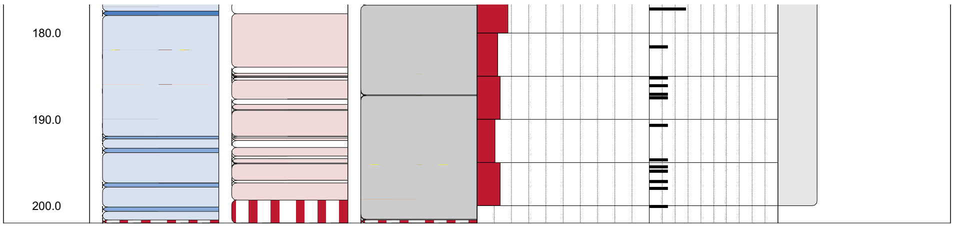
Generalised geophysical logs; HFM20, HFM21 and HFM22

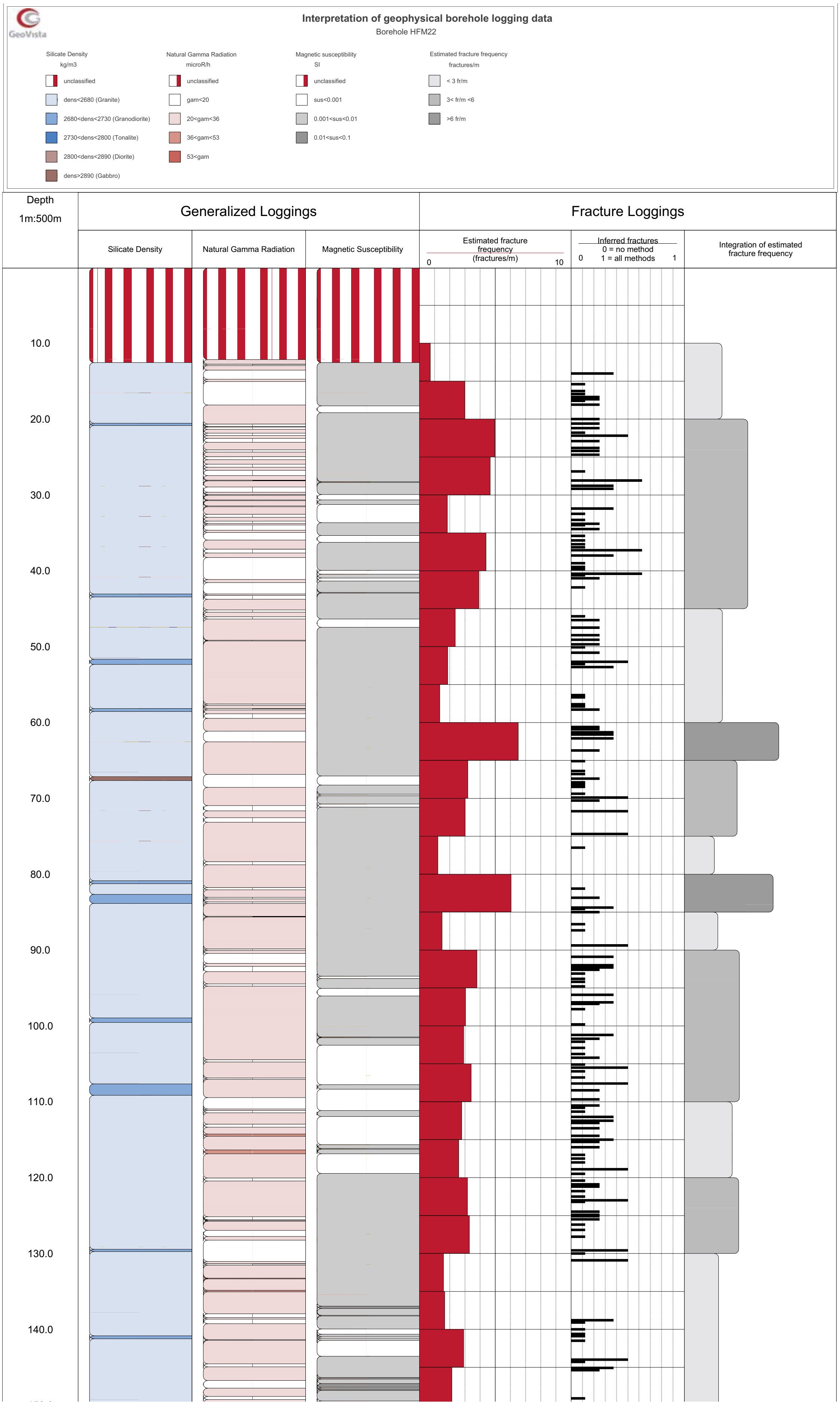


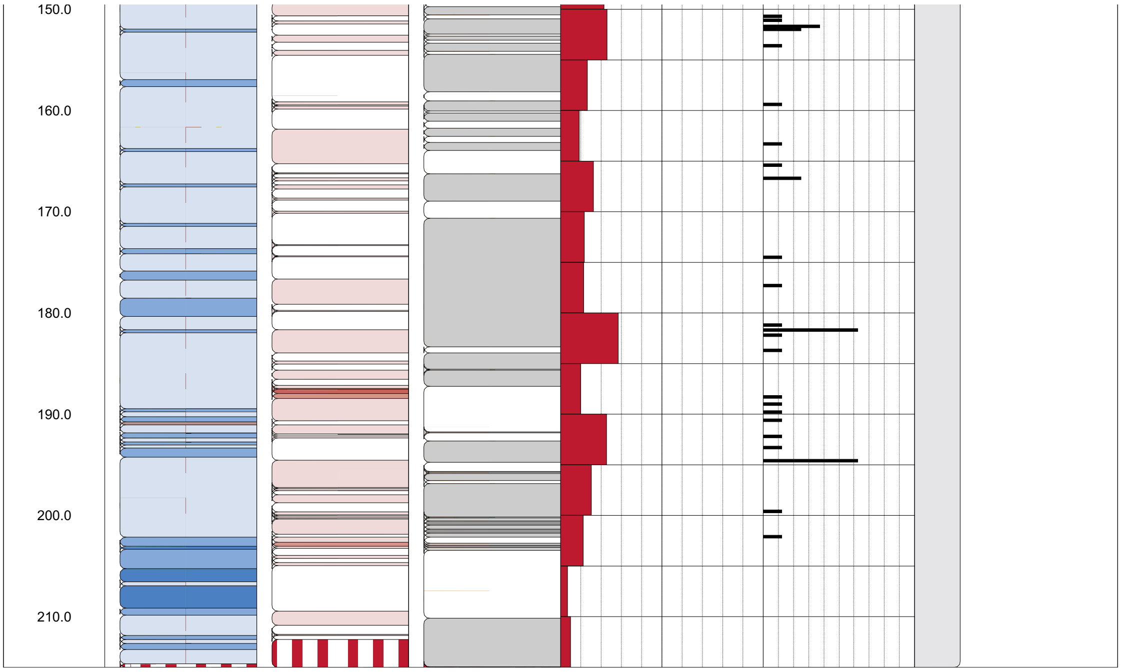

160.0
170.0
180.0
190.0
200.0
210.0
220.0
230.0
240.0
250.0
260.0
270.0
280.0
290.0
300.0



Interpretation of geophysical borehole logging data
Borehole HFM21
Silicate Density
kg/m3
unclassified
dens<2680 (Granite)
2680<dens<2730 (Granodiorite)
2730<dens<2800 (Tonalite)
2800<dens<2890 (Diorite)
dens>2890 (Gabbro)
Natural Gamma Radiation
microR/h
unclassified
gam<20
20<gam<36
36<gam<53
Magnetic susceptibility
SI
unclassified
sus<0.001
0.001<sus<0.01
Estimated fracture frequency
fractures/m
< 3 fr/m
3< fr/m <6
>6 fr/m
Depth
1m:500m
Generalized Loggings
Fracture Loggings
Silicate Density
Natural Gamma Radiation
Magnetic Susceptibility
Estimated fracture frequency (fractures/m)
0
10
Inferred fractures
0 = no method
1 = all methods
0
1
Integration of estimated fracture frequency
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
110.0
120.0
130.0
140.0
150.0
160.0
170.0


180.0
190.0
200.0


GeoVista
Interpretation of geophysical borehole logging data
Borehole HFM22
Silicate Density
kg/m3
unclassified
dens<2680 (Granite)
2680<dens<2730 (Granodiorite)
2730<dens<2800 (Tonalite)
2800<dens<2890 (Diorite)
dens>2890 (Gabbro)
Natural Gamma Radiation
microR/h
unclassified
gam<20
20<gam<36
36<gam<53
53<gam
Magnetic susceptibility
SI
unclassified
sus<0.001
0.001<sus<0.01
0.01<sus<0.1
Estimated fracture frequency
fractures/m
< 3 fr/m
3< fr/m <6
>6 fr/m
Depth
1m:500m
Generalized Loggings
Fracture Loggings
Silicate Density
Natural Gamma Radiation
Magnetic Susceptibility
Estimated fracture frequency (fractures/m)
0
10
Inferred fractures
0 = no method
1 = all methods
0
1
Integration of estimated fracture frequency
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
110.0
120.0
130.0
140.0


150.0
160.0
170.0
180.0
190.0
200.0
210.0