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Äspö Hard Rock Laboratory

Long Term Sorption Diffusion Experiment (LTDE-SD)

Over-core drilling and extraction of core samples

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Abstract

The present report is written as a complement to SKB report R-10-68 and in more detail describes the procedures of post-experimental activities following the *in situ* LTDE-SD campaign (Long Term Diffusion Sorption and Diffusion Experiment) performed in Ävrö granodiorite at about 410 m depth at Äspö Hard Rock Laboratory. The procedures include exchange of the radioactive tracer labelled experiment groundwater for isopropanol, injection of Epoxy resin, 300 mm diameter over-core drilling of the experimental rock volume used, geological characterization and drilling of 24 mm core samples aimed for subsequent analysis of tracer penetration profiles. The borehole sections that were over-cored and previously in contact with the radionuclide tracer labelled groundwater consisted in part of a natural fracture surface and a borehole section in the unaltered matrix rock, devoid of natural fractures.

Sammanfattning

Föreliggande rapport utgör ett komplement till SKB-rapport R-10-68 och beskriver mer utförligt förfarandena för post-experimentella aktiviteter efter LTDE-SD-försöken *in situ* (Long Term Diffusion Sorption and Diffusion Experiment) utfört i Ävrö granodiorite vid ca 410 m djup på Äspölaboratoriet. Förfarandena innefattar utbyte av försöksgrundvatten innehållende radioaktiva spårämnen mot isopropanol, injektion av Epoxy, 300 mm diameter överkärnborrning av den experimentella bergvolymen, geologisk karakterisering och borrning av 24 mm kärnprover avsedda för efterföljande analys av penetrationsprofiler. Borrhålssektionerna som överborrades och tidigare var i kontakt med det radionuklidmärkta grundvattnet bestod delvis av en naturlig sprickyta och delvis av en borrhålssektion i den opåverkade bergmatrisen som saknar naturliga spickor.

Contents

1 Introduction

1.1 Background

The Long Term Sorption Diffusion Experiment (LTDE-SD) is one of the experiments within the Natural Barriers research programme at the SKB Äspö Hard Rock Laboratory (HRL), the goal of which is to increase the scientific knowledge of the safety margins of the final repository for spent nuclear fuel and to provide data for performance and safety assessment calculations. Transport of radionuclides in water-conducting rock fractures over 5–50 m distances has been studied within the Tracer Retention and Understanding Experiments (TRUE) experimental programme since the late 90's (Winberg et al. 2000, Andersson et al. 2002). Advection, dispersion, sorption and diffusive mass transfer are relevant processes of which dispersion and diffusive mass transfer can be difficult to distinguish by modelling alone of concentration-time curves. Because the evaluation of the results of the TRUE experiment (Winberg et al. 2003a) identified diffusion processes as an important retention mechanism, a demand for extended knowledge of diffusion and sorption processes over longer time scales in a controlled rock volume was identified. A sorption-diffusion experiment without advection and dispersion effects, LTDE-SD, was consequently set up. The LTDE-SD experiment aims at increasing knowledge of sorption and diffusion under *in situ* conditions and to provide data for performance and safety assessment calculations, i.e.:

- To obtain data on sorption properties and processes of individual radionuclides on natural fracture surfaces and inner surfaces in the rock matrix.
- To investigate the magnitude and extent of diffusion into matrix rock from a natural fracture *in situ* under natural rock stress and hydraulic pressure and groundwater chemical conditions.
- To compare laboratory derived diffusion constants and sorption coefficients for the investigated rock with the sorption behaviour observed *in situ* at natural conditions, and to evaluate if laboratory scale sorption results are representative also for *in situ* conditions.

The main *in situ* experiment was performed from September 2006 through April 2007. During this time period of ~7 months, radionuclide tracers were circulated, sampled and monitored in the test section of borehole KA3065A03. This stage is reported in SKB report R-10-67 (Widestrand et al. 2010b). In the present report, the performance of the termination of the *in situ* experiment is described including exchange of tracer labelled test section groundwater for isopropyl alcohol, over-core drilling of the target rock volume by drilling of a 300 mm diameter borehole, subsequent sample drilling and geological characterization. The core samples were analysed for trace element concentration profiles within the rock and the results are reported in SKB report R-10-68 (Nilsson et al. 2010). A laboratory program was performed in parallel with the *in situ* experiment and the subsequent analysis of the rock material. The aim of the laboratory experiments was to produce site-specific laboratory derived retention parameters (e.g. diffusivity and sorption distribution coefficients) for which the applicability to the actual *in situ* experiment results can be tested. The laboratory experiments were performed with material from the exploration borehole KA3065A02, the core of the 36 mm extension borehole and fracture material from the opposite side of the stub surface in KA3065A03. A common tracer solution was prepared and divided for use *in situ* and in the laboratory experiments. The results from the laboratory experiments are presented in SKB report R-10-66 (Widestrand et al. 2010a).

1.2 Objective and scope

The objective of this report is to describe procedures and results of; 1) exchange of test section groundwater to isopropyl alcohol 2) epoxy resin injection and removal of borehole installations, 3) 300 mm diameter over-core drilling aiming to extract the core stub and the rock surrounding the slim hole, 4) geological characterisation of the over-cored rock volume, incl. core stub 5) extraction of small, 24 mm, diameter cores from the over-core and core stub, and 6) geological characterisation of the small diameter cores.

The 24 mm diameter drill cores were cut in to small slices and analysed for their content of tracers aiming at determining penetration profiles for the tracers used in the LTDE-SD in situ experiment.

The present report provides complementary and more detailed information of the post-*in situ* performance of the LTDE-SD experiment and is not intended as a standalone report. For an over-view and a more complete description of the aim and scope of the experiments, as well as of experimental procedures prior to the over-core drillling, the SKB reports R-10-66 (Widestrand et al. 2010a), R-10-67 (Widestrand et al. 2010b) and R-10-68 (Nilsson et al. 2010) are recommended for a better understanding.

2 Over-core drilling

2.1 Epoxy resin injection in borehole KA3065A03

Epoxy resin injection of boreholes has previously been performed at Äspö HRL within "TRUE-1 Continuation project – Characterization of fault rock zones using epoxy resin injection" (SKB internal controlling document AP TD F83-03-018) where much of the method used in the activity was developed.

The objectives of the resin injection in LTDE-SD experimental borehole KA3065A03 were to:

- Mechanically stabilize the fracture surface on the core stub and wall/perimeter in the slim hole during the over-core drilling.
- Form a protective cover against outwash of radionuclides by the drilling flushing water during over-core drilling.
- Form a protective cover against outwash of radionuclides and cross contamination between core samples by the drilling flushing water during extraction of small diameter core samples.

2.1.1 Exchange of test section groundwater for isopropyl alcohol

The injection of epoxy resin was preceded by injection of isopropyl alcohol. The isopropyl alcohol was injected to: 1) replace the radionuclide labelled water in the test section, 2) facilitate the injection and adhesion of the epoxy resin to the rock and fracture mineral surfaces (by improving the wetting or the contact angle between the fluid and the solid surfaces).

The preparations for isopropyl alcohol injection started by disconnecting the electrochemical flow cell from the circulation loop and stopping the pressure regulator at a low-volume position.

Before the exchange procedure started the tank in the injection equipment (Figure 2-1) was filled with isopropyl alcohol and a tube was connected between the tank and the injection valve (Appendix 1, valve No 15) in the experimental set-up (Figure 2-2). The injection tube from the tank was flushed with isopropyl alcohol, to get rid of any air, before it was connected to valve No 15.

The pressure in the test section was monitored with a manometer and pressure gauge connected via the 1/8″ PEEK (PolyEther Ether Ketone) tubing in the experimental set-up, see Figure 2-2. An extra high resolution pressure gauge was also connected to the system for better control of small pressure changes during the isopropyl alcohol injection.

The exchange was carried out in accordance with the method described in Appendix 2, "Procedure for changing groundwater to isopropyl alcohol".

Table 2-1. Technical specification of equipment used for isopropyl alcohol and epoxy resin injection.

Device	Specification
Pressure gauges (not shown in Figure 2-1)	50 and 60 Bar (calibrated to reference GEO2555 070321)
Pressure vessel for Isopropyl alcohol	Volume: 12.0 litres. Inside diameter: 154.1 mm Fluid volume per fluid level change: 18.65 mL/mm
Pressure vessel for epoxy resin	Volume: 0.8 litres. Inside diameter: 44.1 mm Fluid volume per fluid level change: 1.58 mL/mm

The exchange of test section groundwater to isopropyl alcohol was started on 12 April 2007 using valve 15 both to inject isopropyl alcohol into the system and to withdraw the exchanged fluid.

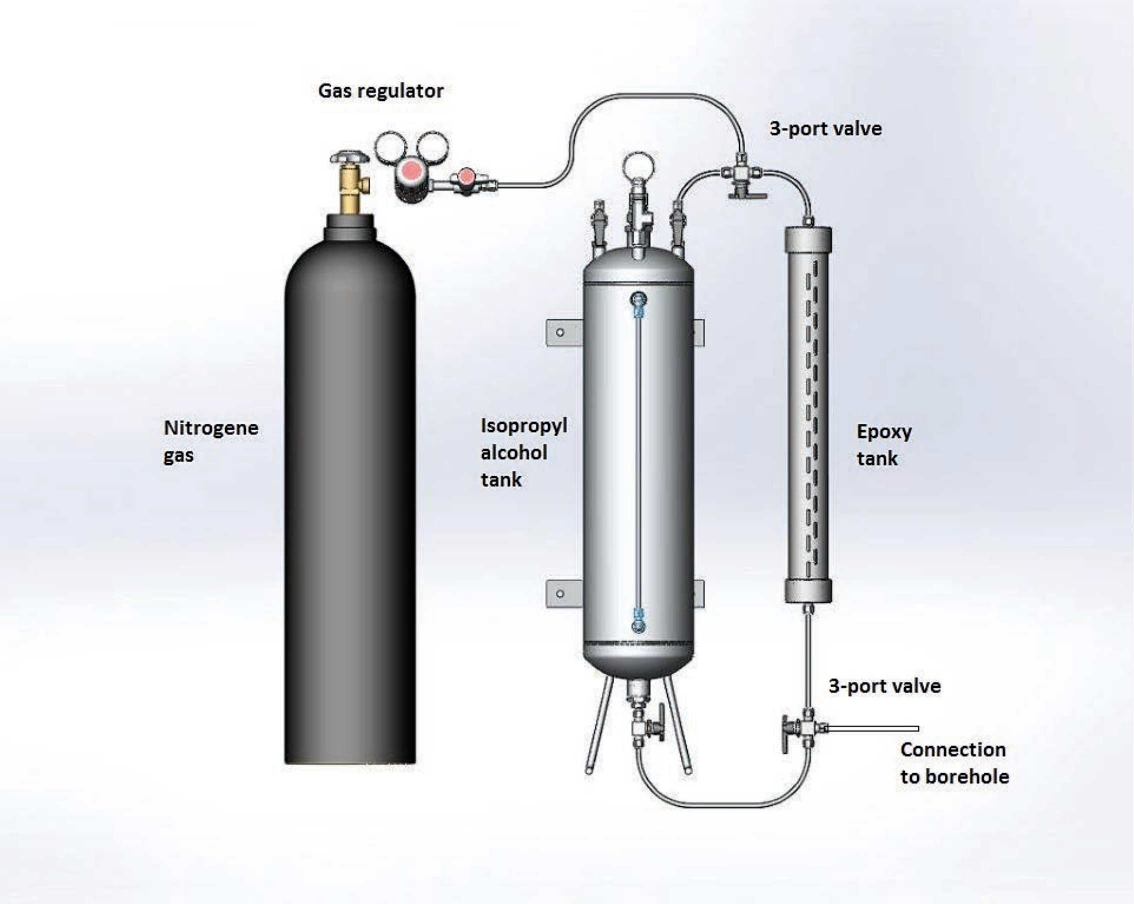

Figure 2-1. Schematic illustration of injection equipment for isopropyl alcohol and epoxy resin.

Initially the circulation was run through the 36 mm hole. To ensure good mixing during the exchange the circulation path was repeatedly switched between the test section in the slim hole and the test section in front of the core stub.

At the start of the exchange a small leakage occurred in the needle valve used to control the flow rate. A small bottle was used to collect the liquid and the effects of the leakage were hence kept at a minimum. After about 20 minutes the leakage stopped.

The isopropyl alcohol was injected in such quantity that it securely washed out the radionuclide labelled water from the experimental set-up. The experimental set-up had a total volume of about 1 000 ml, out of which the test sections and tubing in the borehole constituted about 300 ml and the amount of isopropyl alcohol injected was about five times the volume of the experimental set-up. The total injected volume, flow rates and pressures are presented in Table 2-2. The flow rate during the isopropyl alcohol injection was initially about 9 ml/min but was increased to 15 ml/min after half an hour. At 14:48 the flow rate dropped to 7.5 ml/min and the pressure increased. The flow rate was restored to approximately 17 ml/min by opening the needle valve further. After this a rather stabile flow rate was maintained.

During the simultaneous injection (isopropyl alcohol) and withdrawal (groundwater with radionuclides and isopropyl alcohol) the withdrawn liquid was poured into pre-weighed 0.5 litres bottles, to facilitate, if desirable, later analysis of radionuclide content and activity. The pouring into bottles was carried out inside the inert glovebox in the experimental container, in order to get an extra shield against radiation from the nuclides.

The progress of the exchange was followed closely with online γ-spectrometry (HPGe) and dos-rate meter (RNI). The HPGe-results for Co-57, Sr-85, Cs-137 and Na-22 are presented in Figure 2-3. Co-57 had been strongly adsorbed to the tubing in front of the detector during the experiment; hence the activity resulting from this has been subtracted.

