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Abstract

Borehole KAV01 (c 757 m long) was drilled during two campaigns, one in 1977 (0-502 m) and the other in 1986 (502-757 m). The borehole is telescopic, which means that 0–68.8 m were percussion drilled, and 68.8–757.31 m, was core drilled.

Fractures were studied in the drill core together with acoustic televiewer images, while rock types, alterations and other structures only were observed in the drill core. The information was documented in the software Boremap. The mapping data will be used in further interpretation of the bedrock conditions in the area down to a depth of 757.31 m.

Homogeneous Ävrö granite is the only principal lithology in KAV01, and therefore the lithology could not be used for sectioning KAV01. The borehole could, however, be rather clearly subdivided into two longer sections, based on the variations of geological structures.

Section I, 0–400 m, has a normal frequency of open fractures (interpreted), few short intervals with crush, lacks sealed fracture networks and have very few and short intervals with oxidation.

Section II, 400–743 m, have a high frequency of open fractures (interpreted), several shorter and longer intervals with crush and several intervals with sealed fracture network. It is also almost continuously oxidized. Intervals with strong oxidation occur at the same borehole length as maxima in the frequency of open fractures (interpreted).

The coincidence between frequency peaks for crush, open fractures (interpreted), sealed fractures (interpreted), sealed fracture network, breccia and oxidized intervals, indicate short, probably < 10 m long, weakness sections, for example, at 450 m, 530 m and 730 m. These rather thin weakness sections do, however, not separate longer intervals in KAV01 with significant differences in lithology or other geological parameters.

Sammanfattning

Borrhål KAV01 (ca 757 m långt) borrades under två kampanjer, en 1977 (0-502 m) och den andra 1986 (502-757 m). Borrhålet är teleskopiskt vilket betyder att intervallet 0–68.8 m rymdes upp i efterhand med hammarborrning och 68.8–757.31 m med kärnborrning.

Sprickor studerades i både borrkärnan och akustiska televiewer-bilder medan bergartstyper, omvandlingar och andra strukturer endast kunde observeras i borrkärnan. Informationen dokumenterades i programmet Boremap. Dessa data kommer att ligga till grund för framtida tolkningar av bergets egenskaper i Simpevarpsområdet ner till 1000 m djup.

Homogen Ävrögranit är den enda litologi som förekommer i KAV01 förutom gångar och kortare intervaller av möjliga enklaver. Den litologiska parametern kunde därför inte användas för att sektionera KAV01. Emellertid så kunde intensitetsvariationer hos geologiska strukturer användas för en ganska tydlig uppdelning av KAV01 i två längre sektioner.

Sektion I, 0–400 m, uppvisar normala frekvenser för öppna sprickor (tolkade), har få korta intervaller med kross, saknar läkta spricknätverk och har få och korta intervaller med oxidering.

Sektion II, 400–743 m, uppvisar höga frekvenser av öppna sprickor (tolkade), har flera kortare och längre intervaller med kross, samt flera intervaller med läkta spricknätverk. Denna sektion är kontinuerligt oxiderad genom nästan hela sin längd. Intervaller med kraftig oxidering uppträder på samma djup som maxima i frekvensen av öppna sprickor (tolkade).

Möjligheten att upp till 10 m långa svaghetssektioner förekommer i KAV01 indikeras av att flera geologiska parametrar förekommer på samma djup. Så är exempelvis fallet vid djupen 450 m, 530 m och 730 m där intervaller med kross förekommer tillsammans med höga frekvenser av öppna sprickor (tolkade), höga frekvenser av läkta sprickor (tolkade) samt oxiderade intervaller. Dessa svaghetssektioner verkar emellertid endast utgöra korta klart avgränsade strukturer i KSH02. De delar inte upp borrhålet i längre intervaller med signifikanta olikheter hos de geologiska parametrarna mellan de olika intervallerna.

Contents

1 Introduction

This document reports data gained by Boremap mapping of the core drilled, 757.31 m deep, borehole KAV01 (Figure 1-1).

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

KAV01 was drilled during two campaigns, one in 1977 (0-502 m) and the other in 1986 (502-757 m). Then the first 68.8 m was enlarged by percussion drilling and the borehole was cased down to 68.0 m. The section 68.8–70 m was core drilled with a diameter of 76 mm while the main part of the borehole, from 70 m to 757.3 m, was core drilled with a diameter of 56 mm.

Detailed mapping of the drill cores are essential for a three dimensional understanding of the geology at depth. The Boremap mapping is normally based on the use of BIPS-images of the borehole wall and on the study of the drill core itself. Other images like acoustic televiewer images can, however, also be mapped with the Boremap system. The images, BIPS as well as acoustic televiewer images, enable the study of orientations, since the Boremap software calculates strike and dip of planar structures such as foliations, rock contacts and fractures. In BIPS-images the fracture apertures in the rock can be estimated. Important to keep in mind is that the mappings only represent the bedrock where this is intersected by the drill holes.

Acoustic televiewer images were used in the Boremap mapping of KAV01.

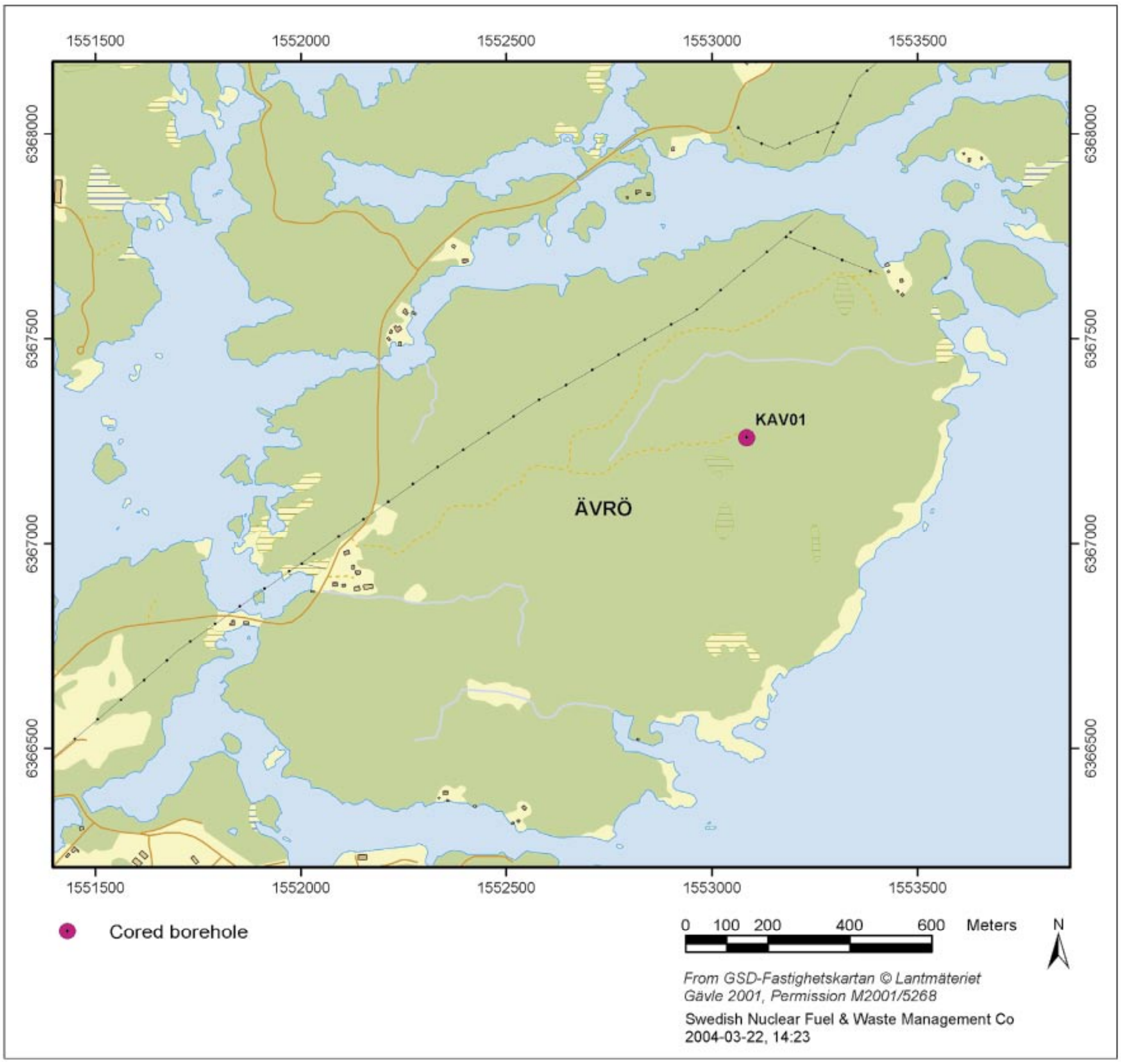


Figure 1-1. *Location of the core drilled borehole KAV01.*

2 Objective and scope

The principal aim of the mapping activities presented in this report is to obtain a detailed documentation of geological structures and lithologies intersecting borehole KAV01. Geological structures will be correctly orientated in space along the borehole. The results will serve as a platform for forthcoming investigations of the drill core, as well as various site descriptive modelling.

3 Equipment

3.1 Description of Software

The mapping was performed in Boremap v 3.3.2, loaded with the bedrock and mineral standards of SKB. The final data presentation was made using StereoNet and WellCad v 3.2.

Boremap is a computerized system that unite orthodox core mapping with modern video mapping. Boremap is the brain of the system and deals with the mapping as well as the internal communication between programs. Boremap shows the video images from BIPS (Borehole Image Processing System) or the acoustic televiewer images and extracts the geometrical parameters: length, width, strike and dip from the image.

