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Keywords: TRUE-1, KXTT3, KXTT4, Overcoring, Epoxy Injection, Fracture.

Abstract

Boreholes KXTT3 and KXTT4, located at the TRUE-1 site in the Äspö tunnel, were overcored during the time period from May 12 to August 16, 2007. The target structures were located at 12.67–14.72 m in KXTT3 and at 11.67–13.68 m in KXTT4. These depths covered the identified open fractures called Feature A in KXTT3 and Feature A and A' in KXTT4, previously being focus of extensive tracer tests with radioactive sorbing tracers. Prior to overcoring the target sections were injected with fluorescent epoxy. The existing resin-filled boreholes (56 mm diameter) were first reamed with a diameter of 76 mm down to the target section. The holes were then used as pilots for the overcoring with a diameter of 300 mm, producing 278 mm cores. A detailed drilling schedule was made for drilling and recovery of the core in each target section in order to optimize the chance to recover intact cores. However, the drilling schedule could only be implemented to a limited degree, because of problems in retrieving the large diameter, often segmented, core pieces out of the inclined boreholes, especially so in KXTT3. The overcoring of borehole KXTT3 produced broken core pieces of the identified target section with considerable amounts of visible epoxy, while borehole KXTT4 produced somewhat less broken core pieces of the identified target sections, but with smaller amounts of visible epoxy. Epoxy was found in the fractures that had been classified as open in previous characterisations of the cores and BIPS images from the 56 mm boreholes. Epoxy was also found in some fractures with a strike and/or dip not coinciding with Feature A, suggesting in a more complex system of connected open fractures within the target sections than previously interpreted for the borehole interval where Feature A is intersected by the boreholes. The cores from the target zones in the two boreholes were oriented and the length was measured using BIPS images from the 56 mm pilot boreholes as reference. The retrieved large diameter cores were also photographed and geologically mapped. The mapping was digitized and modelled in 2D and, in the case of KXTT3, also in 3D.

Sammanfattning

Borrhålen KXTT3 och KXTT4, belägna vid experimentplatsen TRUE-1 i Äspö tunneln, överborrades från 12:e maj till 16:e augusti 2007. Målstrukturerna var belägna vid 12.67–14.72 m i KXTT3 och 11.67–13.68 m i KXTT4. Dessa interval täcker de öppna sprickorna som kallas Feature A i KXTT3 och Feature A och A’ i KXTT4, som tidigare varit i fokus för omfattande spårförsök med radioaktiva ämnen. Inför överborrningen injekterades målsektionerna med fluorescerande epoxi. De två existerande epoxi-fyllda borrhålen (56 mm) blev först rymda med diameter 76 mm ner till målområdet. Borrhålen användes sedan som pilothål för överborrningen med 300 mm diameter borrkrona som producerade kärna med 278 mm diameter. En noggrann borrningsplan var skriven för borrning och hämtning av kärna för varje målområde, men kunde bara följas till en viss del på grund av problem, speciellt i KXTT3, vid upptag av de stora, men ofta uppbrutna kärnbitarna i de lutande hålen. Överborrningen av KXTT3 producerade brutna kärnbitar från det identifierade målområdet med ansenlig mängd epoxi, medan KXTT4 gav något mindre uppbrutna kärnbitar från målområdet, med mindre mängder epoxi. Epoxi hittades i de sprickor som vid tidigare karakterisering av kärnan och BIPS-bilder från 56 mm borrhålen blivit klassade som öppna. Men epoxi hittades dessutom i sprickor med en strykning och/eller lutning som inte sammanfaller med Feature A vilket indikerar ett mer komplext system av öppna konnekterade sprickor än vad som tidigare tolkats för borrhålssintervallen där Feature A återfinns i KXTT3 och KXTT4. Kärnan från målområdena i de två borrhålen blev orienterad och längdmätt utifrån BIPS bilder från 56 mm-hålen. Den upptagna stora kärnan fotograferades också och karterades geologiskt. Karteringen digitaliserades och modellerades i 2D och för KXTT3 även i 3D.

Contents

1 Introduction

The Tracer Retention Understanding Experiments (TRUE) included several field tracer experiments performed to develop understanding of transport and retention of dissolved solids, especially sorbing radioactive tracers, in fractured crystalline bedrock. At present the First TRUE Stage (TRUE-1) (Winberg et al. 2000), and the TRUE Block Scale parts (Andersson et al. 2002a, b, 2007, Poteri et al. 2002, Winberg et al. 2003) of the programme have been completed.

As a part of the TRUE programme the TRUE-1 Completion was performed as a part of the TRUE-1 Continuation Project at the TRUE-1 site located in the Äspö Hard Rock Laboratory (HRL) in a niche of the TASA tunnel at approximately 2,945 m tunnel length, see Figure 1–1. The target borehole sections of interest to TRUE-1 Completion were KXTT3:S3 (12.67–14.72 m) and KXTT4:T3 (11.67–13.68 m), respectively. These sections are connected between the two boreholes through a fracture called Feature A in KXTT3 and Feature A and A' in KXTT4, see Figure 1-2. This flow path, established in Feature A between the two boreholes, is well characterised from earlier investigations at the TRUE-1 site (Winberg et al. 2000, Andersson et al. 2002c). After several complementary *in situ* experiments performed within TRUE-1 Completion (Nordqvist et al. 2014), the target sections in the two boreholes were injected with epoxy in March of 2007. The subsequent steps in TRUE-1 Completion were the overcoring of the target sections, photographic documentation and strategic sectioning of the retrieved core pieces, followed by analyses of the internal pore structure and possibly identification of sorption sites on exposed surfaces and the rock matrix beyond.

This report describes the re-installation, epoxy injection and subsequent overcoring of the two boreholes KXTT3 and KXTT4, including the core retrieval, photo documentation and geological mapping of the target sections of the two boreholes. A plan was made and documented in a SKB internal document before the initiation of the activities described in this report. All data were stored in the Sicada database.

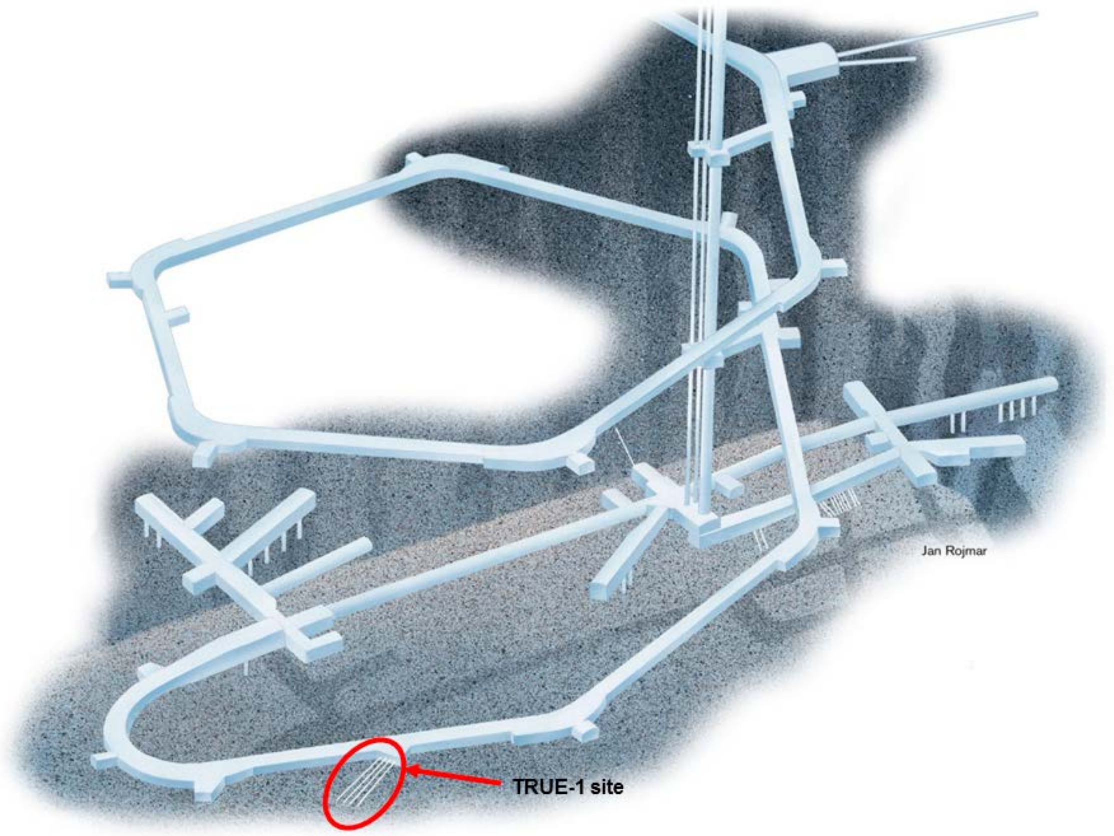

Figure 1-1. *Plane view of main experimental level at the Äspö HRL showing location of the TRUE-1 experiment in red (taken from Winberg et al. 2000, Figure 1-3, p 42).*

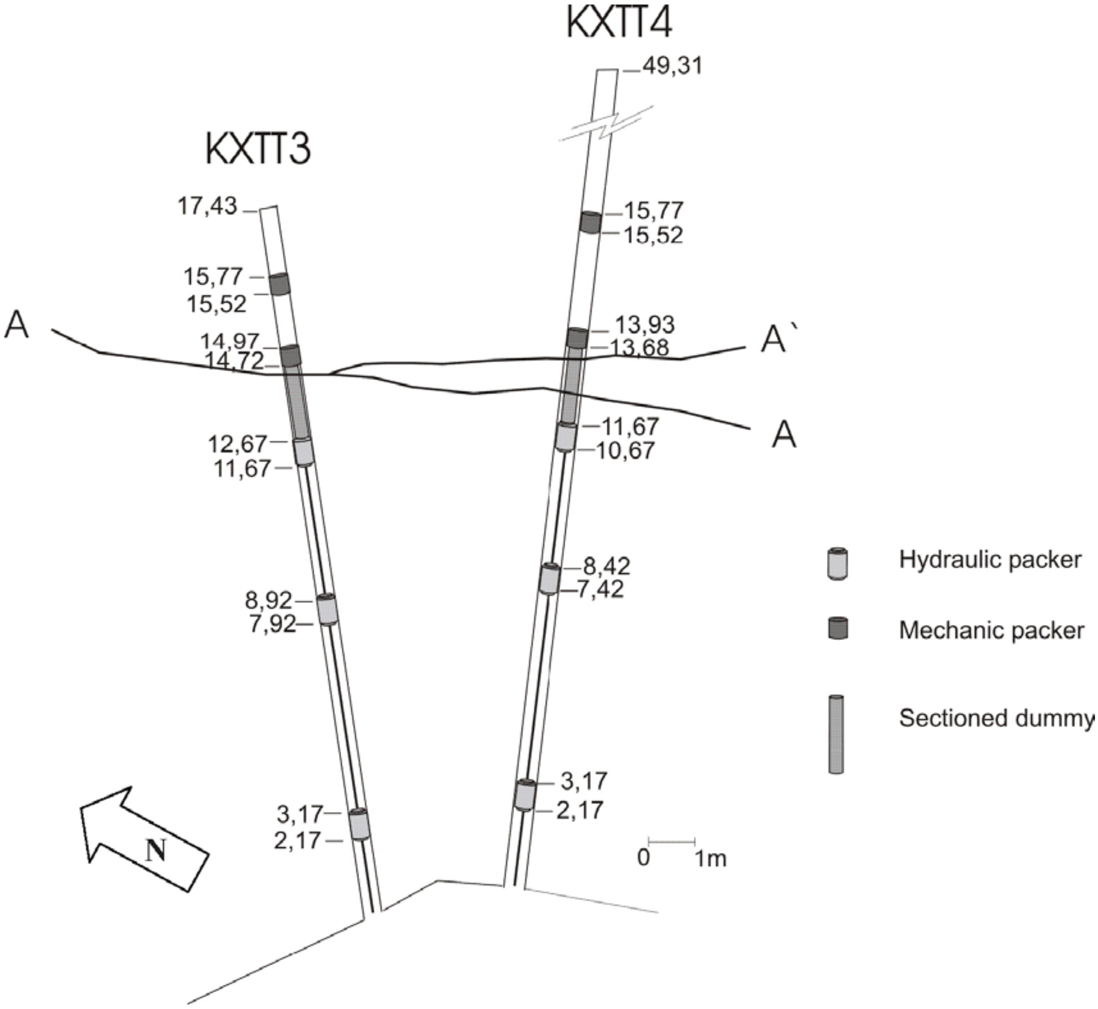

Figure 1-2. *Schematic drawing (plan view projection) of the test sections and flow path used in the TRUE-1 completion campaign. Arrow indicates approximate direction of geographic north.*

2 Objective and scope

The general objectives of TRUE-1 Completion were to:

- Improve the knowledge of the internal structure of Feature A through epoxy injection and subsequent analyses, including improvement of the identification and description of the immobile zone(s) involved in the observed retention effects.
- Perform complementary hydraulic and transport tests useful to SKB Site Investigations (PLU), in-situ Kd and SWIW-test.
- Improve the description of zones of immobile water that contributes to observed retention effects. The approach is identification and mineralogical-chemical characterisation of the sorption sites where Cs is found.
- Update the Feature A conceptual microstructural model and sorption models.

The specific objectives of the re-installation of borehole equipment, epoxy injection and overcoring activities described in this report were to:

- Re-install borehole equipment in KXTT3 and KXTT4 in order to:
  - restore the site to the same packer configuration as being in place during the STT-tests (Winberg et al. 2000),
  - ensure that the activities of TRUE-1 Completion do not disturb other projects at Äspö HRL,
  - realize complementary tracer tests,
  - realize the epoxy injection and the subsequent overcoring.
- Perform epoxy injection of KXTT4:T3 and KXTT3:S3 in order to:
  - stabilize the investigated feature in the vicinity of the borehole in the target section before the subsequent over-coring of the boreholes,
  - provide a protection against flushing of adsorbed tracers during the over-coring,
  - facilitate subsequent mapping of the inner structure of Feature A.
- Perform over-coring at the TRUE-1 site in order to recover cores from the target sections KXTT4:T3 and KXTT3:S3.
- Perform an overview characterisation of the retrieved large diameter cores, with special focus on the cores form the target sections.
- Handle the cores so that subsequent preparation and analysis will be possible.

Besides the epoxy injection and overcoring, the geological overview mapping of the target section of each borehole as well as the handling of the core is also described in this report.

The mapped parameters are:

- Fractures and fracture fillings (brittle structures).
- Rock types and rock occurrences.
- Rock contacts.
- Alteration.
- Ductile structures (e.g. foliation, shear zones etc.)

A 2D map of the target area of each borehole as well as a 3D map of the target area of KXTT3 can be found as appendices at the end of this report. Colour photographs of the core target areas and fracture surfaces are also attached.

Some borehole data have been summarized in Table 2-1. All borehole lengths given in this report origins at the average rock surface of the tunnel wall at the starting point of each borehole. This is consistent with borehole lengths given earlier regarding KXTT3 and KXTT4 such as in BIPS images and in Bossart et al. (2001).

The terms used in this report to describe borehole direction, core orientation and position are illustrated in Figure 2-1. *Down hole* and *up hole* are used to describe the direction of the borehole. For example, *down hole* to the left in a figure means that the part of the core to the left in the picture was situated further down the borehole than the right part of the core. The core piece surface situated furthest down in the borehole is referred to as bottom of the core piece and vice versa. Four orientation lines were used to describe the core relative its original orientation in the borehole (*vertical up of core*, *left side of core* and so on). Left and right side of core is seen from the tunnel.

Table 2-1. Geometric and technical data applicable to overcoring of boreholes KXTT3 and KXTT4.

Parameter	KXTT3		KXTT4	
Drilling period overcoring	2007-05-12 – 2007-06-07		2007-08-01 – 2007-08-16	
Overcored borehole length (m)	0.0–14.73		0.0–13.60	
Borehole total length (m)	0.0–17.43		0.0–49.31	
Core bit diameters used (m)	0.300 / 0.116 / 0.076 / 0.300		0.300 / 0.116 / 0.076 / 0.300	
Starting point coordinates (coordination system: Äspö96) (m)	Northing: 7,429.95 m Easting: 2,313.55 m Elevation: –391.07 m.a.s.l.		Northing: 7,428.80 m Easting: 2,313.86 m Elevation: –391.10 m.a.s.l.	
Borehole azimuth (0–360°)	44.36°		60.11°	
Borehole inclination at starting point (0–90°)	–36.92°		–36.45°	
Water yield after overcoring (measured 080829 for 3 min)	0.50 l/min		0.58 l/min	
	Interval (mbl)	**Diameter (m)**	**Interval (mbl)**	**Diameter (m)**
Borehole diameter	0.0–14.73 14.73–17.43	0.300 0.056	0.0–13.60 13.60–49.31	0.300 0.056
Core diameter	0.0–14.73 14.73–17.43	0.278 0.042	0.0–13.60 13.60–49.31	0.278 0.042

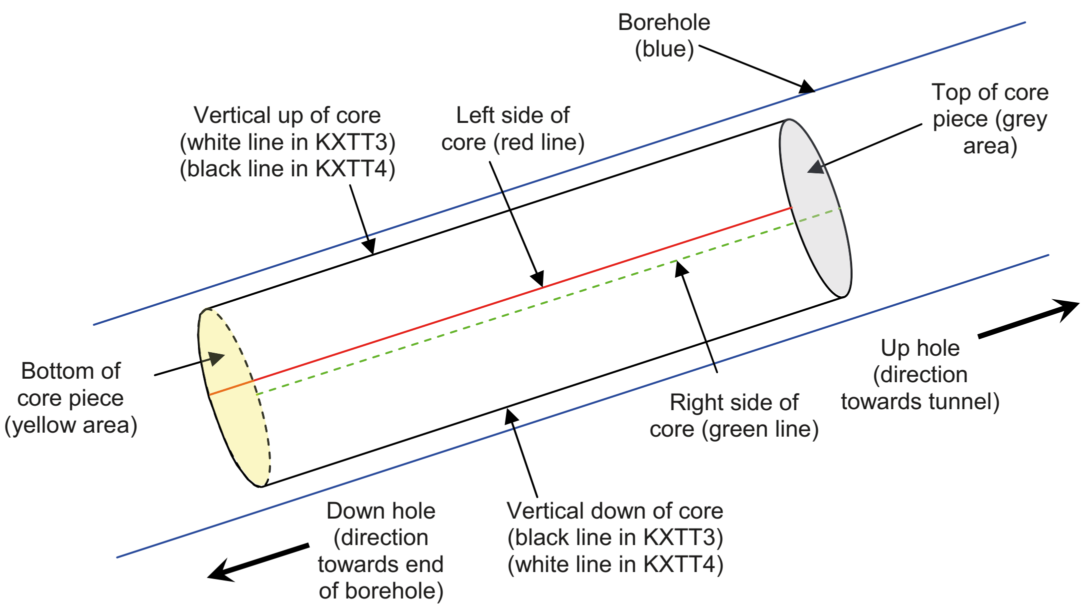

Figure 2-1. *Illustration showing the terms used to describe core orientation and position as well as borehole direction.*

3 Equipment and methods

Epoxy injection and subsequent over-coring of boreholes have previously been performed at the Äspö HRL within the TRUE-1 Pilot Resin Experiment as reported by Birgersson et al. (2000a, b) and the TRUE-1 Continuation Fault Rock Zones Characterisation project (Mærsk Hansen and Staub 2004) where much of the methods and procedures used in the current activity were originally developed.

There are, however, some differences in this project compared to the previously performed over-corings. In Mærsk Hansen and Staub (2004), the pilot borehole inclinations were close to horizontal and the target sections where located between c. one and five metres into the rock. Both KXTT3 and KXTT4 have a borehole inclination of c 36° (downward from the horizontal plane) and the target sections were located between c. 11 and 15 m into the rock, respectively. These differences between the overcoring described by Mærsk Hansen and Staub (2004), and that employed here for KXTT3 and KXTT4 were prior to the current activity identified as potential problems, especially for core recovery and induced core breaking. Another difference compared with earlier overcorings is that tracer experiments at the TRUE-1 site have included radioactive tracers and the site is therefore classified as a controlled area. Hence, special arrangements were made regarding radiation safety issues during the activities.

3.1 Re-installation of borehole equipment

The first activity within the TRUE-1 Completion project was to re-install the borehole equipment in KXTT3 and KXTT4. The new borehole instrumentation was designed with three hydraulic packers and two mechanical packers in each borehole, see Figure 1-2. With this configuration it was considered to be possible to extract the three outermost hydraulic inflatable packers by force while the two innermost mechanical packers remain in place, which was desirable in order to reduce the pressure and water inflow from the deeper parts of the boreholes while overcoring. However, the epoxy injected prior to the overcoring in the target sections may have glued the innermost of the three hydraulic packers such that it not could be pulled out. Due to this identified risk, the packer system was designed with a breaking point just outside packer number three.

In Mærsk Hansen and Staub (2004), a solid dummy was used in the borehole sections used for epoxy injection. This solid dummy had to be removed prior to the overcoring since it made the intentional breakage of the core difficult. In TRUE-1 Completion, the target sections of KXTT3 and KXTT4 were instrumented with a sectioned dummy. This dummy consists of a number of slices, 1 cm thick, in HD1000 material (white plastic as in regular cutting boards) attached to each other with M6 screws. The intention was that this sectioned dummy could remain in the borehole while the target section was overcored.

3.2 Epoxy injection

The epoxy injection in section KXTT3:S3 and KXTT4:T3 was performed in accordance with the methods and material used successfully in Fault Rock Zones Characterisation project using the epoxy EpoTek 301 with an added fluorescent substance EpoDye (Uranine) by the amount of 14 g per litre of base fluid. Uranine is essential for the subsequent analysis. Uranine is essential for facilitating subsequent analysis of fracture pore volume geometry using photography in UV-lighting. Prior to the epoxy injection, isopropanol was injected in order to facilitate the injection and adhesion to the structures of the epoxy by replacing the water. The equipment used for the injection is shown in Figure 3-1. The epoxy vessel was kept in water to ensure sufficient cooling since a heat release was initiated when the epoxy base and hardener were mixed.