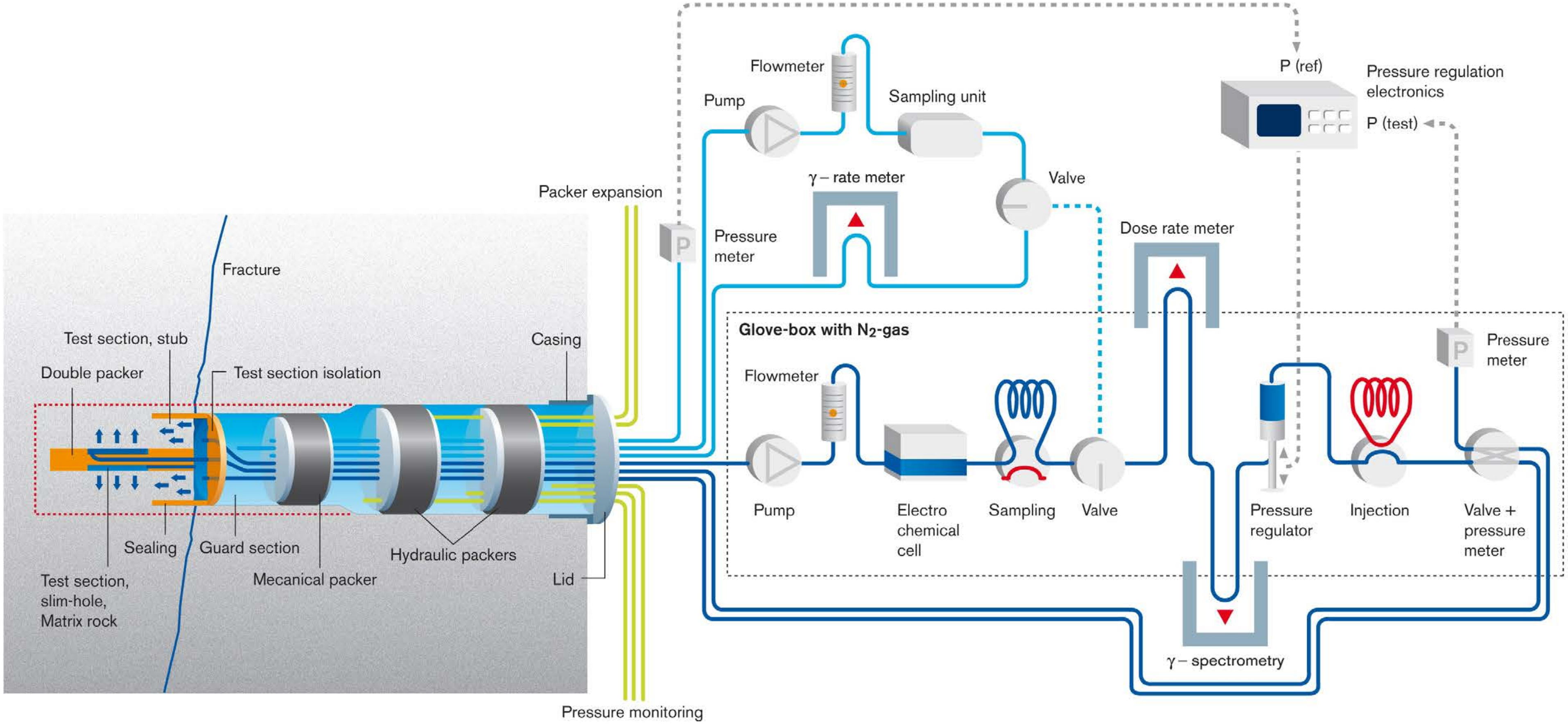

Figure 2-2. *LTDE experimental set-up in the experimental borehole KA3065A03 including the water circulation system for the test-sections and the hydraulic pressure control system.*

Approximately 5 litres of isopropyl alcohol was used during the exchange corresponding to roughly five set-up volumes. The last HPGe-measurement carried out in the tracer labelled groundwater in the test section, prior to the exchange to isopropyl alcohol, was used to calculate starting concentrations. Na-22 and Cs-137 values stabilized below 1 % of their initial concentration after approximately 2.5 litres of isopropanol had been injected. At this point the Sr-85 levels were still at 6 %. After about 5 litres had been injected, the strontium seemed to have stabilized at around 6 % of its initial concentration, this raised the questions whether this was caused by contamination on the tubing in front of the detector or due to desorption from the test section. It was decided to stop the exchange at this point based on the sodium and cesium results.

Table 2-2. Injection of isopropyl alcohol in KA3065A03.

Time (hours)	Level in vessel (mm)	Level decrement (mm)	Volume since last level reading (mL)	Flow rate (mL/ min)	Pressure in vessel (bar)	Pressure in test section (bar)	Pressure difference* (bar)
14:07	435				36.30	35.85	−0.26
14:20	425	10	0.19	14.3	36.38	35.86	−0.25
14:35	419	6	0.11	7.5	36.74	35.95	−0.16
14:45	412	7	0.13	13.1	36.75	36.40	0.29
15:00	400	12	0.22	14.9	36.76	36.12	0.01
15:15	386	14	0.26	17.4	36.79	36.06	−0.05
15:45	358	28	0.52	17.4	36.88	36.08	−0.03
16:15	329	29	0.54	18.0	36.85	36.09	−0.02
16:45	301	28	0.52	17.4	37.03	36.08	−0.03
17:45	241	60	1.12	18.7	36.82	35.97	−0.14
18:45	187	54	1.01	16.8	36.86	36.02	−0.09
19:05	172	15	0.28	14.0	36.87	35.83	−0.28

Injection start: 2007-04-12 at 14:07 hours
Total injected volume: 4905 mL
Injection flow rate, mean value: 16.5 mL/min

* Compared to pressure in test section prior to start of injection, 36.11 bar, which also was the pressure in the first guard section (situated between the two mechanical packers, see Figure 2-2) throughout the injection procedure.

To clarify the cause of strontium activity above reference line, the gamma rate-meter – loop was filled with water from the first guard section after completed isopropyl alcohol injection. The HPGe analyses results indicate that there was no contamination on the tubing in front of the detector. This implies a considerable part of strontium is desorbed somewhere in the system during the exchange from groundwater to isopropyl alcohol, most likely from the rock surfaces in the experimental test section.

The negative values for Co-57 could be explained by isopropyl alcohol dissolving some of the adsorbed Co-57 from the tubing in front of the detector.

The wavelike pattern corresponds well with the changes made in flow paths. The first series of points is taken with water from the guard section standing in the HPGe-loop prior to the exchange. Just after the start of the exchange at 14:07 hours, mainly original test section groundwater from the slim hole is passing through the detector loop, the activity then drops until approximately 14:45 when it again begins to rise due to valve 4 being changed to inject at 14:45 and the test section groundwater from the lower part of the stub and corresponding tubing is now leaving the system. After this the activity drops again and begins to stabilize.

The RNI-instrument measuring the activity in the test section showed a similar course of events but due to software problems, data could not be stored and printed.

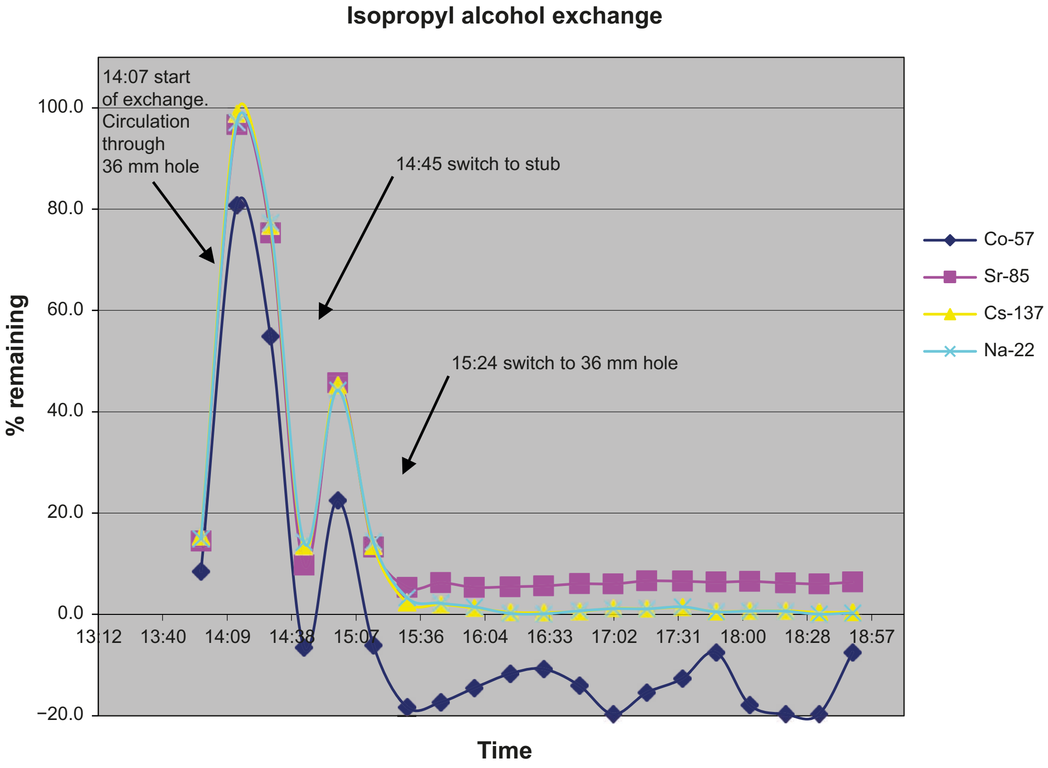

Figure 2-3. Remaining Co-57, Sr-85, Cs-137 and Na-22 in the experimental set-up in borehole KA3065A03 based on the concentrations just prior to the exchange from radionuclide labelled groundwater to isopropyl alcohol. Activity resulting from Co-57 adsorbed on the tubes has been subtracted.

2.1.2 Epoxy resin injection

Preparations

Large quantities of the epoxy EpoTek 301 purchased for the "Fault rock zones characterization" within TRUE-1 Continuation project in 2003 had been left over and stored at Äspö HRL. The EpoTek 301 is a two component epoxy resin consisting of a base and a hardener. The fluorescent substance EpoDye was mixed into the epoxy by the amount of 14 g per litre of base, which facilitates checking that unwanted penetration of epoxy resin into the rock has not occurred.

After a first visual control of mixing, curing and that the EpoDye had not deteriorated during storage, the epoxy portion from Äspö HRL was used for further tests and for the injection in the experimental borehole KA3065A03 as described in this section.

The dyed base of the epoxy was mixed with the hardener to the proportions of four volume shares of base to one volume share of hardener. It was carried out by adding the hardener to the base during manual mixing. The epoxy was poured into the "Epoxy tank" (cf Figure 2-1) after c 5 minutes of manual mixing.

One of the major risks in resin injection is incomplete intrusion of epoxy into the test section volumes in front of the core stub and in the slim hole.

If the epoxy does not fully intrude the test section volumes, the subsequent over-core drilling may flush out radionuclide tracers from the core stub and the rock surrounding the test section in the slim hole. Also, the over-core drilling may mechanically damage the stub and rock surrounding the test section if it is not protected by an epoxy resin cover. A critical issue was whether it is possible to inject the epoxy resin through 11 metres of small diameter (2 mm) PEEK tubing to finally reach the test section volumes in front of the core stub and in the slim hole. A test was therefore carried out prior to injection in the experimental borehole. The result of the test, carried out with the equipment shown in Figure 2-1 at about 20 degrees Celsius, is presented in Table 2-3. A prerequisite for the epoxy injection in the experimental borehole at Äspö HRL was that the injection flow rate could be at least 0.5 ml/min. If the flow rate falls below that limit it is not possible to carry out a successful injection through the tubes in the borehole equipment, since the resin will cure before enough amount has been injected to fill up the test section volumes. As can be seen in Table 2-3, the injection flow rate was above that limit if injection pressure at the vessel was kept at 3.0 bars or more above ambient pressure.

Table 2-3. Result of testing EpoTek 301 epoxy resin injection in 12 meter PEEK tubing having an inner diameter of 2 mm.

Injection pressure (bar)	Duration of injection (minutes)	Injection flow rate* (mL/min)
0.35	10	0.11
1.1	10	0.23
2.1	10	0.42
3.0	10	0.53
4.0	10	0.66
5.0	10	0.82
6.0	10	0.92
7.0	10	0.99
8.0	10	1.06
9.0	10	1.10
Test date: 2007-03-08		

* Calculated value based on an epoxy resin density of 1.0 gram per mL.

Injection of epoxy

In order to prevent pushing radionuclide tracers further into the rock than they have penetrated during the course of the experiment due to natural diffusion and sorption processes, the injection of epoxy resin was carried out with a minimum excess pressure. Preferably the pressure in the test sections shall not raise more than 0.2 bar above natural background.

The injection of epoxy followed a procedure in accordance with the method described in Appendix 3. The flow versus pressure governed injection scheme that was adopted for the epoxy resin injection is presented in Appendix 4.

The epoxy injection started on 12 April 2007 at 20:50 hours, after cutting the tubes under pressure as close to the borehole as possible using a specially developed technique (Appendix 3; Figure 2-4). The purpose of cutting the tubes was to ensure that filling up of the borehole sections with Epoxy resin would be obtained before it had cured and to reduce the pressure due to flow friction.

The injection (Figure 2-5) continued for about five hours, see Table 2-4. As expected the injection flow rate was reduced with time as the epoxy resin cured. At 23:48 hours a clearly visible epoxy front was noticed in the outgoing tube. (A mixture of isopropanol and Epoxy is present in the bottle in Figure 2-6). An increased g-dose rate was indicated in the front between the isopropanol and the Epoxy resin, measured using portable equipment. Targeted measurements indicated that the activity was not in the Epoxy resin in the bottom of the sampling bottle, but in the entire bottle, thus indicating that the activity was transported in the Epoxy front in contact with the isopropanol.

At this point approximately 300 ml of easy flowing liquid had been collected at the outlet, at a flow rate averaging about 1.7 ml/min. At 01:01 approximately 350 ml had been injected and the epoxy started to cure. At 01:30 the epoxy injection was stopped as the flow rate was close to zero due to the epoxy curing. The total amount epoxy injected was 364 ml, and the estimated experiment volume including short tubings in and out was 307 mL. The equipment was left at the borehole overnight in order to maintain the pressure in the borehole until the epoxy had cured completely.

Figure 2-4. Cutting circulation tubes under pressure at initial phase of epoxy resin injection.

Figure 2-5. The yellow coloured (EpoDye) epoxy resin being injected at the KA3065A03 borehole collar.

Figure 2-6. Mixture of isopropyl alcohol and yellow coloured epoxy resin collected at KA3065A03 outlet tube during epoxy resin injection.

Table 2-4. Injection of epoxy in KA3065A03.