3.2 Other equipment

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

3.3 The acoustic televiewer image

The BIPS-image is a registration of reflected light (an optical televiewer method), while the acoustic televiewer image is a registration of reflected sound waves. The acoustic televiewer image is thus quite different from the BIPS-image. Further on the BIPS-image is a photo like colour image of the borehole wall, while the acoustic televiewer image is a black and white image.

3.3.1 Acoustic televiewer image quality

The BIPS-image quality depends on the visibility in the borehole water and on dirt stuck to the borehole walls. The quality of the image thus decreases with the amount of clayey suspensions in the borehole water.

The acoustic televiewer image mainly register differences in hardness between different lithologies/mineralogies, and between fractures/structures and wall rock. It is not believed that dense clayey suspensions and blackish coatings from the drilling equipment have any significant influence on the registration quality of the acoustic televiewer image.

The acoustic televiewer images have a slight to very noisy background of disturbing bands and lens shaped forms orientated in systematic patterns that are either parallel, diagonal or at right angle to the borehole (Appendix 4). At a first glance, these background patterns seem to be very disturbing for the mapping. However, the systematic arrangement of the background noise makes it very easy to differentiate the noise and the fracture traces and the background noise was rather soon ignored by the mapping personnel. The problem is not to differentiate the noisy background from geological parameters but to know what geological parameters that are registered by the acoustic televiewer method.

The quality evaluation of acoustic televiewer images is not comparable with the quality evaluation of BIPS-images, since the two methods register different information. The BIPS-image quality is based on sharpness and richness in details since it registers light. For this reason the BIPS-image quality might be very good even though many fractures are invisible.

When looking at an acoustic televiewer image we do not know, however, if it is sharp and rich in details in the same way as the BIPS-image. The quality of the acoustic televiewer image can thus not be directly related to the amount, or the intensity, of background noise. The acoustic televiewer image quality is instead judged from whether fractures can be detected or not. If many fractures are invisible in the acoustic televiewer image the quality is regarded as bad. In section 703 -737 m, for example, the acoustic televiewer image in KAV01 have a regular amount of background noise but of 160 open fractures only 20 are visible or slightly visible.

The acoustic televiewer image of KAV01 covers the interval 2.1–743 m in one single file.

The image quality is classified into four classes; good, acceptable, bad and very bad. The quality was as follows along the borehole; 2.1–70 m very bad to unacceptable, 70–91 m acceptable to good, 91–101 m good, 101–130 m acceptable to bad, 130–330 m good to very good, 330–703 m acceptable to good, 703–737 m very bad and 737–743 m acceptable.

3.3.2 Geological parameters registered in the acoustic televiewer image

Lithological parameters like rock contacts, foliation, sealed network and alteration as well as structural parameters could not be identified in the acoustic televiewer image of KAV01. These parameters were thus observed only from the drill core. When possible, these parameters were orientated according to the guide-line method for orientation of fractures/structures not visible in the BIPS- or acoustic televiewer images. Generally, however, these parameters were only registered as planes at right angle to the drill core to show at what depth they occurred.

3.3.3 Detectability of fractures in the acoustic televiewer image

Open as well as sealed fractures were often easily detectable in the acoustic televiewer image. Sealed fractures were generally observed as light grey – often rather weak – traces, while open fractures were observed as darker grey to blackish traces.

The lack of a detailed background reflecting texture and mineralogy in true colours as in the BIPS-images, often made fractures stand out in a more obvious way compared to the BIPS-images. Therefore there was never any need to search for fracture traces in the acoustic televiewer images. They simply were there or not.

The variability of how well a sealed fracture is detected by the acoustic televiewer image is here exemplified by calcite and quartz sealed fractures. Calcite sealed fractures are generally very easy to detect with the acoustic televiewer and even extremely thin calcite fractures that are hardly visible in the drill core are picked up by the acoustic televiewer. These very thin calcite sealed fractures are often even more clearly visible in the acoustic televiewer image than open fractures. On the contrary, quartz sealed fractures are almost impossible to detect even if they are 2–3 cm thick. These differences are probably related to the hardness of the mineral filling the fracture. If the hardness of the mineral is close to the hardness of the wall rock, it will most likely be very difficult or impossible to detect the fracture. On the other hand, if the mineral in the fracture is much softer than the wall rock it will easily be detected. Sealed fractures with quartz that are easily detected in KAV01 are thus believed to contain at least one more mineral type.

Occasionally it was difficult to follow fracture traces in intervals with a large amount of fractures, since the fracture traces showed up as an entangled ball of yarn. It was then important to orientate fractures with the guide-line method to be sure that the right fracture trace was delineated in the acoustic televiewer image.

In times, the corresponding fractures to obvious fracture traces in the acoustic televiewer image could not be seen in the drill core. This was the case, for example, around 76.6 m depth. These fractures were mapped with the mineral code X9 as first mineral fill, as were the same type of fractures detected by BIPS. Such fractures are much more obvious in the acoustic televiewer image than in the BIPS-image.

Also fresh fractures without mineral fillings are more often visible in the acoustic televiewer image than in the BIPS-image. These fractures were mapped with X7 as first mineral fill.

Fractures are always represented by a rather thick fracture trace with even width in the acoustic televiewer image and the fracture trace always has the same width all through the image. It is thus not possible to estimate the fracture width from the acoustic televiewer images. Open fractures do not cast any shadows along their traces in the acoustic televiewer image why it is not possible to evaluate aperture from these images.

3.3.4 Orientation problems in the acoustic televiewer image

The location of an observation at the correct depth was occasionally problematic in the acoustic televiewer images, since the only orientation references that exists in the acoustic televiewer image are open and sealed fractures. No other structures or rock contacts that could help with the orientation were observed in KAV01. This lack of orientation references might be problematic for acoustic televiewer images in general, especially in intervals that are rich in fractures.

3.3.5 Comparison between the BIPS- and the acoustic televiewer image

The BIPS-image is clearly superior to the acoustic televiewer image if all geological parameters are considered as well as the possibility to position features at their exact depths.

An important advantage of the acoustic televiewer method is that dense clayey suspensions in the borehole water as well as blackish coatings on the borehole walls do not seem to have any negative effects on the possibility to detect fractures as they have for BIPS-images.

Further on, colour contrasts between fracture and wall rock, which seem to be very important in BIPS-images, does not influence the ability to detect fractures in the acoustic televiewer images. It can thus be very difficult to observe fractures with low colour contrast to the wall rock in the BIPS-image; for example, red fractures in a red rock type or a dark fracture in a dark rock type. This is not the case for the acoustic televiewer image. However, hardness contrast between fracture minerals and wall rock is essential for the detection of fractures in acoustic televiewer images. Such hardness contrast is of no importance for the detection of fractures in BIPS-images.

The acoustic televiewer image picks up fractures just as well as the BIPS-image does. The fracture visibility might even be better in some acoustic televiewer images than in BIPS-images.

Because of the easiness to observe fractures at a first glance in the acoustic televiewer images, the mapping of fractures might even be faster compared to mapping with BIPS-images.

It is possibly easier to detect extremely thin sealed fractures, for example fractures sealed with calcite, with acoustic televiewer images than with BIPS-images. This might be of some interest, since these fractures sometimes are quite weak and has a tendency to break up during drill core handling. Also sealed network fractures might be easier to detect with acoustic televiewer images.

4 Execution

The Boremap mapping of the telescopic drilled borehole KAV01 was performed and documented according to activity plan AP PS 400-03-057 (SKB, internal document) referring to the Method Description for Boremap mapping (SKB MD 143.006, v.1.0, SKB, internal controlling document).

The acoustic televiewer image covered the interval 2.1–743 m and was mapped without interruption.

The drill cores were displayed on inclined roller tables and mapped in their entire length with the Boremap system at Simpevarp. The core mapping was carried out without any detailed geological knowledge of the area. Geophysical logs from the borehole were available and they were of good help for some detailed problems (see chapter 6 Discussion).

To maintain systematic judgements in the mapping, each geologist had the same task throughout the mapping. Vladislav Stejskal was responsible for handling the drill core and Jan Ehrenborg for the delineation of structures in the acoustic televiewer image.

4.1 Preparations

Any depth registered in the acoustic televiewer image deviates from the true depth in the borehole, a deviation which increases with depth. This problem was eliminated by adjusting the depth according to reference slots cut into the borehole every fiftieth meter (Appendix 8). The level for each slot was measured in the acoustic televiewer image and then adjusted to the correct level using the correct depth value in SICADA.

The orientations of the observations were adjusted to true space. Data necessary for this adjustment were borehole diameter and deviation; both collected from SICADA (Appendices 6 and 7).

4.2 Execution of measurements

Concepts used during the Boremap mapping are defined in this chapter.

4.2.1 Fracture definitions

Definitions of different fracture types are found in “Nomenklatur vid Boremapkartering” by Larsson and Stråhle (PM, 2004-02-05 SKB, internal controlling document). Apertures for broken fractures have been mapped in accordance with the definitions in this PM with the exception that fracture trace shadow effects have not been used since they do not occur in the acoustic televiewer image.

In the mapping phase, fractures that have parted the core are mapped as "Broken" and fractures that have not parted the core, are mapped as "Unbroken". All fractures are described with their fracture minerals and other characteristics, such as width and aperture. Since apertures could not be mapped from the acoustic televiewer image all apertures were estimated from the drill core. Core pieces with very bad fit and/or fracture surfaces with euhedral crystals ≥ 1 mm were characterized as "certain" and given a value ≥ 1. Smaller apertures were denoted a value of 0.5 mm. Core pieces with bad fit were characterized as "probable aperture" and fractures with a dull or altered surface as "possible aperture".

All fractures in the SICADA data base that possess apertures > 0 mm are interpreted as "Open" and fractures with apertures = 0 mm, are interpreted as "Sealed". "Unbroken" fractures which possess apertures > 0 mm, are interpreted as "Partly open" and are included in the "Open"-category. "Open" and "Sealed" fractures are finally frequency calculated and shown in the composite log (see Appendices 6 and 7).