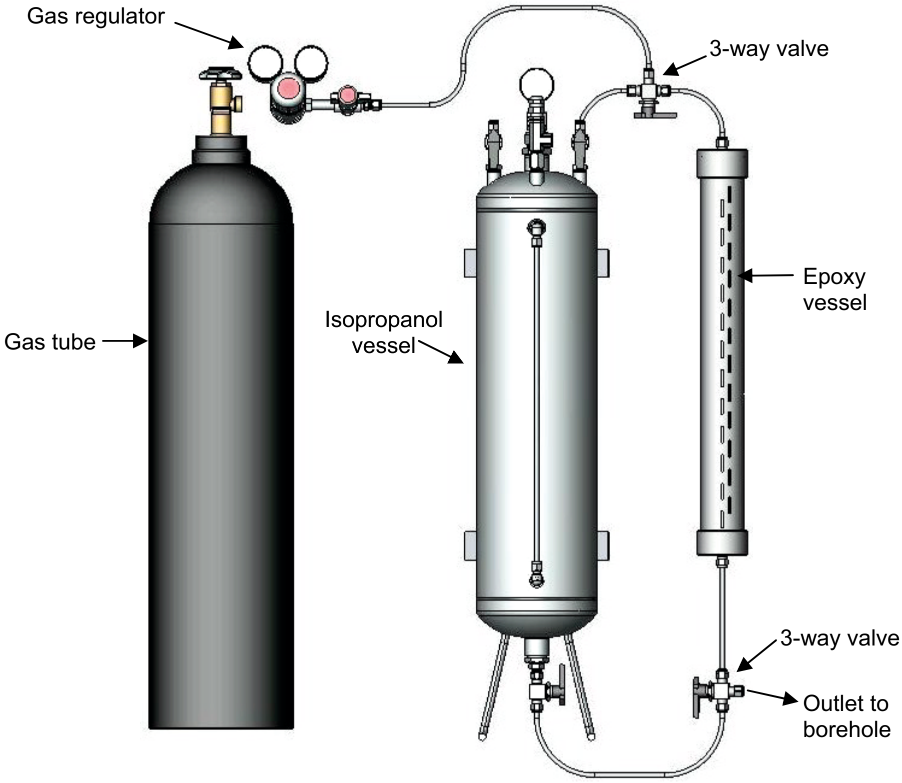

Figure 3-1. Schematic illustration of equipment used for injection of epoxy and isopropanol.

The injections of isopropanol and epoxy were carried out according to a pre-defined made strategy. The strategy included establishment of appropriate flow rates and pressures required in order to inject the desired amount of isopropanol and epoxy within a reasonable time. The injection strategies of isopropanol and epoxy are shown in Figure 3-2 and Figure 3-3. Based on prior injections of water in KXTT4:T3 during a SWIW-test (Nordqvist et al. 2014), it was foreseen that an injection pressure of 2 to 3 bars above the natural pressure would be sufficient, despite the slightly higher viscosity of the epoxy. Feature A has a higher hydraulic transmissivity in KXTT3 than in KXTT4 (Winberg et al. 2000), implying that 2–3 bars also would be sufficient in the case of KXTT3:S3. The reason for not using a higher injection pressure than necessary is the increased risk for displacement of fracture material in the fracture.

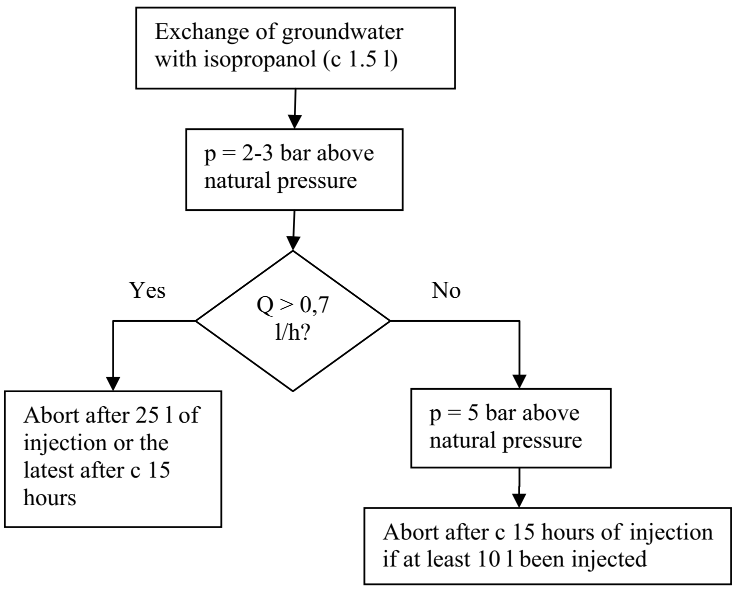

Figure 3-2. Strategy for injection of isopropanol.

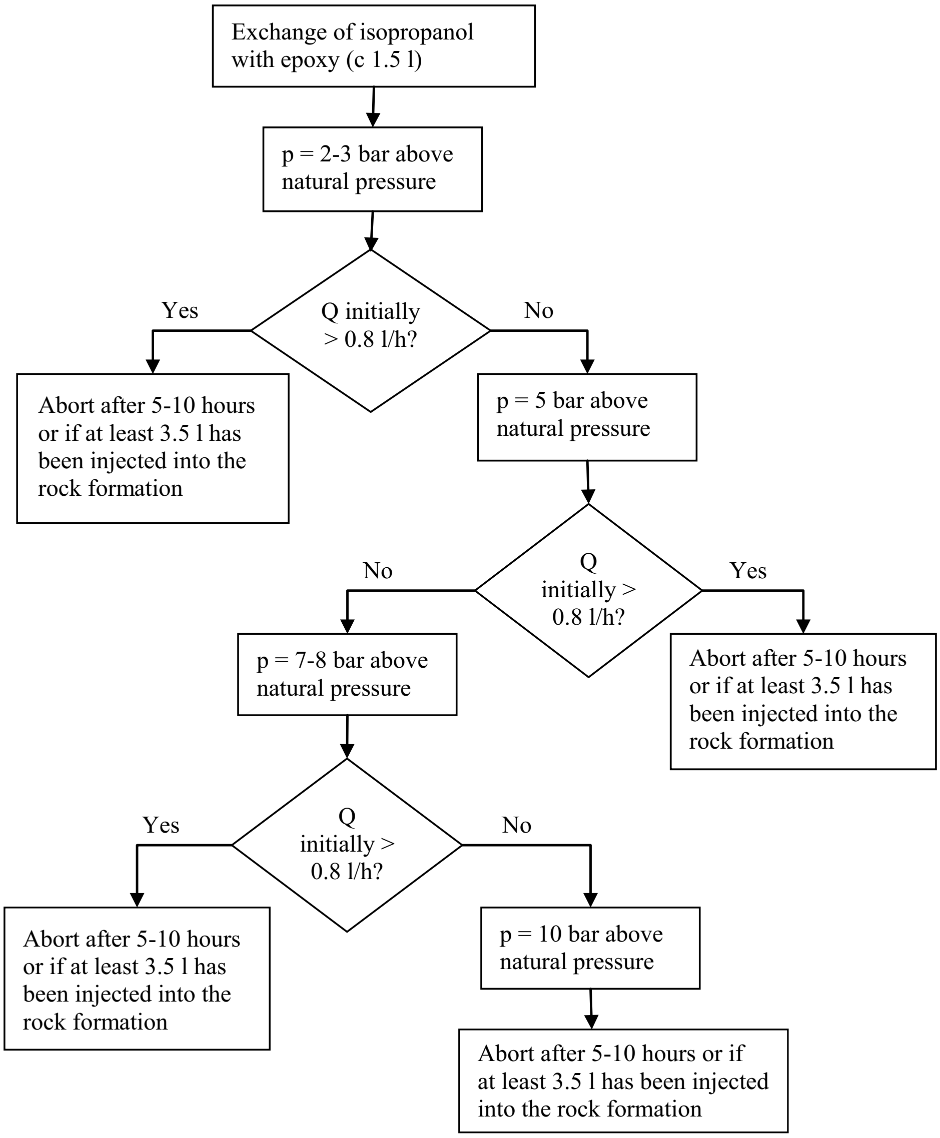

Figure 3-3. *Strategy for injection of epoxy.*

3.3 Removal of borehole instrumentation

After the epoxy injection, but before the overcoring, the borehole instrumentation in the borehole outside the target section was removed. The identified risk that the injected epoxy could clue the innermost of the three hydraulic inflatable packers, such that it not could be pulled out, was found to have come true in both boreholes, implying that only the two outermost hydraulic packers could be removed in each borehole.

3.4 Large diameter overcoring

The preparations at the site included the building of a concrete structure at the start of each borehole prior to the overcoring. These concrete structures were built to assist in the positioning of the drill rig so that the collaring will be perpendicular to the borehole direction as well as facilitating the collection of returned drilling water, see Figure 3-4 (a–d). A scaffold was built for the drill rig to place it at a suitable level for each borehole.

The overcoring of the boreholes KXTT3 and KXTT4 was made with an Onram 2000 CCD (Computer Controlled Drilling) drilling rig operated by the contractor Drillcon AB, see Figure 3-5 and 3-7 (a–d).

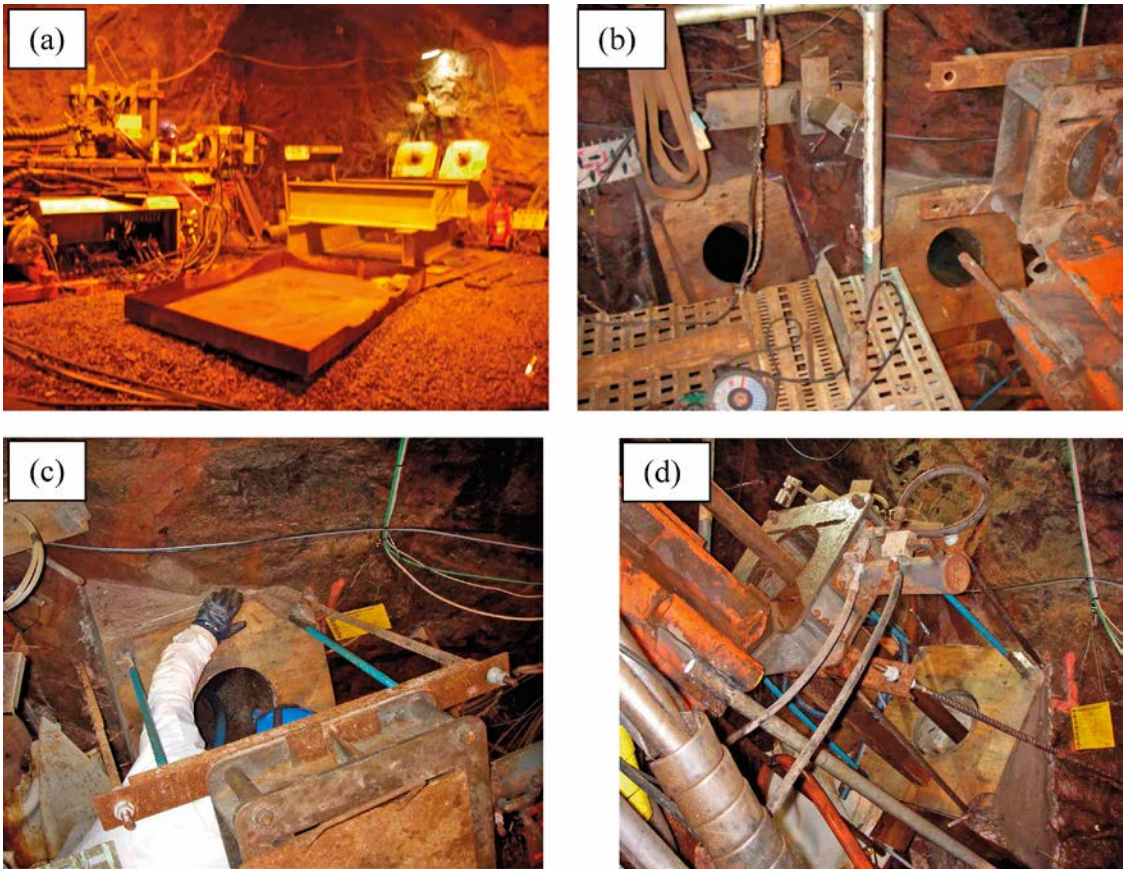

Figure 3-4. (a) The drill site after building of the concrete structures and before the arrival of the drilling machine. Scaffold in place for drilling at KXTT3. (b) Close-up of the two concrete structures after the overcoring of KXTT4. (c) Positioning rods (indicated in blue) at the KXTT4 site, driller doing a visual check of borehole. (d) Positioning rods at the KXTT4 site, drill rod in hole.

Figure 3-5. The Onram 2000 CCD computer controlled drill rig used for the overcore drilling of KXTT3 and KXTT4. The screen of the computer-aided control unit can be seen centre-left, behind the drillers.

The drilling water and drilling debris was handled according to a specified flow chart, see Figure 3-6, in order to avoid drill mud and cuttings from entering the drainage system of the Äspö HRL as well as for enabling continuous measurements of the radioactivity in the returned flushing water with a contamination monitoring instrument. In addition, the radioactivity was measured intermittently by a hand held high sensitive scintillation probe. The system was designed to manage a possible increase of inflow of water that widening of the borehole diameter might cause.

As previous experiments at the TRUE-1 site have included use of radioactive tracers, the site was classified as a controlled area and is therefore enclosed by a fence, see Figure 3-7.

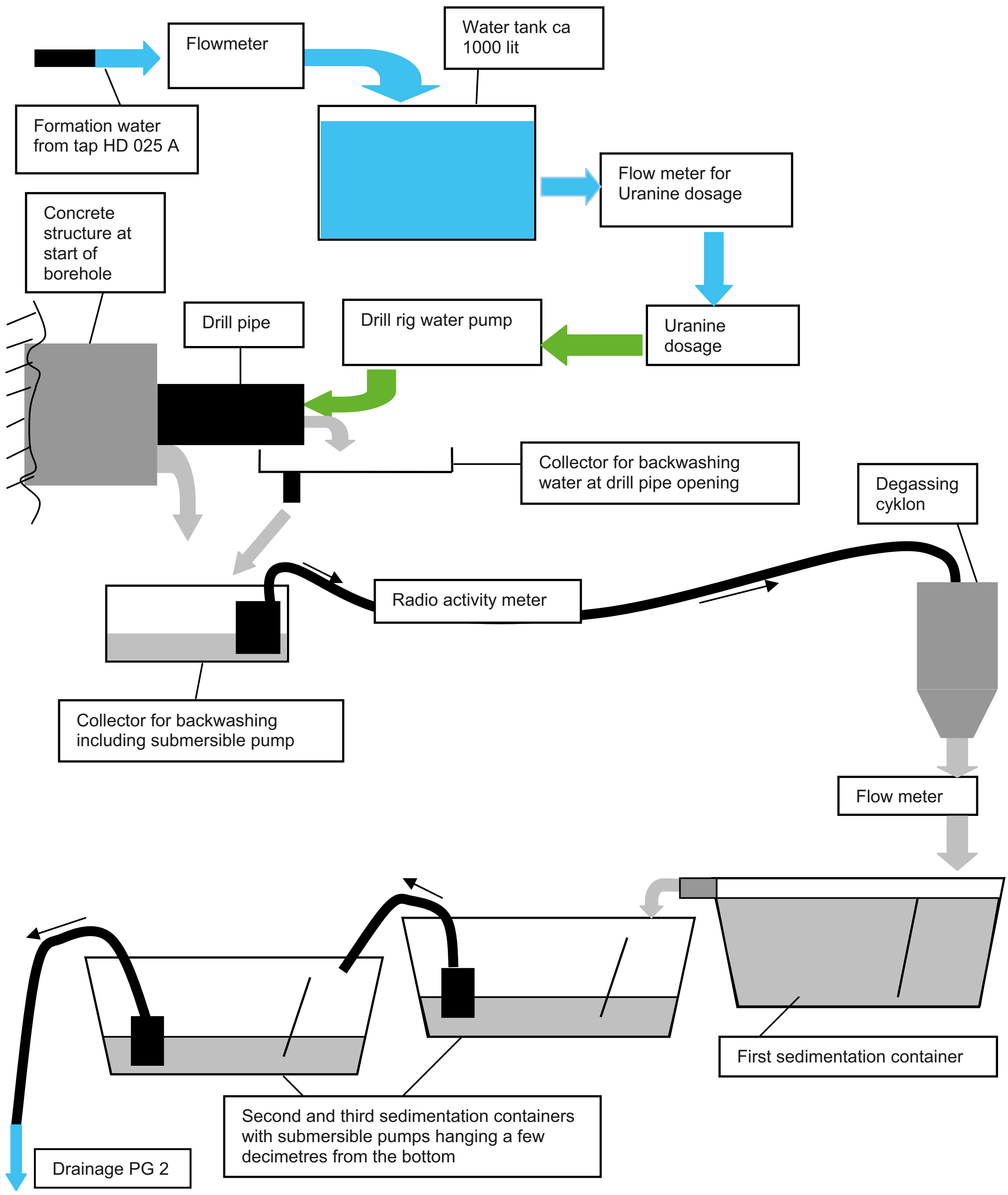

Figure 3-6. *System for management of flushing and returned flushing water during overcoring drilling at the TRUE-1 site.*

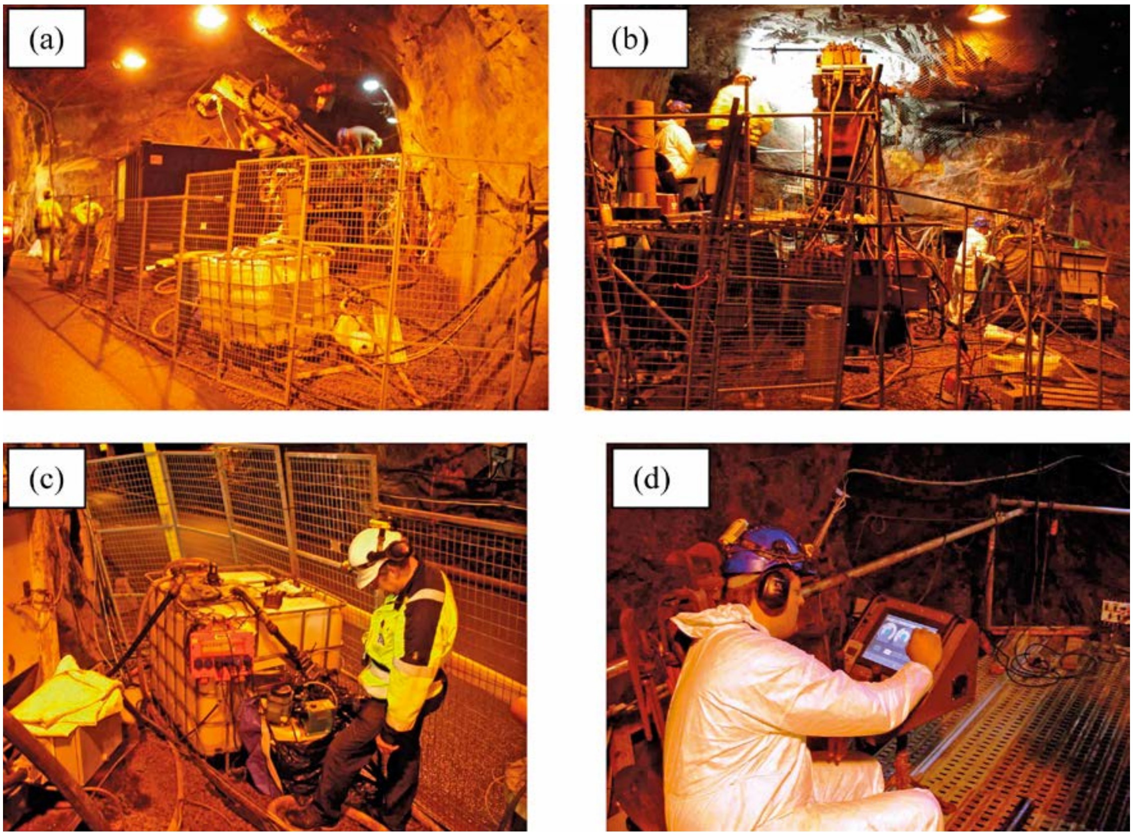

Figure 3-7. (a) Fenced-in niche with drilling machine in place at KXTT3. (b) Fenced-in niche with drilling machine in place at KXTT4. Visual check being made before drilling of flow meter and first sedimentation container (to the right of core platform). (c) Uranine container with automatic dosage unit. Visual check being made before drilling. (d) Driller at the computer aided control unit at the KXTT4 site. Note protective clothing being used.

Drilling was carried out in accordance with the methodology and plan made before the activity started, with some exceptions. Below, a general description is provided of the overcoring employed for both boreholes.

1. The concrete structure outside the borehole (a few decimetres thick) was penetrated with 300 mm core drilling in order to reach the bedrock for further drilling.
2. The borehole casing (c. 2 m) was removed by overcoring with diameter 0.116 m. Diameter 0.098 m was recommended beforehand, but was found too small for the purpose.
3. The remainder of the borehole was reamed to 76 mm from the original 56 mm down to the target section with the dual purpose of supplying better guidance for the subsequent overcoring and to enable removal of the innermost hydraulic packer.
4. Overcoring: The overcoring was a repetitive process with three steps:
   a. Overcoring with a core bit diameter of 300 mm, resulting in a core with a diameter of 278 mm, see Figure 3-8, to a specified depth or until a natural break in the core occurred.
   b. If a natural break in the core did not occur within a suitable length, induced core breakage was necessary. This was done by expanding a double steel plate by means of hydraulic oil in the annular space between the core and the borehole wall, see Figures 3-9, 3-10 and 3-11.

c. Core recovery was performed by means of a specific core recovery tool, see Figure 3-14. The core recovery barrel was pushed over the drilled out core in the borehole so that the core capturing ring would slide over the core and then hold it while being hoisted out of the borehole using the drill rig, see Figure 3-15. The core recovery barrel was then hoisted from the drill rig to the drilling platform by a small electric lifting device, see Figure 3-16. The barrel was subsequently lifted from the drill rig platform to the tunnel floor at the drill site with the same lifting device, see Figures 3-15 and 3-16. The core capturing ring was finally removed, see Figure 3-17, and the core was put in the core box, followed by preliminary logging, see Figures 3-18, 3-19, 3-20 and 3-21. The core recovery was often difficult to execute and needed considerable adaptation to the given situation.

Specific instructions for drilling lengths specified for safe extraction of target sections from both boreholes, see Appendix 6, were revised because of problems that arose during drilling. When drilling across open fractures the rock often broke into wedge-formed pieces which then became loose and started to rotate within the core barrel, causing grinding of the core pieces. These loose core pieces could also be instrumental in further fracturing of the core, so early uptakes of core were often needed, see Figure 3-21 and Appendix 6.

All cores were checked by radiation protection personnel from Clab (Central interim storage facility for spent nuclear fuel) for radioactivity, before transportation from the enclosed area. The drill rig and other equipment were also tested for radioactivity both during drilling and at the end of the activity. The overcoring drilling started at KXTT3, as higher levels of radioactivity were expected in KXTT4, in order to keep the site and equipment uncontaminated for as long time as possible. All core material from KXTT3 and most of the core material from KXTT4 were cleared regarding radiation, as was also all equipment parts. The core material from the target area of KXTT4 showed only low levels of radioactivity above the natural background.