Time (hh:mm)	Level in vessel (mm)	Level decrement (mm)	Volume since last level reading (mL)	Flow rate (L/min)	Pressure in vessel (bar)	Pressure in test section (bar)	Pressure difference* (bar)
20:50	255				35.80	32.90**	−3.21
21:00	227	28	0.044	4.4	41.15	36.15	0.04
21:15	200	27	0.043	2.8	40.88	36.12	0.01
22:00	138	62	0.098	2.2	41.50	36.15	0.04
22:30	110	28	0.044	1.5	42.30	36.20	0.09
00:00	46	64	0.101	1.1	43.45	35.85	−0.26
01:30	25	21	0.033	0.4	43.80	36.00	−0.11

Injection start: 2007-04-12 at 20:50 hours
Injection stop: 2007-04-13 at 01:30 hours
Total injected volume: 364 mL
Injection flow rate, mean value: 1.3 mL/min

* Compared to pressure in test section prior to start of injection, 36.11 bar, which also was the pressure in the first guard section throughout the injection procedure.

** Pressure drop caused by a valve shift before cutting the tube.

2.2 Removal and dismantling of equipment in borehole KA3065A03

2.2.1 Description of equipment

The equipment was built up of three stainless steel pipes; a centre, middle, and an outer pipe, Figure 2-7. One mechanical packer (200 mm diameter) and two hydraulic packers (300 mm diameter) were mounted on the outer pipe to build up guard sections preventing effects of the acting hydraulic gradient on the test conditions around the stub. The middle pipe was used to expand the mechanical packer by means of an expansion gear. The centre pipe, sealed off at the end of the mechanical packer, was used to dock a custom shaped disc of PEEK-material to a cylindrical PU (polyurethane) sealing previously mounted around the stub. The PEEK-disc, which was cast to minimise the volume of water in the test section, was pushed toward the end of the polyurethane cylinder, which expanded in the slot between the stub and the borehole wall and sealed off the test section.

Tubes for circulation of water and for pressure measurements in the test section (1/8” PEEK) together with three plastic tubes (PA 12, Tecalan 6/4) from the inner guard section were led through inside the centre pipe. The tubes for pressure measurements in the outer guard sections ran via lead-throughs in the hydraulic packers to the outer seal. The tubes for inflation of the hydraulic packers were all Tecalan 6/4-tubes.

To reduce the risk of a simultaneous packer deflation the two hydraulic packers were individually expanded using separate packer inflation lines. At the borehole collar a steel lid, with lead-through for the outer pipe, made up the outermost seal.

2.2.2 Preparations at site

A prerequisite for the removal and dismantling of the borehole equipment was that the test sections in the experimental borehole had been emptied on radionuclide tracers and that epoxy resin had been injected in the test section in front of the core stub and in the test section in the slim hole.

A container was placed under the borehole collar to collect the water flowing out of the borehole when the packer system was removed.

Since the LTDE-SD in situ experiment included radioactive tracers, the site was restricted and controlled area, enclosed by a fence. The controlled area was enlarged to make it possible to keep the borehole equipment and installation/dismantling rack inside the fence during the removal and dismantling work.

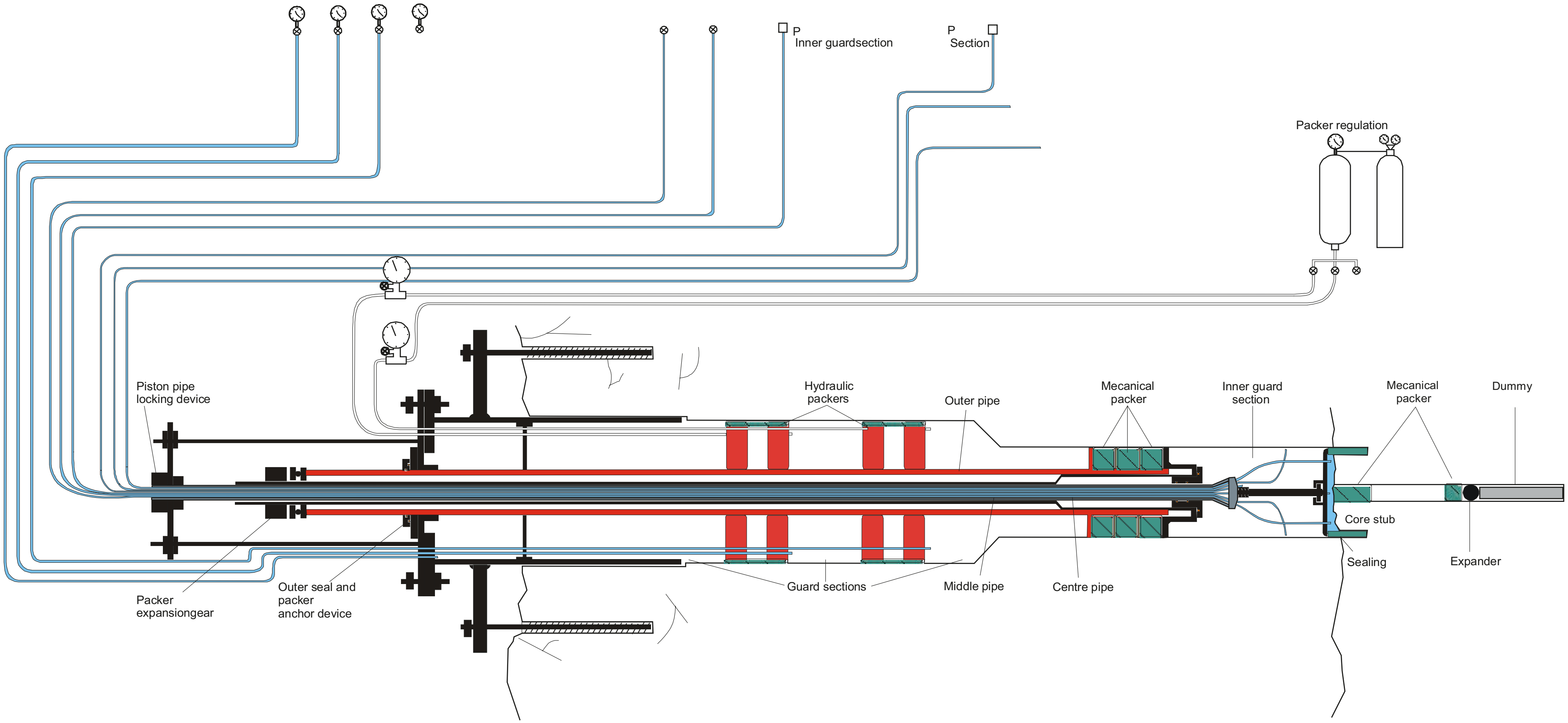

Figure 2-7. *Schematic of installations in the LTDE-SD experimental borehole KA3065A03.*

The alarm functions for pressure in the experimental borehole KA3065A03 and pilot borehole KA3065A02 were switched off before removal of the packer system. Also the alarms for low pressure in the hydraulic packers and packer pressure vessels were switched off before removal of the packer system.

2.2.3 Removal and dismantling

The removal and dismantling of the borehole equipment started on April 17th, 2007 and was completed on April 18th, following a procedure in accordance with Appendix 5. The equipment was designed to leave two devices in the borehole after removal; 1) the cylindrical PU sealing in the slot between the stub and the borehole wall, and 2) the mechanical double packer and dummy in the 36 mm diameter extension borehole, see Figure 2-7.

The epoxy resin injected in the test section in front of the core stub, i.e. in the space between the core stub and the PEEK lid, did not adhere only to the surface on the core stub but also to the PEEK lid. Special care was therefore taken during removal of the borehole equipment aiming at leaving an intact epoxy cover on the core stub while removing the PEEK lid together with the other parts of the borehole equipment. As it turned out the epoxy adhesion was strong both to PEEK lid and the core stub resulting in the PEEK lid loosen from the supporting steel plate. As a result, the PEEK lid was left adhered to the stub by the epoxy resin in the borehole while all other equipment, except for the cylindrical PU sealing and the packer in the 36 mm borehole, was removed from the borehole. A collection of photographs showing the removal and dismantling of borehole equipment in KA3065A03 is presented in Appendix 6.

A scintillation detector was used to measure the radioactivity during the procedure of removal and dismantling, with most borehole equipment showing no rise above the background (10–15 cps = counts per second). The hydraulic packers and the supporting steel plate for the PEEK lid gave values of about 20–25 cps (Figure 2-8). This may be a result of extra Rn daughters accumulating on the borehole walls sticking to these larger objects as they were slowly hauled out of the borehole. The smaller pipes that didn’t touch the walls gave lower count rates. Smear testing by Clab (intermediate storage for spent nuclear fuel in Oskarshamn) radiation safety personnel cleared the entire equipment for storage.

All water emanating from the borehole was collected in an open vessel and measured for radioactivity and sampled before it was further poured into the tunnel drainage system, see Appendix 6. An RNI-instrument was used for the monitoring of the activity in the water flowing from the borehole. It was installed at 16:11 hours on April 17th and the data is presented in Figure 2-9.

Figure 2-8. *Measurement of radioactivity by scintillation detector during the procedure of removal and dismantling.*

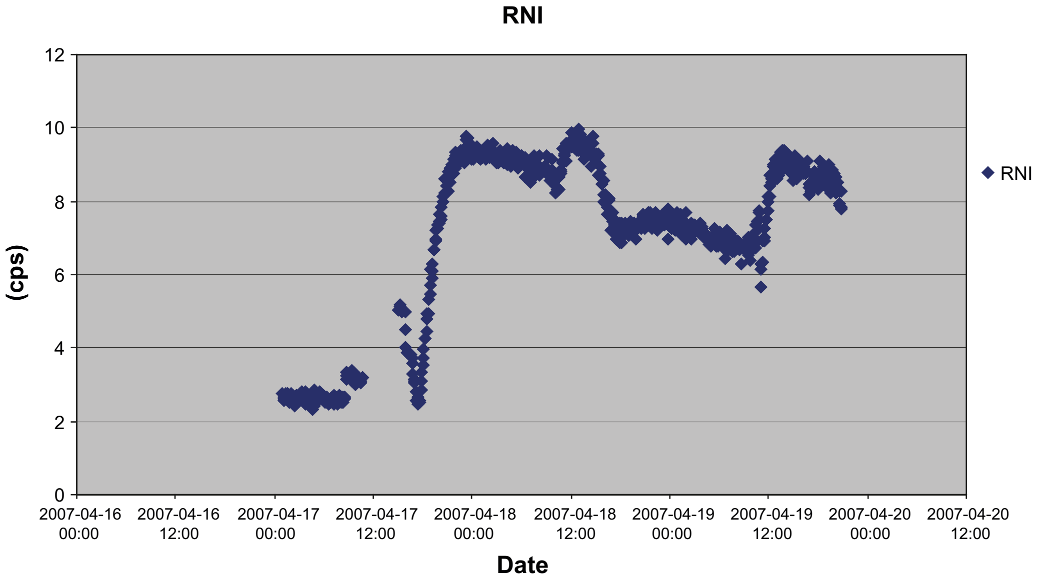

Figure 2-9. *RNI γ-radiation measurement count rate (cps) during removal and dismantling of borehole equipment in KA3065A03.*

After a couple of hours, the count rate stabilized at approximately 9–10 cps. HPGe-analysis during this time period shows that this was a result of an increase in Rn daughters, some low levels of Na-22 (hardly visible in most spectra), Co-57, Sr-85, Ba-133 and Cs-137 were detected but naturally occurring Rn daughters dominated the radioactivity. When all equipment had been removed and the borehole was sealed at 14:37 hours on April 18th with a lid mounted on the borehole collar, the instrument measured standing water. Consequently, the count rate dropped as a result of Rn leaving the water. When the borehole was opened for sampling at 09:50 hours on April 19th the count rate again rose to about 9 cps due to an increase in Rn and its daughters.

2.3 Over-core drilling KA3065A03

Large diameter over-core drilling (300 mm) has previously been performed at Äspö HRL within the TRUE-1 Continuation project (Hansen and Staub 2004). Much of the method and experiences gained in that project were applied in the over-core drilling of KA3065A03. However, special measures and safeguards were taken for protection against radioactivity and handling of backwashing water and drilling debris.

The objective of the 300 mm diameter over-core drilling of KA3065A03 from 9.678 to 11.824 m was to extract the core stub and the rock surrounding the slim hole. It was further of outmost importance to:

- Retrieve the core stub in one piece, with no damages.
- Retrieve a one piece 278 mm core, from 10.80 to 11.36 m borehole length, including the rock surrounding the test section in the slim hole.

Subsequent analysis partly focused on the position of the tracers diffused into and sorbed on the inner surfaces of the core stub and matrix rock surrounding the test section in the slim hole. Hence, it is of utmost importance that orientation and length position of the core from the target sections is correct.

2.3.1 Drilling of borehole KA3065A03

The large diameter borehole KA3065A03, which hosted the experiment, was drilled in a telescoped fashion. The diameter is 300 mm from collar to 9.678 m borehole length. From about 9.73 m and down to the target fracture at 10.737 m the diameter is 196.5 mm. See Figure 2-10. The drilling continued 150 mm beyond the target fracture, leaving a core stub of 177 mm diameter and 150 mm length in the bottom of the borehole. The resulting slot between the borehole wall and the stub made it possible to hydraulically isolate the fracture surface on the core stub with a cylindrical PU sealing. The face of the core stub is an irregularly shaped sub-planar fracture surface almost orthogonal to the borehole axis. A slim hole was drilled in the centre of the core stub and 1.1 m further into unaltered rock. A 0.3 m long test section has been hydraulically isolated in the slim hole at 10.93 – 11.23 m borehole length. The nominal diameters of the borehole segments and the associated cores are presented in Table 2-5.

Table 2-5. Overview of diameters used when drilling the LTDE telescoped large diameter experimental borehole KA3065A03.

Outer segment		**Inner segment**		**Slim hole**	
0.00 – 9.68 m		**9.68 – 10.74 m**		**10.74 – 11.82 m**	
Outer diameter (OD)	**Core**	**OD**	**Core**	**OD**	**Core**
300 mm	270 mm	196.5 mm	177 mm	36 mm	22 mm

The over-core drilling was planned to be carried out in two phases; 9.678 – 10.737 m and 10.737 – 11.824 m.

The drill core from the 9.678 – 10.737 m part of the borehole is not of great importance for the project. The core will have an OD of 278 mm and a centre hole of 196.5 mm diameter. Natural fractures will be used as breaking points for the core. A fracture zone breaches the borehole at 10.08 – 10.28 m and the open target fracture, of which a part was isolated with a cylindrical PU sealing during the experiment, intersects the borehole at 10.73 m. It was anticipated that the core would break at both the fracture zone and at the target fracture.