4.2.2 Fracture alteration and joint alteration number

The joint alteration number is principally related to the thickness of, and the clay content in, a fracture. Thicker fractures rich in clay minerals therefore get joint alteration numbers 2–3. The absolute majority of fractures in KAV01, however, are very thin to extremely thin and do rarely contain any clay minerals. Therefore they get joint alteration numbers between 1 and 2.

A subdivision of fractures with joint alteration numbers between 1 and 2 was introduced to facilitate both the evaluation process for fracture alterations and the possibility to compare the alterations between different fractures in the boreholes. The subdivision is based on fracture mineralogy and was as follows: a) fracture wall alterations, b) fracture mineral fillings assumed to have been deposited from circulating water rich solutions and c) fracture mineral fillings most likely resulting from altered wall rock material.

Joint alteration number equal to 1

Fractures without mineral fillings but with fracture wall alterations were both considered as alterations of the wall rock and not as fracture alteration minerals. Examples are fractures without mineral fillings but with red coloured oxidized fracture walls and/or dirty greenish coloured epidotized fracture walls. The joint alteration was classified as fresh for these fractures and the joint alteration number set to 1.

The minerals calcite, quartz, fluorite and zeolites like laumontite as well as sulphides were regarded as deposited by circulating water rich solutions in open fractures and not as true fracture alteration minerals. The joint alteration number was thus set to 1 also for these minerals.

Joint alteration number equal to 1.5

Epidote, prehnite, hematite, chlorite and/or clay minerals were regarded as fracture minerals most likely resulting from altered wall rock material. A weak alteration was thus assumed and the joint alteration number was set to 1.5. Extra attention was given to clay minerals since the occurrence of these often resulted in a higher joint alteration number.

Joint alteration numbers higher than 1.5

When the mineral fillings were thicker and contained a few mm thick bands of clay minerals, often together with minerals like epidote and chlorite, the joint alteration number was set to 2. In the extremely rare cases, when fractures contain 5-10 mm thick clayey bands, together with epidote and chlorite, the joint alteration number is set to 3.

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

4.2.3 Mapping of broken fractures not visible in the acoustic televiewer image

Not all fractures that cut the drill core are visible in the acoustic televiewer images. Such fractures have been orientated using the *guide-line method*, based on the following data:

- Absolute depth.
- Amplitude (measured along the drill core). The amplitude is the interval along a drill core which is cut by a fracture.
- Exact orientation of the fracture trace, measured on the drill core in relation to a close lying, well defined, geological structure visible in the acoustic televiewer image.

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

When using the guide-line method the difference between the 41 mm drill core diameter and the 56 mm borehole diameter must be considered. This difference result in displacements of the structures seen in the drill core compared with the structures seen in the acoustic televiewer image, which represents the borehole walls. This displacement is zero for structures that cut the drill core at right angle and successively becomes larger as the orientation of the structure approximates the direction of the drill core axis. This displacement always has to be corrected for, since displacements of a few cm are common even if they seldom reach 10 cm.

Orientation of fractures and other structures with the guide-line method is done in the following way: The first step in the guide-line method is to correct the amplitude of the fracture trace in the image to the higher amplitude value. The second step is the correction of strike and dip. This is done by rotating the fracture trace in the acoustic televiewer image relative to a feature with known orientation. The fracture is then located at the correct depth according to the depth measured on the drill core.

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

The importance of orientating broken fractures that are not visible in the acoustic televiewer images is highlighted by the fact that a high percentage of these fractures are not visible in the images.

4.2.4 Definition of veins versus dikes

Veins and dykes were differentiated by the width; veins having 0–20 cm width and dykes having 20–100 cm width. Since the maximum width of *rock occurrences* is 100 cm wider dykes are mapped as *rock types*.

Veins within composite dykes were not mapped separately.

4.2.5 Use of mineral codes

Mineral codes have been used as follows:

X6 The drill core is broken at right angle to the drill core and the broken surfaces have a polished appearance. This is believed to indicate a sealed fracture that opened up during drilling and where the two drill core parts have rotated against each other milling the mineral fill.

X7 Broken fractures with a fresh appearance and no mineral fill.

X9 Sealed fractures visible in the acoustic televiewer image but not in the drill core.

4.3 Data handling

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

The mapping was quality checked by a routine in Boremap before it was exported to and archived in SICADA. Personnel from SKB also performed spot test controls and regular quality revisions.

All primary data are stored in the SKB SICADA database under field note no Simpevarp 306. Only these data are to be used for further interpretation and modelling.

5 Results

The results of the Boremap mapping of KAV01 are principally found in the Appendices. The information in SICADA has been compressed to the size of an A4-sheet in the Geological Summary table, Appendix 1. The search paths for this table are presented in Appendix 2. Stereographic diagrams of the orientation of open fractures are presented in Appendix 3, while examples of the acoustic televiewer images of KAV01 are shown in Appendix 4 and the corresponding WellCad diagram in Appendix 5. In data, like borehole length and diameter, are presented in Appendices 6, 7 and 8.

5.1 Geological summary table, general description

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

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

The search paths cannot, however, yet be used in an automatic way and therefore the geological information has first been extracted from the SICADA database, then reworked on separate Excel-files, and last presented in the Geological Summary table. At the moment it is only possible to extract the Rock Type and Alteration parameters directly from the SICADA database.

The main reason why the information in the SICADA database cannot be extracted automatically is the lack of a mathematical formula to calculate frequencies for different parameters. Such a formula will be added.

The need to rework the SICADA information on separate Excel-files exists because some information is written in the Comment field for individual observations in Boremap and therefore has to be extracted manually. This problem is also being dealt with.

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

5.1.1 Columns in the Geological Summary table

The Geological summary table includes the following 23 columns:

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

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

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

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

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

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

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

Column 8. *Structure/Brecciated < 1 m wide* is a frequency column. Breccias <1m wide are mapped under rock occurrence in Boremap. Very narrow micro breccias along sealed/open fracture planes are generally not considered.

Column 9. *Structure/Brecciated ≥ 1 m wide* is an interval column. Breccias >1m wide are mapped under rock type/structure in Boremap.

Column 10. *Structure/Mylonite < 1 m wide* is a frequency column. Mylonites <1m wide are mapped under rock occurrence/structure in Boremap.

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

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

Column 13. *Structure/Foliation ≥ 1 m wide* is an interval column. Foliation structures >1m wide are mapped under rock type/structure in Boremap.

Column 14. *Sealed fractures (interpreted)/All* is a frequency column. This column includes all fractures interpreted as sealed with the Boremap system. It includes sealed fractures where the drill core is not broken as well as sealed fractures interpreted to have broken up artificially during/after drilling.

Column 15. *Sealed fractures (interpreted)/Broken fractures with aperture = 0* is a frequency column. This column includes sealed fractures interpreted to have broken up artificially during/after drilling.

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

Column 17. *Sealed fractures (interpreted)/Sealed Fracture Network ≥ 1 m wide* is an interval column.

Column 18. *Open fractures (interpreted)/All Aperture > 0* is a frequency column. This column includes all open fractures; both fractures that with certainty were open before drilling and fractures that probably or possibly were open before drilling.

Column 19. *Open fractures (interpreted)/Uncertain, Aperture = 0.5 probable + 0.5* possible is a frequency column. This column includes fractures that probably or possibly open before drilling.

Column 20. *Open fractures (interpreted)/Certain Aperture = 0.5 certain and > 0.5* is a frequency column. This column includes fractures that with certainty were open before drilling.

Column 21. *Open fractures (interpreted)/Joint alteration > 1.5* is a frequency column. This column show fractures with stronger joint alteration than normal. This parameter generally goes hand in hand with the location of lithologies with a more weathered appearance.

Column 22. *Open fractures (interpreted)/Crush < 1 m* wide is a frequency column. This column includes shorter sections with crush.

Column 23. *Open fractures (interpreted)/Crush ≥ 1 m* wide is an interval column. This column includes longer sections with crush.

5.2 Geological summary table, KAV01

The Geological Summary table for KAV01 is presented in Appendix 1. All length information in this chapter is taken from the Geological Summary table and therefore includes an error of 5–10 m. Only the interval 0–743 m was mapped.

The lithology in KAV01 is made up of Ävrö granite cut by pegmatite, granite, fine-grained dioritoid and diorite-gabbro veins and dykes.

The bedrock almost lack structures except for a breccia at 450 m and very sparsely distributed thin sections with foliation.

Sealed fractures (interpreted) are not common compared to boreholes KSH01 and KSH02. Sealed fracture networks and open fractures (interpreted) are more frequent at lower depths in KAV01.

The interval 435–480 m might be regarded as a weakness section since a broad maximum in the frequency of open fractures (interpreted) coincide with peaks in crushed sections, with sealed fracture networks and sealed fracture, with the breccia at 450 m and the with the sections with strongest oxidation in KAV01.

Much thinner weakness sections might occur at approximately 660 m and 735 m borehole length, where peaks in crushed sections, open fractures (interpreted), sealed fracture networks and oxidation occur.

5.3 Orientation of open fractures

Stereograms for open fractures for each 100 m interval in KAV01 are presented in Appendix 3. The stereographic information is from plane to pole plot data. Fracture orientation values are strike/dip values using the right hand rule.

The orientation for borehole KAV01 at ground level is 225/-89.2.

Open fractures not visible in the acoustic televiewer image were mapped as planes at right angle to the borehole. These fractures show up as a small artificial semicircular high anomaly maxima at right angle to the borehole in the stereographic plots. It should be noted that the location of this artificial maxima varies with depth according to the deviation of the borehole.