Figure 3-8. *300 mm Core barrels of 76 cm and 225 cm core length, respectively (from Mærsk Hansen and Staub 2004).*

Figure 3-9. *Tools for inducing core breakage, double steel plates (before being expanded using hydraulics), (from Mærsk Hansen and Staub 2004).*

Figure 3-10. *Insertion of tool for core breakage, sliding below core (from Mærsk Hansen and Staub 2004).*

Figure 3-11. *Tool for inducing core breakage, double steel plates (after being expanded using hydraulics, up to 80 bars).*

***Figure 3-12.** A sledge constructed on site for core breakage, sliding the tool for core breakage into the borehole above the core.*

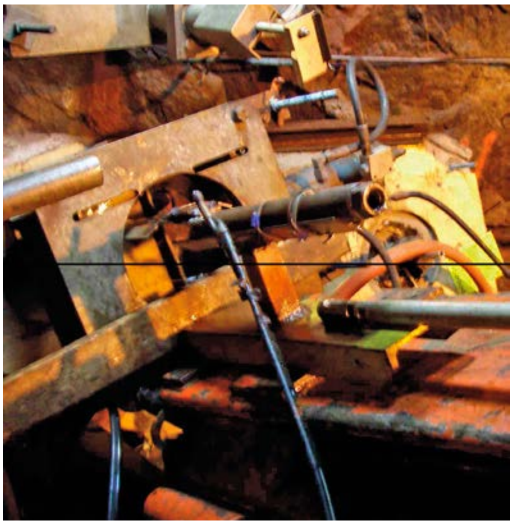

***Figure 3-13.** The sledge holding the tool for breaking, lined up to be connected to the drill stem for lowering into the hole.*

***Figure 3-14.** Drillers tightening the leading edge attached to the end of the capturing ring on the end of the core recovery barrel at ground level at the TRUE-1 drill site.*

Figure 3-15. *Core recovery barrel fastened to lifting device above drill rig for hoisting from the borehole to the drill rig platform.*

Figure 3-16. *Core recovery tool on drill rig platform, drillers preparing for lowering the core recovery barrel with core down to ground level beside drill rig.*

Figure 3-17. *Drillers extracting core piece from the capturing ring at the end of the core recovery barrel.*

Figure 3-18. Core recovery barrel on ground level beside drill rig with core capturing ring still attached to the barrel, containing a core piece from KXTT3, showing the fracture at 13.9 m (looking up hole), with chlorite (black) and some epoxy (green) filling.

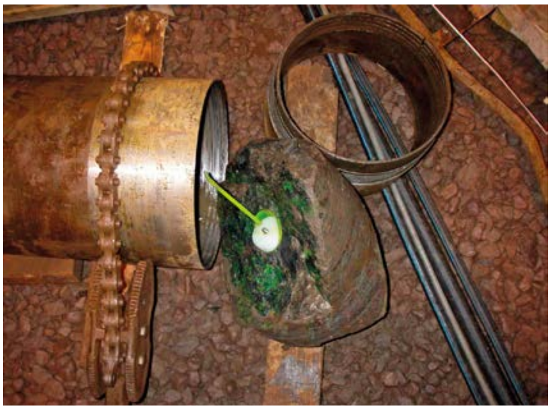

Figure 3-19. Core recovery barrel on ground level beside drill rig after core capturing ring has been removed, freeing core piece from KXTT3 with the fracture at 13.9 m (looking down hole), with chlorite (black) and some epoxy (green) filling.

3.5 Core orientation and core logging

Core orientation and core logging was carried out with some modification to the methodology made beforehand.

Initially the plan was to mark the bottom end of the core facing the tunnel at the start of drilling and then sequentially orient the core after fitting the pieces together, see Figure 3-20. This was made difficult from the start by the concrete structures that were established at the start of each borehole prior to the overcoring, making the marking of the core at the start of drilling impossible. Notwithstanding, knowing the inclination of the core, a lowest point would be possible to mark from the interface between the concrete and the tunnel rock face, see Figure 3-20.

It became readily apparent shortly after the drilling commenced that the core pieces did not always come out of the borehole intact, see Figure 3-21. This made the orientation of the core by fitting the pieces together very difficult and sometimes impossible due to many small core pieces in some sections. Instead, BIPS images previously made in the 56 mm holes were used as a reference for deciding the orientation and location (depth) of those core pieces that had recognisable features by which to orient the core from (e.g. fractures, rock veins etc.), see Figure 3-21. Data on strike and dip from the BIPS logging of the various mapped structures was obtained from Bossart et al. (2001, Appendix 1.1). The data in Bossart el al. (2001) is in agreement with BIPS images in the Sicada archive for the target sections. The BIPS images from the target sections in the 56 mm holes are shown in Appendices 3 and 4. All core pieces in the target sections that could be re-fitted together were given a number for easier identification, see Figure 3-23. Four orientation lines were drawn along the core in four colours with length markings every 10 cm.

***Figure 3-20.** The first core pieces from borehole KXTT3 in core box at drill site, where preliminary core logging, orientation and photographing was performed. Top of core to the left, concrete slab visible, black line marks vertical down of core. Length of core is approximately 0.0–0.74 m.*

***Figure 3-21.** Core pieces from target section of KXTT3 in core box at drill site, paper print of BIPS image left of core in core box. Subsequent logging in the core shed at Äspö HRL revealed that the right side of the core is facing the camera, down hole to the left, with the fracture at 13.9 m furthest to the left. Core length is approximately 13.3–13.9 m.*

Overview logging and photography was done at the drilling site, but because of lack of space in the tunnel niche, see Figure 3-22, the core down to the target sections of each borehole were only tentatively checked and registered, except for the first part of KXTT3. Instead, the cores were packed into boxes which were clearly marked in sequential order and transported off the site. The core from KXTT3 was transported to the Äspö HRL core shed. The same also applied to the material from KXTT4, with the exception of material from the target section in KXTT4, which was transported to Clab, because of radiation protection measures and regulations. The main logging and photography sessions of the target sections were carried out in their respective location at Äspö HRL and Clab.

Figure 3-22. The fenced-in drill site for the TRUE-1 overcoring activity, drill rig in position for overcoring of KXTT3.

Figure 3-23. Mapping of core pieces from target area of KXTT3 in progress in core boxes in the core shed at the Äspö HRL. Numbers of identified core pieces can be seen and black orientation line on core pieces #1 and #2 which indicates vertical down of core.

The target sections of both boreholes were mapped in detail in scale 1:5, including core length, fracture position, fracture orientation, fracture wall alteration, fracture mineral fill and locations of identified epoxy filling. Fracture position and orientation were determined by measuring the borehole length to the interception between the fracture and the four orientation lines. The maps were computer drawn using a CAD program (Microstation 7). The cores were also photographed using a digital camera (Canon G5). Fractures grouted with Uranine tagged epoxy were in addition photographed at UV light with a wavelength spectrum of approximately 254–336 nm at the Äspö core shed. At Clab, where the mapping of the target section of KXTT4 took place, the lighting intensity in the mapping locality was too strong to enable photography at UV light.

The KXTT3 core is broken up, especially close to the target section centred on Feature A. This made handling the core very difficult, since one of the objectives of the overcoring was to facilitate detailed sampling and investigation of those sections. In order to improve the handling and protection of the core after having been re-fitted together, plastic pipes of suitable dimension were used as additional supports, see Figure 3-24.

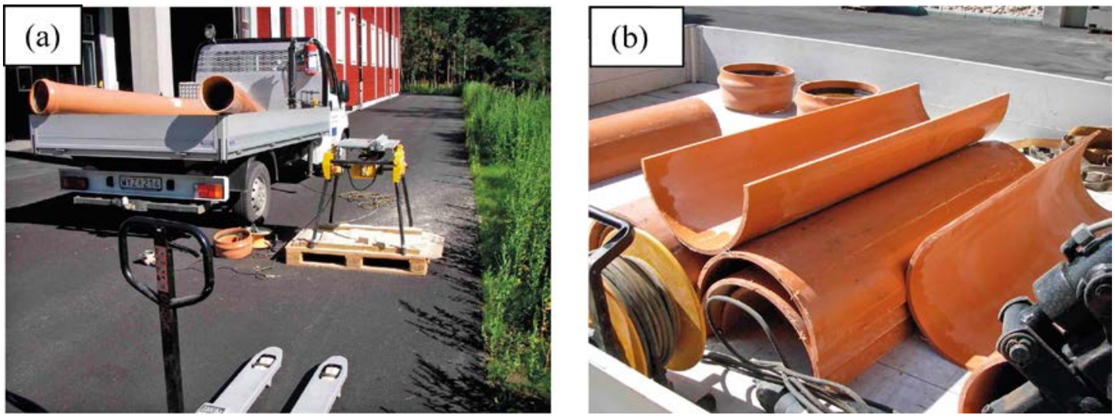

Figure 3-24. *(a) The plastic pipes being cut into appropriate lengths and split in two halves. (b) The final product (core cradles) for easier handling and protection of the broken-up cores.*

4 Results

4.1 Epoxy injection

The epoxy injection was carried out in accordance with the specified injection strategies stipulated beforehand. In both borehole sections the groundwater pressure prior to the injection was 32.2 bars. In KXTT3, c. 4.2 litres of epoxy was injected during c. 5 hours following the exchange from isopropanol to epoxy. In this case, the final pressure in the target section was c. 2.5 bars above the original section hydraulic pressure. In KXTT4 a much higher pressure had to be applied during the epoxy injection than applied during the injection of isopropanol in order to achieve a reasonable injection flow rate. Only c. 0.4 litres of epoxy was injected during c. 12 hours, even though the final pressure in the target section was c. 10 bars above the original section hydraulic pressure. This was not expected considering previously performed water injections in KXTT4:T3 (Nordqvist et al. 2014). Still, the amount of epoxy injected in KXTT4 was considered sufficient to fully impregnate and stabilize the target section for the subsequent overcoring and analysis of core material.

As described later in this report, it is considered proven that the amount of epoxy injected in the target sections was sufficient to penetrate well into the target fractures associated with Feature A in the two boreholes. However, the stabilisation effect of the epoxy was not sufficient to withstand the forces acting on the core during drilling and retrieval, such that the fractures containing epoxy were not recovered intact from the boreholes.

4.2 Overcoring

The overcoring of KXTT3 and KXTT4 proved to be more difficult than anticipated, mainly because of more breakage of the core than expected, which in combination with the borehole depth of the target section and relatively steep inclination of the boreholes made the capture and retrieval of core pieces difficult.

Especially important for the outcome of the overcoring was that the injected epoxy in the target sections did not provide sufficient stabilisation for safely retrieving the target fractures intact. Instead, the fractures containing epoxy, including Feature A and A', broke in two or more core pieces while overcoring and retrieving the cores. However, there were no signs of internal breakage of the epoxy itself. Instead, the point of breakage seemed to be associated with where the epoxy should be attached to the fracture surface mineral or between the fracture surface mineral and the rock matrix.

The overcoring of KXTT4 started, as was the case with overcoring KXTT3, with a 76 mm pilot borehole used for steering. However, after a few metres it became apparent that the overcoring in KXTT4 was deviating from the desired direction. Efforts were made to correct the direction without success. It was then decided to continue the overcoring without having established steering using the 76 mm pilot borehole. Fortunately, the deviation was limited such that the original 56 mm borehole was included in the retrieved core covering the target section.

The problems associated with retrieving the core pieces was firstly to capture the broken core into the retriever and secondly to keep it in place while retrieving the core. In the case when the core broke naturally because of fractures or had been broken with induced core breaking tools, the core segment was rarely in only one piece and small wedges then could, and often did, stop the retriever barrel when the drillers tried to slid it around the core for retrieval. Also in the case when the core could be slid into the core retriever, the fastening rings in the retriever sometimes did not manage to hold on to the core. The core pieces were often too small or too short to lie still in the core recovery barrel and often moved and slipped out when the string of rods was pulled out of the borehole.

The methodology developed during the drilling was to lower the drill bit with the retriever barrel behind it. This made it possible for the driller to revolve the drill bit while gently sliding down around the main core, in spite of smaller pieces which otherwise would wedge between the core and borehole wall and stop the core retrieving barrel. When the drill bit had reached the bottom of the hole, the core retrieving barrel was long enough to keep the core inside. The drillers carefully avoided all sudden movements when retrieving the barrel from the hole, to further increase the chances of keeping the core segments and pieces in place within the barrel.

In the end, a balanced mix of rough pushing and grinding, to force the drill bit over the core followed by very delicate pulling out of the core recovery barrel was the method employed to retrieve the core. This applied especially to those parts which were weakened because of fracturing, as was the case for the target section in KXTT3.

Another important component of the methodology was the breaking of the core, which also caused considerable problems. In the end the drillers had both a tool which broke the core from below as well as a specially constructed sledge that held a core breaking tool which could then be slid in above the core for breaking it. The rule was to try and break the core first from below and if that did not succeed, sometimes because the core breaking tool could not be slid in under the core, the sledge was lowered to try and break the core from above.

Early in the overcoring, there were indications that the core breaking tool was sliding out of position while expanding it. By switching to a core breaking tool made of thinner metal this problem was solved.

The overcoring, breakage of the core and core retrieval are described in detail in Appendix 6.

The basic result of the overcoring of the target section of KXTT3 in terms of retrieved geologic material, was 34 core pieces of various sizes that were possible to identify and orient, collected from approximately 12.45 to 14.65 m borehole length. In borehole KXTT4 the corresponding basic result was 11 identified and oriented core pieces, collected from approximately 11.70 to 13.50 m borehole length. During the process of documenting the cores it became apparent that some core loss had taken place during the overcoring, in spite of the great care taken during drilling.

4.3 Core documentation

4.3.1 KXTT3

According to the plan made beforehand the target section in the borehole is between 12.67–14.72 m borehole length. The retrieved core reported here from the target section is between 12.45–14.65 m borehole length. Exact borehole lengths of fractures were obtained after comparison with BIPS images from the original 56 mm borehole.

The use of plastic half-pipes helped the handling, re-fitting, orienting, photographing and mapping of the broken up target section of KXTT3. Still, several smaller pieces could not be fitted to the core at all, because of their small size and core loss. Remaining holes in the core after fitting it together indicate that parts of the core was lost during the drilling, ground out by the drill bit while trying to arrange the broken up core pieces in the inclined borehole, such they could be captured and retrieved to the surface.

The four orientation lines attached to the core of KXTT3 are; white (vertical up of core), black (vertical down of core), red (left side of core) and green (right side of core). The map in Appendix 1 shows the mapping of KXTT3 folded out in planar in two dimensions cut along the vertical up of core. A fracture intersection with the core is shown as a sinusoidal form in this map. In total 34 core pieces were fitted together, oriented, marked, photographed and mapped. Due to the complexity induced by the many core pieces in KXTT3, the target section is also presented in a 3D map made in the computer program 'Rhino 3D', see Appendix 5. The coordinates (borehole length) of Feature A and other epoxy carrying fractures in the KXTT3 core can be seen in Table 4-1 and the lengths as well as strike/dip of mapped comparable fractures is the 56 mm BIPS image are provided in Table 4-2 for comparison.

Photographs of fracture surfaces and the core, including core piece numbers, orientation data and short comments, in the target section of KXTT3 are stored digitally by SKB..

From Appendices 1 and 5 it is readily apparent that occasional core loss has occurred during overcoring of KXTT3.

The main rock type is medium to coarse grained, mainly massive Äspö diorite (porphyritic quartz monzonite to granodiorite) with minor amounts of finer grained granite. The rock types are usually massive, with some deformation occurring in conjunction with Feature A. The main fracture filling mineral is chlorite, with lesser amounts of epidote and calcite. Chlorite and epidote occur in both open and closed fractures, while calcite only appears in open fractures within the target section of KXTT3. The observed features in the retrieved core from the overcoring coincide with the lithological description presented by Bossart et al. (2001) for borehole KXTT3.

Generally, the dominating strike of open fractures in the Äspö area is northwest to southeast trending and mainly steeply dipping. This coincides approximately with the main direction of epoxy filled fractures in the target section of borehole KXTT3. Due to the short length of the target section and thereby a small number of observed fractures, no extensive analysis of fracture geometries and fracture fillings etc was made. However, this can be found in Bossart et al. (2001).

Fractures that are characterised as being open within the target section are found at 13.075, 13.39, 13.41 and Feature A at 14.10 m borehole length (Bossart et al. 2001). These fractures were also found to contain epoxy during the overcoring, with the exception that the fractures at 13.39 and 13.41 m only contained trace amounts of epoxy. However, the distribution of epoxy-filled fractures indicates a more complex situation compared to that given by earlier characterisation in that the fracture found at 14.13 m (at vertical up of the core) has a distinctly different dip than the rest of the fractures associated with Feature A. In fact, this fracture has a dip and strike similar to the fracture at 13.12 m (at vertical up of the core), see Appendix 1. The epoxy filled fracture at 14.13 m (at vertical up of the core) intersects the fracture at 13.93 m (at vertical up of the core, which is interpreted as Feature A) within the large diameter core. The epoxy filled fracture at 13.12 m (at vertical up of the core) should intersect with Feature A, if the fracture planes are extrapolated, within 1 m above KXTT3 and within 2.5 m to the right of KXTT3. Epoxy was found to cover the entire overcored part of Feature A in KXTT3, implying that a sufficient amount of epoxy had been injected.

Table 4-1. KXTT3. Coordinates (borehole length) of fractures containing epoxy, cf. Appendix 1.

Feature	Orientation lines Vertical up of core White (m)	Right side of core Green (m)	Vertical down of core Black (m)	Left side of core Red (m)	Comment
Not Feature A	13.12	13.10	13.02	13.06	Bottom of core piece 2 and top of core piece 3.
Not Feature A	13.28	13.35	13.49	13.47	Core pieces 5 and 7 to a small degree closest to the pilot hole.
Possibly part of Feature A?	13.75	13.86	13.97	13.94	Bottom of core pieces 14 and 12 and top of core piece 15. Small core pieces 16, 18, 19 and 20 are also involved
Feature A	13.93	14.07	14.25	14.15	Bottom of core pieces 15, 28, 29, 25 and 30. Top of core pieces 32, 33, 29, 34 and 31
Feature A	14.02	14.07	14.25	14.15	Bottom of core pieces 33, 15, 29 and 31. Top of core pieces 36, 35 and 34
Feature A	14.08	14.07	14.25	14.15	Bottom of core pieces 36, 33, 15, 29, 31 and 36. Top of core pieces 35 and 34
Feature A	14.13	14.12	14.04	14.07	Bottom of core pieces 35, 15, 26, 27, 30 and 25 (and 31, 36 and 35?). Top of core pieces 34, 29, 26, 27, 21, 22, 23, 25 and 34
Feature A	13.93		14.11	14.03	Bottom of core pieces 15, 23, 24 and 21. Top of core pieces 32, 30, 29 and 27

Table 4-2. KXTT3. Coordinates (Borehole length) of fractures according to BIPS imagery in 56 mm boreholes, cf. Appendix 3.

Feature	BIPS image Vertical down of hole (m)	Right side of hole (m)	Vertical up of hole (m)	Left side of hole (m)	Right hand rule Strike/dip (degrees)	Aperture (mm)	Comment
	13.09	13.08	13.07	13.07	096/39	4	Between core pieces 2 and 3?
	13.95	13.95	13.89	13.90	331/77	3	Bottom of core pieces 15 and 29?
	14.08	14.06	14.04	14.05	308/89	1	Just above Feature A
Feature A?	14.12	14.12	14.09	14.08			Not mapped
Feature A	14.13	14.12	14.08	14.08	325/78	5	

4.3.2 KXTT4

According to the plan made before the drilling, the target section is in this case between 11.67–13.68 m borehole length. The retrieved core reported here from the target section is between 11.7–13.5 m borehole length. Exact borehole lengths of fractures were obtained after comparison with BIPS image.

The four orientation lines attached to the KXTT4 core were; white (vertical down of core), black (vertical up of core), red (left side of core) and green (right side of core). Appendix 2 shows the mapping of KXTT4 folded out in planar in two dimensions cut along the vertical down of core. A fracture intersection with the core is shown as a sinusoidal form in this map. In total 11 core pieces were fitted together, oriented, marked, photographed, mapped and described. The lengths to Feature A and other epoxy carrying fractures in the KXTT4 core are presented in Table 4-3 and the lengths as well as strike/dip of mapped comparable fractures from the BIPS image in the original 56 mm borehole are provided in Table 4-4 for comparison. The associated part of the BIPS image is presented in Appendix 4.

Photographs of fracture surfaces and the core, including core piece numbers, orientation data and short comments, in the target section of KXTT4 are stored digitally by SKB

From Appendix 2 it is readily apparent that occasional core loss has occurred during overcoring of KXTT4.

The main rock type is medium to coarse grained, mainly Äspö diorite (porphyritic quartz monzonite to granodiorite), finer grained granite occurs also as well as minor amount of fine grained diorite/gabbro (mafic rock). The rock types are usually massive, with some deformation occurring in conjunction with Feature A and A'. The main fracture filling mineral is chlorite, with lesser amounts of epidote and sometimes prehnite as well as calcite. Chlorite, epidote and calcite occur in both open and closed fractures, while prehnite seems to occur only in closed fractures within the target section of KXTT4. The observed features in the retrieved core from the overcoring coincide with the lithological description presented by Bossart et al. (2001) for borehole KXTT4.

Generally the dominating strike of open fractures in the Äspö area is northwest to southeast trending and mainly steeply dipping. This coincides approximately with the main direction of epoxy filled fractures in the target section of borehole KXTT4. Due to the short length of the target section and thereby a low number of fracture observations, no extensive analysis of fracture geometries and fracture fillings etc were made. However, this can be found in in Bossart et al. (2001).

Fractures that are characterised as being open within the target section are found at 12.11 (Feature A), 13.02 (Feature A') and 13.49 m borehole length (Bossart et al. 2001). This is in agreement with the observations of epoxy at the overcoring. However, small amounts of epoxy were also found in the fractures between core piece 1 and 2 as well as between core piece 3 and 7, see Appendix 2. These fractures deviate from Feature A in both strike and dip and have an irregular, rough surface and no natural fracture filling. Considering the lack of natural fracture filling, these two fractures may be interpreted as being not naturally flowing fractures and the epoxy found in them may be an artefact of the high pressure (c 10 bars) used during the epoxy injection. The same interpretation may also be valid for the fracture at the bottom of core piece 11. Epoxy was found to cover, at least partially, the entire overcored part of Feature A in KXTT4, implying that a sufficient amount of epoxy had been injected.

Table 4-3. KXTT4. Coordinates (borehole length) of fractures containing epoxy, cf. Appendix 2.

	Orientation lines				
	Vertical down of core	Right side of core	Vertical up of core	Left side of core	
Feature	White (m)	Green (m)	Black (m)	Red (m)	Comment
Possibly part of Feature A?	12.04	–	–	–	Bottom of core piece 1 and top of core piece 2.
Feature A	12.24	12.09	11.91	12.04	Bottom of core piece 1 and 2. Top of core pieces 3, 4, 5 and 6.
Possibly part of Feature A?	12.26	12.36	12.31	12.24	Bottom of core piece 3. Top of core piece 7. Small amount of epoxy
Feature A'	13.14	13.10	12.87	13.00	Bottom of core piece 8. Top of core piece 11
	13.5	13.53	13.4	13.49	Bottom of core piece 11. Small amount of epoxy

Table 4-4. KXTT4. Coordinates (borehole length) of fractures according to the BIPS imagery in the original 56 mm borehole, cf. Appendix 4).