The over-core from the 10.737 – 11.824 m part is of utmost importance to the project and contains the rock matrix where the radionuclide tracers have diffused and adsorbed. In the slim hole, open fractures were found at 11.347 and 11.637 m. It was anticipated that the core should break at one of these fractures. If the core did not break at a natural fracture, special tools for core breakage should be inserted in the borehole to break the core at the requested borehole length, which was needed (see Section 2.3.4).

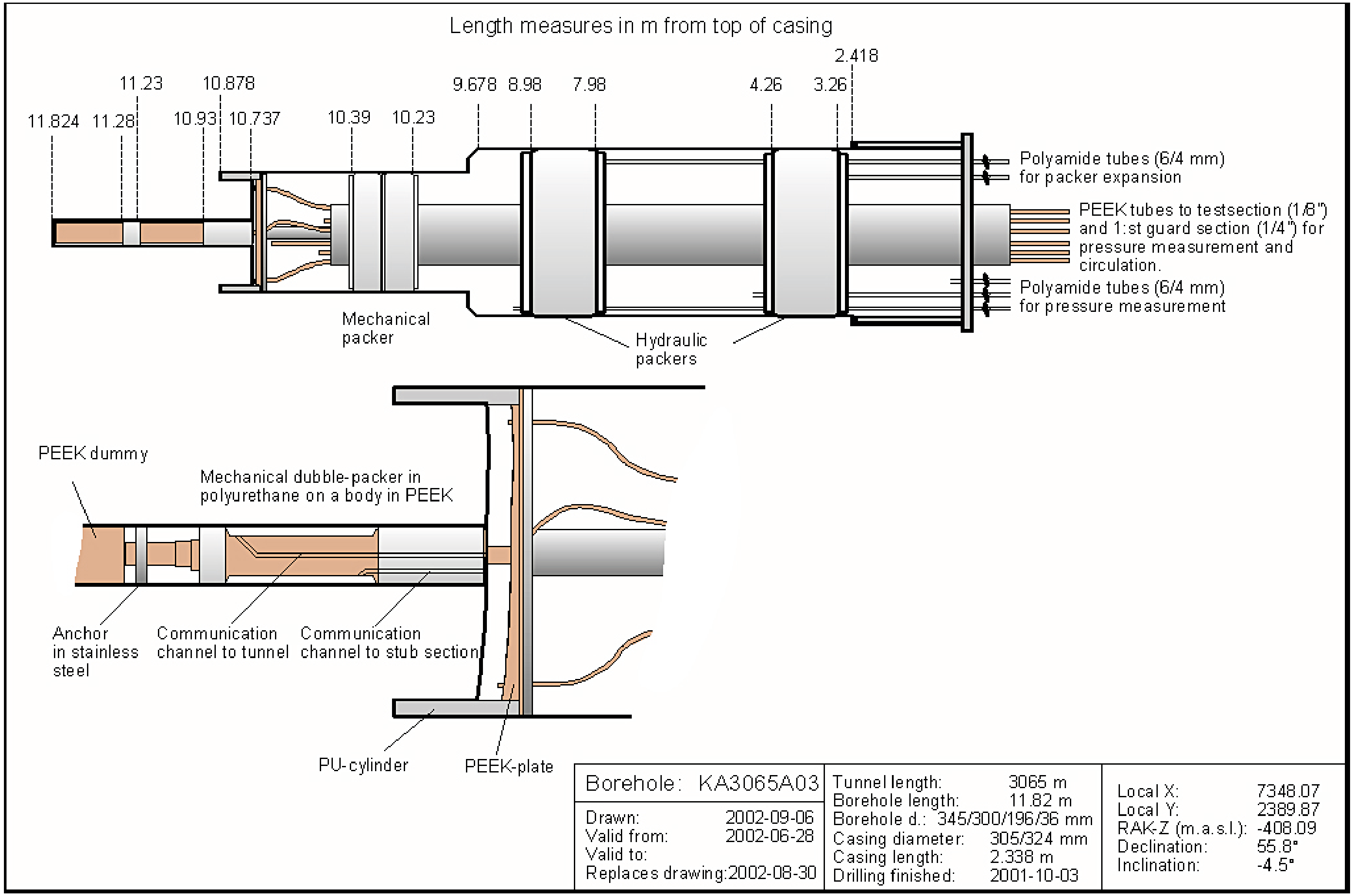

Figure 2-10. *Borehole installation drawing KA3065A03.*

2.3.2 Preparations at site

For the over-core drilling it was required that the borehole plug, i.e. the lid attached to the flange on the borehole casing, was removed. Because radioactive tracers had been used in the borehole this had to be done carefully, by first lowering the hydraulic pressure in the borehole. The valve on the lid was opened and the water flowing out of the borehole was collected in a container beneath the collar and also sampled and measured for any contamination from radionuclides used in the in situ experiment. The lid was removed when the pressure had been lowered.

Because the LTDE-SD in situ experiment included radioactive tracers the site was classed as a controlled area and therefore enclosed by a fence. The controlled area was enlarged for the over-coring, making it possible to keep all drilling equipment inside the fence. To avoid contamination from drill tools, drill cores and water potentially containing radionuclides the drillers, site geologist and other personnel handling the drill equipment and drill cores wore protective clothing (Figure 2-11).

One of the major risk factors regarding this activity is unwanted core breakage in the target section at 10.737 – 11.637 m, which includes the core stub and the rock surrounding the test section in the slim hole. It is vital for the subsequent analysis that this piece of core is intact. Hence, great care was taken when drilling and recovering the target section. Induced breakage of the core within this section must thus be avoided. Hence, identifying of natural breaking points close to but outside 10.737 – 11.637 m prior to the drilling was essential.

The water inflow to borehole KA3065A03 when the equipment was installed was about 10–12 l/min in the fracture zone at 10.08 – 10.28 m. At 11.637 m there is a conductive fracture giving 0.03 ml/min. This fracture has hydraulic contact with the pilot borehole KA3065A02. Hydraulic characterisation of the LTDE-SD site also confirms hydraulic contact between the 196.5 mm part of KA3065A03, most probably the fracture zone at 10.08 – 10.28 m and section P3, 7.5 – 13.0 m in KA3065A02. The distance between the walls in boreholes KA3065A03 and KA3065A02 is only a few decimetres and the over-core drilling in KA3065A03 will shorten this distance. The shortened distance to KA3065A02 and the widening of the borehole may result in an increased water inflow to KA3065A03.

The system of containers and pumps to be used to collect the backwashing water and the natural inflow to the borehole was therefore designed to manage the increased inflow that may be due to the widening of the borehole and the shortened distance to KA3065A02. The system used for handling drilling flushing water and potentially contaminated backwashing water and drilling debris is illustrated in Figure 2-12. See also Appendix 7, Figures A7-1 and A7-2.

Figure 2-11. *Drilling machine (Onram 1000) with 300 mm diameter drillbit and core barrel are checked prior to over-core drilling borehole KA3065A03.*

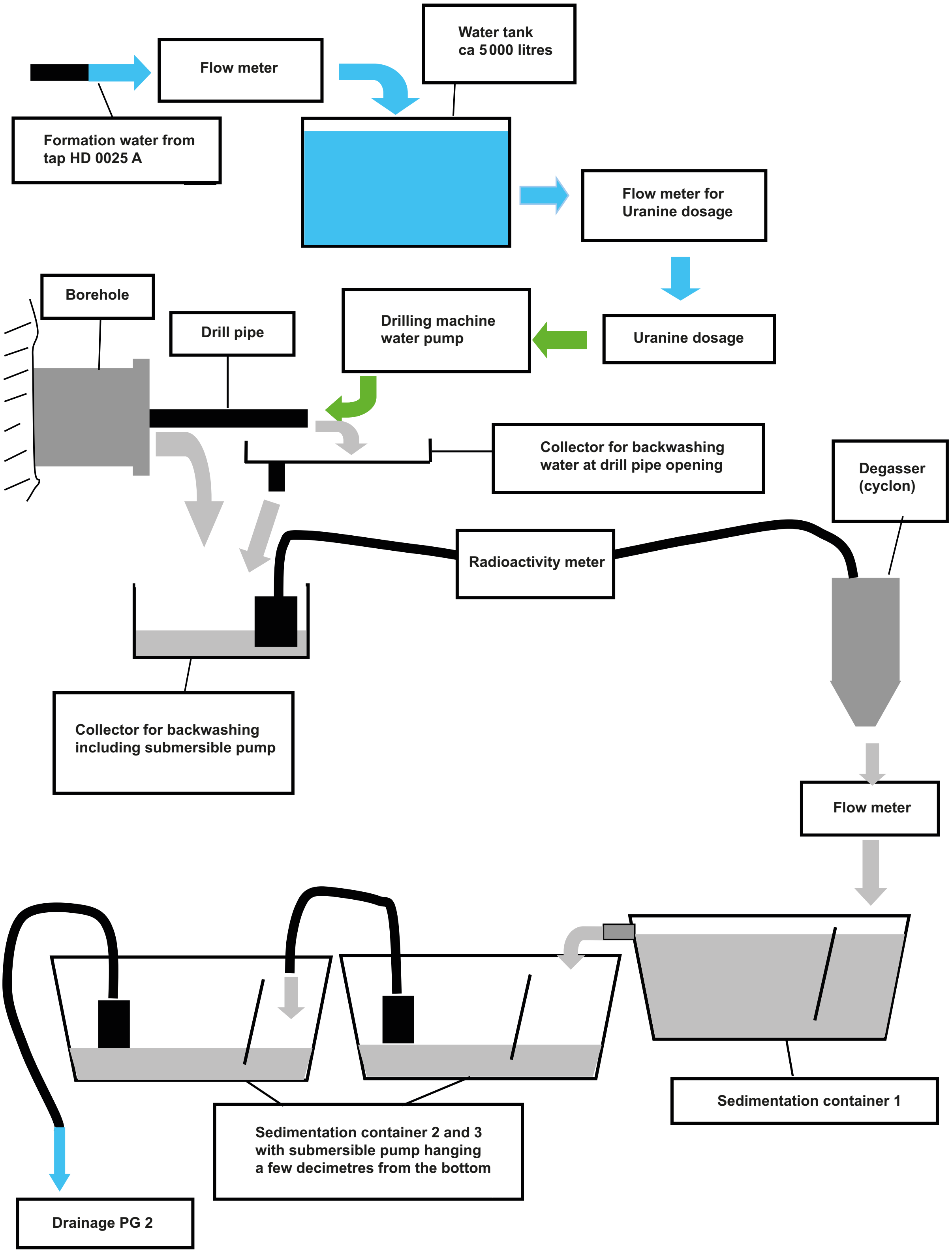

Figure 2-12. *System for flushing and backwashing water at over-core drilling of borehole KA3065A03 at the LTDE-SD site in niche NASA3067A at Äspö HRL.*

2.3.3 Drill phase 1, chainage 9.67 to 10.8 metres

A collection of photographs showing preparations at site and over-core drilling is presented in Appendix 7. Notes from over-core drilling are presented in Appendix 8.

Drill phase 1 comprised chainage 9.67 to 10.8 metres. It was planned to drill in two core runs; 1) 9.67 to 10.3 breaking the core at a natural fracture, and 2) 10.3 to 10.8 where the target section begins. As the borehole was already drilled with a diameter of 196.5 mm, the core could, at best, be retrieved as a hollow cylinder of rock with 4 cm thick walls. The retrieved cores in both runs were, however, broken into pieces by drilling, the appearance being similar to core disking which occur during rock stress measurements with the over-coring method. Subsequently, the remaining core stub was inspected, revealing that the PEEK lid had loosened from the cylindrical PU sealing. It was retrieved together with small amounts of core fragments by means of the core barrel.

Finally, for orientation, the core stub was marked by means of two hammer blows on a pinch bar inserted along the invert of the hole.

2.3.4 Drill phase 2, chainage 10.8 to 12.1 metres

The aim of phase 2 was to drill beyond 11.23 m expecting the core to break at one of the fractures between 11.34 and 11.8. Drilling started on April 27th. Because the PEEK lid had loosened from the cylindrical PU sealing, frequent sampling for HPGe and Scintillation measurement of the water in the collection vessel beneath the borehole collar, as well as check of dose rate on the first sedimentation container, was done during the entire drilling from 10.8 m and onwards. No radioactivity above background values was measured with scintillation and dose rate detectors, even though HPGe measurement of water samples showed occasional radionuclides from the experiment in the water flowing out of the borehole. It was decided to drain the borehole at all pauses and breaks in the drilling by using a suction pump to keep the core stub with adsorbed radionuclides dry, but at high relative humidity, and thereby preventing radionuclides from diffuse into water and contaminate surfaces on the core outside the initially sealed stub surface exposed to radionuclide tracers during the experiment. See Appendix 8 for details.

In the beginning drilling went extremely slow and when pressure was increased, the concrete foundation for the machine suddenly loosened from the tunnel floor at about chainage 11.19 m. After this further drilling was postponed, in order to review drilling equipment and procedure for the remaining core.

After fastening and aligning the drilling machine to the borehole strike and dip, drilling was resumed on April 30th in small steps, sharpening the drill bit very often. Drilling was stopped and attempts made to break the core at potential fractures at 11.4 m, 11.75 and 11.95 m, but the core of phase 2 did not break at any of the expected fractures, see Appendix 8. Further drilling and attempts to break the core were postponed until May 2nd when staff from radiation protection organisation could be on site. Because the suction pump no longer had the capacity to keep the core stub dry, it was decided to stop pumping and put the borehole lid on the borehole collar.

On May 2nd the borehole lid was removed and drilling went on further and was stopped at 12.11 m. By means of a special "barrel" a new core breaking device was inserted on top of the core, far beyond the minimum acceptable borehole length 11.35 m. The core was breached as planned, and an undamaged one-piece core 10.74 – 11.82 m was retrieved successfully (Figure 2-13).

Overall, the effective drilling time was approximately 5.5 hours for the drilling from stub surface on target fracture at 10.74 m borehole length to stop of drilling at 12.11 m. Flushing water flow was 40 litres per minute, giving a total of 13.3 cubic meters of flushing water flowed past the stub surface and outer surfaces of the large 270 mm diameter core until it was retrieved from the borehole. As described above HPGe measurement of water samples showed occasional radionuclides from the experiment in the water flowing out of the borehole. This was caused by desorption of radionuclides from the stub surface due to the flushing during drilling. As a consequence, radionuclides may have sorbed on core surfaces outside the initially sealed stub surface exposed to radionuclide tracers during the experiment.