There is a general strong overrepresentation of open fractures cutting the borehole at high angles compared to fractures cutting the borehole at low angles. This results in artificially high anomaly values for fractures cutting the borehole at high angles and in distortion of anomaly shapes in the stereographic plots. These distortions show up as a tendency for anomalies to obtain a semi circular shape, effects that are stronger the longer the plotted depth interval. It is therefore not recommended to plot intervals longer than 100 m in the same stereogram.

In the interval 0–100 m two fracture sets can be observed: one SE-striking moderately dipping (30° dip) and one SE-striking strongly dipping set (75° dip).

The interval 100–200 m has a SSW-striking fracture set with moderate dip (50° dip). This fracture set is observed all through the borehole from the interval 100–200 m to the interval 700–742 m. It varies in strike from SSW in the interval 100–300 m to SW in the interval 300–700 m and changes back somewhat to SW-WSW in the interval 700–742 m.

An ENE striking fracture set with steep dip (70° dip) occurs in the interval 200–400 m. It is replaced with an ENE striking gently dipping (30° dip) fracture set in the interval 400–500 m. This fracture set is not observed deeper down in KAV01.

A WNW-striking and gently dipping (35° dip) fracture set occur in the interval 500–600 m. Also an almost vertical NW-striking fracture set (85° dip) occurs in the interval 500–600 m. This fracture set show up as a weaker anomaly also deeper down in KAV01, in the interval 600–700m.

6 Discussion

Fractures not visible in the acoustic televiewer images were, if possible, mapped using “the guide-line method”. When this method could not be used, for example, because of lack of guiding structures, these fractures were mapped as if they lay 90° towards the borehole.

In the mapping of KAV01 a new version of Boremap was used (v. 3.3.2). A new way of mapping crushed sections was introduced, where not only the upper and lower limits of the crushed section are delineated, but also the two dominating fracture orientations within the crushed section. As before, no other observations can be mapped within the section with crush. This new way of mapping crushed sections works very well.

A new parameter, *sealed fracture network*, was also introduced with the new version of Boremap. It was designed in the same way as the crushed section parameter. However, since no other observations could be marked within the sealed fracture network interval this parameter could not be used. Since the sealed fracture networks can be up to tens of meters long, it must be possible to map also other parameters, like broken and unbroken fractures, within the intervals. Especially broken and unbroken fractures must be prioritized over sealed fracture networks. Until other features can be mapped within the sealed fracture networks, the latter will be written in the comment to a broken or unbroken fracture observation close to the upper limit of these intervals as for KSH01 and KSH02. Sealed fracture networks were called micro breccias in KSH01.

In December 2003 a new way to estimate apertures was introduced (“Nomenklatur vid Boremapkartering” by Larsson and Stråhle, PM, 2004-02-05). Fractures with apertures in KAV01 were re-mapped in accordance with these directives, using only the drill core, since apertures cannot be measured in the acoustic televiewer images.

Geophysical logs were available for KAV01 and they were a good help for solving minor lithological problems. These logs included silicate density, magnetic susceptibility and natural gamma radiation. Composite dykes were, for example, very characteristic with high silicate densities, very low magnetic susceptibilities and often high natural gamma radiation within narrow intervals. The geophysical logs were a good help for the identification of the lithology in intervals with intermediate to mafic dykes. The extra focusing to these areas also resulted in that rock contacts, overlooked during the Boremap mapping, were identified.

Appendix 1

Geological Summary table, KAV01

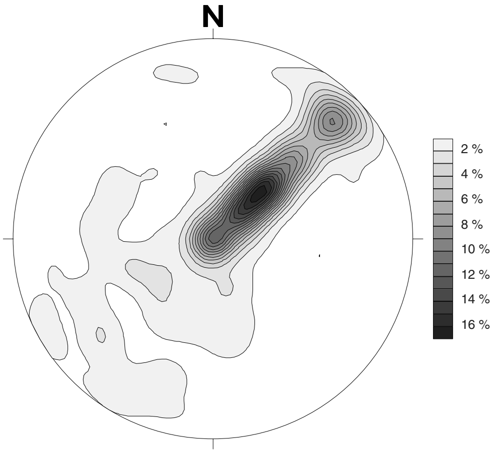
Appendix 2

Search paths for the Geological Summary table

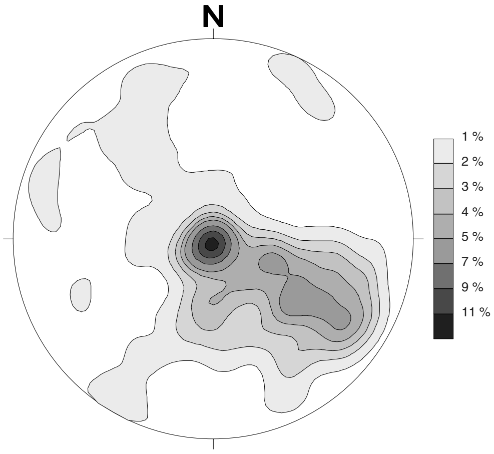
TABLE HEAD LINES		INFORMATION SOURCE				PRESENTATION
Head lines	**Sub head lines**	**Database**	**Varcode**	**First suborder**	**Second suborder**	**Interval/frequence**
Rock type	Lithology	SICADA	5	Sub 1		Interval
	Grain size	SICADA	5	Sub 5		Interval
	Texture	SICADA	5	Sub 6		Interval
Alteration	Oxidation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

Appendix 3

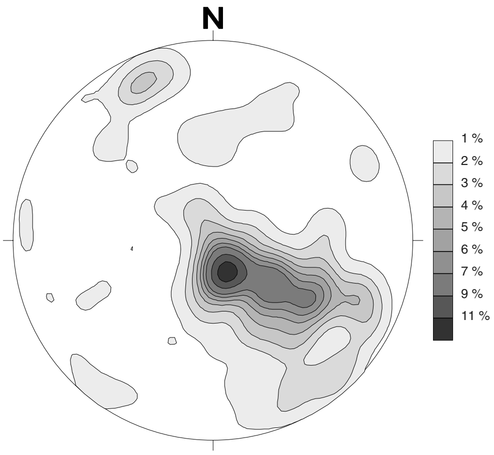
Stereographic projections of open fractures, KAV01



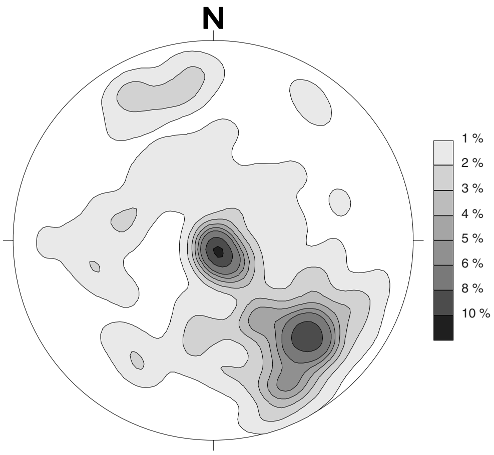
KAV01 0-100 m (190 fractures)



KAV01 100-200 m (221 fractures)

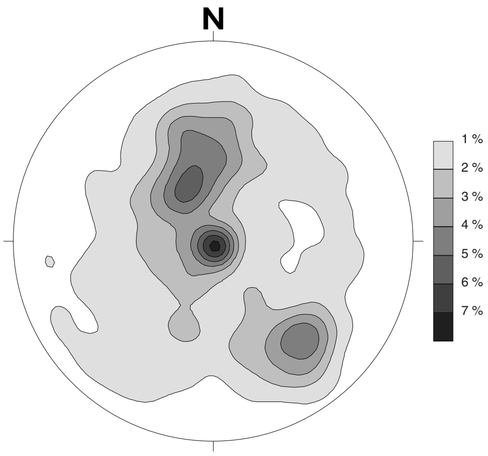


KAV01 200-300 m (191 fractures)

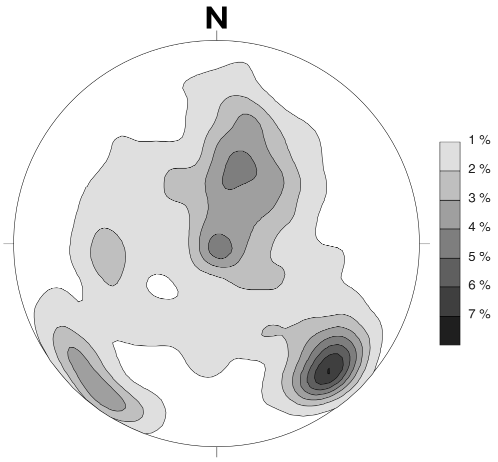


KAV01 300-400 m (139 fractures)

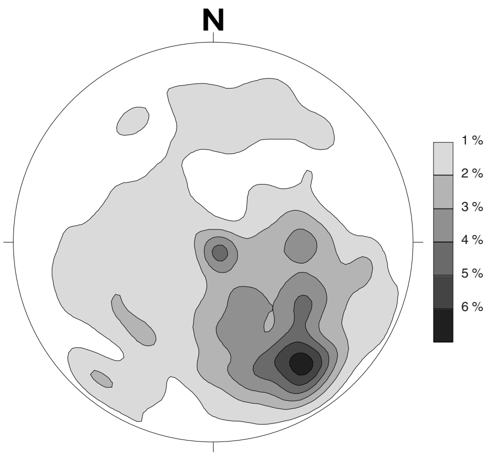
Stereograms of poles to planes of open fractures with aperture in borehole KAV01, Schmidt's Net, lower hemisphere.