	BIPS image						
	Vertical down of hole	Right side of hole	Vertical up of hole	Left side of hole	Right hand rule		Comment
Feature	(m)	(m)	(m)	(m)	Strike/dip (degrees)	Aperture (mm)	
Feature A	12.13	12.10	12.06	12.09	326/76	4	Between core pieces 1 and 3?
	12.20	12.19	12.17	12.18	326/80	3	Above Feature A
Feature A'	13.07	13.04	13.02	13.04	314/80	1	Between core pieces 8 and 11?

5 Summary and discussion

The re-installation of borehole equipment, epoxy injection and overcoring of KXTT3 and KXTT4 described in this report fulfilled most parts the specified objectives for these activities.

The re-installation of borehole equipment made it possible to carry out the TRUE-1 Completion project basically as planned and without unnecessary disturbances of other projects at Äspö HRL.

The epoxy injection has overall worked out well even though a high pressure had to be employed in order to inject sufficient amounts of epoxy into the fractures of the target section of KXTT4. The difference between KXTT3 and KXTT4 regarding epoxy take is correlated with the differences in transmissivity of Feature A in the two boreholes and the slightly higher viscosity of epoxy compared with water. In Winberg et al. (2000), the transmissivity of Feature A as measured in KXTT3 was about 10^{-7} m^2/s while the transmissivity in KXTT4 was about 10^{-8} m^2/s.

The removal of the inflatable hydraulic packers also worked well except that the last hydraulic packer was glued so tightly by the epoxy that it had to be left and drilled out later.

The objective with the overcoring was to retrieve the cores from the target section and, if possible, with the target fractures, Feature A and A´, intact. Cores from the predefined target sections of boreholes KXTT3 and KXTT4 were retrieved, although the cores were more broken up than planned, and some core loss occcurred. In summary, the objective of the overcoring was partially fulfilled as the cores were retrieved, however with target fractures broken.

The end result of the activities presented in this report were a better general understanding of Feature A and other fractures situated in the target sections as well as documented core material with injected epoxy possible to use in coming analysis.

The core from the target section of KXTT3 was particularly broken up which lead to major problems with the down hole core breaking and retrieval and the plan for the drilling had to be revised at several occasions.

In the KXTT4 overcoring, problems arose relating to the steering of the drilling, resulting in the overcoring deviating from the desired direction. Overcoring using the small diameter pilot borehole turned out impossible and had to be abandoned. After some deliberation it was decided to continue with long drill core barrels attached to the drill bit seconded by continuous measurements of the deviation. Despite the fact of not using the pilot borehole, the target fractures of KXTT4 were reached and contained within the large diameter core.

The sectioned dummy used in the target section worked as intended and was breaking at approximately the same positions as the core itself. However, the dummy did not seem to provide structural support the core to any significant degree.

Generally, with time and accumulated experience, the drillers improved their capability of solving the breaking and retrieving problems. The retrieved KXTT4 core was found to be more intact than that of KXTT3. This is in part attributed to the experience gained, but also to the fact that the core of KXTT4 contains fewer fractures than that of KXTT3.

In the TRUE-1 Continuation "Fault rock zones characterisation" project, four out of seven overcorings showed a successful result with the target fractures retrieved intact (Mærsk Hansen and Staub 2004). The main reasons why the overcoring within the present activity was more difficult compared with previous campaigns resulting in the target fractures retrieved not intact are considered to be:

- The more complex character of Feature A in KXTT3 than anticipated, see Section 4.3.1 and Appendices 1 and 5.
- The fracture filling in the open fractures is mainly chlorite resulting in a core relatively easily broken during drilling.
- Core pieces that were too small to be collected by the collecting ring of the core collecting barrel, resulting in forced drilling through smaller core pieces until a large enough retrievable core piece was acquired.
- The inclination of the boreholes, approximately 37 degrees downwards, compared with approximately horizontal boreholes employed in Mærsk Hansen and Staub (2004), posed problems because smaller broken core pieces blocked either or both the breaking device or/and the core collecting barrel. Core pieces that had been collected in the core collecting barrel also fell out while being hoisted along the borehole if they were too small for the capturing ring to retain them.
- The distances to the target sections were typically longer (11–15 m) in this campaign compared that reported by Mærsk Hansen and Staub (2004) (1–5 m).

The distance to the target section and the inclination were identified prior to the overcoring as potential risks. However, the problems faced due to the borehole inclination and distance to target section exceeded expectations.

The orientation, photographing and mapping of the target sections of both KXTT3 and KXTT4 required more time and efforts than initially planned, due to the broken-up character of the target cores. At the drill site it was difficult to handle the cores due to limited working space. To limit the handling and preserve the core pieces to the extent possible, it was decided to move them to the core shed at Äspö HRL for orientation, photographing and mapping. The target section of KXTT4 proved to be radioactive, as expected, so it was moved to Clab for the same type of measurements and documentation.

The main rock type is medium to coarse grained, mainly massive Äspö diorite (porphyritic quartz monzonite to granodiorite) with minor amounts of finer grained granite, as well as fine grained diorite/gabbro (mafic rock) in KXTT4. The main fracture filling mineral in both boreholes is chlorite, with lesser amounts of epidote and calcite, some prehnite occurs also in KXTT4, mainly in association with epidote. Chlorite and epidote occurs in both open and closed fractures in both boreholes, while calcite only occurs in open fractures in KXTT3 and prehnite only in closed fractures in KXTT4. The geological observations of the overcored core bits from the target sections in both KXTT3 and KXTT4 coincide with the description in Bossart et al. (2001).

For both KXTT3 and KXTT4, the fractures earlier characterised as open by Bossart et al. (2001) were also found at the core mapping to contain epoxy. This is considered satisfactory from a methodology point of view regarding core mapping. However, some additional fractures are containing epoxy that had not previously been identified as open by Bossart et al. (2001). This may possibly suggest a more complex system of open fractures within the target sections than previously interpreted for the borehole interval where Feature A intersects the boreholes. However, some of these fractures in KXTT4 may contain epoxy as a result of the high injection pressure (c 10 bars) used during the epoxy injection and not naturally flowing fractures. Fractures containing epoxy not being interpreted as a part of Feature A or A', intersect Feature A or A' either within the large diameter cores or, if extrapolated, within a short distance of the KXTT3 and KXTT4 overcore peripheries.

5.1 Important experiences and recommendations for future overcoring activities

Several experiences from this activity should be considered when planning similar overcoring activities in the future.

- The epoxy injection overall worked well, but for fractures with low transmissivity an epoxy with lower viscosity and/or longer time for hardening need to be considered.
- A sectioned dummy is recommended for reducing the annular space of the target section in any future application. However, the sectioning of the dummy should be made in such a way that it provides mechanical support to the core. This will reduce unintended breakage but will also facilitate breakage at the intended positions. This demands a careful plan, identifying the intended breakage points prior to the packer installation in the borehole.
- When dealing with this type of rather complicated overcoring and drilling it is crucial to establish an inventivene atmosphere and a continued ongoing day-to-day discussion involving the drillers, site geologist and project leader in order to meet the objectives of the activity.
- The distance to the target sections and inclinations of the boreholes faced in this activity posed a greater problem than anticipated. The methods for drilling, breaking and retrieving the cores were continuously improved during the campaign but the difficulties still remained for the most parts. A tentative conclusion may be that the method for overcoring may not be suitable for the distances and inclinations experienced in this activity. For example, it can be assumed that overcoring would be easier if the borehole was directed upwards. Alternative methods should be considered if larger pieces of overcored rock are to be extracted at similar conditions.
- In the case of KXTT3 and KXTT4 it seems that the points of breakage for the most part occurred between the fracture wall rock boundary and the fracture surface mineral (mainly chlorite) while the epoxy infill remained intact. Hence, the type of fracture minerals present seems to be an important factor for the successful retrieval of intact epoxy-filled fractures by way of overcoring and should be considered when planning similar activities.

6 Acknowledements

The patience and endless efforts by Drillcon AB and its drillers in finding workable solutions for safe retrieval of the target cores is acknowledged.

The guidance and support during execution of this activity as well as careful review of this report by Anders Winberg, project leader of TRUE-1 Continuation, is also gratefully acknowledged.

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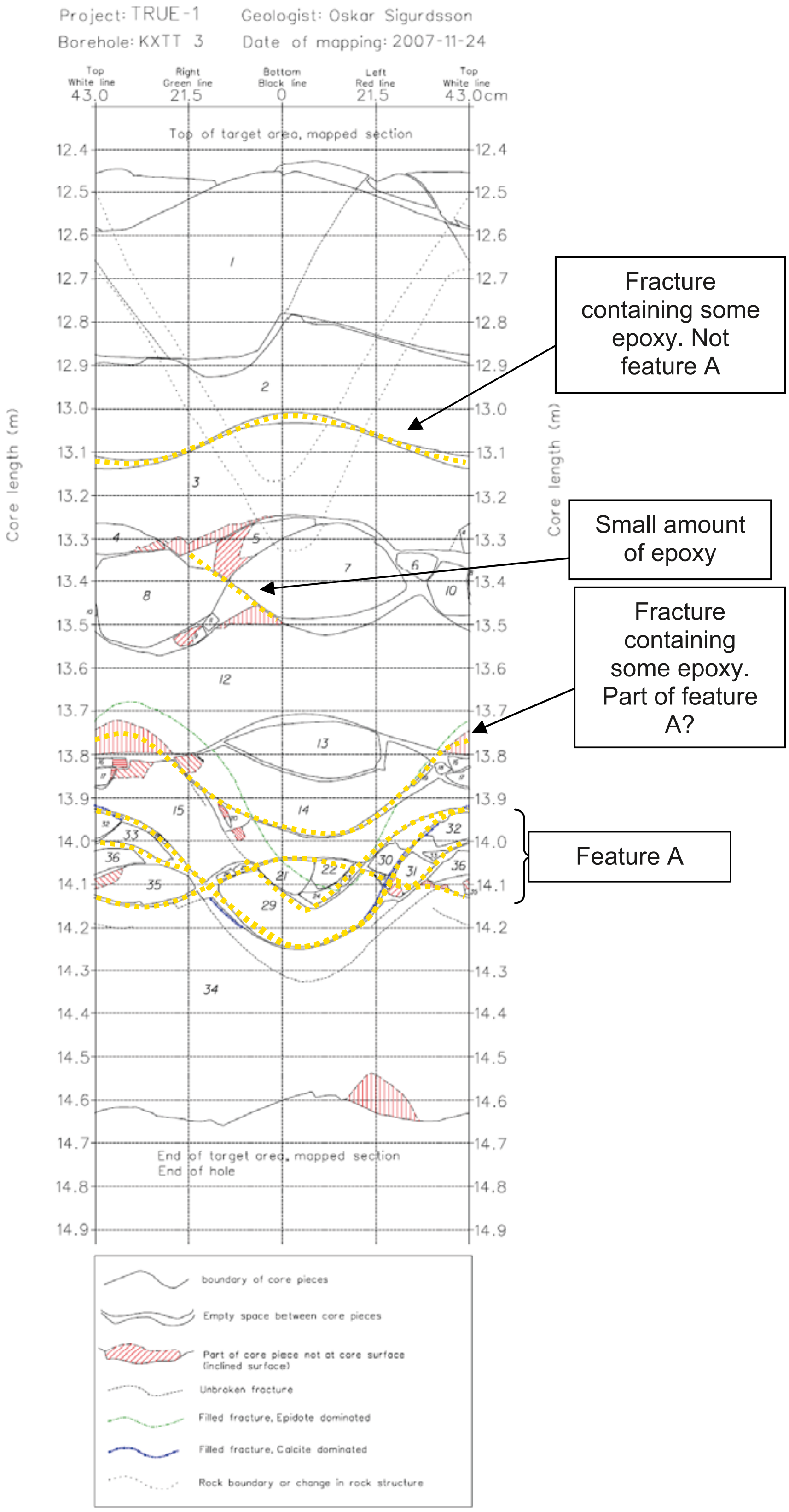
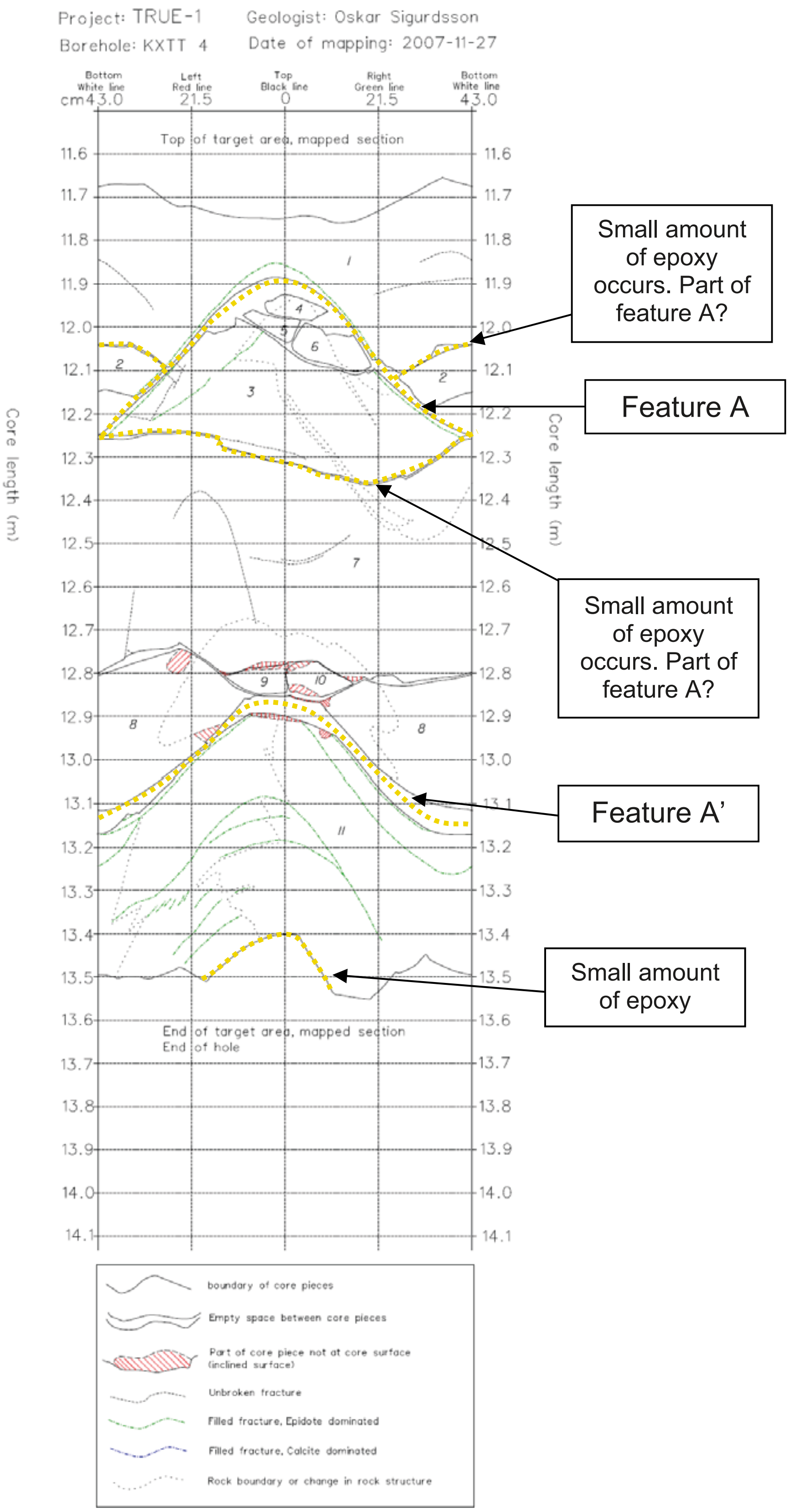
Structural geology and observations of epoxy in target section of KXTT3

Observe that this map shows the structures as they appear in the borehole wall. Core pieces are indicated with numbers 1–34 in the map.



Structural geology and observations of epoxy in target section of KXTT4

Observe that this map shows the structures as they appear in the borehole wall. Core pieces are indicated with numbers 1–11 in the map.