On the day after retrieving the core it was totally covered in cellophane plastic and heavy plastic foil to prevent it from drying.

Figure 2-13. *One piece, 278 mm diameter, 10.74–11.82 m core retrieved from over-core drilling of borehole KA3065A03. Target fracture with the 177 mm diameter core stub inside the cylindrical PU sealing where radionuclide tracers were circulated.*

2.3.5 Environmental monitoring

The radioactivity in the backwashing water was measured continuously with a low dose scintillation detector. In addition, the incoming water in the water tank and the backwashing water in the container beneath the casing and in the sedimentation container 1 were measured for radioactivity intermittently by means of a hand held high sensitive scintillation probe. Water samples were taken for radionuclide specific measurement by means of HPGe during the course of drilling.

During the removal and dismantling of borehole equipment and during the over-core drilling, measurement of potential losses/desorption of tracers was performed both by on-line measurement of the drilling fluid and by combined sampling/measurement of the sampling fluid. A critical part during the drilling was the time when the PEEK lid cylindrical PU sealing accidently got removed from the core and the fracture surface was exposed for flushing water causing desorption of tracers. An extended summary of the tracer losses obtained during the drilling is reported in Nilsson et al. (2010). The tracer with the evidently highest loss during removal of borehole equipment and over-core drilling was Cs-137 for which 8.5 % of the injected amount was lost during the drilling.

2.3.6 Post drilling activities

A timeline of events during the experiment, focused on post drilling activities is provided in Appendix 9. After the completion of the drilling, the drilling machine and belonging equipment was controlled for radioactivity contamination. The smear tests performed by Clab radiation safety personnel cleared the entire equipment, after which it was removed from the experimental site.

Due to the large core diameter, giving a weight of 150–170 kg per metre of core, lifting had to be done with a tractor equipped with a crane beam.

The borehole was plugged with a lid attached to the flange on the borehole casing, in order to stop the outflowing water.

No further activities are planned to be executed in the LTDE-SD experimental borehole KA3065A03. However, it may be necessary to employ a control program regarding the radioactivity on the site. The extent of control program, i.e. water sampling and analysis, depends on if and how much of the activity that it left on the site after the over-core drilling.

The cores resulting from the over-core drilling was put into wooden boxes and transported to Clab with an industrial truck. The transportation was supervised by radiation safety personnel.

3 Mapping and characterisation of large (278 mm) diameter core

3.1 Unpacking and marking of core

The drill core was hoist to the core-logging desk by means of a fork lift and a travelling crane. The drill core was covered with plastic foil, which was removed and the core was examined for radiation by means of a scintillation meter. Only at the upper end (Figure 3-3) minor radiation was detected. Before drilling, the core top end had been punched twice at hole invert by means of a pinch bar, for core orientation purpose. Top end of core was examined for these marks. Two probable punch marks and two uncertain marks were identified. Additional information concerning the assumed orientation of the drill core is presented in Section 4.1.1.

The core was marked as follows:

A. With a line along the core axis marked in cm, with chainage zero at top end of core (Figure 3-1 and Figure 3-2).

B. With 8 letters from A at chainage line, to H, all approximately equally distributed clockwise (as viewed from core top) around the perimeter of the core at top end.

C. Two probable pinch bar marks end of core were marked with double rings, and the two uncertain with single rings (Figure 3-4).

The induced breakage of down end of the drill core is shown in Figure 3-5.

Figure 3-1. Marking of core lengths starting from zero at top of core.

Figure 3-2. *Drill core with chainage markings.*

Figure 3-3. *Upper end of core with PU cylindrical sealing and epoxy filled 36 mm pilot centre hole.*

Figure 3-4. Pinch bar marks highlighted on upper end of core. Double rings indicate probable marks, single rings indicate uncertain marks.

Figure 3-5. Induced breakage of down end of drill core also showing the 36 mm extension hole filled with equipment for sealing test section.

3.2 Core photography and method of geological characterisation

Photographs of the entire core were taken with the core in dry and wet condition, in each case from eight positions, with the markings A to H facing the camera. Core photography comprises also details of fractures andhe photographs are shown in Appendix 9. It may be possible to merge the photographs to show the entire unfolded envelope surface of the core, similair to a BIPS image. Photographs of details such as fractures are shown in Section 3.4, where these features are treated further.

Rock type was described by means of unaided eye inspection. Subsequently, the core envelope surface was covered with transparent drawing film, on which fracture traces were drawn (Figure 3-6).

3.3 Rock type and rock structure

The rock type is a so-called Ävrö granodiorite with lineation or a slight foliation. The grain size is medium to coarse, and the colour is greyish red. Along three fractures sealed with a hard mineral (quartz?) the rock is miscoloured in red about 2 cm on either side of the fractures (Figure 3-7).

Figure 3-6. *Mapping fracture traces on core.*

Figure 3-7. *Drill core rotated to position A (chainage line) facing camera lens. Rock is a so-called Ävrö granite with a diffuse foliation or lineation. Reddish miscolouring is aligned with fractures sealed with quartz or another hard mineral.*

3.4 Fractures

Three types of fractures were identified and mapped:

1. Open discontinuous fractures (mapped in green colour).
2. Short sealed fractures (mapped in red colour).
3. Sealed continuous fractures (mapped in red colour).

Figure 3-8 to Figure 3-11 show the down end of the core, chainage 50–110 cm, wrapped with drawing film with mapped fractures of the first two types. As can be seen from the figures, the fractures do not propagate continuously through the core, which explains why the fractures failed to break during drilling.

Figure 3-8. *Down part of core 50–110 cm rotated to position A. Two traces of open fractures are marked with green and three short sealed fractures marked with red. The open fracture at 60 cm intersects the core with an angle of 90°, and the other at 80 cm has an angle with core axis of 45°.*

Figure 3-9. *Down part of core 50–110 cm rotated to position C, showing that the open fracture at 80 cm with 45° to core axis is not continuous.*

Figure 3-10. *Down part of core 50–110 cm rotated to position D, showing another view of the non-continuous open fracture at 80 cm.*

Figure 3-11. *Down part of core 50–110 cm rotated to position between F and G, showing that the open fracture at 60 cm with 90º to core axis is also not continuous.*

3.4.1 Open fractures

After photography in wet condition, the core surface was left to dry for about half on hour. It was then detected that the rock along the open fractures dried more slowly, which gave an opportunity to see the open fractures more clearly. The cores were photographed in this stage and the results are shown in Figure 3-12 to Figure 3-16. It can be clearly seen that the fracture at 60 cm (chainage 11.3–11.4) is discontinuous, the same being the case for that at 80 cm (chainage 11.6). It is obviously seen why these fractures did not break spontaneously during drilling (Figure 3-12). Seen from the opposite side of the core (Figure 3-13), these fractures appear to be continuous as was the case for the core from the 36 mm extension hole. Figure 3-14, Figure 3-15, and Figure 3-16 show other views of the fractures.

Figure 3-12. *Drill core with open, discontinuous fractures at 60 cm and 80 cm (dark streaks, caused by moist) from the right hand side. Core rotated to position B.*

Figure 3-13. *Drill core with open, continuously looking (which they are not) fractures at 60 cm (left of centre) and 80 cm (right of centre) from the upper core end. Core rotated to position G.*

Figure 3-14. *Drill core with open fractures at 60 cm and 80 cm (dark streaks, caused by moist) from the right hand side. Core rotated to position F.*

Figure 3-15. *Drill core with open, discontinuous fractures at 60 cm and 80 cm (dark streaks, caused by moist) from the right hand side. Core rotated to position C.*

Figure 3-16. *Drill core with open, discontinuous fractures at 60 cm and 80 cm (dark streaks, caused by moist) from the right-hand side. Core rotated to position B, detail.*

3.4.2 Sealed continuous fractures

Three continuous sealed fractures with an angle to core axis of 20–30º were identified, sealed with a hard mineral (quartz?), and with a 1–2 cm rim of red miscolouring on either side of the fracture. The fracture traces are shown in Figure 3-17 and Figure 3-18. One of the fractures cuts the centre of the core at 40 cm (c 11.2 m) near the down end of the test section.

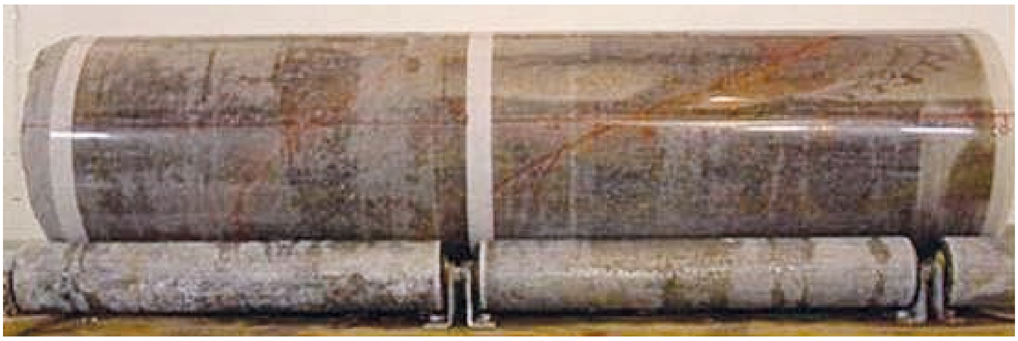

Figure 3-17. *Core rotated to position A. Sealed fracture traces marked in red.*

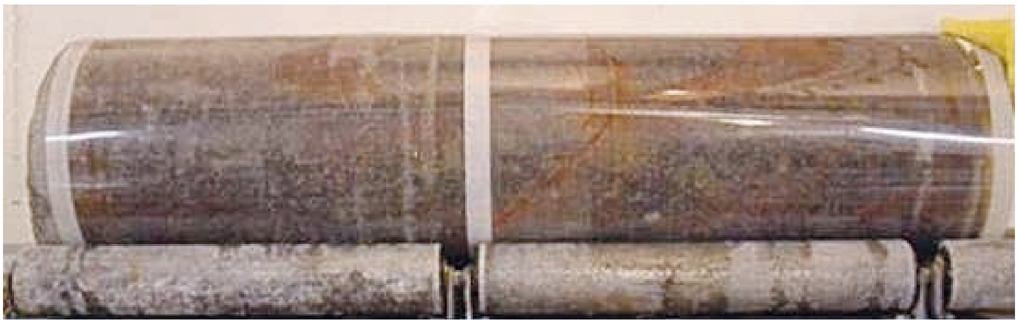

Figure 3-18. *Core rotated to position C. Sealed fracture traces marked in red.*

3.5 Repacking of core

After mapping and photography, the core was repacked in transparent drawing film and thin plastic foil for storage until the next work phase (Figure 3-19).

3.5.1 Recommendations for further activities

- Digitising fracture traces from drawing film
- Remodelling of fracture traces back to a 3D cylinder in CAD (µStation)
- Merging core photos into a picture of the envelope surface of the core
- Remodelling the envelope surface in 3D in CAD

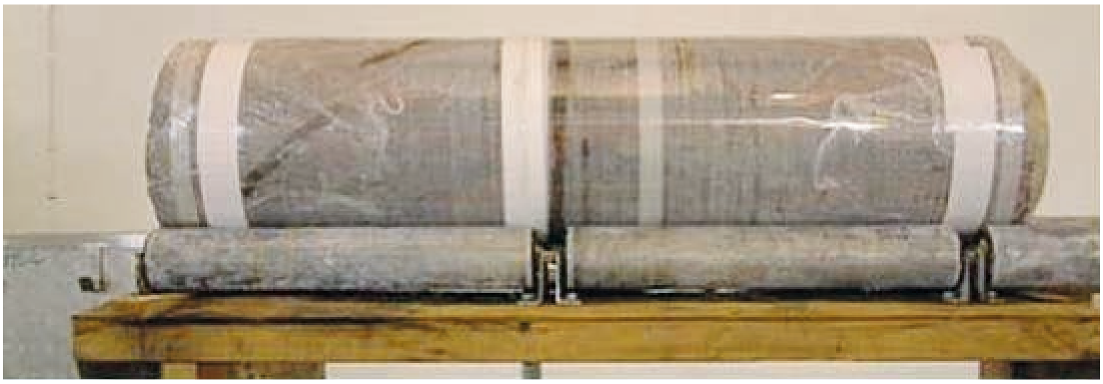

Figure 3-19. *Drill core repacked in drawing film and plastic foil for transport and short-term storage.*

4 Extraction of small diameter core samples

Extraction of small diameter cores (24 mm) from the over-core (278 mm) was done to facilitate subsequent analysis of tracer sorption and diffusion. The small diameter drill cores were later cut into small slices and analysed for their content of tracers aiming at determining penetration profiles for the tracers used in the LTDE-SD in situ experiment.

Since the experiment included radioactive tracers the drilling work for extraction of small diameter core samples was carried out at Clab. The working site was prepared under supervision of radiation safety personnel, enclosed by a fence and administrated and handled as a separate controlled area inside Clab.

To avoid contamination from drill tools, drill cores and water potentially containing radionuclides, the driller, site geologist and other personnel handling the drill equipment and drill cores wore protective clothing, including gloves and face protection.

4.1 Orientation and scaling of the core

4.1.1 Orientation of the core

As described in Section 3.1 the core top end had before drilling been punched twice at hole invert by means of a pinch bar, for core orientation purpose. Top core top end was examined for these marks. Two probable punch marks and two uncertain marks were identified and used for a first orientation of the core.

A more precise orientation was done before drilling of the core samples. The over core was then orientated my means of the PEEK lid used to seal the test section in front of the core stub, i.e. the natural fracture at core top end. The peek lid can be matched only in one position to the fracture surface and the position of the PEEK lid in the borehole during the in situ test is known; see Figure 4-1. Using this method for orientation the low side of the core was determined in between the two punch marks judged as probable low side of core (marked with double rings in red colour). The low side of the core was marked with a black line on the cylindrical PU sealing and a black line on the drill core perimeter; see Figure 4-2. The orientation is also consistent with the scaling of the core stub made in the borehole prior to instrumentation for the in situ test (Winberg et al. 2003b). Photographs to show the orientation of the target fracture at core top end, as in the borehole during the in situ experiment are presented in Appendix 10.