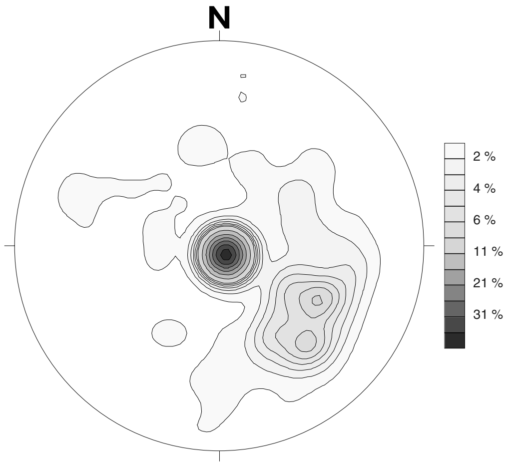
KAV01 400-500 m (607 fractures)



KAV01 500-600 m (460 fractures)



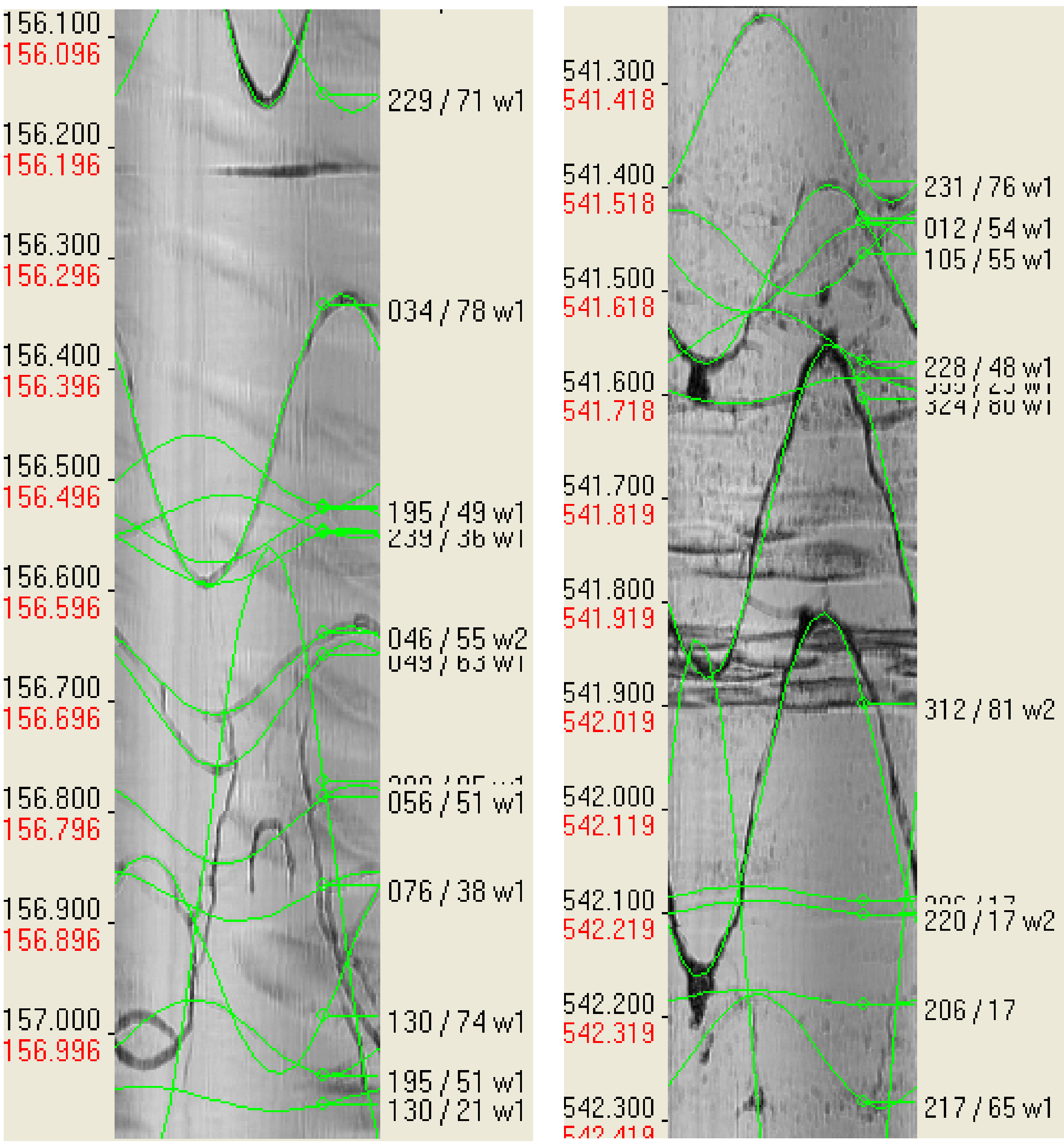
KAV01 600-700 m (409 fractures)



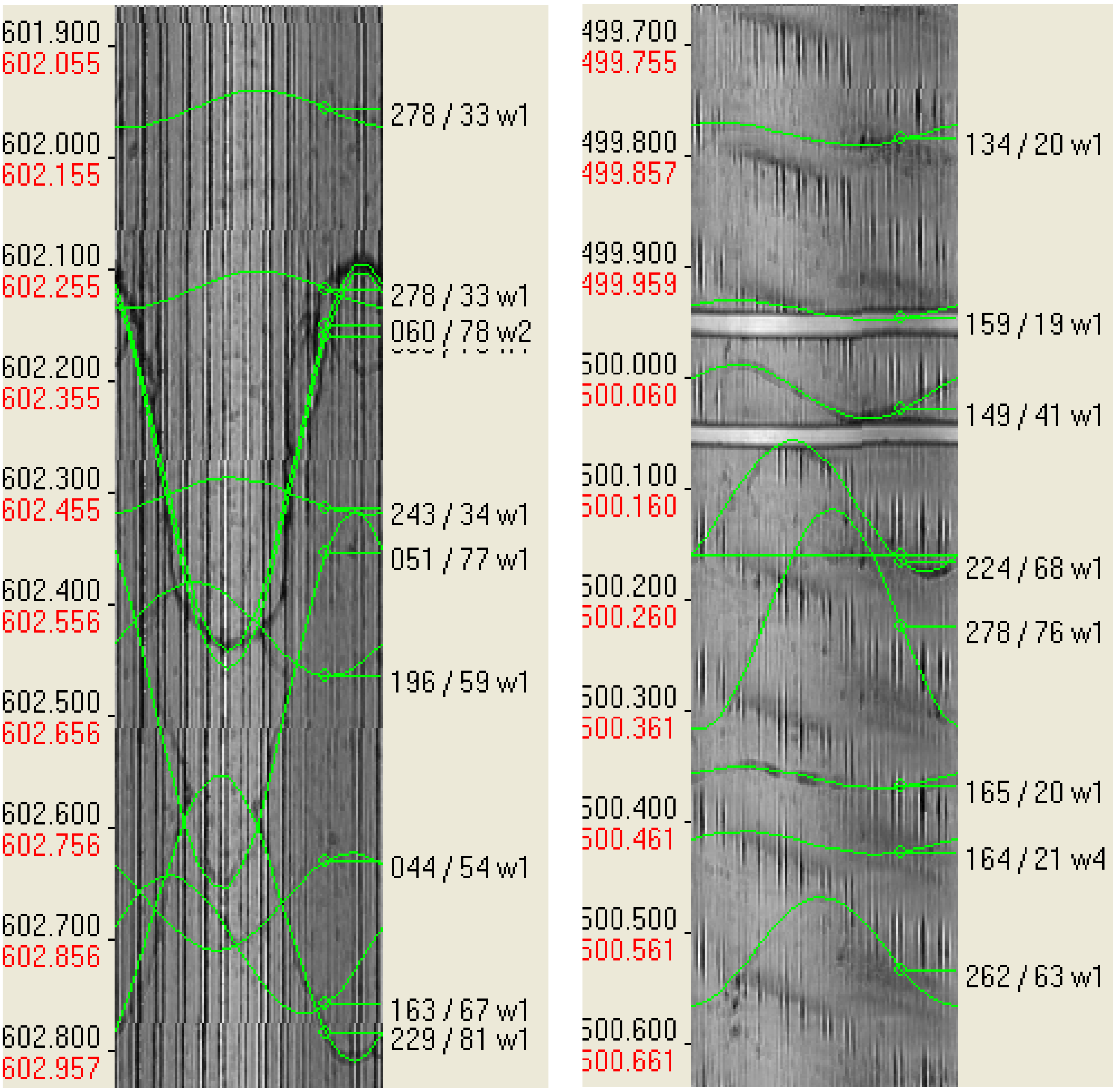
KAV01 700-742 m (209 fractures)

Stereograms of poles to planes of open fractures with aperture in borehole KAV01, Schmidt's Net, lower hemisphere.

Examples of acoustic televiewer images of KAV01



Examples of acoustic televiewer images from KAV01. To the left is a relatively undisturbed image, where only slight spiral marks are disturbing the image. To the right the fractures are clearly discernible in the image.



Examples of acoustic televiewer images from KAV01. To the left is an image with strong vertical, disturbing, bands of unknown origin. To the right spiral marks can be observed, as well as weaker vertical bands. The reference marks can be clearly observed in the acoustic televiewer images (see image to the right).