BIPS images of KXTT3

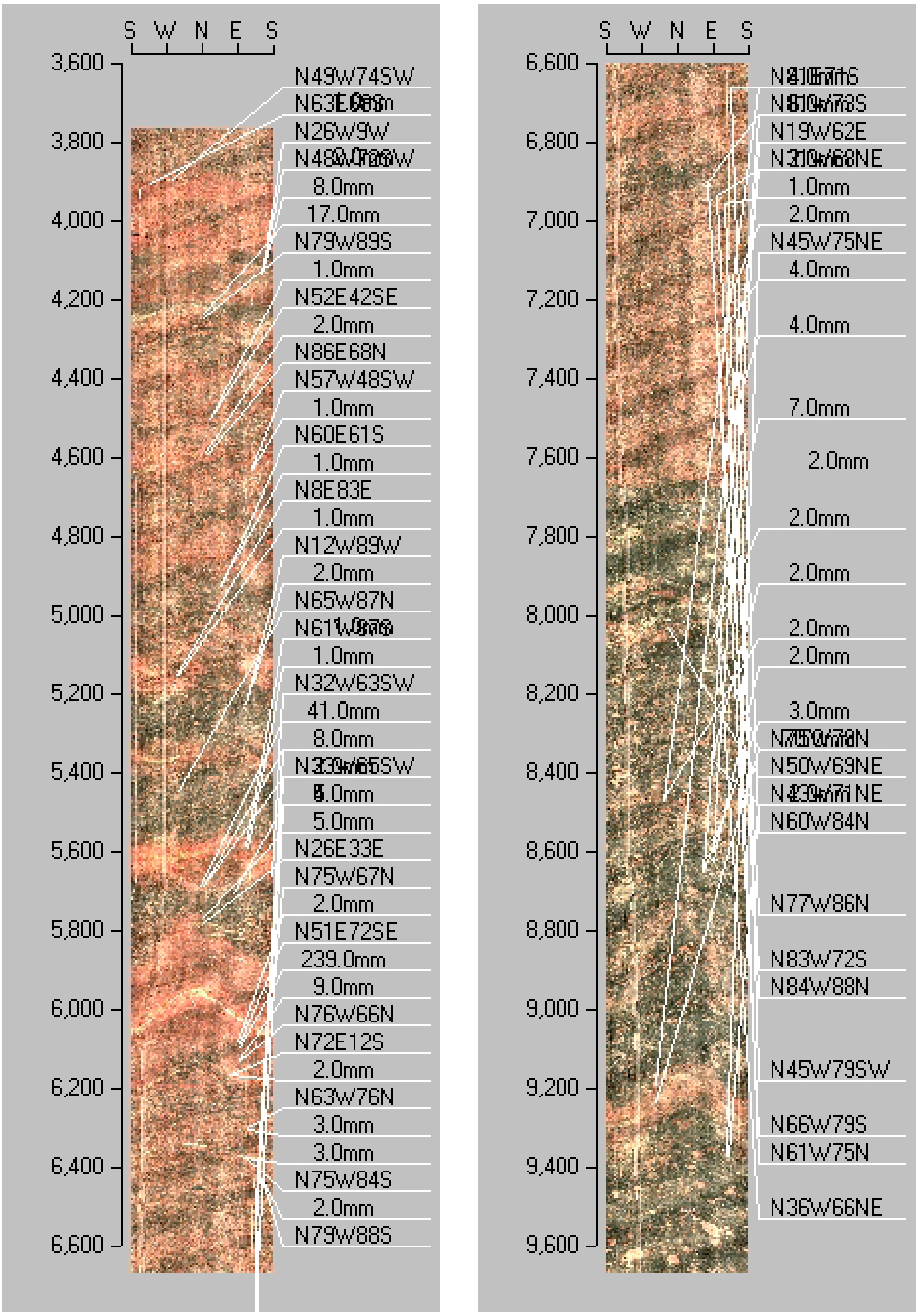


Figure A3-1. *Left: BIPS_KXTT3_3,6–6,6 m. Right: BIPS_KXTT3_6,6–9,6 m.*

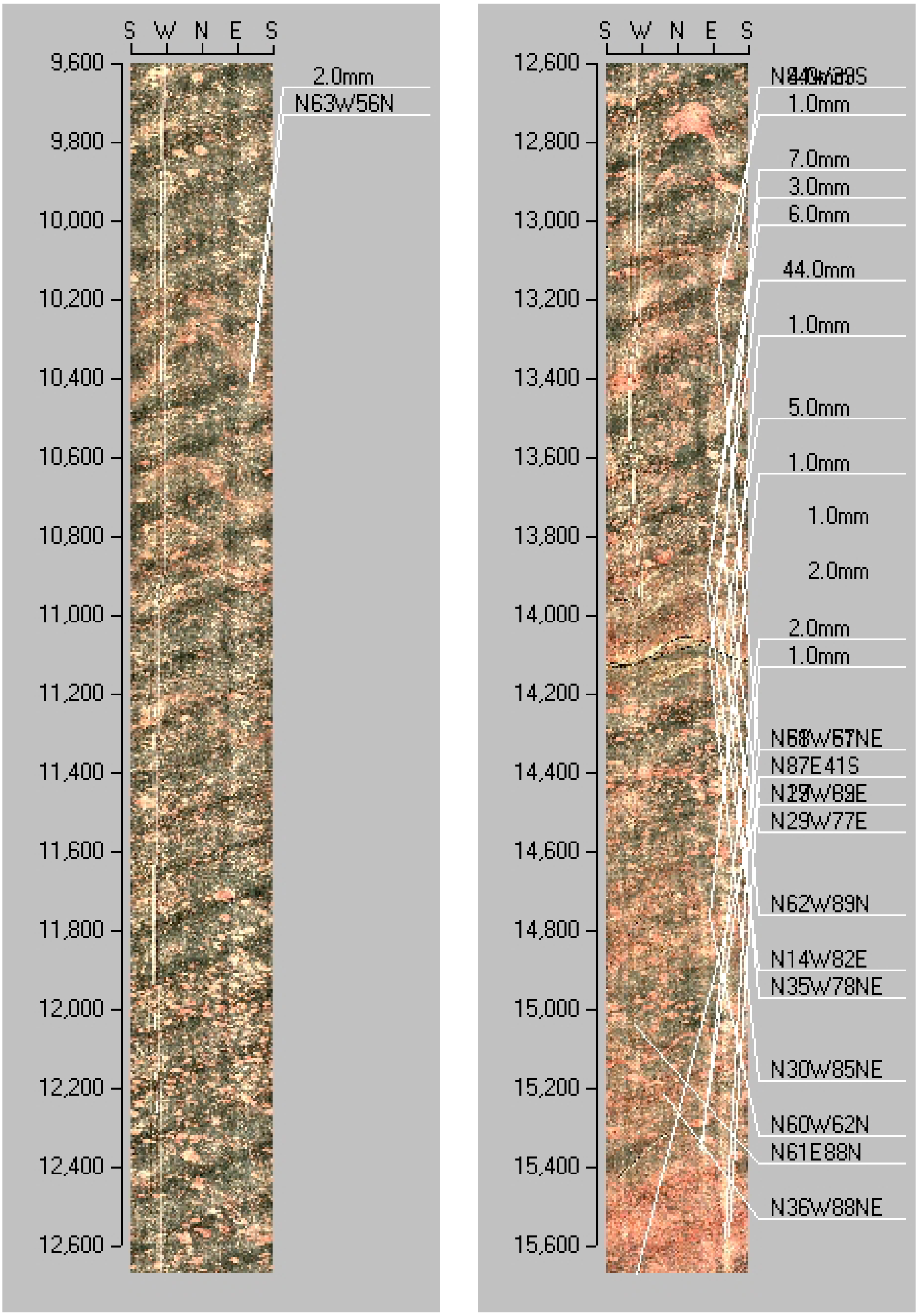


Figure A3-2. *Left: BIPS_KXTT3_9,6–12,6 m. Right: BIPS_KXTT3_12,6–15,6 m.*

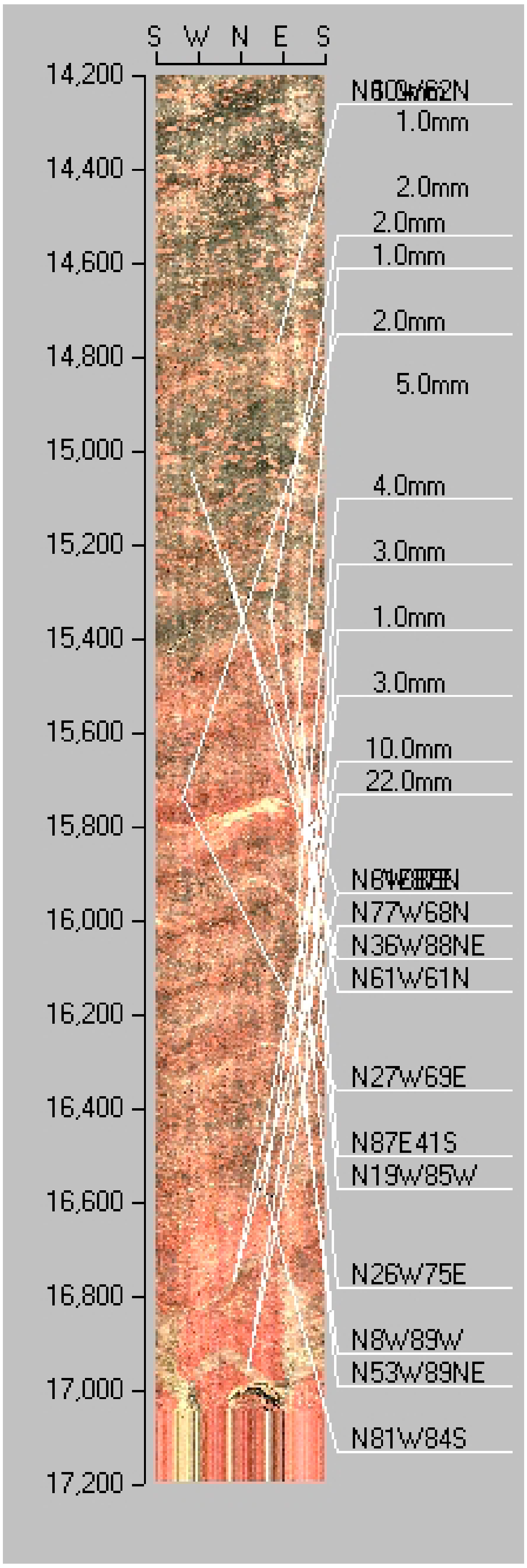


Figure A3-3. *BIPS_KXTT3_14,2–17,2 m.*

BIPS images of KXTT4

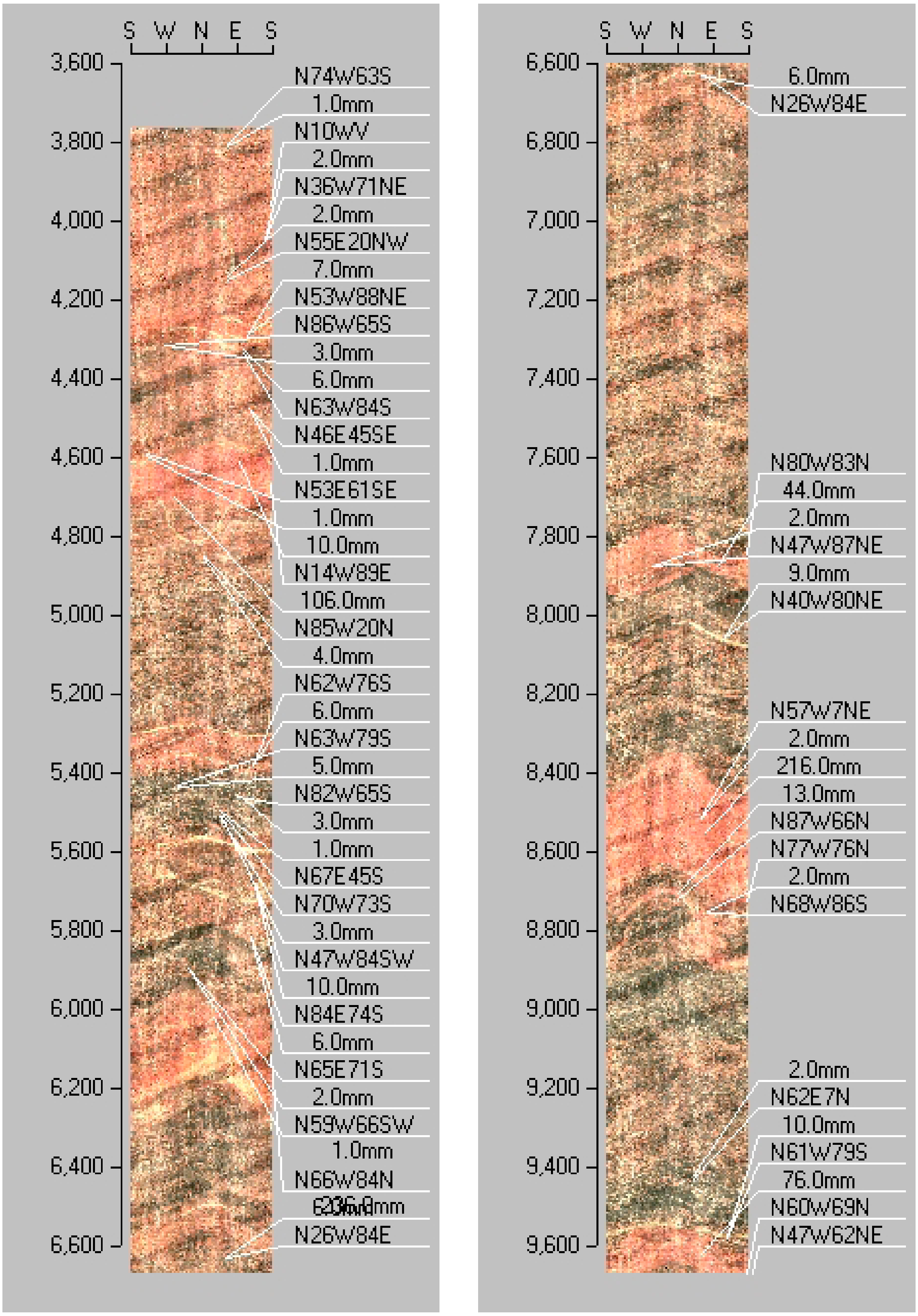
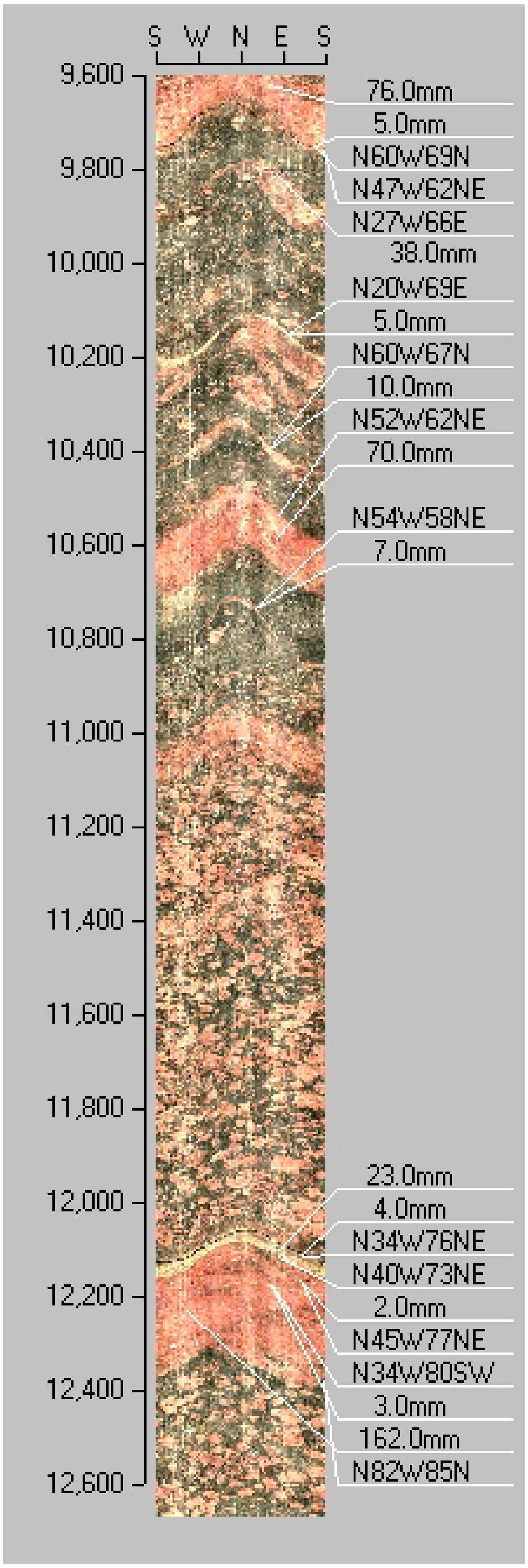


Figure A4-1. *Left: BIPS_KXTT4_3,6–6,6 m. Right: BIPS_KXTT4_6,6–9,6 m.*



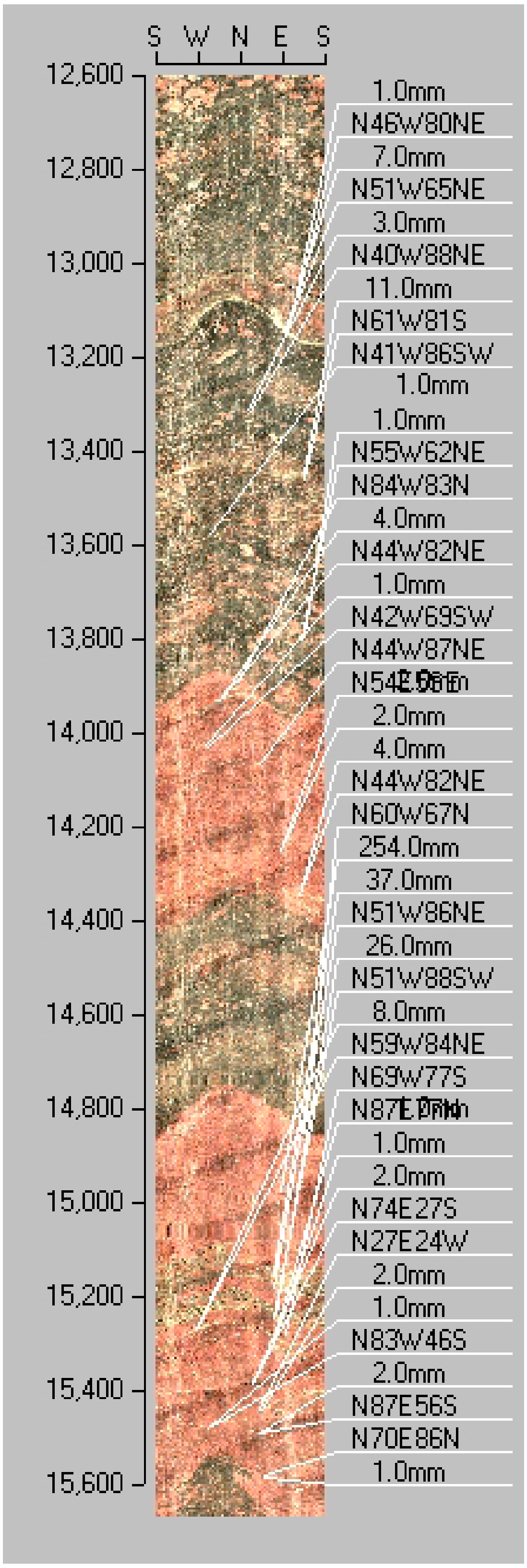


Figure A4-2. *Left: BIPS_KXTT4_9,6–12,6 m. Right: BIPS_KXTT4_12,6–15,6 m.*

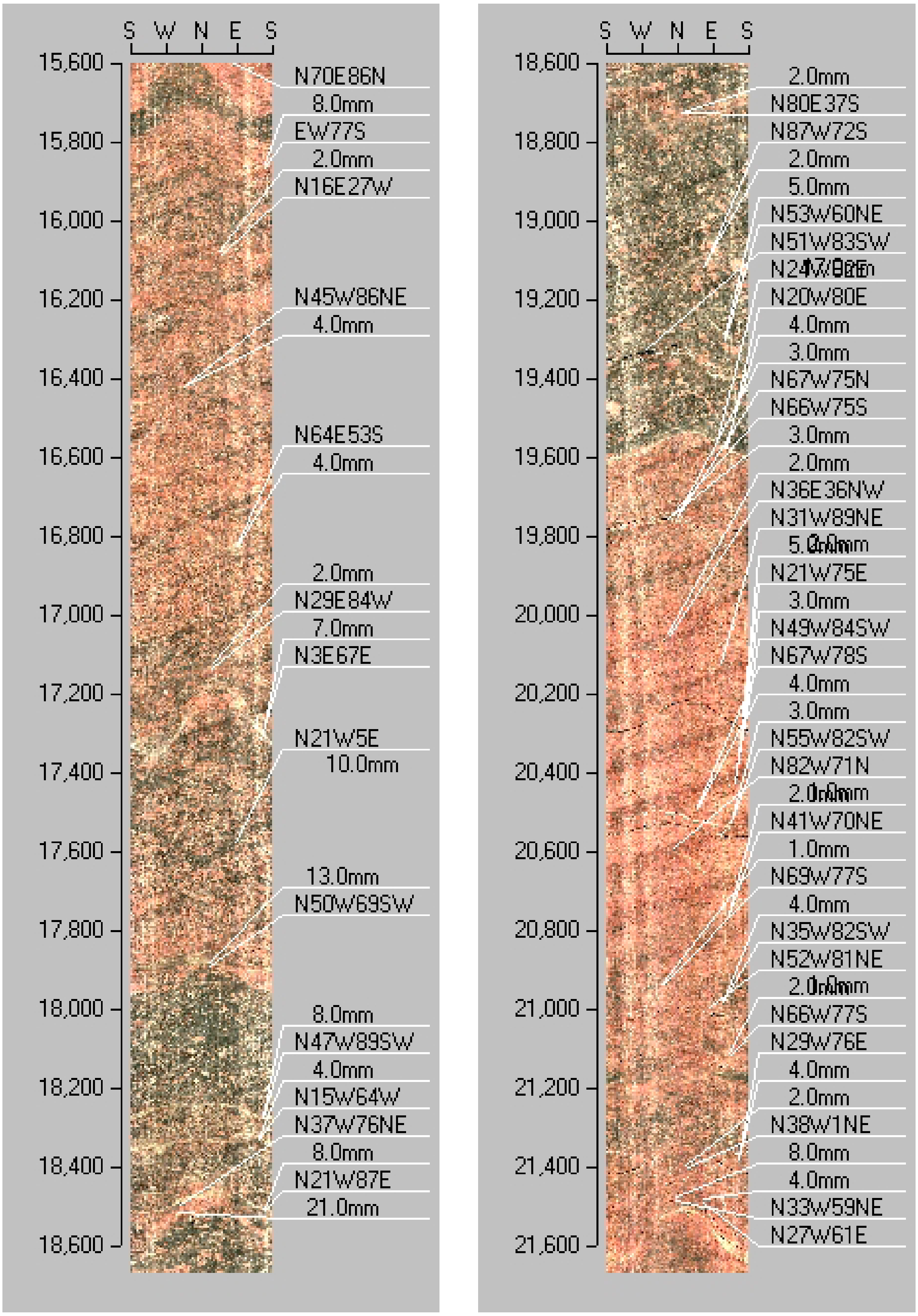


Figure A4-3. *Left: BIPS_KXTT4_15,6–18,6 m. Right: BIPS_KXTT4_18,6–21,6 m.*

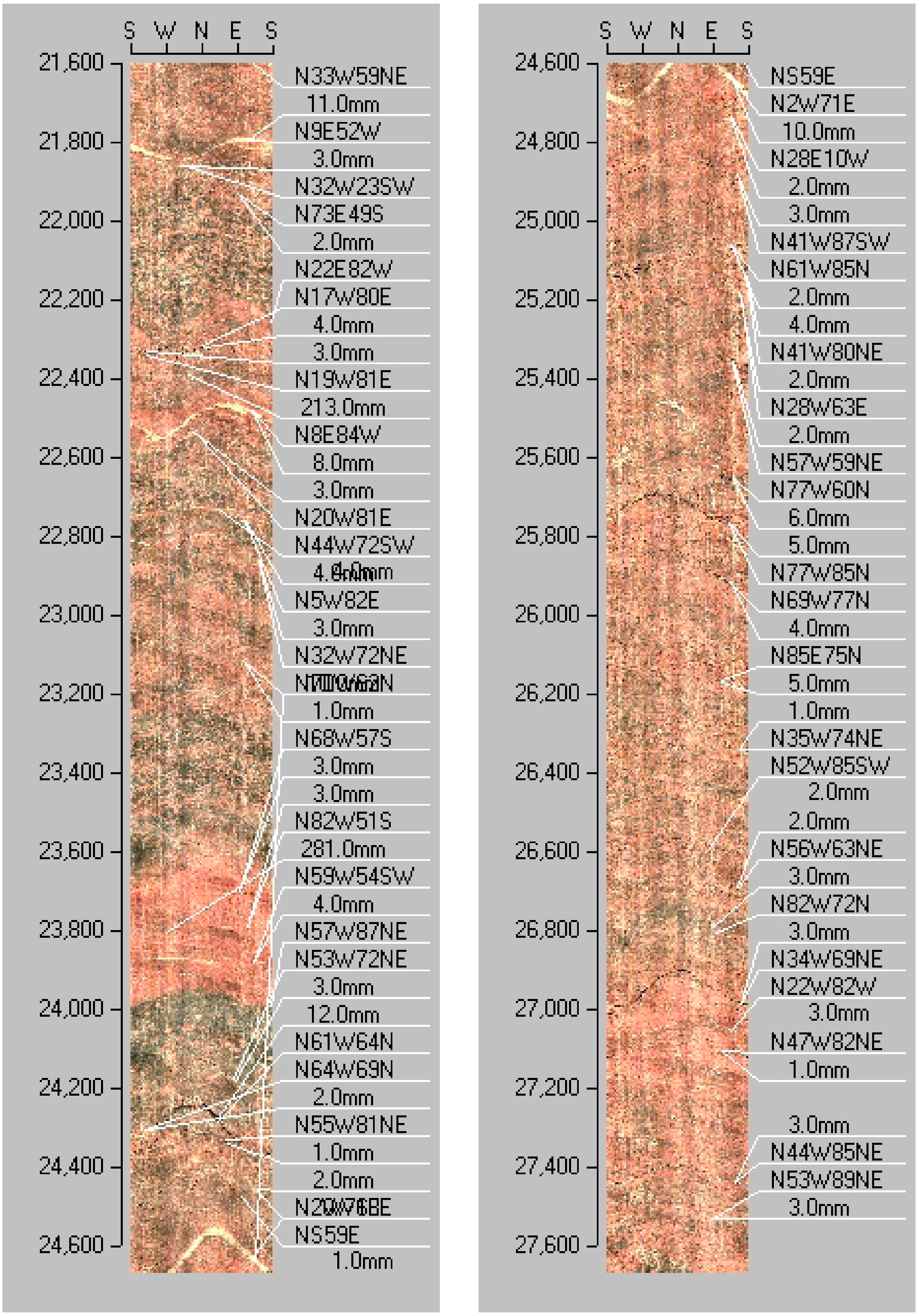
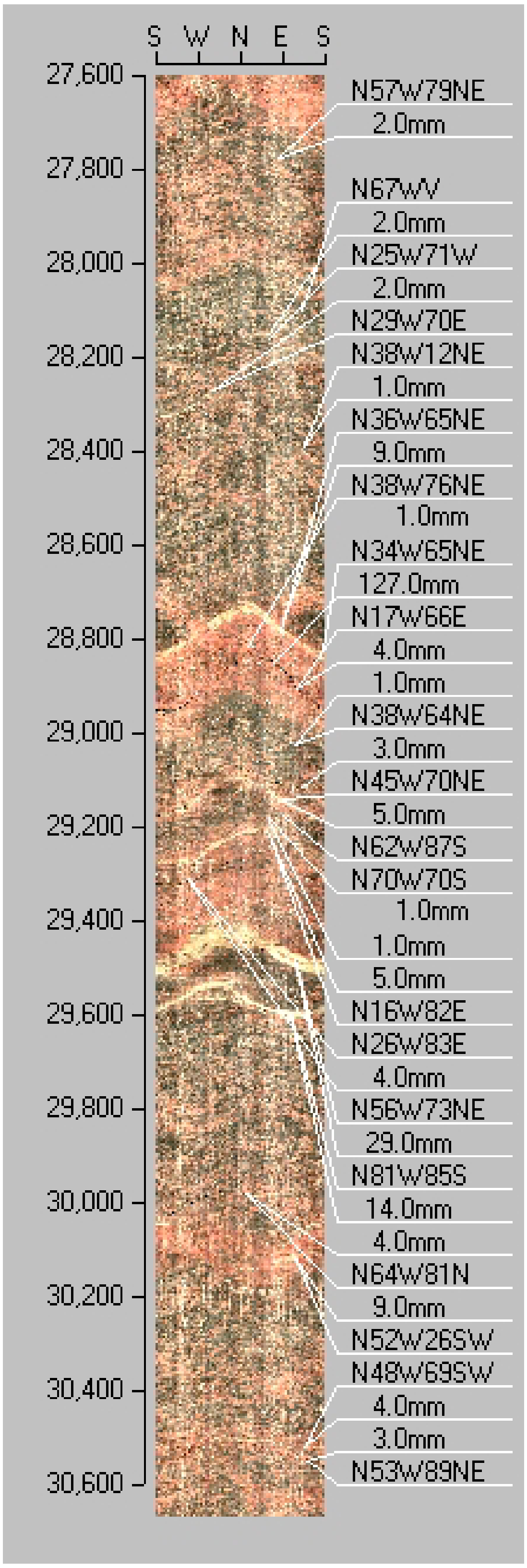