***Figure 4-1.** The PEEK lid matched to the fracture surface on the core stub. The core and PEEK lid having same orientation as in the borehole KA3065A03 during the in situ experiment. The eccentricity of over-core relative core stub is 4.5 mm but the angle of the view makes it look larger.*

4.1.2 Scaling of the core

Length reference

The position of the test section along the slim hole is dependent and determined by the position of the mechanical double packer, sealing the test section. For that reason a new scaling of the core was done, with the outer end of the double packer as reference zero. The position of the double packer and all other instrumentation is given by drawings (Figure 2-10 and Appendix 10) and the position of the natural fracture surface (core stub) and top end of the slim hole is given by borehole mapping. The reference point 0.000 m is at 10.737 m borehole length, as given in Table 4-1. The previously determined reference point chainage zero (Section 3.1) deviates by 0.004 m from the new one.

A reference line (black marking) with starting point zero at the position for the outer end of the double packer was drawn on the low side of the core. At drilling for extraction of core samples, the cores were positioned considering this reference.

Centring

The core stub (dia 177 mm) was completely centred on the slim hole (diameter 36 mm). The centring of the large diameter over-core was not fully aligned with the stub and extension borehole. It was centered in left – right position but not in up – down position. The deviation was + 4.5 mm at the core stub (10.737 m) and + 7.0 mm at the lower end of the core (11.824 m), see Figure 4-10 and Figure 4-13. At the position where the core was later on cut (11.387 m) the deviation was + 6.0 mm.

Figure 4-2. New length reference chainage zero (scaling 2007-06-08), based on position of borehole equipment in the 36 mm diameter extension borehole. The black line marks the lower side of the core, as it was oriented in the rock during the in situ experiment. The end mark of this line next to the black "0" on the stub marks the new length reference chainage.

Table 4-1. Positions along the experimental borehole KA306503A and along the extracted large diameter (278 mm) over-core. Numbers within parentheses are adjusted according to drawing No 3-2054.

Part	Position in KA3065A03 according to installation drawing (m)	Position from natural fracture (stub surface) according to installation drawing (m)	Position from natural fracture according to instrument drawing 3-2054 (m)
Natural fracture (Stub surface)	10.737	0.000	0.000
Bottom of stub	10.878	0.141	Not included
Test section SECUP	10.93 (10.949)	0.193	0.212
Test section SECLOW	11.23 (11.249)	0.493	0.512
SECLOW + 12 cm	11.35 (11.369)	0.613	0.632
Dummy bottom end	11.824 (11.819)	1.087	1.082
Expander SECUP	Not included	-	0.562
Expander SECLOW	Not included	-	0.709
Over-core stop	11.824	1.087	Not included

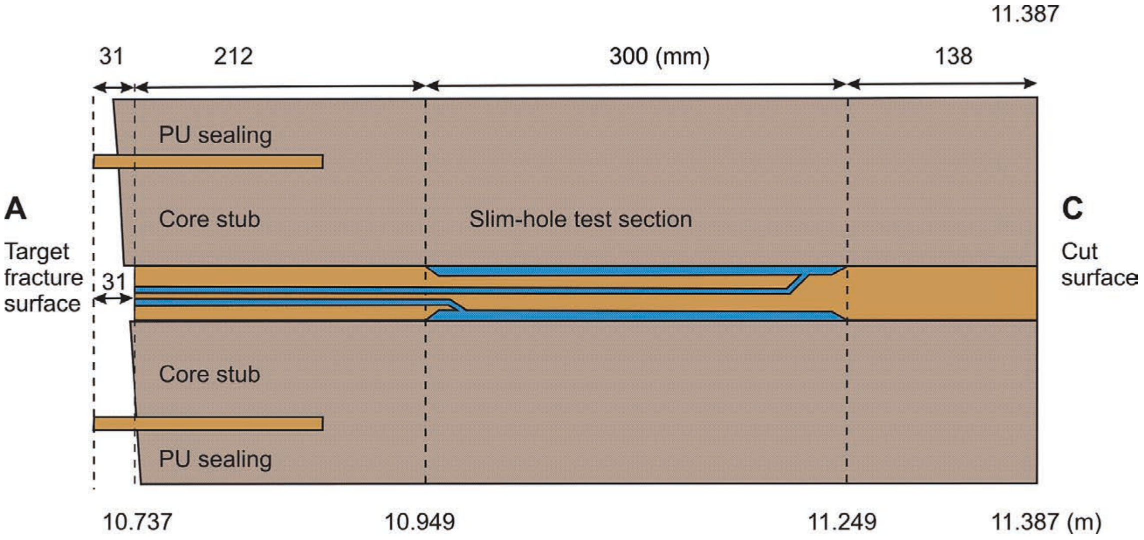

Figure 4-3. *Schematic cut away view of the over-core (278 mm diameter), containing the core stub with the natural fracture surface and the test section in the slim (36 mm) hole. Note, total length is after cutting, see Section 4.2.*

4.2 Cutting of the core

In order to facilitate the drilling of small diameter core samples the large core, with a diameter of 278 mm and length of 1.1 m, was first cut. Prior to the cutting, the whole core including the fracture surface outside the PU cylinder was coated with clear epoxy in order to avoid cross contamination during cutting and in the subsequent drilling for core samples, see Figure 4-4. The epoxy EpoTek 302 was used in a ~1 mm layer on the perimeter and a ~2 mm layer on the natural fracture surface, including the core stub.

The cutting was done with a diamond saw with water flushing at 0.65 m from the natural fracture surface (11.387 m), perpendicular to the length axis. The cutting action is illustrated in Figure 4-5.

Figure 4-4. The Epoxy coated 278 mm diameter core before cutting.

Figure 4-5. Cutting of the core.

4.3 Drilling of core samples

Core samples were drilled:

- from the natural fracture surface (inside and outside the cylindrical PU sealing),
- perpendicular to the slim hole,
- from the cut end of the core,
- from the epoxy covered PEEK plastic lid.

The diameter of each core sample is 24 mm and the drill used had a diameter of 28 mm.

Drilling water and drilling debris were collected in order to enable an investigation of any potential contamination during the sample extraction phase, see Figure 4-6 and Figure 4-7. After a hole had been drilled, it was plugged with rubber cork in order to prevent flushing water from flowing into the hole and contaminate the sampled rock. For the same reason, the drill bits and core barrel were carefully cleaned with water using first a brush for the outside of the drill bit/core barrel and a bottle brush for the inside the drill bit/core barrel. Thereafter the same procedure was repeated using ethanol followed by rinsing with ethanol. This procedure was followed for all of the core sample drillings. A collection of photographs showing drilling of core samples is presented in Appendix 11. Notes from drilling of core samples are presented in Appendix 12.

Figure 4-6. *Drilling of a D core sample.*

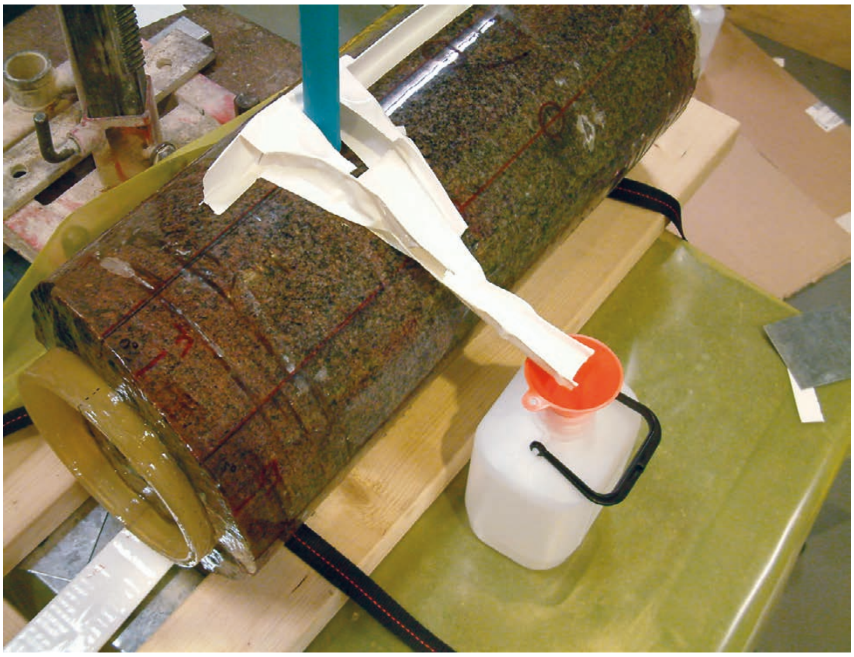

Figure 4-7. *Drill water and drilling debris collection and sampling.*

4.3.1 Samples from the natural fracture surface

The stub had a diameter of 177 mm and was confined by a polyurethane cylinder. Before drilling for extraction of core samples, the stub surface was coated with clear Epoxy to prevent contamination from sample to sample (Figure 4-4). 18 cylindrical core samples (labelled A1 – A18) at different positions (each with a diameter of 24 mm and length of about 15 cm) were drilled out, perpendicular to the stub surface, cf Figure 4-8 and 4-9. Additionally, three blank samples located outside the cylindrical PU sealing (therefore expected to not have been in contact with the test section groundwater) were sampled and were labelled A19–A21 (Figure 4-10).

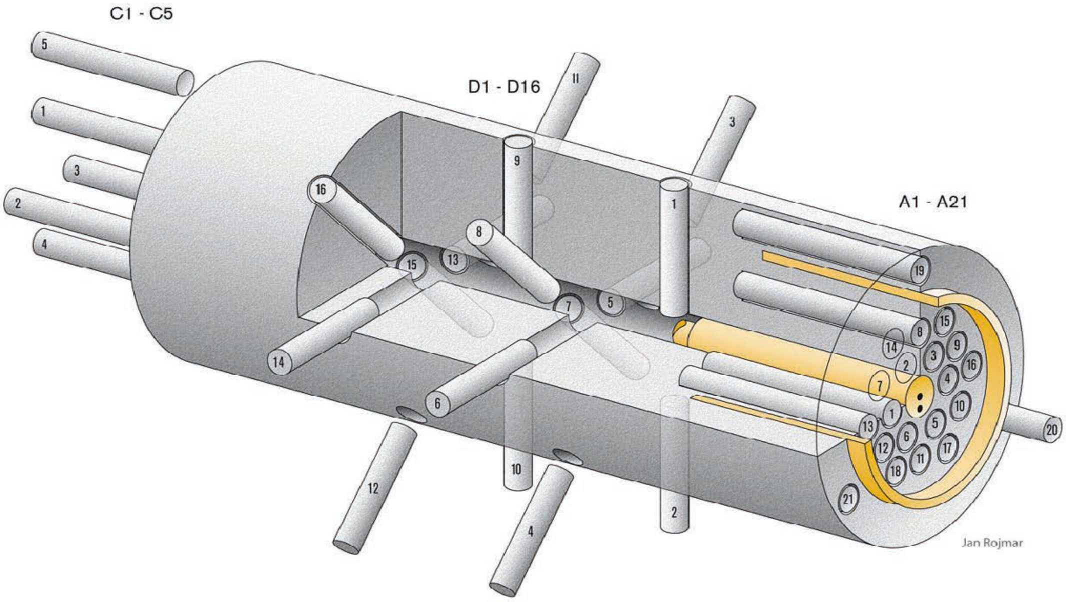

Figure 4-8. *Cutaway drawing showing core sample scheme of the 278 mm diameter over-core from the experimental borehole KA3065A03. The test section at the target fracture (diameter of 177 mm) is confined by a polyurethane cylinder (yellow). The test section (diameter of 36 mm) in the matrix rock away from the fracture is confined using a specially designed packer. The system also contains a PEEK dummy in the test section, but not shown in the figure.*

Core samples labelled with A1–A18 were collected by drilling from the surface of the target fracture and into the undisturbed rock adjacent to the fracture. Thus, the drill cores include a sequence fracture minerals, altered rock and unaltered matrix rock.

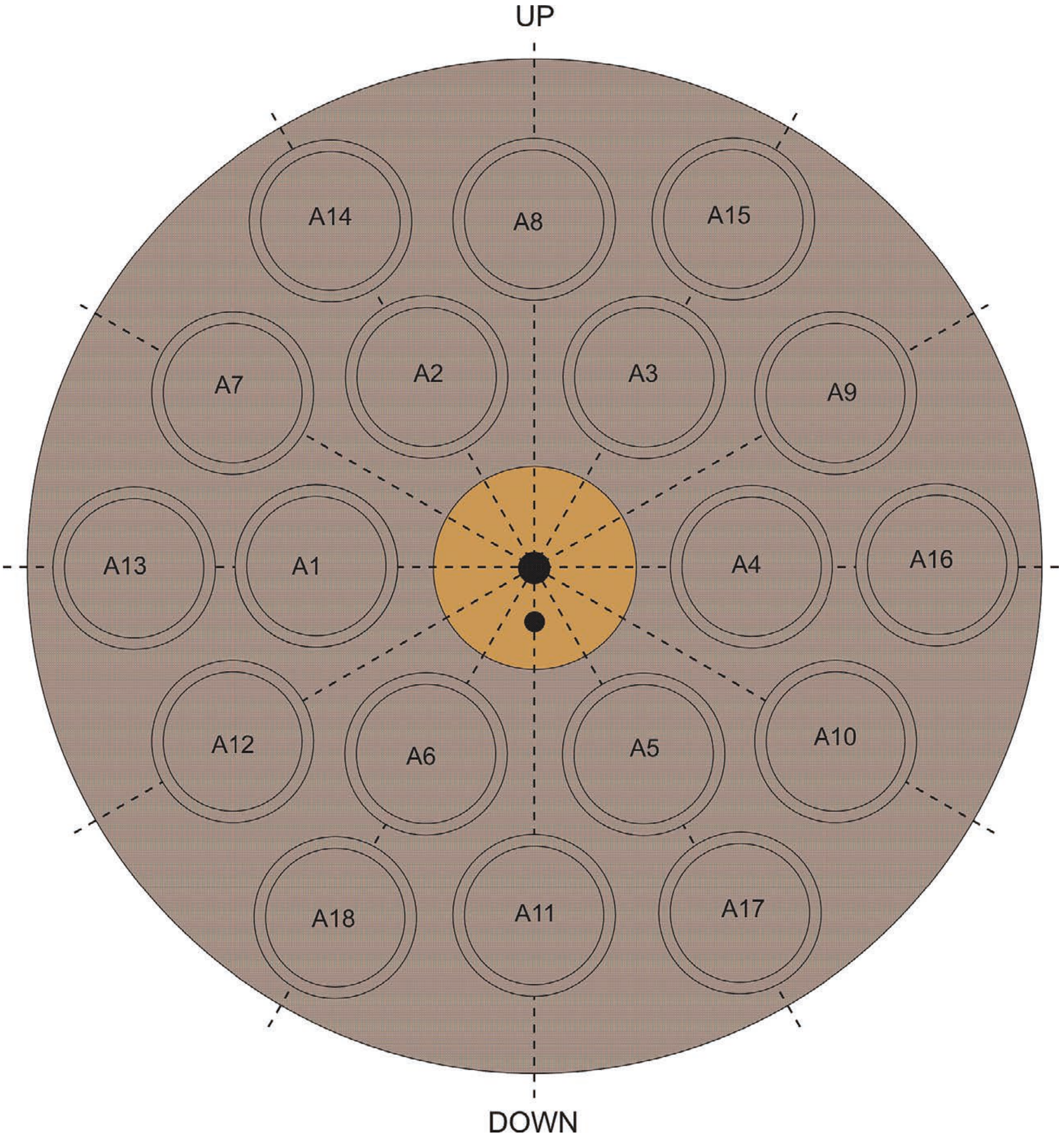

Figure 4-9. *Sampling strategy for extraction of 18 small diameter drill cores on the177 mm diameter core stub (i.e. inside the cylindrical PU-sealing shown in Figure 4-8). Core samples A1–A6 are set in a ring with radius 37.5 mm from centre of large diameter core. Samples A7–A12 are set in a ring with radius 59.0 mm and samples A13–A18 in a ring with 69 mm radius. In centre of large diameter core is the slim (36 mm) hole occupied by a packer (yellow). Inlet (in centre) and outlet from the test section in the slim hole are illustrated as black dots.*