WellCad diagram of KAV01

Title LEGEND FOR SIMPEVARP KAV01

Site	ÄVRÖ
Borehole	KAV01
Plot Date	2004-04-18 21:03:29

ROCKTYPE ÄVRÖ

- Dolerite / Diabas
- Fine-grained Götemargranite
- Coarse-grained Götemargranite
- Fine-grained granite
- Pegmatite
- Granite
- Ävrö granite
- Quartz monzodiorite
- Diorite / Gabbro
- Fine-grained dioritoid
- Fine-grained diorite-gabbro
- Sulphide mineralization
- Sandstone

ROCK ALTERATION

- Oxidized
- Chloritisized
- Epidotisized
- Weathered
- Tectonized
- Sericitisized
- Miarolitic
- Silicification
- Argillization
- Albitization
- Carbonatization
- Saussuritization
- Steatitization
- Uralitization

MINERAL

- Epidote
- Hematite
- Hypersthene
- Calcite
- Potash Feldspar
- Chlorite
- Quartz
- Unknown
- Pyrite
- Jaspis
- Laumontite
- Oxidized Walls

STRUCTURE

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

TEXTURE

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

GRAINSIZE

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

STRUCTURE ORIENTATION

- Schistose
- Gneissic
- Bedded
- Ductile Shear Zone
- Brittle-Ducktile Shear Zone
- Viened
- Banded
- Lineated
- Massive
- Brecciated
- Mylonitic
- Foliated

INTENSITY

- No intensity
- Faint
- Weak
- Medium
- Strong

ROUGHNESS

- Planar
- Undulating
- Stepped
- Irregular

SURFACE

- Rough
- Smooth
- Slickensided

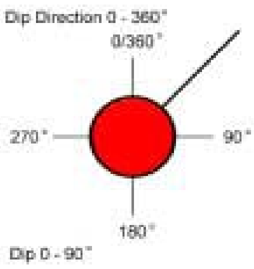
CRUSH ALTERATION

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

FRACTURE ALTERATION

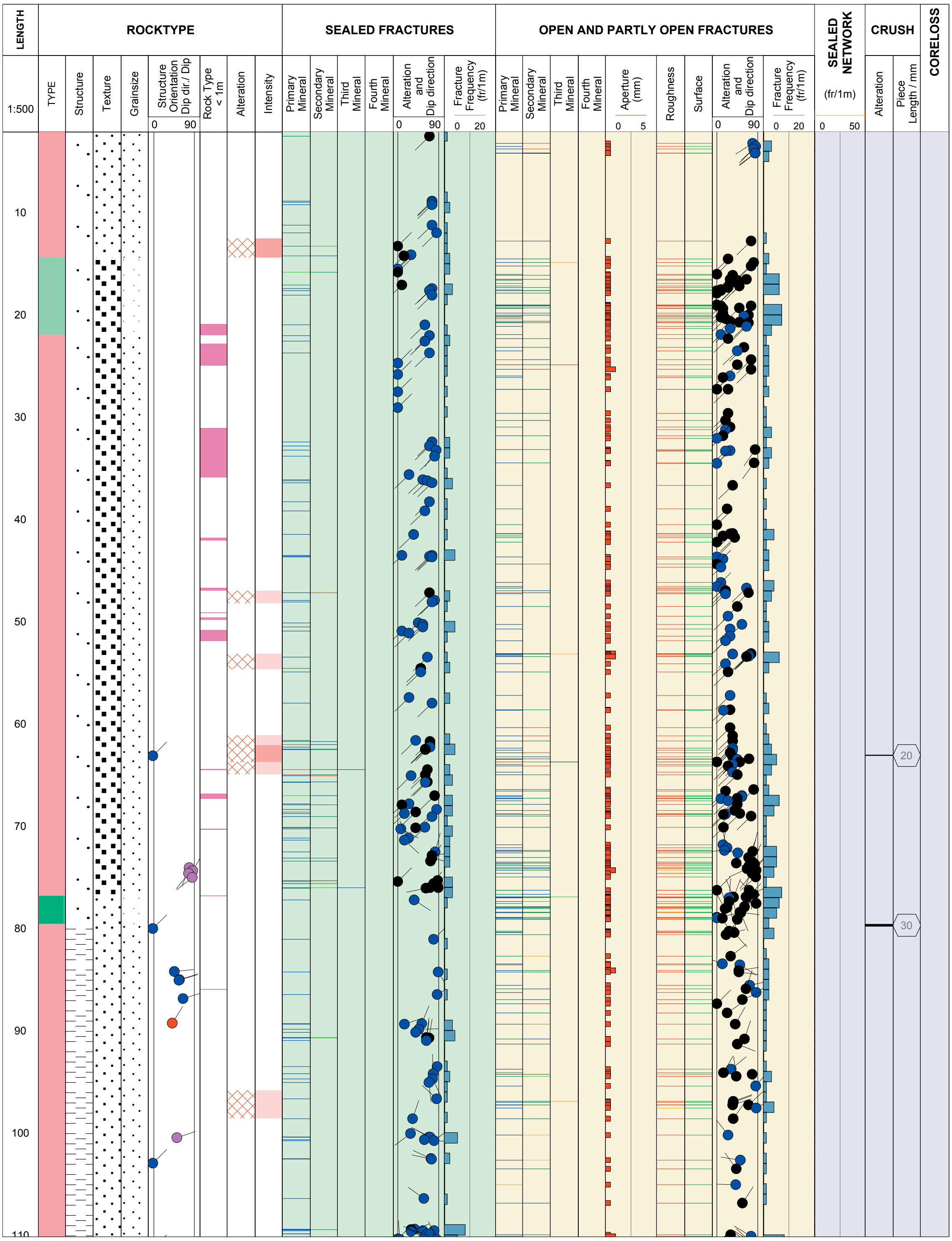
- Fresh
- Gouge
- Completely Altered
- Highly Altered
- Moderately Altered
- Slightly Altered

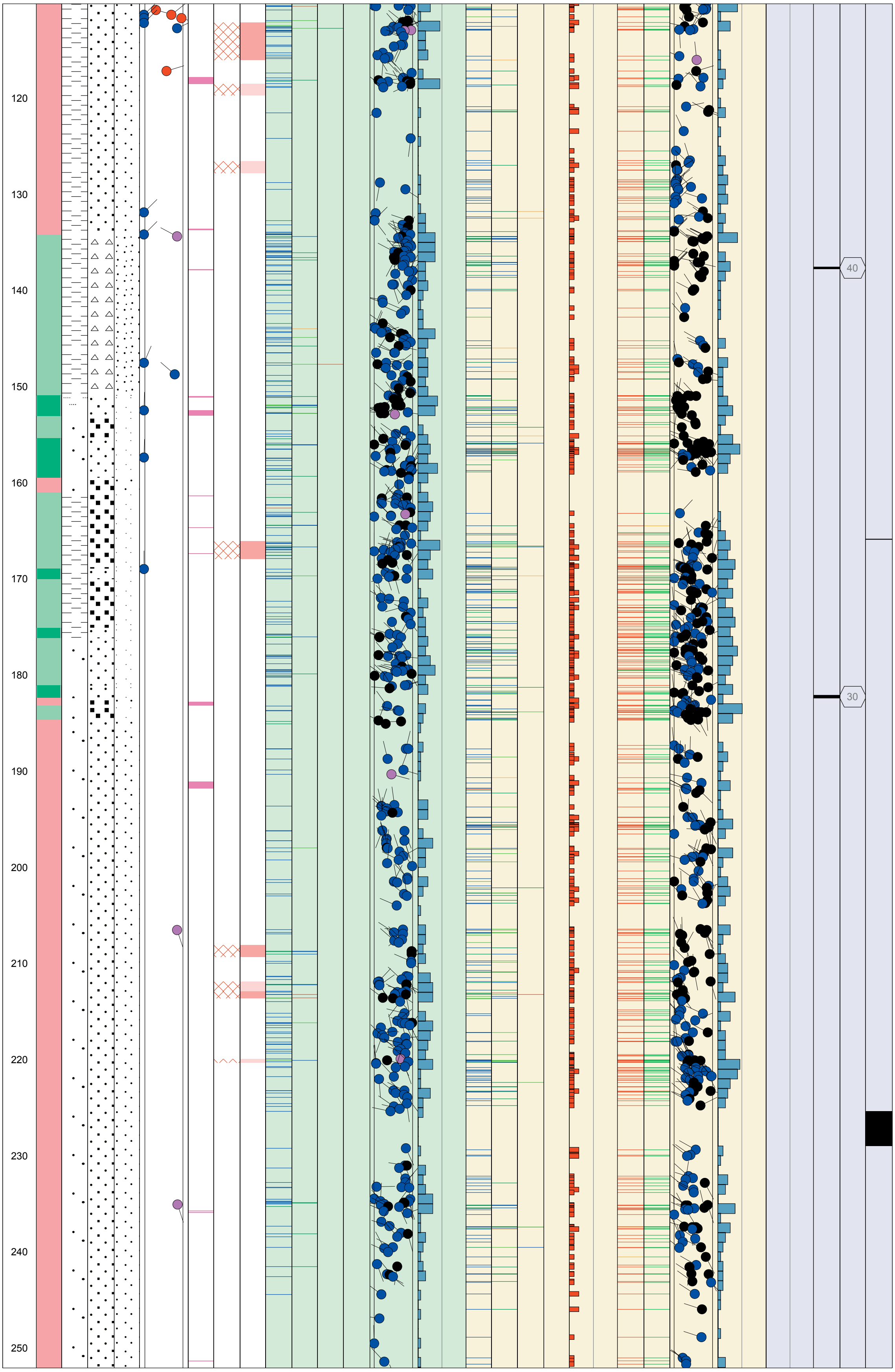
FRACTURE DIRECTION



Title GEOLOGY IN KAV01 **Appendix:**

Site	ÄVRÖ	**Coordinate System**	RT90-RHB70
Borehole	KAV01	**Northing [m]**	6367256.71
Diameter [mm]	56	**Easting [m]**	1553084.97
Length [m]	757.310	**Elevation [m.a.s.l.]**	14.03
Bearing [°]	225.61	**Drilling Start Date**	1977-04-21 00:00:00
Inclination [°]	-89.19	**Drilling Stop Date**	2004-01-10 10:00:00
Date of coremapping	2004-03-22 12:53:00	**Plot Date**	2005-09-14 00:02:30
Rocktype data from	p_rock	**Fracture data from**	p_freq_1m