Figure A4-4. *Left: BIPS_KXTT4_21,6–24,6 m. Right: BIPS_KXTT4_24,6–27,6 m.*



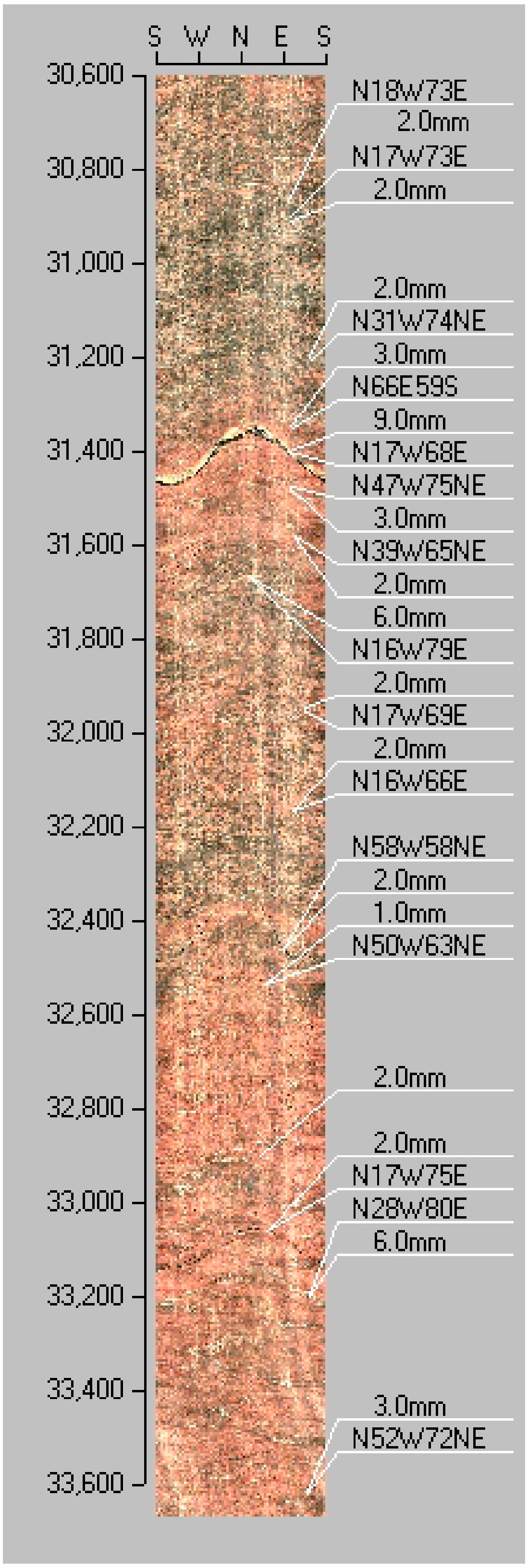


Figure A4-5. *Left: BIPS_KXTT4_27,6–30,6 m. Right: BIPS_KXTT4_30,6–33,6 m.*

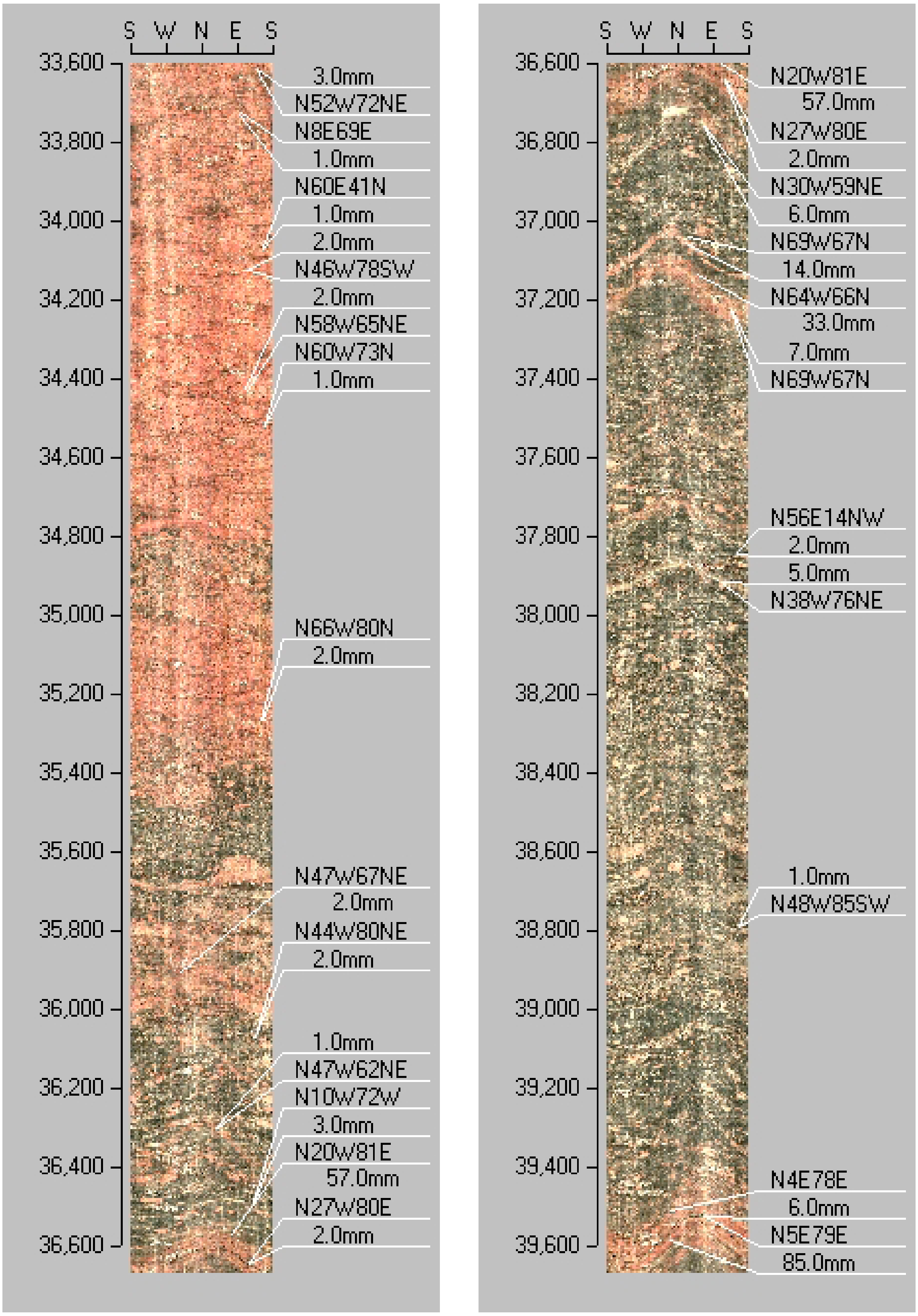


Figure A4-6. *Left: BIPS_KXTT4_33,6–36,6 m. Right: BIPS_KXTT4_36,6–39,6 m.*

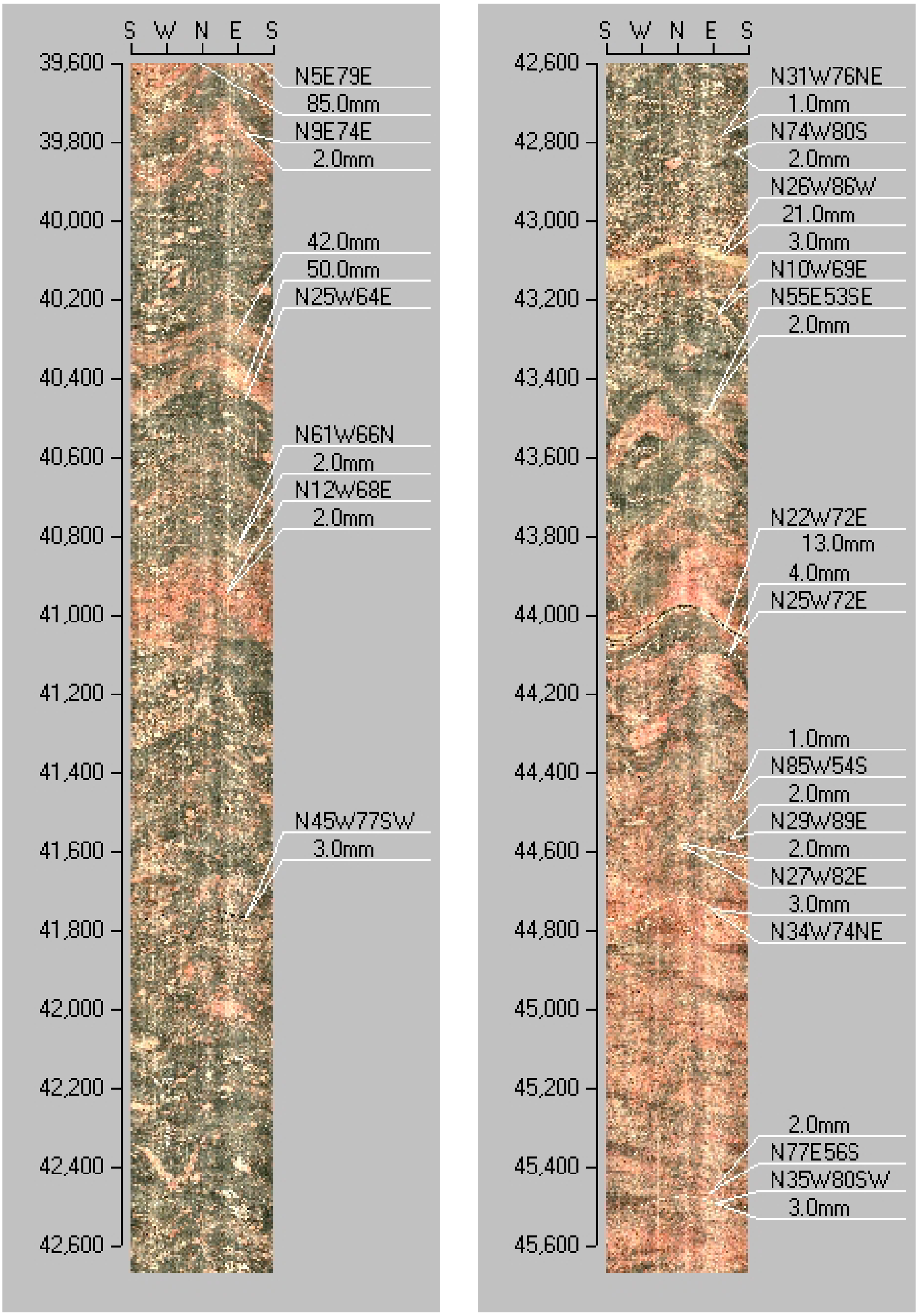
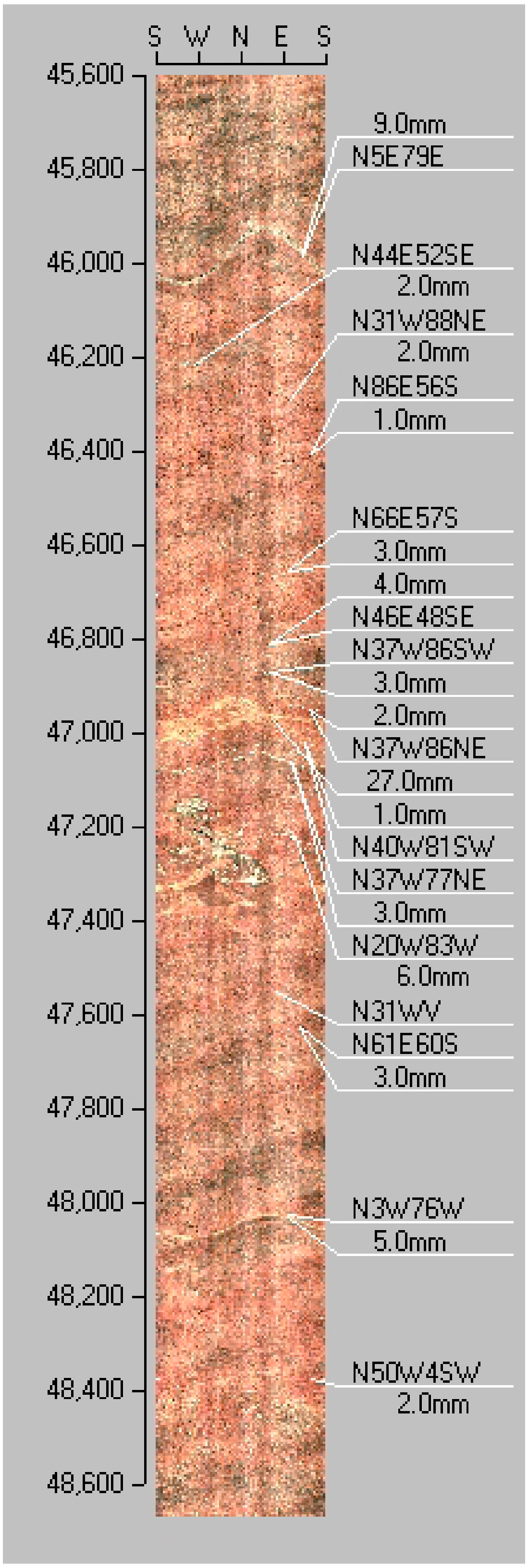


Figure A4-7. *Left: BIPS_KXTT4_39,6–42,6 m. Right: BIPS_KXTT4_42,6–45,6 m.*



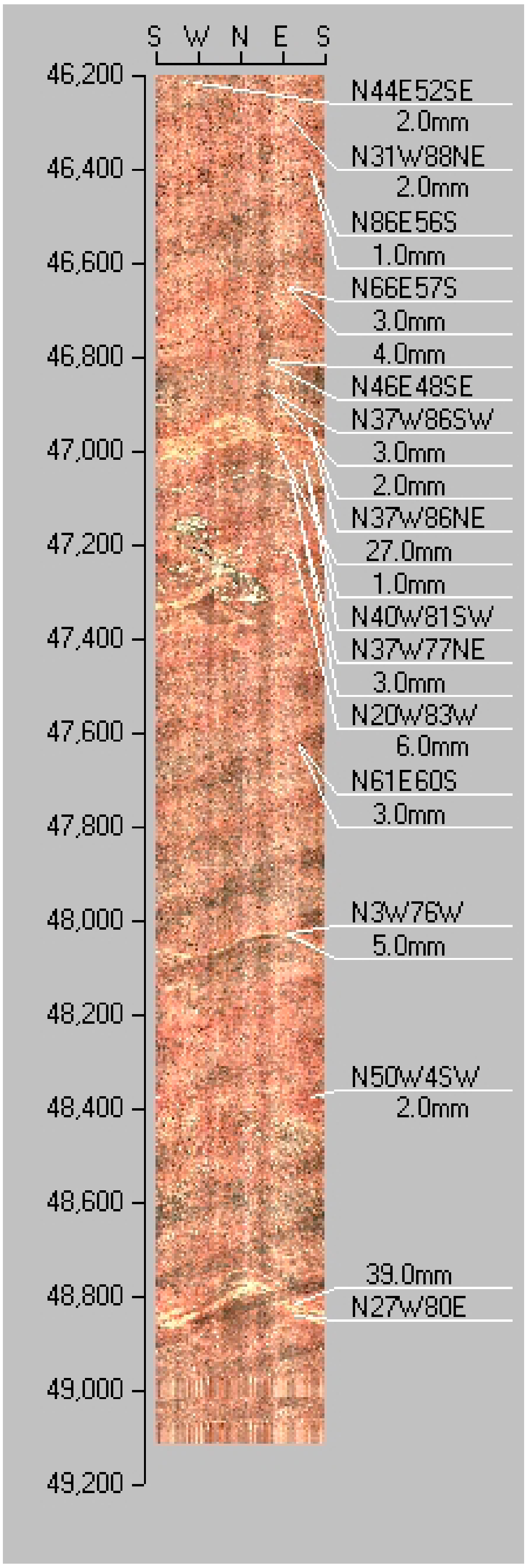
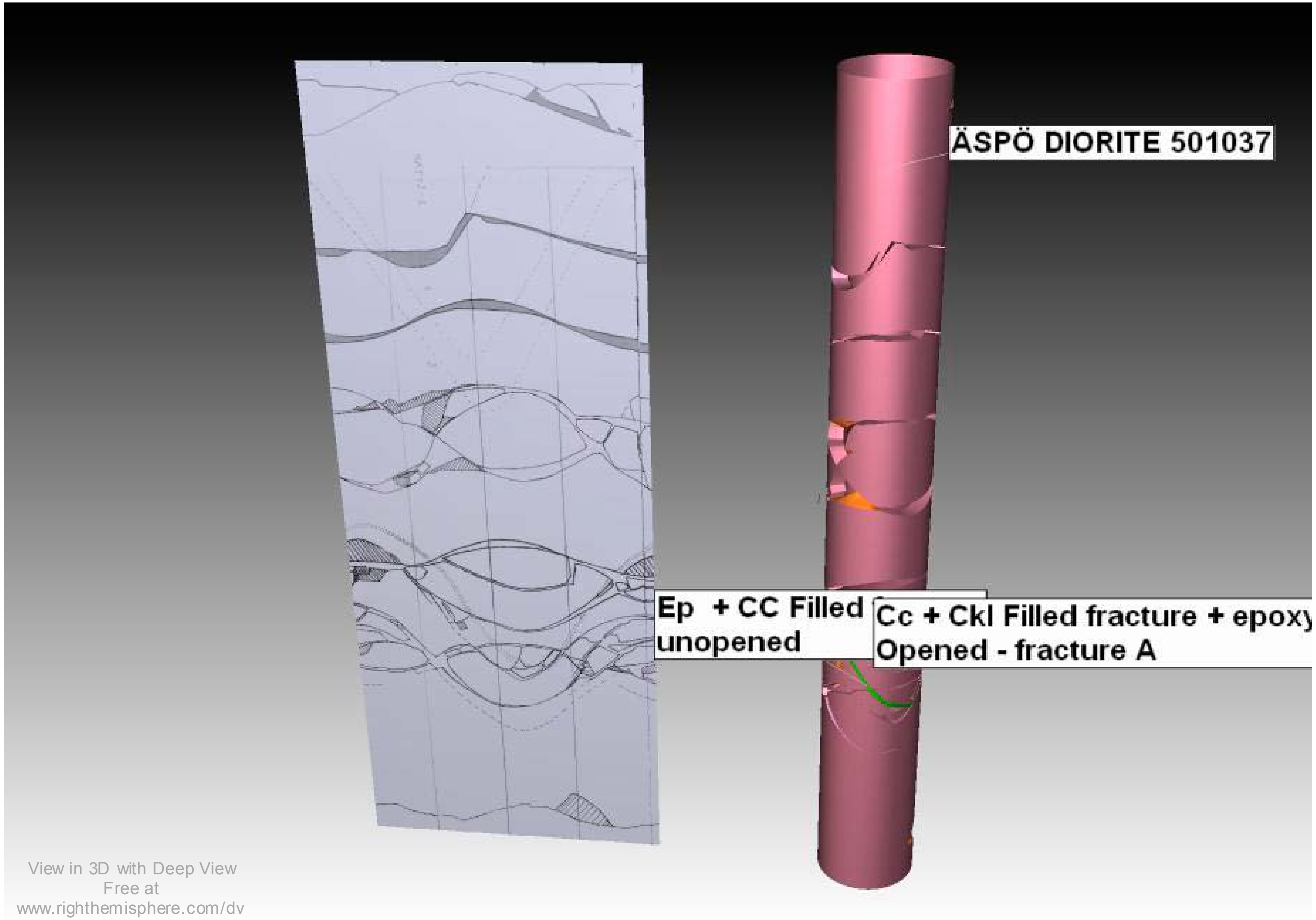


Figure A4-8. *Left: BIPS_KXTT4_45,6–48,6 m. Right: BIPS_KXTT4_46,2–49,2 m.*

3D-image of KXTT3

KXTT-3



Appendix 6

Details regarding the overcorings of KXTT3 and KXTT4

This appendix describes in detail the overcoring of the two boreholes KXTT3 and KXTT4, with special emphasis on the two target sections in the two boreholes. The experience from KXTT3 was used to optimise the overcoring routine for KXTT4. Tables A6-1 to A6-6 show the drilling procedure in table form, while Sections A6.1 and A6.2 provide detailed description and documentation of the respective drilling procedure for each borehole.

Table A6-1. Comparison of instructions in the activity plan and actual applied drilling procedure in boreholes KXTT3 and KXTT4.

Instructions in activity plan	KXTT3	KXTT4
Removal of casing by over drilling with drill diameter of 0.098 m	Drill diameter 0.116 m was used, because 0.098 m was too small	
Removal of packer by over drilling with drill diameter of 0.076 m down to target section of each borehole	Approximately 1 m longer than planned	Approximately 0.7 m shorter than planned
Overcoring with a core diameter of 0.300 m down to target section of each borehole. Measuring core length and orienting the core as the drilling proceeds	No core length or orientation determinations were possible because the broken core pieces got more or less ground while drilling, making it impossible to fit core pieces together. Instead the BIPS image of the original boreholes was copied from Sicada and used to orient the core	
Overcoring in predetermined steps through the target zones and breaking and retrieving each core piece in order	Not possible because of broken core, broken core pieces started to rotate inside core barrel (getting grounded) and therefore needed to be retrieved before damaging fracture fillings, which in turn was often very difficult because the core pieces kept falling out of the retrieval barrel during retrieval	
Length determinations by fitting core together at drill site. Marking a reference line and length on the core	Core is compared to the BIPS images of the original boreholes making accurate length determinations and orientation of core in the target sections possible. For KXTT3 in core shed and KXTT4 in Clab	
Photographing core at drill site	Core photographed in core shed at Äspö. When lights are turned off, UV photography is possible to a certain degree	Core is photographed in Clab, strong lighting at core mapping locality makes UV photography inapplicable
Geological mapping/logging of drill core	Core mapping/logging is performed in core shed	Core mapping/logging is performed in Clab
Data reporting	Core mapping/logging is drawn on mm paper and drawing plastic in 2 dimensions	
	Core mapping/logging is digitized/drawn on computer in 2 dimensions	
	Core mapping is represented in 3 dimensions	

Table A6-2. Planned drilling lengths and core piece diameters as well as target depths of boreholes KXTT3 and KXTT4 in activity plan.

Parameter	KXTT3	KXTT4
Drilling through concrete structure with drill bit diameter of 0.300 m	–0.37–0.00 m	–0.39–0.00 m
Over drilling of packer with drill bit diameter of 0.116 m	0.0–1.98 m	0.0–2.29 m
Over drilling of packer with drill bit diameter of 0.0758 m	1.98–13.60 m	2.29–10.95 m
Overcore drilling with drill bit diameter of 0.300 m	0.00–14.73 m	0.00–13.60 m
Target depth	12.67–14.72 m	11.67–13.68 m

Table A6-3. Specified 0.300 m overcoring lengths in target zone of boreholes KXTT3 and KXTT4, as specified in the activity plan.

Parameter	KXTT3	KXTT4
Overcoring down to target depth	0.00–12.60 m	0.00–11.80 m
Overcoring step #1	12.60–12.95 m	11.80–12.60 m
Overcoring step #2	12.95–13.40 m	12.60–12.80 m
Overcoring step #3	13.40–13.85 m	12.80–13.60 m
Overcoring step #4	13.85–14.65 m	
Target depth	12.67–14.72 m	11.67–13.68 m

Table A6-4. Actual 0.300 m overcoring lengths in target zones of boreholes KXTT3 and KXTT4, including dates of drilling and retrieval activities.