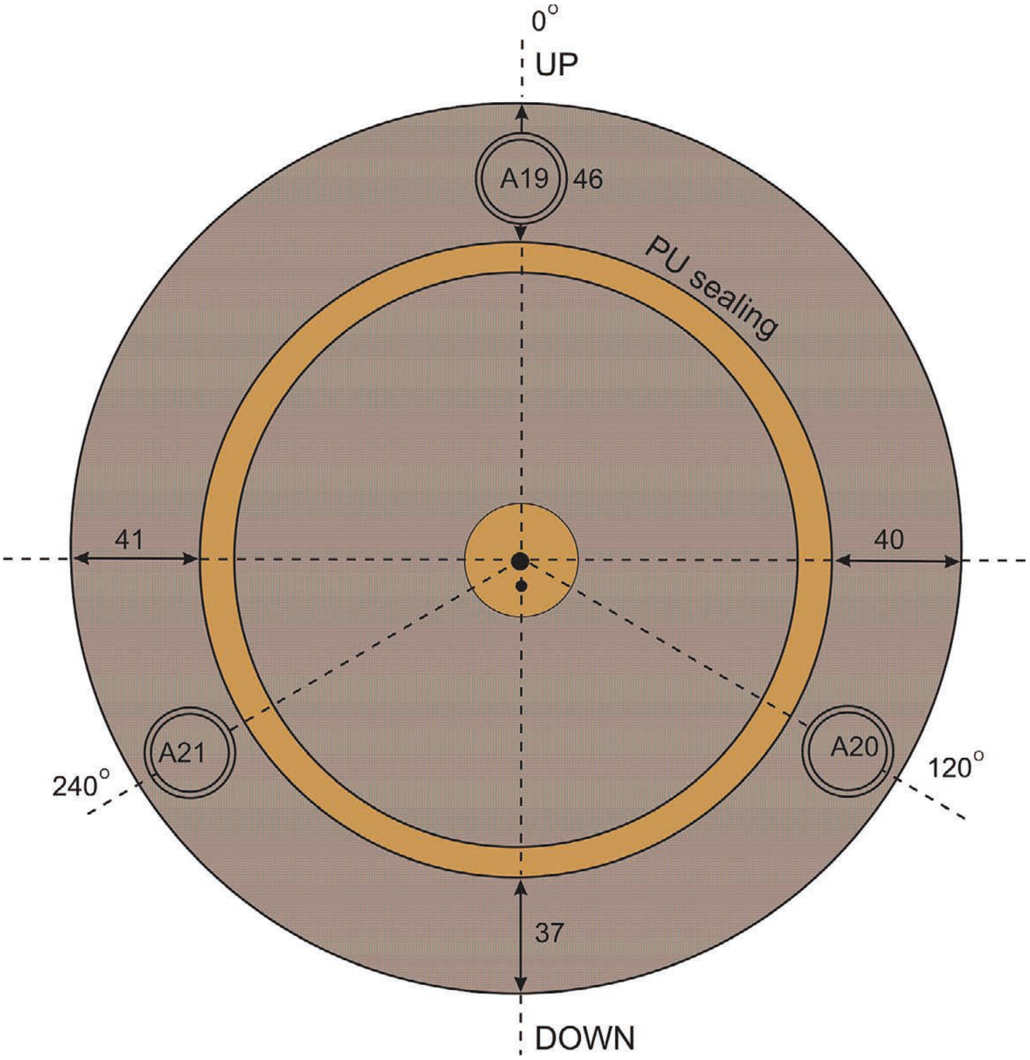

Figure 4-10. *Sampling strategy for extraction of the 3 small diameter drill cores A19, A20, A21 on the natural fracture surface outside the core stub. The drill was set at 118 mm from the centre of large (278 mm) diameter core. Note the core stub inside the cylindrical PU-sealing is fully centered to the slim hole (filled with a packer). Over-core is centered in left – right position but not in up – down position; deviation is +4.5 mm. The distances in the figure are given in mm.*

4.3.2 Samples perpendicular to the slim hole

In the part of the 278 mm core that surrounds the test section in the slim hole (36 mm diameter), 16 core samples with 24 mm diameter were drilled. The drillings were performed diametrically, perpendicular to the length axis of the core. This was carried out by drilling 8 core holes with a 28 mm drill through the core. Every core was split into two, one from each side of the test section in the slim hole. The core holes were fixed in a relation of 45° to each other. The core holes pass the slim hole, where in the middle, there is a PEEK solid dummy and the gap between the dummy and the borehole wall filled with yellow coloured Epoxy resin, injected prior to over-core drilling, cf Section 2.1.2. The core samples were labelled D1 – D16 and their positions are shown in Figure 4-8, Figure 4-11 and Figure 4-12. Positions of the D-core samples along the test section in the 36 mm diameter slim hole section are given in Table 4-2.

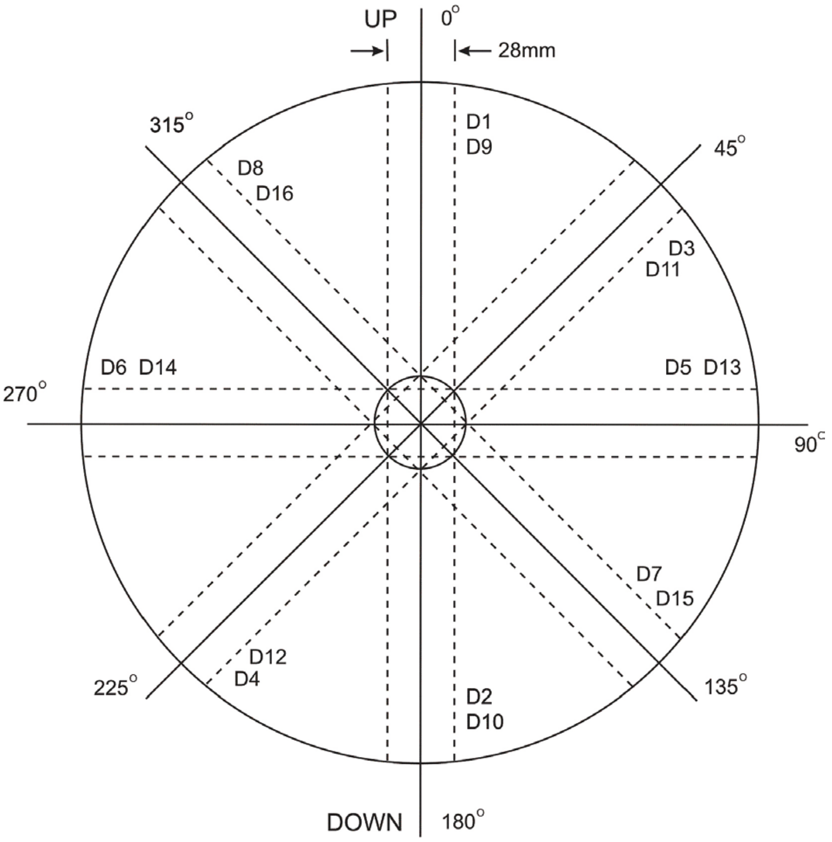

Figure 4-11. Sampling strategy for extraction of 16 small diameter drill cores from over-core of the rock around the slim hole section. The cores are distributed in 8 cuts, with 2 cores in each cut. The cuts are revolved 45 degrees to each other, cf Figure 4-8 and Figure 4-12.

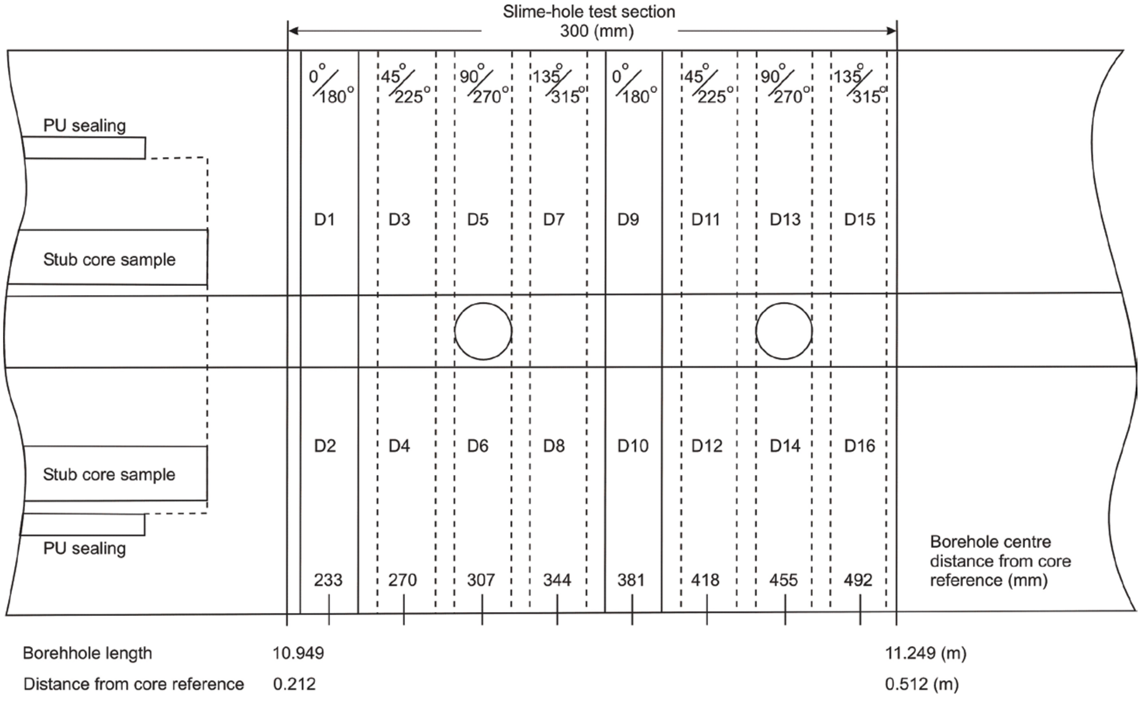

Figure 4-12. Sampling strategy for extraction of 16 small diameter drill cores from over-core of the slim hole section. The cores are distributed in 8 cuts, with 2 cores in each cut. The cuts are revolved 45 degrees to each other, cf Figure 4-11.

The drilling of the D core samples resulted in 16 complete core samples, see Appendix 14. Three of the extracted core samples, D11, D14 and D16, were completely covered with the yellow Epoxy resin on the surface facing towards the slim hole. One core, D12, was partly covered with Epoxy on the surface facing towards the slim hole. When the other samples were taken out, the Epoxy was not stuck on the sample surface, but remained on the PEEK dummy in the slim hole or went into pieces. It is also possible that the injected Epoxy did not fill the gap between the PEEK dummy and the slim hole wall completely at all positions along the test section, as indicated when drilling the D9 core, see Appendix 12. The implication of incomplete coverage may be some desorption of radionuclides from the surface facing towards the slim hole during drilling of the sample cores.

Table 4-2. Positions of D-core samples along test section in the 36 mm diameter slim hole extension in KA3065A03.

D-core sample	Length from core stub (m) [1]	Length along borehole KA3065A03 (m)	Comments
	0.000	10.737	Point of length reference at core stub surface, see Table 4-1.
	0.212	10.949	Beginning of test section in 36 mm diameter extension.
D1	0.233	10.970	
D2	0.233	10.970	
D3	0.270	11.007	
D4	0.270	11.007	
D5	0.307	11.044	
D6	0.307	11.044	
D7	0.344	11.081	
D8	0.344	11.081	
D9	0.381	11.118	
D10	0.381	11.118	
D11	0.418	11.155	
D12	0.418	11.155	
D13	0.455	11.192	
D14	0.455	11.192	
D15	0.492	11.229	
D16	0.492	11.229	
	0.512	11.249	End of test section in 36 mm diameter extension.
	0.650	11.387	Large, 278 mm diameter, core cut at this position. C-cores are drilled from this cut surface and inwards to slim hole test section

1) Length is from point of reference to centre of the 24 mm diameter drill core.

4.3.3 Samples from the cut end of the core

Five blank samples (representing the matrix rock) were sampled from the cut end of the core by drilling parallel to the length axis of the core. The core samples were labelled C1 – C5 and their positions are shown in Figure 4-8 and Figure 4-13.