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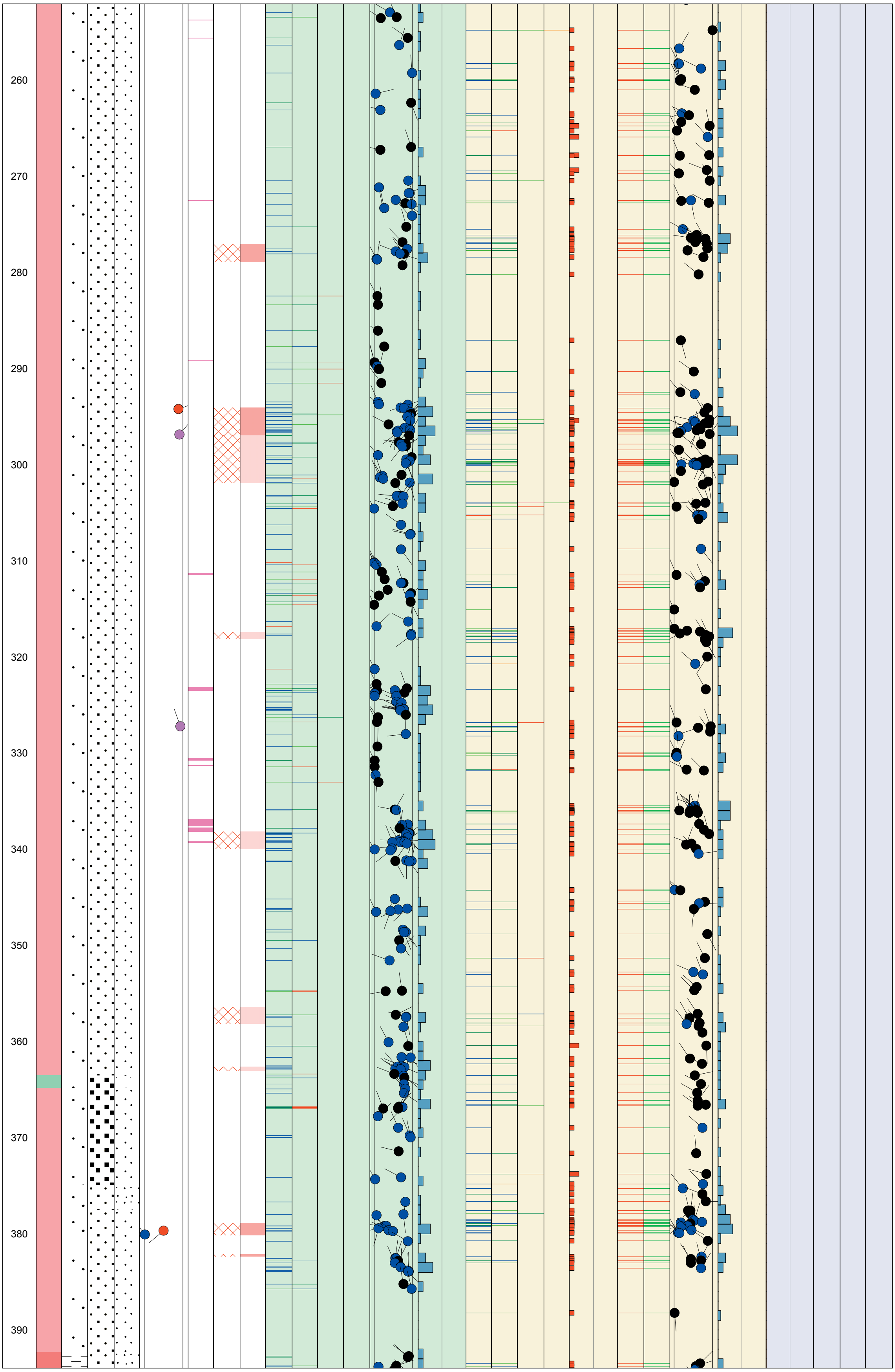
130
140
150
160
170
180
190
200
210
220
230
240
250
40
30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300
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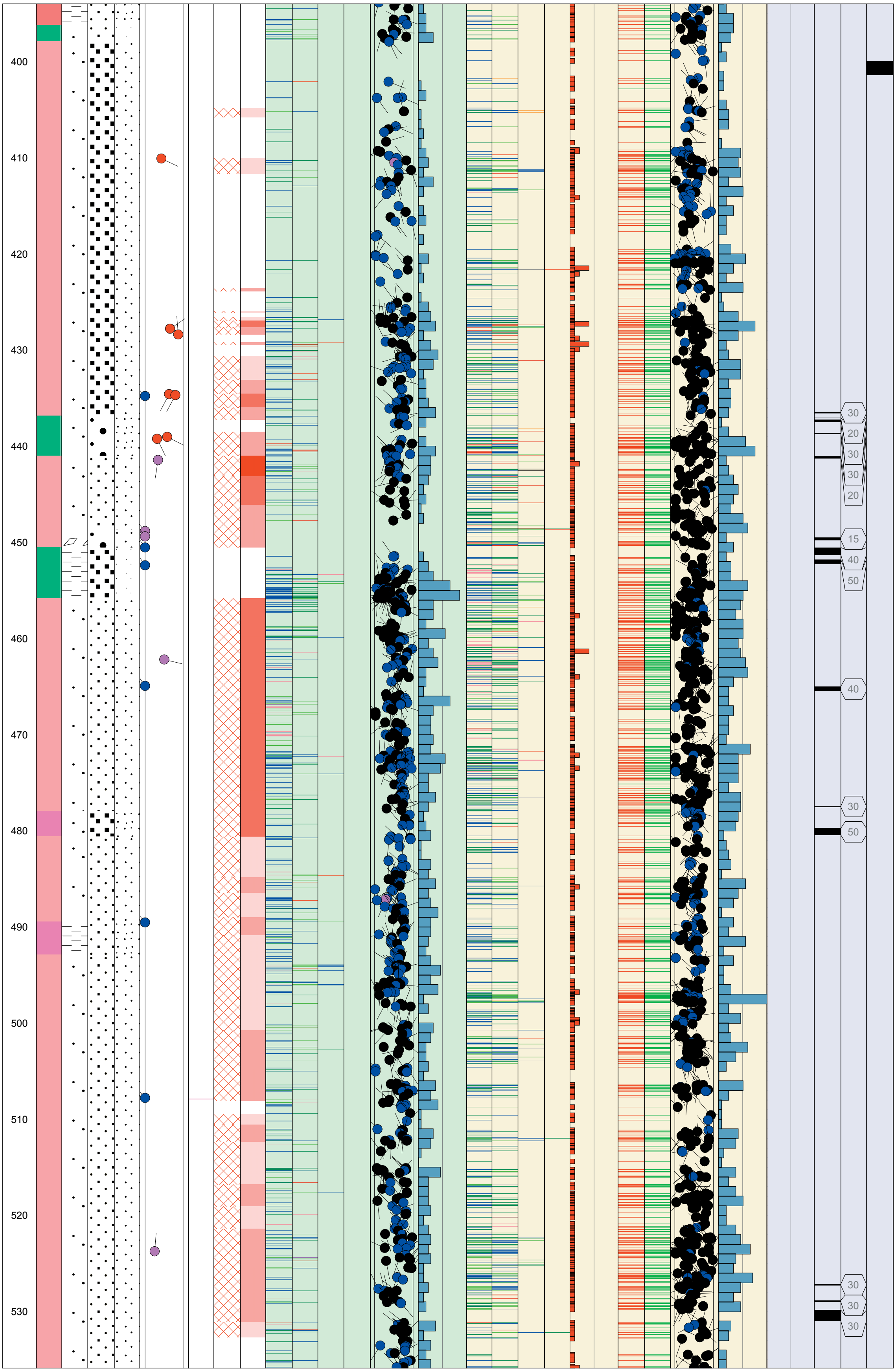
320
330
340
350
360
370
380
390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410
420
430
440
450
460
470
480
490
500
510
520
530
30
20
30
30
20
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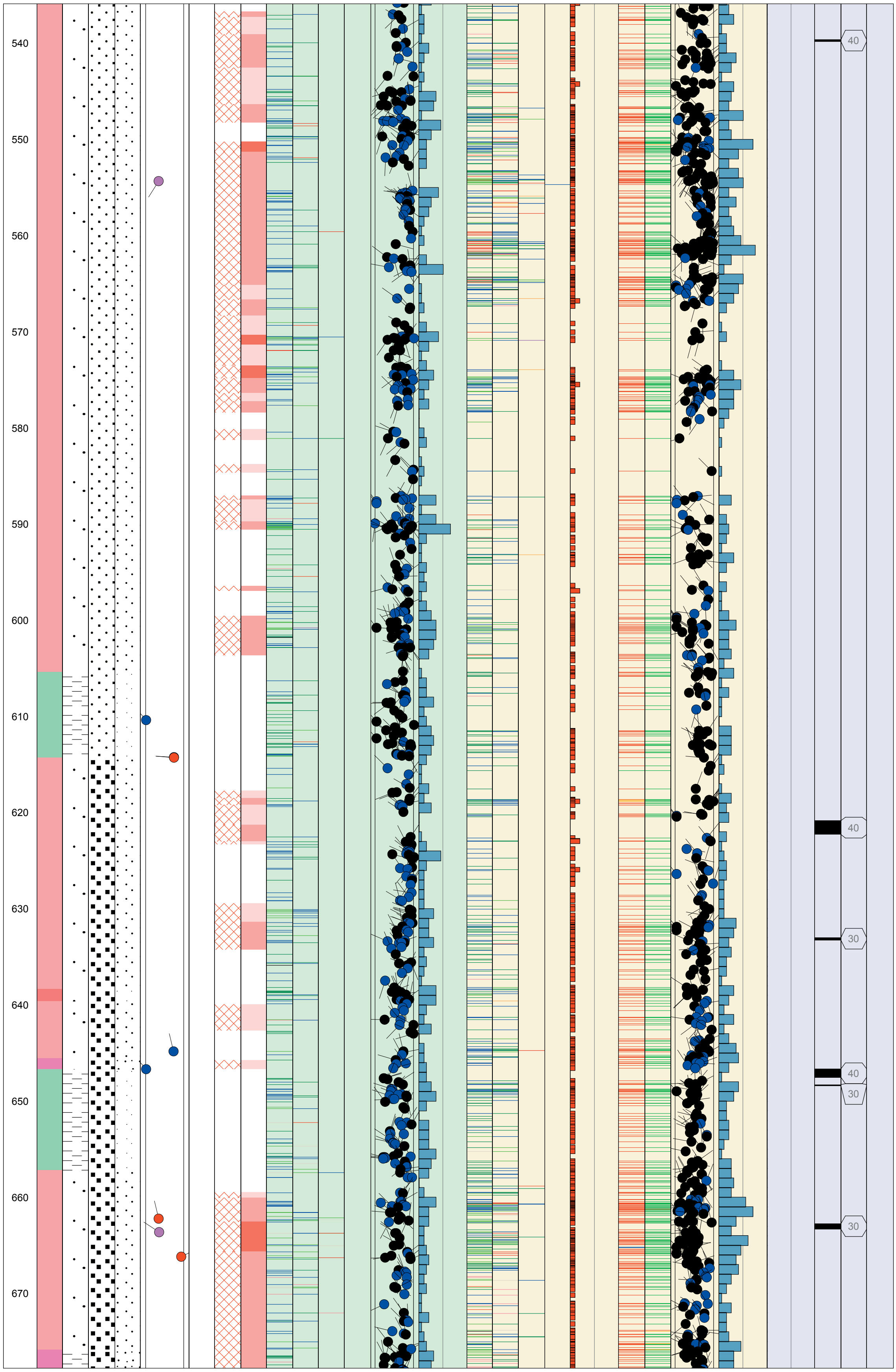
30
50
30
30
30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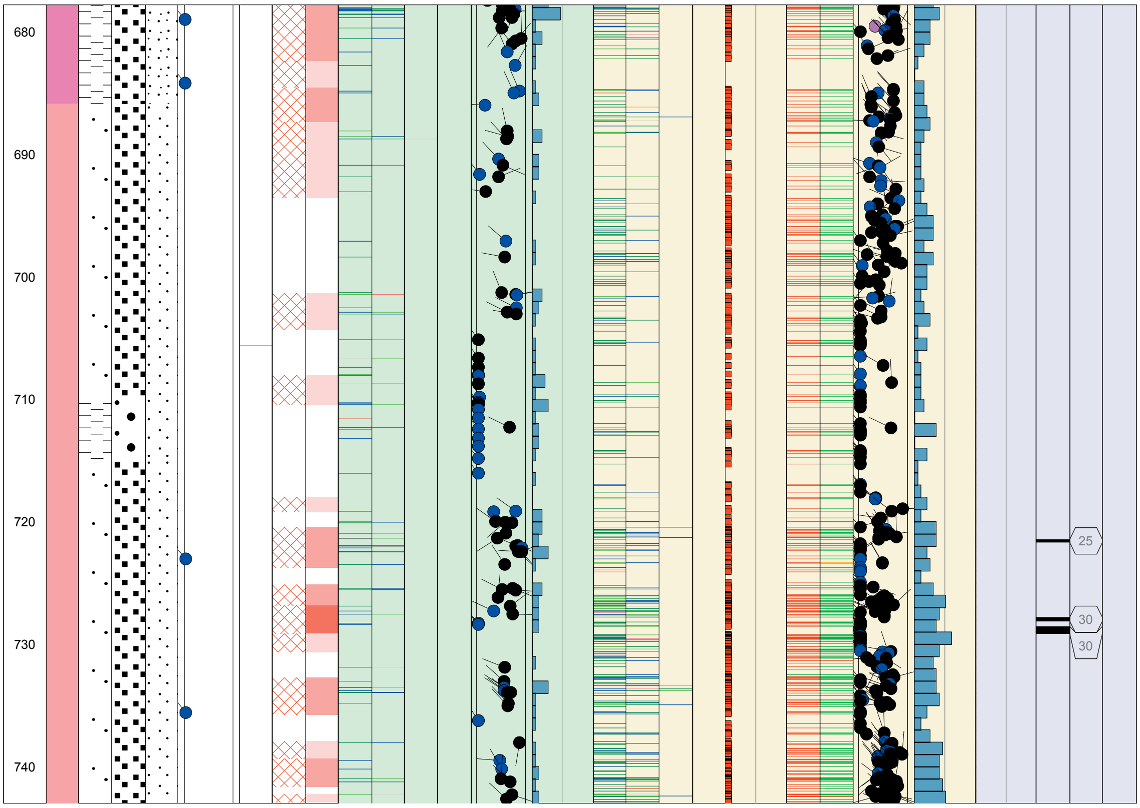
550
560
570
580
590
600
610
620
630
640
650
660
670
40
40
30
40
30
30