KXTT3			KXTT4		
Length (m)	Time Drilling	Retrieving	Length (m)	Time Drilling	Retrieving
0.00–12.53	070512–070528	070512–070528	0.00–11.27	070803–070813	070804–070813
12.53–12.95	070529	070529–070530	11.27–12.50	070814	070814–070815
12.95–13.40	070530	070531–070601	12.50–13.47	070815	070815
13.40–13.93	070602	070602–070607	13.47–13.60	070816	070816–070817
13.93–14.73	070607	070608–070618			

Table A6-5. Actual 0.300 m overcore drilling lengths in target zone of boreholes KXTT3 as well as dates of drilling, number of trials to break the core, number of trials to retrieve the core pieces, lengths of core pieces retrieved and the designated numbers given to those core pieces that could be re-fitted to the projected core and subsequently logged in the core shed at Äspö.

Date	Drilling (m)	Breakage trials	Retrieving trials	Retrieved core (m)	Core piece number	Comments
070529	12.95	2	3	–		No core pieces
070530	13.40	–	1	12.84	1	Loose core pieces above core piece #1
070531	–	1	1	13.10	2	
070601	–	1	1	–		No core
070602	13.93	1	2	13.3	3	Core pieces #3 and #4
070603–04	–	1	> 5	13.5	5 and 7 or 8	Small pieces + pieces #7 or #8
070605	–	–	1	–		No core
070606	–	–	1	–		Core barrel stuck in hole
070607	14.73	–	1	13.8	12	Plus #6 and #9–#11
070608	–	1	1	13.9	13 and 14	Core piece with core ring
070609	–	1	1	–		No core
070610	–	2	1	14.18	15 and 16–20	Core piece with core ring
070611	–	2	1	14.25	21–33	Core piece with core ring
070612	–	1	1	–		Core barrel stuck in hole
070613–17	–	–	–	–		Trying to unfasten string
070618	–	–	–	14.7	34–36	KXTT3 finished at 12:15

Table A6-6. Actual 0.300 m overcoring lengths in target zone of boreholes KXTT4 as well as dates of drilling, number of trials to break the core, number of trials to retrieve the core pieces, lengths of core pieces retrieved and the designated numbers given to those core pieces that could be re-fitted to the projected core and subsequently logged at Clab.

Date	Drilling (m)	Breakage trials	Retrieving trials	Retrieved core (m)	Core piece number	Comments
070814	11.80	1	1	11.7		
070814	12.50	1	1	–		No core pieces
070515	–	1	2	12.1	1	
070515	13.47		1	–		No core pieces
070516	13.60	1	1	12.8	2–7	
070517	13.60	1	1	13.5	8–11	KXTT4 finished 17:30

A6.1 KXTT3

The casing of KXTT3 was overcored using a diameter 116 mm core piece down to 1.98 m, and removed from the borehole. The original 56 mm borehole was reamed with a 75.6 mm drill bit to 10.85 m length. The overcoring of packers took place with a 75.6 mm core piece down to 13.6 m because of a miscalculation of drill rods. The activity plan stipulated that the overcoring of the packer should not go further than the target depth, which had been determined to be between 12.67–14.72 m, see Table A6-2. Packers and core down to 13.52 m were retrieved, packed into a barrel and stored at the core shed at Äspö HRL.

The overcoring with a 300 mm drill bit was then started. Complications, both with the core breaking device and the retrieval of the overcored core from the borehole arouse soon and led to some modifications of the methodology described in the activity plan.

The activity plan stipulates a drilling procedure for the target section which was only partly followed, see Table A6-3. Drilling to target section was recommended to approximately 12.6 m, but reached approximately 12.53 m, and after several trials the core was broken and retrieved. Later logging reveals that the actual length is down to approximately 12.45 m, which hence becomes the actual starting core length of the target zone.

Drilling from approximately 12.6 m to 12.95 m was recommended in the activity plan. The drilling was performed according to specifications, but problems arouse when the breaking and subsequent recovery of core was to take place. The core breaking device was lowered down and inflated twice and the core recovery tool was lowered three times and came out empty. It was only during the fourth trial that a core piece was retrieved and then with three smaller core pieces.. Later logging revealed that the actual length of the drill-induced fracture at the end of this first numbered core piece of the target zone is 12.84 m, see also Tables A6-4 and A6-5.

The activity plan then recommended drilling to 13.40 m and breaking the core there. The possibility of a natural break at 13.1 m was foreseen, but still the breaking at 13.40 m was deemed necessary. The drilling was performed according to specifications and after a few trials to clean the borehole from some smaller core fragments the core was broken with the breaking device. A core piece with the lower end corresponding to a natural fracture at c. 13.1 m length was retrieved, see Figure A6-1 (a–d). Several additional attempts were made to retrieve more core material, but without success.

The activity plan recommended drilling to 13.85 m and breaking the core there. The drilling proceded to 13.93 m, after which the core breaking device was lowered but got stuck after breaking the core. The result was that the next core piece was retrieved using the packer, i.e. the central hole, down to the drill induced fracture at approximately 13.3 m, see Figure A6-2, (a–b).

The rest of the core in the borehole was fragmented in smaller core pieces and could only be retrieved after considerable efforts in the next five days, see Figure A6-3 (a–b). One by one, three smaller pieces of core were retrieved until the last and largest piece (core piece #12), with three smaller core pieces on top, was retrieved using the core piece at the end of the retrieving barrel. The method was to carefully turn the drill bit while lowering the core retrieving barrel over the core. If there were core pieces of sufficient size at the end to get caught in the retrieving barrel they blocked the smaller pieces above from falling out while the barrel was retrieved.

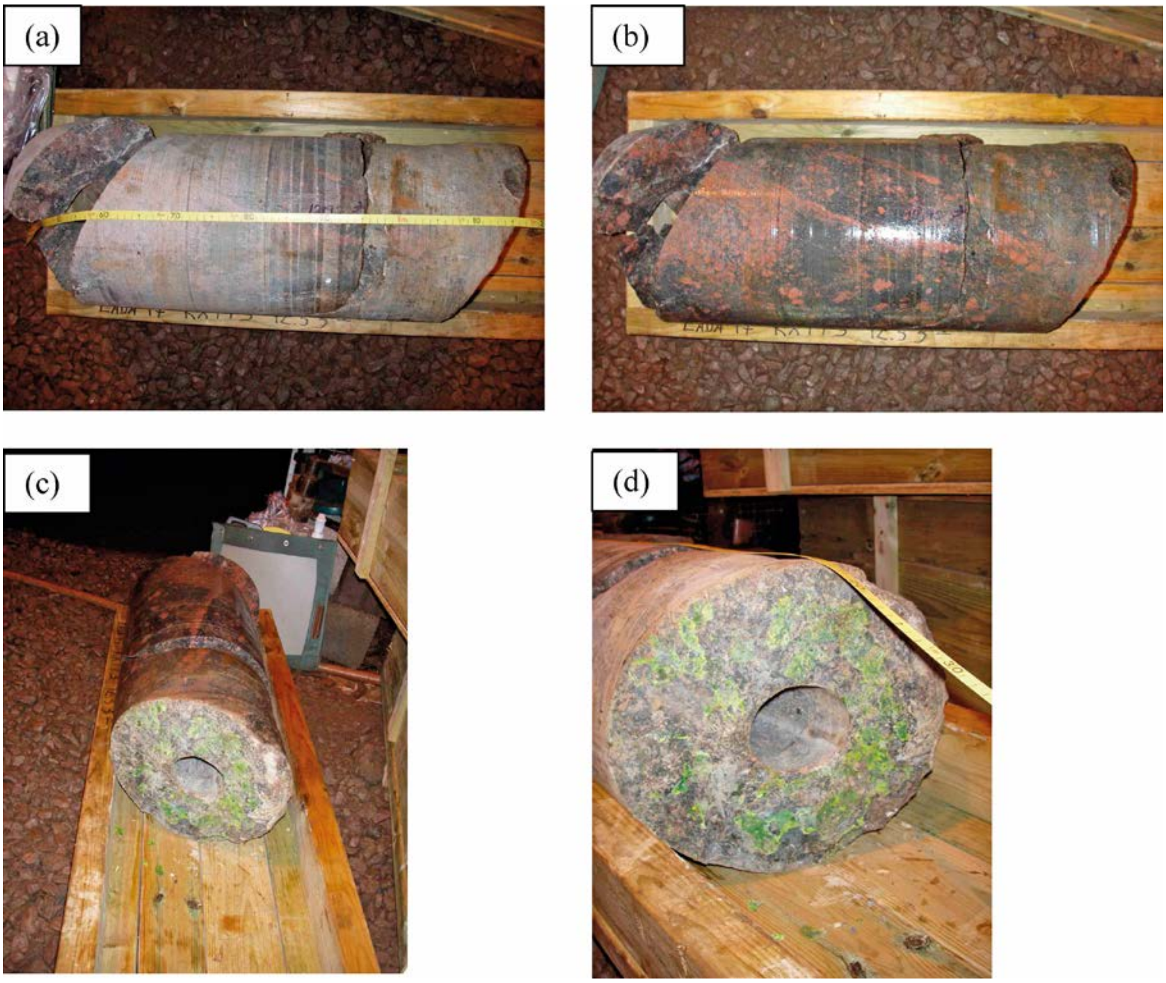


Figure A6-1. Core pieces #1 and #2 from target section of KXTT3 at the drill site. (a) Dry, down hole to the right. Position of measuring tape indicates approximately right side of core (green orientation line). (b) Wet, down hole to the right. (c) Natural fracture at 13.1 m, looking up hole. (d) Natural fracture at 13.1 m, looking up hole. Fracture filling epoxy (yellow-green) and chlorite (black).

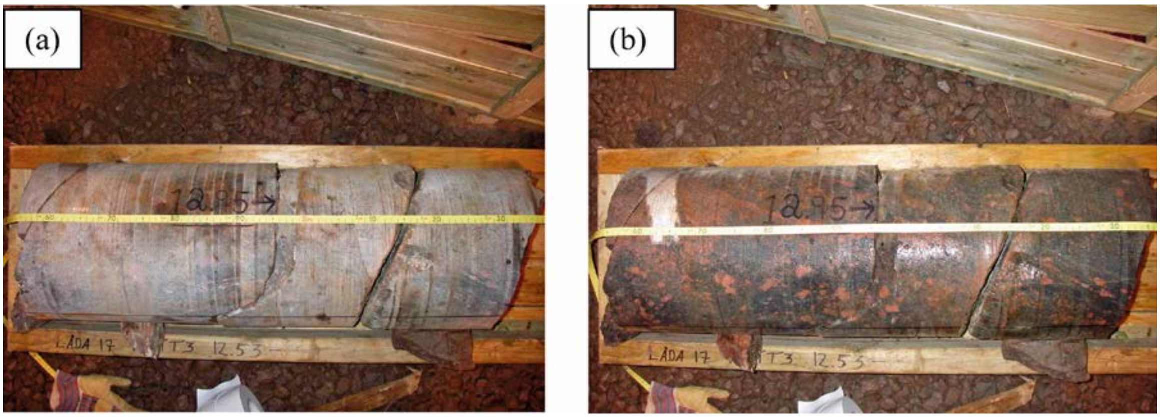


Figure A6-2. Core pieces #1–#3 (and #4) from target section of KXTT3 at the drill site. (a) Dry, down hole to the right. Position of measuring tape indicates approximately right side of core (green orientation line). (b) Wet, down hole to the right.

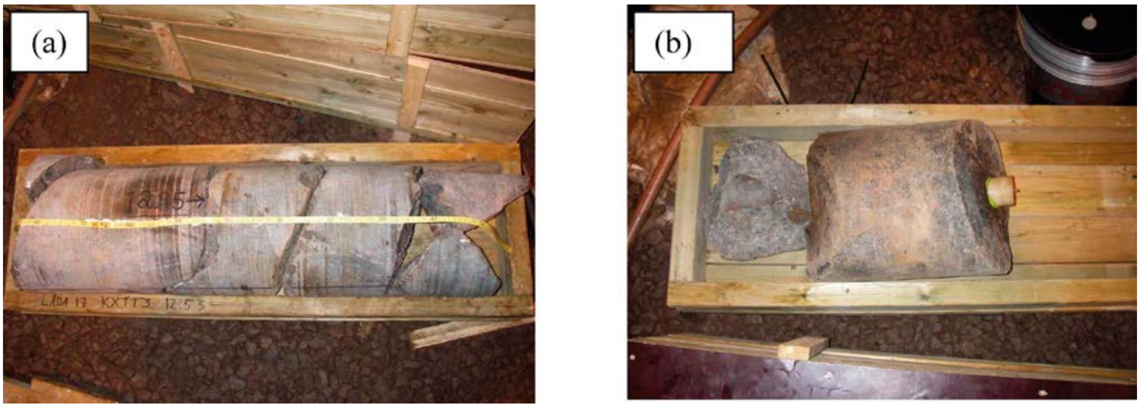


__Figure A6-3.__ Core pieces #1–#4, probably #7 and #8 and core piece #12 from target section of KXTT3 at the drill site. (a) Core pieces #1–#4, and probably core pieces #7 and #8, dry, down hole to the right. Position of measuring tape indicates approximately right side of core (green orientation line). Black orientation line indicates approximate position of vertical down of the core. (b) Core piece #12 and probably core piece #8, dry, down hole to the right.

The activity plan recommended drilling to 14.65 m and breaking the core there. The drilling went down to 14.73 m, the breaking tool was lowered and stopped at approximately 14.33 m length. The tool has thinner metal than before so it should stay in place while being inflated. It was pumped up to 80 bars, which is assumed to be enough to break the core. The breaking device was then retrieved with the drill string, see Figure A6-4 (a–b).

The core retrieving barrel was then fastened to the drill string and lowered. The plan was to sink it approximately 30 cm down over the core in the hole and then retrieve it with approximately 50 cm of core hanging out beneath the core piece. The retrieving barrel was lowered down to the core, then pressed in over it, but could only be pressed a few cm in over the core. Too much load could damage the core so careful uplifting commenced, no core got stuck in the retrieving barrel, see Figure A6-5 (a–b).

Possibly some small core pieces (gravel size) were in the way so that the core capturing barrel got stuck before it could be pressed down over the core. To solve this problem an old drill bit was fastened at the front of the retrieving barrel. Then while pressuring the capturing ring in over the core the drill bit was rotated somewhat to get gravel pieces and sand out of the way so the core would get caught by the capturing ring in the core barrel. The result was core piece with fluorescing epoxy on the fracture surface, see Figure A6-6 (a). Above it the smaller core piece that probably stopped the retrieving barrel from sliding over the core was captured also, see Figure A6-6 (b).

__Figure A6-4.__ Drill site of TRUE-1, core breaking in KXTT3. (a) Disconnecting core breaking sledge (for breaking core from below) from drill string. (b) Core breaking device after being inflated to 80 bars.

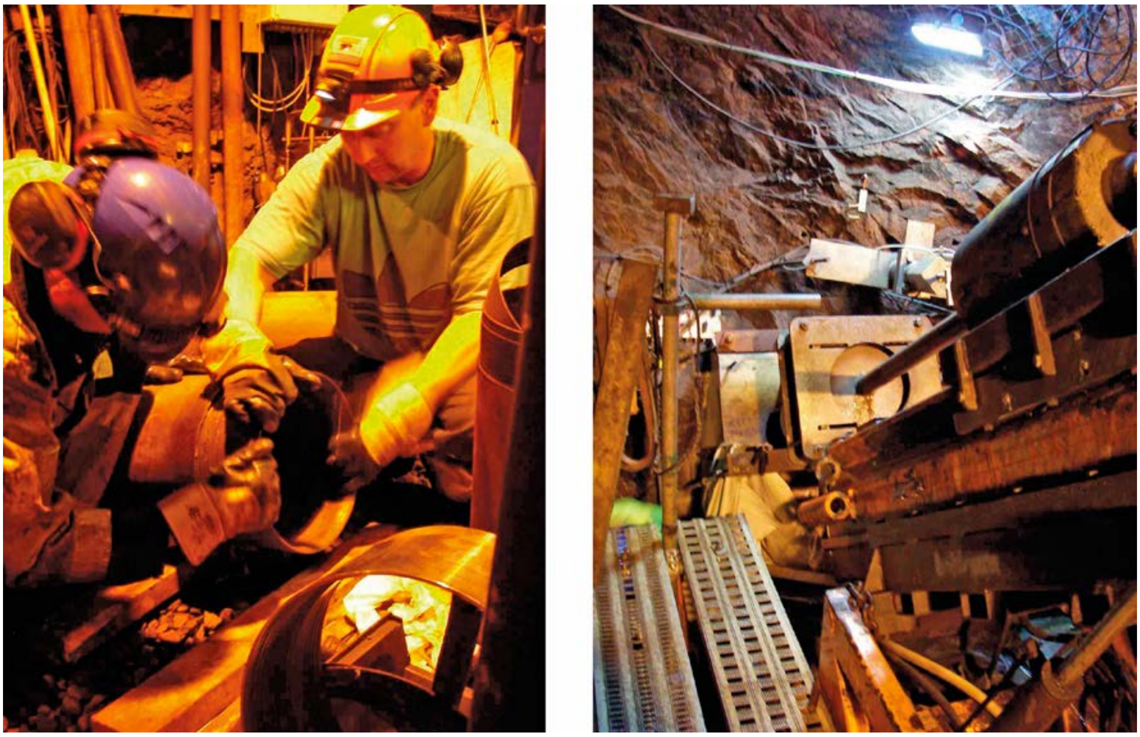


Figure A6-5. *Drill site of TRUE-1, core capturing in KXTT3. (a) Assembling the core capturing barrel. (b) Core capturing barrel connected to the drill string just out of borehole KXTT3.*

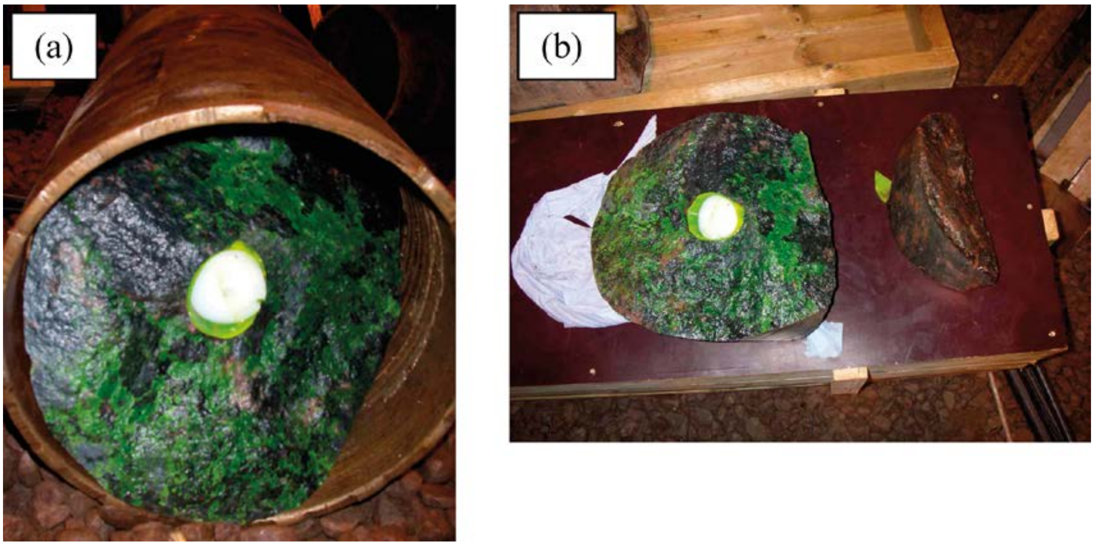


Figure A6-6. *Core pieces #13 and #14 from the target section of KXTT3. (a) Core piece #14 in core retrieving barrel with old core piece at the end, looking up hole at fracture surface 13.9 m with epoxy (yellow green) and chlorite (black) fracture fillings. (b) Core pieces #13 and #14 on top of a core box, after having been taken out of the core retrieving barrel. Down hole to the left.*

The breaking tool was then sent down above the core on a specially constructed sledge and pumped up to break the core. The breaking tool was pushed down as far as possible, so that the supporting bars bent, see Figure A6-7 (a), but still only a corner of the breaking tool seems to have gone in over the core, see Figure A6-7 (b).

Then the retrieving barrel with drill bit at the front was lowered down and succeeded in retrieving some additional core. The largest core piece was given the number #15 and the five small core pieces above are numbered #16–#20, see Figure A6-8 (a–d).