680
690
700
710
720
730
740
25
30
30

In data: Borehole length and diameter for KAV01

Hole Diam T - Drilling: Borehole diameter

KAV01, 2003-06-11 15:10:00 - 2004-01-10 10:00:00 (0.000 - 757.310 m)

Sub Secup (m)	Sub Seclow (m)	Hole Diam (m)	Comment
0.000	68.740	0.200	Hammarborrning
68.740	68.840	0.165	Hammarborrning
68.840	70.040	0.076	Rymning
70.040	757.310	0.056	

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Appendix 7

In data: Deviation data for KAV01

Boremac T - Borehole orientation: Boremac

KAV01, 1987-02-01 - ?

Length (m)	Inclination (degrees)	Bearing (degrees)	Meth Group	Meth Code
10.00	-89.2	225.0		
20.00	-89.3	225.0		
30.00	-89.2	225.0		
40.00	-89.2	225.0		
50.00	-89.3	225.0		
60.00	-89.4	225.0		
70.00	-89.3	225.0		
80.00	-89.3	225.0		
90.00	-89.4	225.0		
100.00	-89.3	225.0		
110.00	-89.3	225.0		
120.00	-89.3	225.0		
130.00	-89.3	225.0		
140.00	-89.3	225.0		
150.00	-89.3	181.0		
160.00	-89.3	180.0		
170.00	-89.3	179.0		
180.00	-89.3	170.0		
190.00	-89.3	179.0		
200.00	-89.3	179.0		
210.00	-89.2	178.0		
220.00	-89.1	177.0		
230.00	-89.3	179.0		
240.00	-89.2	179.0		
250.00	-89.2	179.0		
260.00	-89.1	172.0		
270.00	-89.0	170.0		
280.00	-88.8	167.0		
290.00	-89.0	164.0		
300.00	-89.7	148.0		
310.00	-89.7	157.0		
320.00	-88.7	153.0		
330.00	-88.4	155.0		
340.00	-88.4	152.0		
350.00	-88.4	145.0		
360.00	-87.9	138.0		
370.00	-87.5	153.0		
380.00	-87.5	146.0		
390.00	-87.5	140.0		
400.00	-87.5	138.0		
410.00	-87.5	141.0		
420.00	-87.5	138.0		
430.00	-87.5	140.0		
440.00	-87.5	135.0		
450.00	-87.3	145.0		
460.00	-87.2	146.0		
470.00	-87.2	145.0		
480.00	-87.2	141.0		
490.00	-87.2	142.0		
500.00	-87.2	143.0		
510.00	-87.2	136.0		
520.00	-87.2	137.0		
530.00	-87.2	142.0		
540.00	-87.2	140.0		
550.00	-86.9	141.0		

560.00	-87.0	147.0
570.00	-86.7	143.0
580.00	-86.7	142.0
590.00	-86.7	141.0
600.00	-86.7	147.0
610.00	-86.5	139.0
620.00	-86.7	141.0
630.00	-86.3	142.0
640.00	-86.3	137.0
650.00	-86.4	142.0
660.00	-86.4	141.0
670.00	-86.2	136.0
680.00	-86.0	141.0
690.00	-85.8	141.0
700.00	-85.8	144.0
710.00	-85.8	145.0
720.00	-85.8	138.0
730.00	-85.8	142.0
740.00	-85.8	141.0

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In data: Reference marks for length adjustments for KAV01

Reference Mark T - Reference mark in drillhole

KAV01, 2003-06-26 08:00:00 - 2003-06-26 16:20:00 (100.000 - 700.000 m)

Bhlen (m)	Rotation Speed (rpm)	Start Flow (l/min)	Stop Flow (l/min)	Stop Pressure (bar)	Cutter Time (s)	Trace Detectable	Cutter Diameter (mm)	Comment
100.00	500.00	400	1000	33.0	80	Ja		100.05
150.00	500.00	400	1000	34.0	80	Ja		150.10
200.00	500.00	240	1000	32.0	70	Ja		200.20
250.00	500.00	400	1000	30.0	100	Ja		250.27
300.00	500.00	400	1000	30.0	120	Ja		300.39
350.00	500.00	400	1000	28.0	160	Ja		350.48
400.00	500.00	460	1000	34.0	150	Ja		400.49
451.00	500.00	400	1000	32.0	170	Ja		451.75
500.00	500.00	260	1000	36.0	125	Ja		500.84
550.00	500.00	440	1000	40.0	195	Ja		557.86
600.00	500.00	400	1000	36.0	120	Nej		Gjorde flera försök
650.00	500.00	460	1000	54.0	195	Ja		Fick ej godkänt, fullt utslag stoptryck! 650.95
700.00	500.00	260	1000	52.0	150	Ja		701.20

Printout from SICADA 2004-03-18 14:41:52.