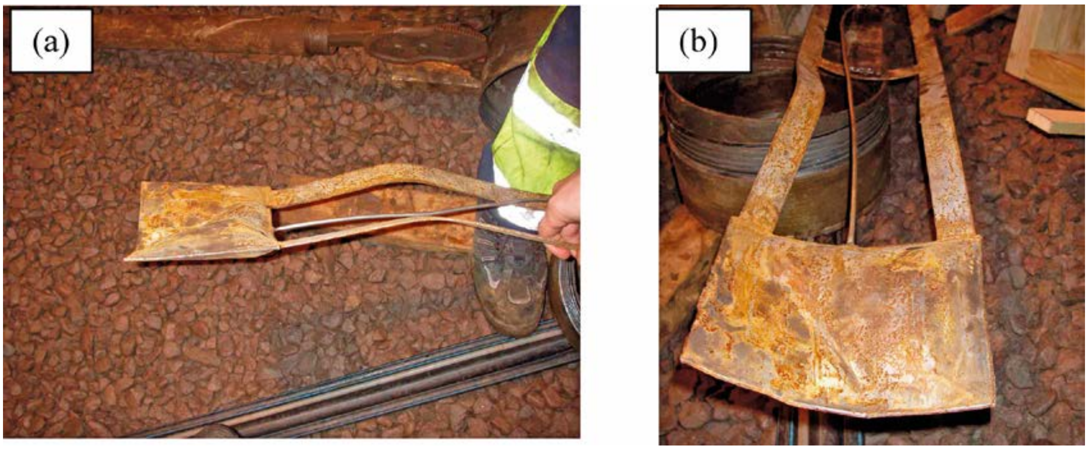


Figure A6-7. *The tool for core breakage, double steel plates after expansion with hydraulics in borehole KXTT3 at the drill site. (a) Supporting bars bent after trying to force breakage tool in overcore. (b) Only a corner of the core breakage tool seems to have been inserted over the core in this case.*

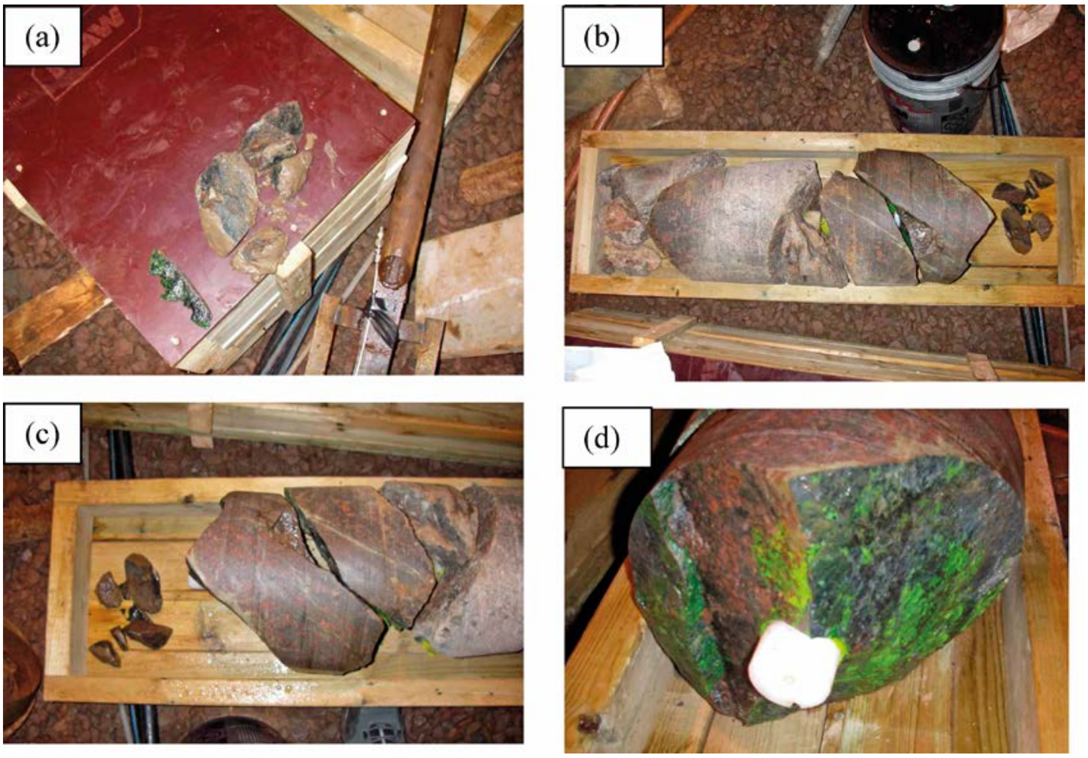


Figure A6-8. *Core pieces #8, #12–#15 and #16–#20 from the target section of KXTT3. (a) Core pieces #16–#20 fresh from the core capturing barrel on top of a core box. (b) Core pieces #8, #12–#15 and #16–#20 from target section of KXTT3 in core box, down hole to the right. (c) Core pieces #12–#15 and #16–#20 from target section of KXTT3 in core box, down hole to the left. (d) Core piece #15, showing two natural fractures at approximately 14.1 m length, looking up hole. Fracture filling epoxy (yellow-green) and chlorite (black).*

After repairing the breaking tool it was sent down again to try and break the core further down. The retrieving barrel with drill bit at the front was then lowered down as before and more core pieces with several smaller core pieces above it was collected again, see Figure A6-9 (a–b).

Once again the breaking tool was used and then the retrieving barrel with drill bit at the front as before, but this time it got stuck approximately 2 m up the hole. After six days of activity the drillers could finally retrieve the last core pieces, see Figure A6-10 (a–f).

A6.2 KXTT4

Overcoring started with drilling using a 300 mm diameter bit through the concrete slab to the bedrock surface. The top most casing was overcored with a 116 mm bit down to 2.28 m, and extracted out of hole. Then reaming/over drilling of packers with 75.6 mm drill bit extended down to 10.95 m. Target section depth had been determined to be between 11.67–13.68 m, so the packer overcoring continued approximately 0.7 m shorter than planned, see Table A6-2.

The overcoring with a 300 mm bit diameter then commenced. At approximately 2.27 m it became evident that the drill rod was deviating from the desired direction of the original 56 mm borehole. After initial trials to correct the direction, drilling was temporarily stopped at 2.54 m length. It was then decided to test overcoring drilling without steering in the small borehole, but lengthening the barrel behind the drill bit for stabilization purposes. At approximately 6.02 m length the drilling machine moved on its platform and needed to be readjusted. After some deliberation it was decided to continue with the overcore drilling, extending the core barrel attached to the drill bit even further, employing continuous measurement of the deviation. At approximately 10.2 m drilling length the core is approximately 44 mm off to one side, showing that the drilling has drifted approximately 5 mm/m for the last 2 m, see Figure A6-11.

The activity plan stipulates a drilling procedure for the target section which was followed to a large degree, see Table A6-3. Drilling to target section was recommended to approximately 11.8 m after which a break should be induced and the core recovered. Core down to approximately 11.7 m length was retrieved and radiologically cleared for transport to the Äspö HRL core shed, see also Tables A6-4 and A6-6.

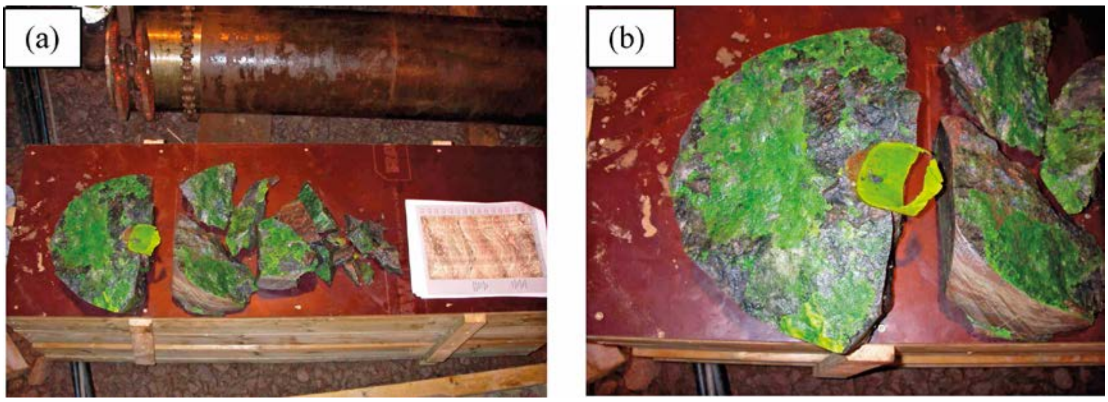


Figure A6-9. Core pieces #29–#33 from target section of KXTT3 at the drill site. (a) Core pieces #29–#33 on top of a core box after having been retrieved from the core retrieving barrel. (b) Close up of core piece #29, showing natural fracture at approximately 14.1 m length, looking up hole. Fracture filling epoxy (yellow-green) and chlorite (black).

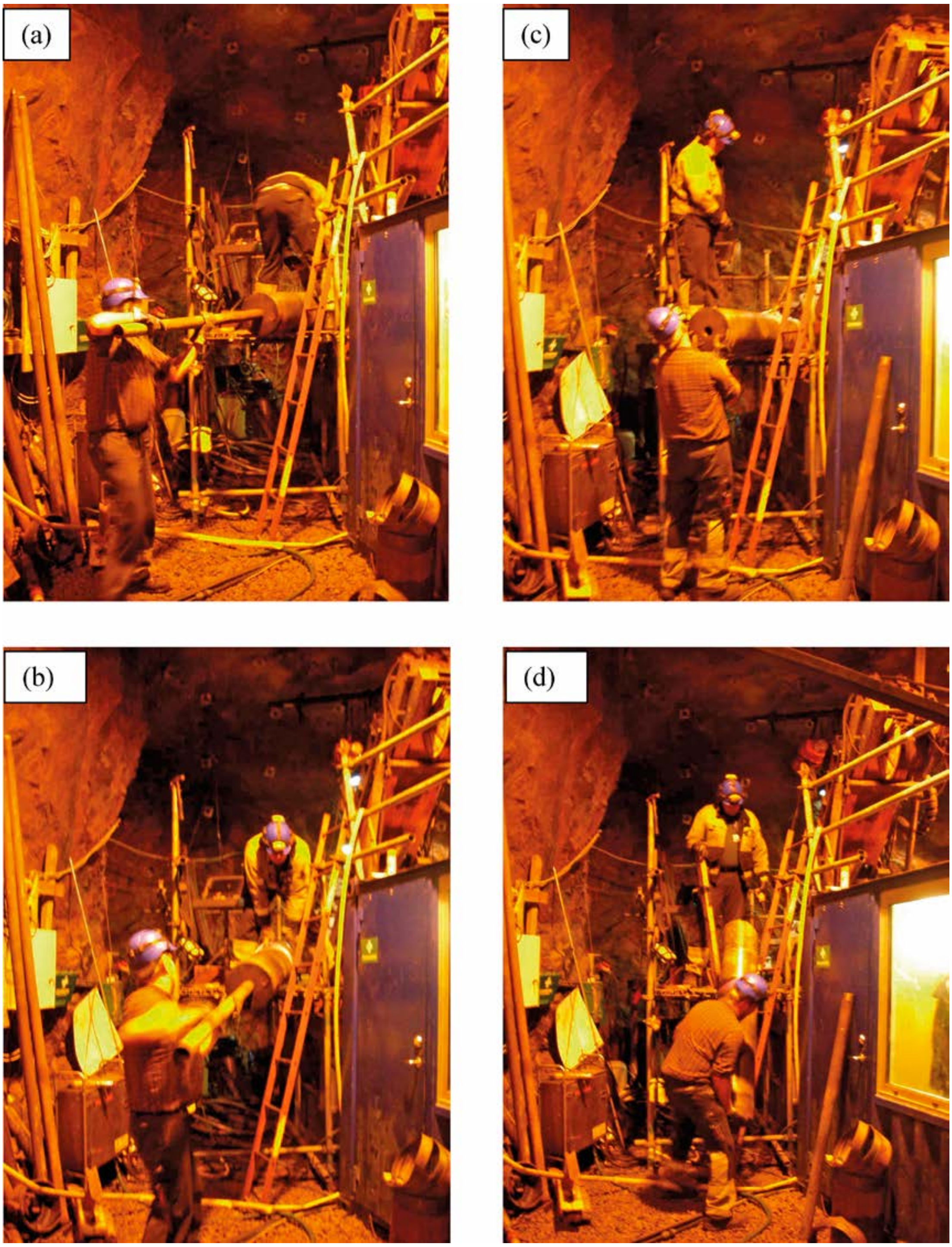


***Figure A6-10.** The taking down of core retrieving barrel containing the last core pieces from the KXTT3 overdrilling from core platform down to ground level beside the drilling machine at the TRUE-1 drill site. Core pieces #29–#33 from target section of KXTT3 at the drill site. (a) Unhitching the core retrieving barrel from the lifting device. (b) Detaching the last bit of drill string from the core retrieving barrel. (c) Preparing to lift down the core retrieving barrel from the drilling platform down to ground level. (d) Lowering the core retrieving barrel down from the drilling platform to ground level. (e) Preparing to dissemble the core retrieving barrel and take out the core. (f) The large core piece #34 with the smaller core piece #35 as support. The fracture surface at approximately 14.1 m length is facing the camera, which is looking down hole. Smaller amounts of epoxy (yellow-green) occur as fracture filling as well as some chlorite (black).*

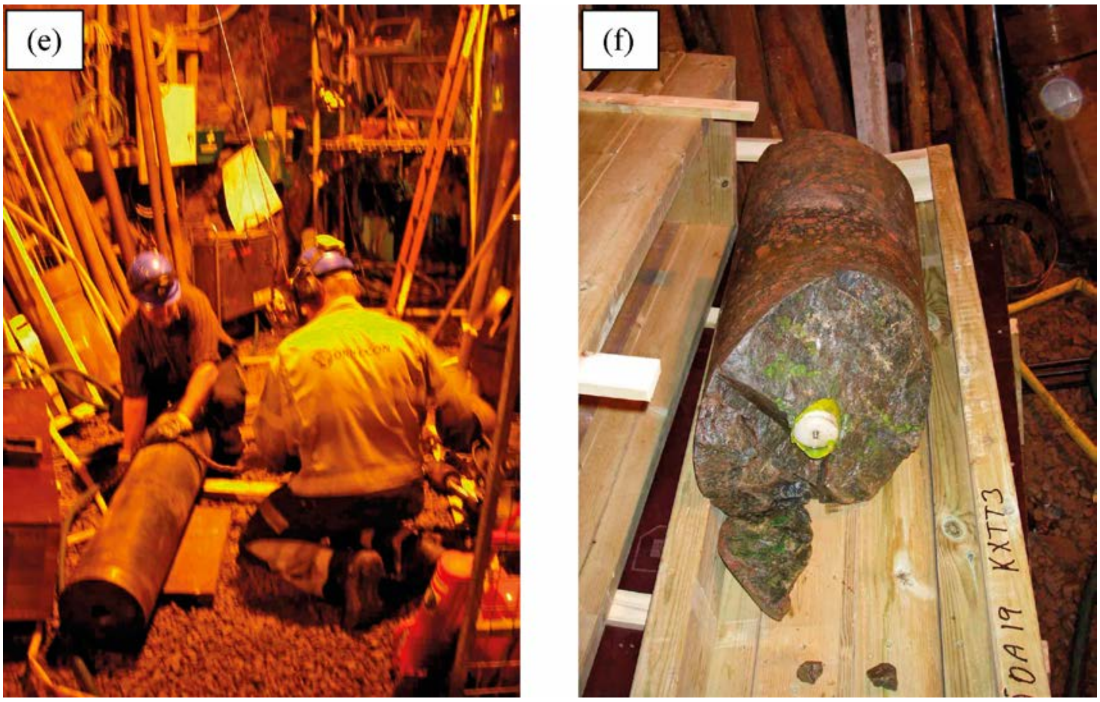


Figure A6-10. *Continued.*

Figure A6-11. *The overcoring of borehole KXTT4 at the TRUE-1 site. The deviation at approximately 10.2 m drilling length is approximately 44 mm of to the side.*

Drilling no further than 12.6 m was then suggested by the activity plan. The drilling was performed down to 12.5 m and then broken with the core breaking device, resulting in one retrieved core piece, see Figure A6-12 (a).

The activity plan then recommended drilling to 12.8 m and breaking the core there. After that a final drilling down to 13.6 m was stipulated, with subsequent core breakage and core retrieval. The drilling continued down to 13.47 m, where the drill bit got stuck, but no core was retrieved when drill bit was hoisted out of the borehole for control. Drilling then continued down to 13.6 m, whereupon the breaking device was lowered and followed by the core retrieval barrel. Core down to approximately 12.8 m length was retrieved, see Figure A6-12 (b) and Figure A6-13 (a–b).

After inserting the drill bit again to clean the hole and the breaking device, the capturing ring was put in place and the drill bit was lowered again. This time the remainder of the core was retrieved, down to approximately 13.5 m borehole length, see Figure A6-14 (a–d).

The drilling equipment and core were then tested for radioactivity, whereby it was decided that the target section of KXTT4 was to be transported to Clab, while the rest of the core and equipment was cleared as being non-radioactive.

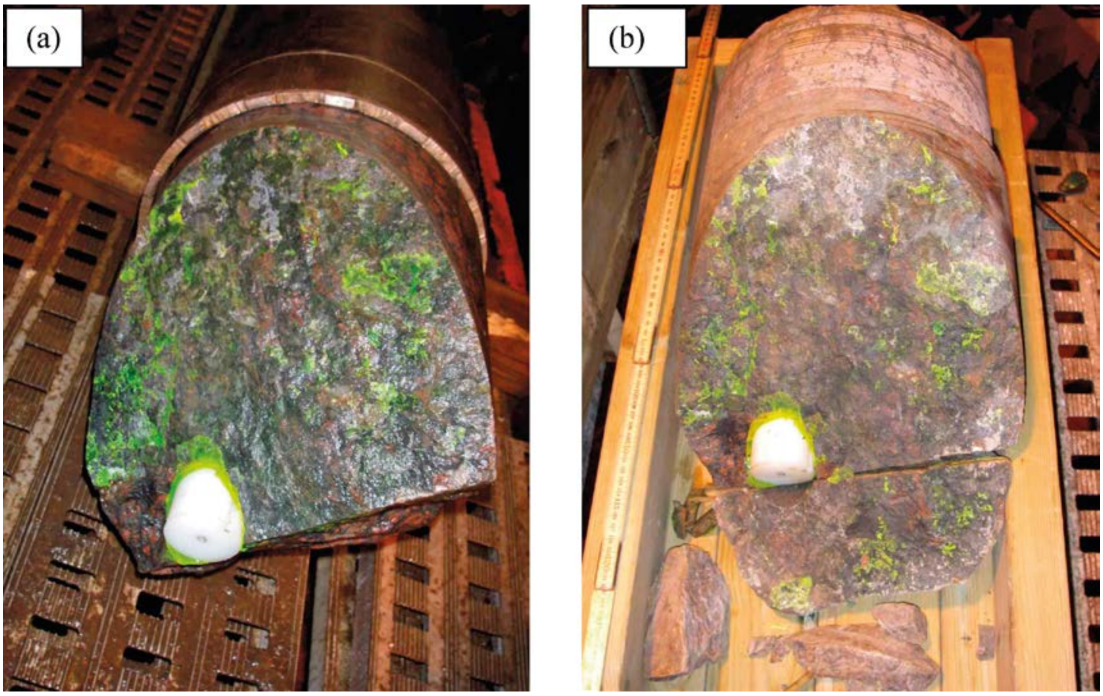


Figure A6-12. *Core pieces #1–#2 from target section of KXTT4 at the drill site. (a) Core piece 1 still in the core capturing barrel, end of old drill bit can be seen. The fracture facing the camera, looking up hole, is at approximately 12.1 m borehole length, fracture filling epoxy (yellow-green), chlorite (black) and some calcite (grey-white). (b) Core piece #1 and #2 in the core box. The fracture facing the camera, looking up hole, is at approximately 12.1 m borehole length, fracture filling epoxy (yellow-green), chlorite (black) and some calcite (grey-white). Core piece #2 came up with the second core retrieval from the target are.*

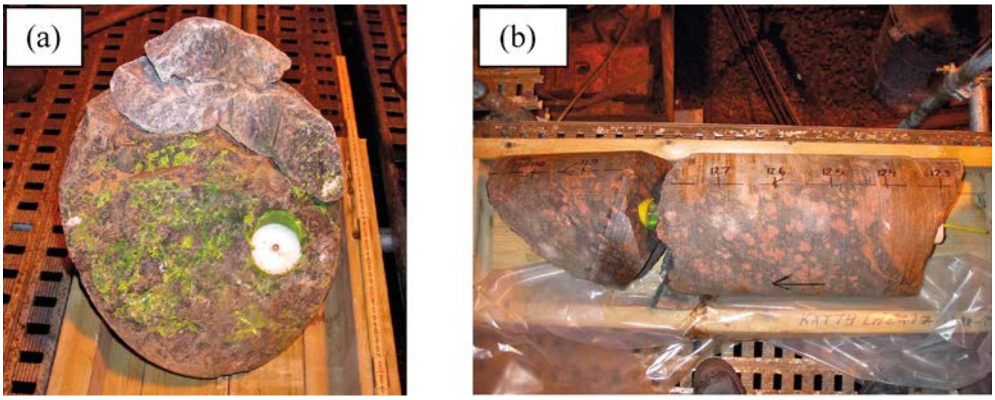


Figure A6-13. *Core pieces #3–#8 from target section of KXTT4 at the drill site. (a) Core pieces #3–#6 in the core box. The fracture facing the camera, looking down hole, is at approximately 12.1 m borehole length, fracture filling epoxy (yellow-green), chlorite (black) and some calcite (grey-white). (b) Core pieces #7 and #8 in the core box, down hole to the left. Length markings in meters and the dashed preliminary black orientation line marks approximate vertical down of the core. Core piece #8 came up with the last core retrieval.*

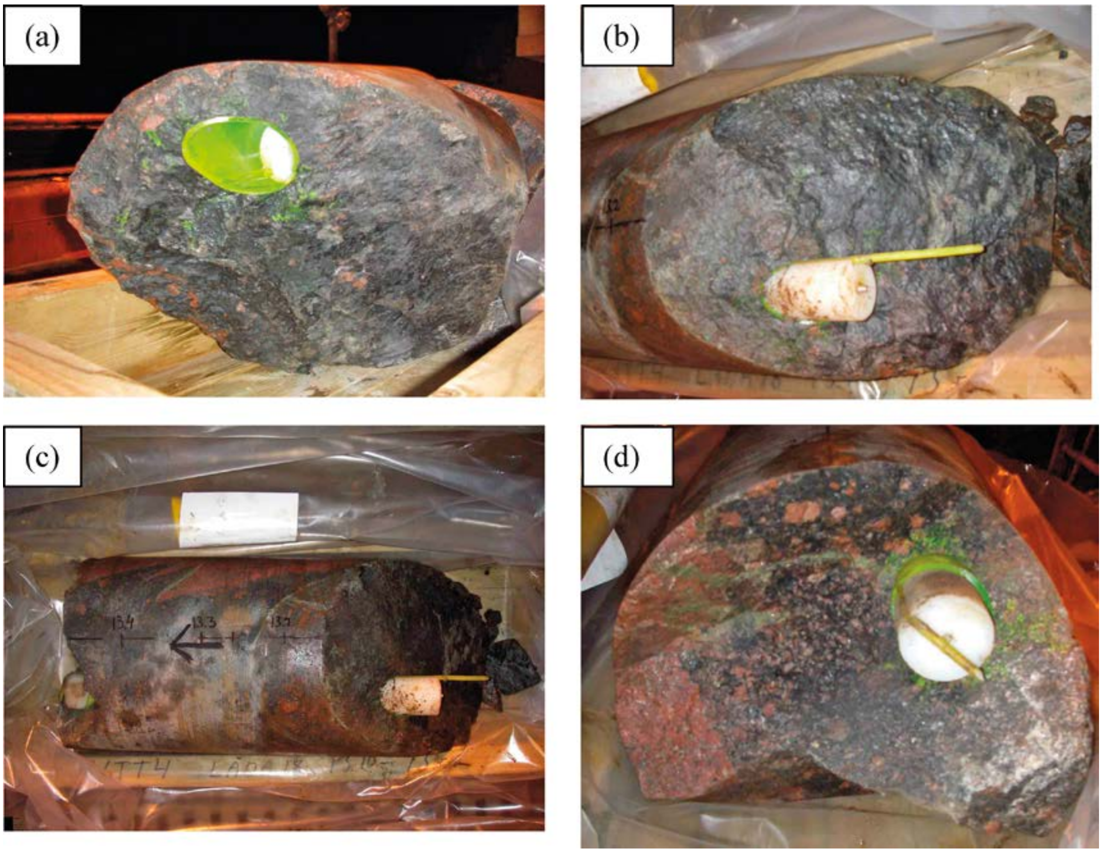


Figure A6-14. *Core pieces #8 and #11 from target section of KXTT4 at the drill site. (a) Core piece #8 in the core box. The fracture facing the camera, looking up hole, is at approximately 13.0 m borehole length, fracture filling chlorite (black) and some epoxy (yellow-green). (b) Core piece #11 in the core box. The fracture facing the camera, looking down hole, is at approximately 13.0 m borehole length, fracture filling chlorite (black) and minor epoxy (yellow-green). (c) Core piece #11 in the core box, down hole to the left. (d) Core piece #11 in the core box. The drill induced fracture facing the camera, looking up hole, is at approximately 13.5 m borehole length, minor epoxy (yellow-green) occurs close to pilot hole.*