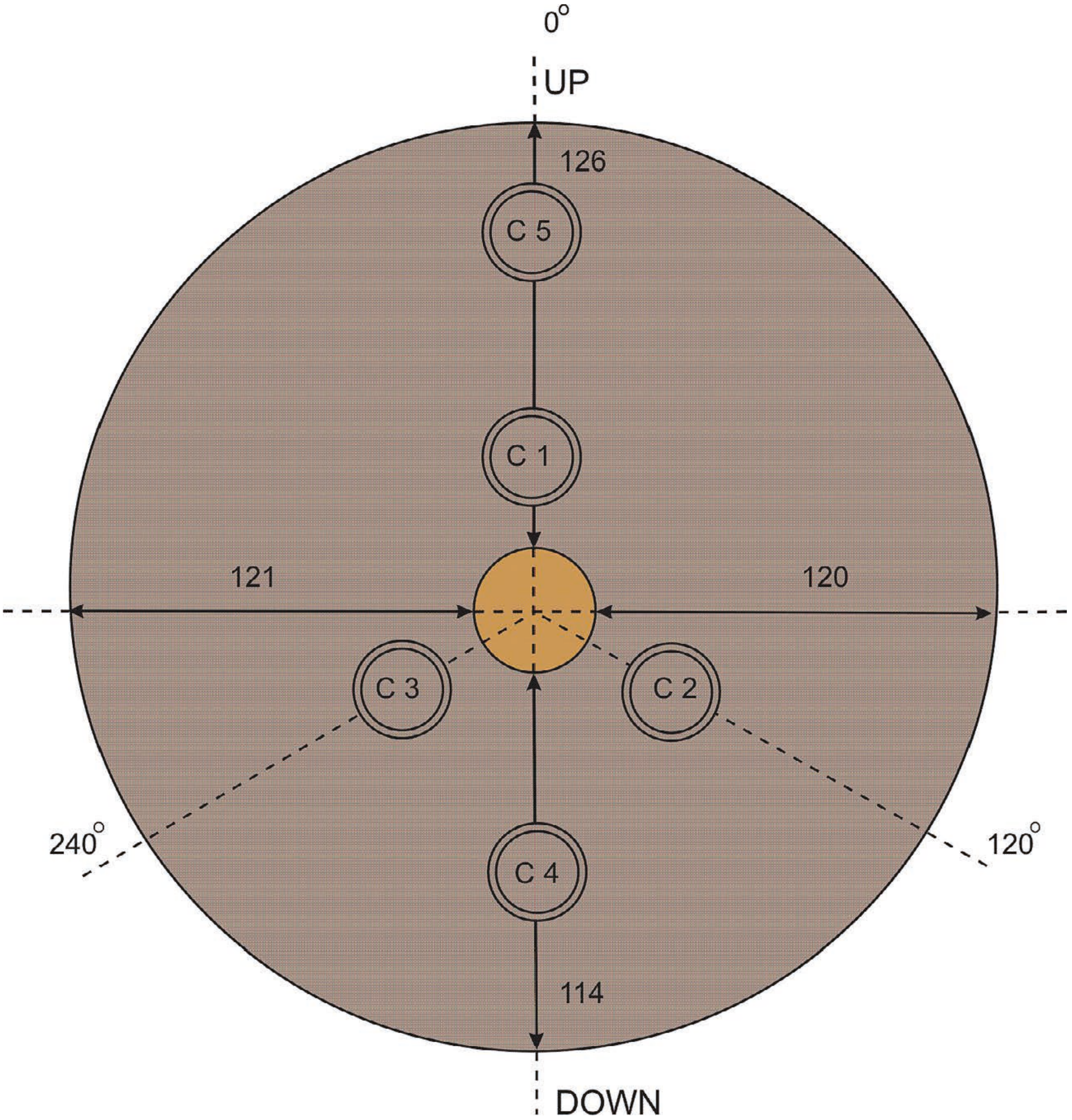

Figure 4-13. *Sampling strategy for extraction of 5 small diameter drill cores on the cut end of the large (278 mm) diameter over-core. Core samples C1 – C3 are set in a ring with radius 46.0 mm from centre of large diameter core. Sample C4 is set with radius of 78.0 mm and sample C5 with radius 112 mm. In centre of large diameter core is the slim (36 mm) hole occupied by a dummy (yellow). Over-core is fairly centred in left – right position but not in up – down position; deviation is +6.0 mm. The distances in the figure are given in mm.*

4.3.4 Samples from the epoxy covered PEEK plastic lid

As described in Section 2.3.3 the post-experimentally injected epoxy resin and the PEEK lid (Figure 4-1 and 4-14) accidently loosened from the fracture surface during the over-core drilling.

One could visually observe that small amounts of fracture coatings were attached to the epoxy surface after the PEEK-epoxy slab loosened from the stub during the drilling (Figure 4-15). These fracture coatings could presumably be identified as having been attached to the fracture surface during the circulation phase of the experiment.

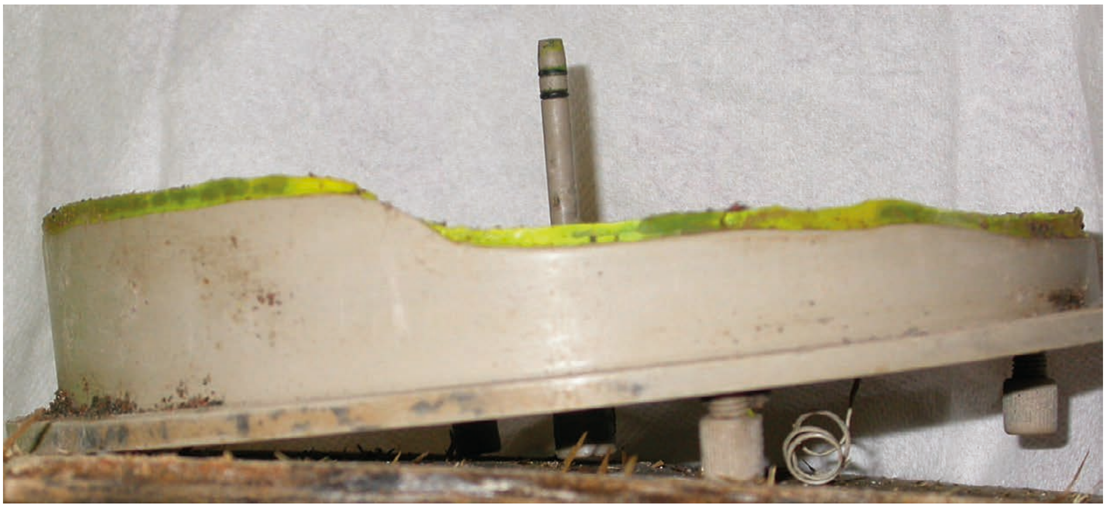

Figure 4-14. *The post–experimentally injected epoxy surface covering the PEEK-disc that accidently loosened from the fracture surface.*

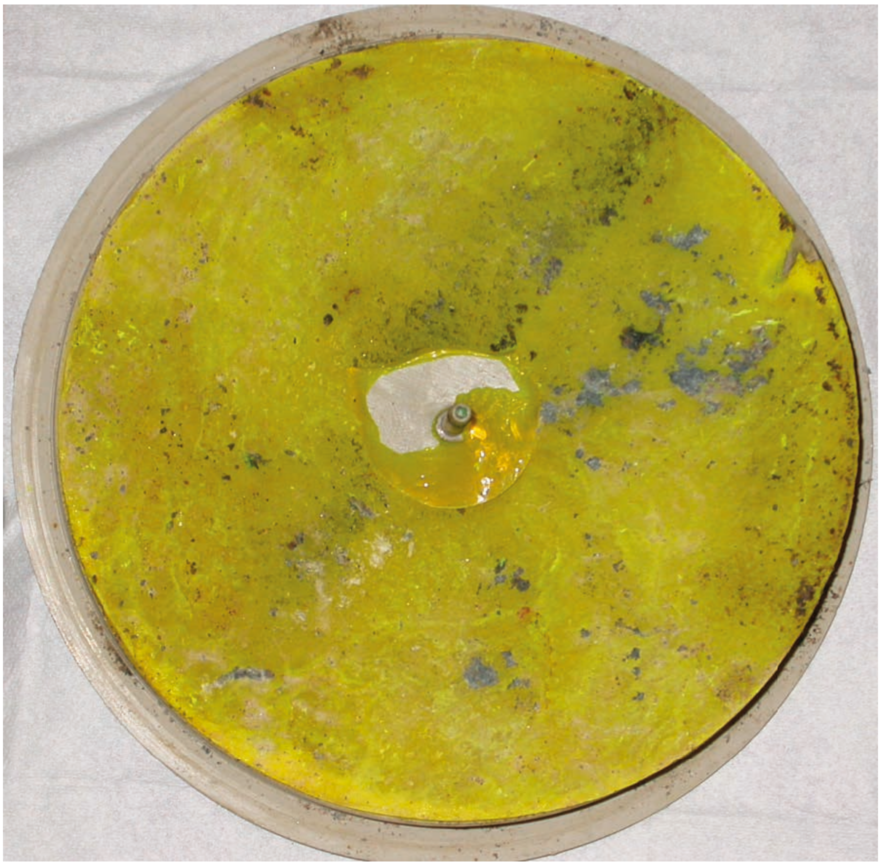

Figure 4-15. *Visible fracture coatings on the epoxy surface.*

In order to quantify the amount of radioactive tracers that came off from the stub surface during the breakage (and, possibly also, the amount of tracer that had adsorbed on the PEEK lid during the circulation phase) core samples were drilled from the PEEK/epoxy disc. Therefore, from the disc, 18 core samples with 24 mm diameter were drilled parallel to the length axis of the core. These core samples were drilled at exactly the same positions as the A samples from the stub by means of a jig (Figure 4-16). The drilling was performed in the direction from the epoxy side straight into the PEEK lid. The core samples were designated with identification numbers B1 – B18. A collection of photographs showing preparations and drilling of epoxy/PEEK core samples is presented in Appendix 13. During the drilling, there were difficulties with finding an appropriate type of drilling machine. Problems that occurred were fastening of the drill, vibrations, heating and cracking of the Epoxy. However, only Epoxy/PEEK samples not exposed to heating have been considered at all for measurement of tracer content.

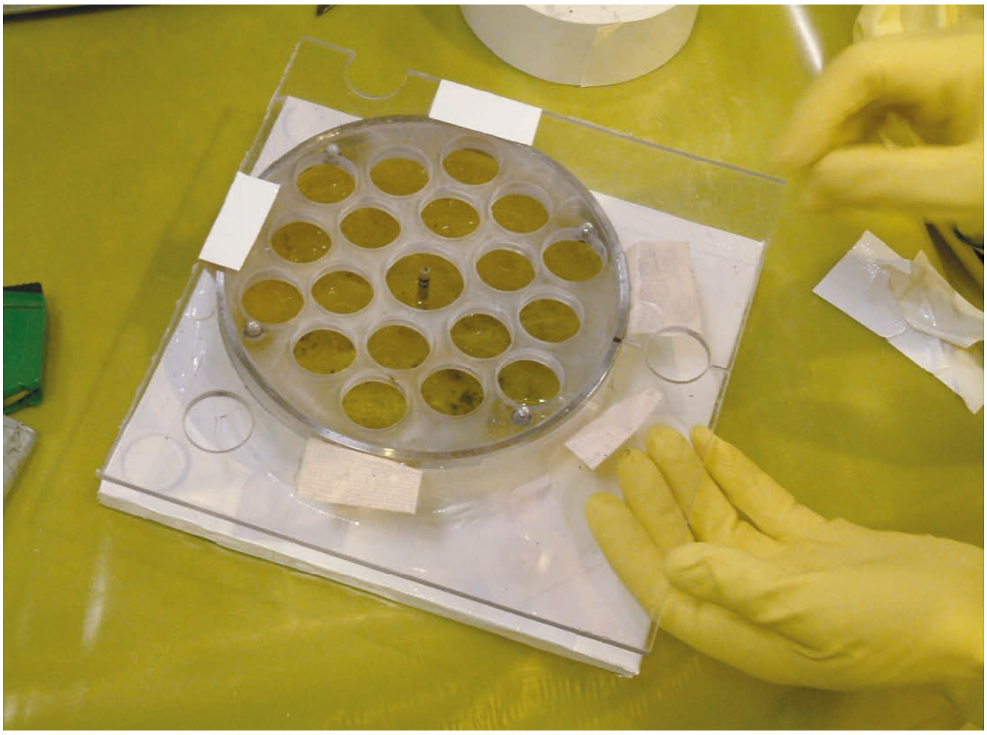

Figure 4-16. *Preparations before drilling of the B-core samples using a jig attached to the epoxy coated PEEK lid for achieving their appropriate positions. At this stage a protective coating of clear epoxy resin had been applied on the first yellow coloured layer of epoxy.*

5 Geological characterisation of small diameter core samples

The small diameter core samples were geologically characterised before they were sent to University of Helsinki and cut into thin slices to facilitate determination of penetration profiles of the radionuclides. The characterisation included mineralogy, alteration, microfractures and fracture coatings.

The geological mapping and documentation (incl. photo) of the small diameter core samples was carried out at Clab, within the same enclosed working site as used for the drilling work to extract the core samples.

The transportation to University of Helsinki followed the ADR-rules radioactive goods and the normal routines at Clab for exportation.

The remaining of the core stub and large (278 mm) diameter core after extraction of core samples has been stored at Clab until a decision is taken whether the remaining material will be deposited or further sampled.

5.1 General information

The A-cores were drilled from the fracture surface at the "stub" and inwards. For the orientation/rotation of the core, 0° refers to a point upwards at the cores (see Figure 4-9), which also shows the positions of the A-cores on the stub surface). However, the orientation of fractures/microfractures in the rock core descriptions only refers to the 0° point, not to the strike and dip in "Äspö tunnel perspective". α (alpha)-angle does in this report refer to the angle between the borehole axis and the fracture plane as described in Figure 5-1. The positions of the A-cores outside the cylindrical PU sealing are shown in Figure 4-10.

For A-cores, the point (A) does always refer to the fracture plane at the "stub" and the B-points are pointing towards the test section in the 36 mm diameter slimhole.

The C-cores were drilled from the cut end of the large 278 mm diameter core. The position of this plane is 0.65 m from the reference point at the fracture plane at the "stub", see Figure 5-2. For C-cores, the point (A) does always refer to the cut plane at 0.65 m.

The 0° positions at the D-cores are pointing towards to the fracture plane at the "stub" (see Figures 4-11 and 4-12). The α-angle is referring to the borehole axis as illustrated in Figure 5-1.

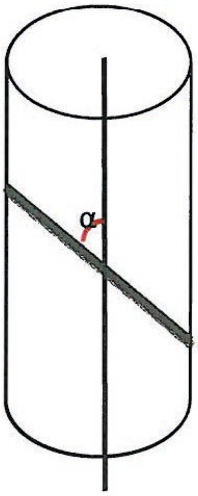

Figure 5-1. *Illustration of the α-angle.*

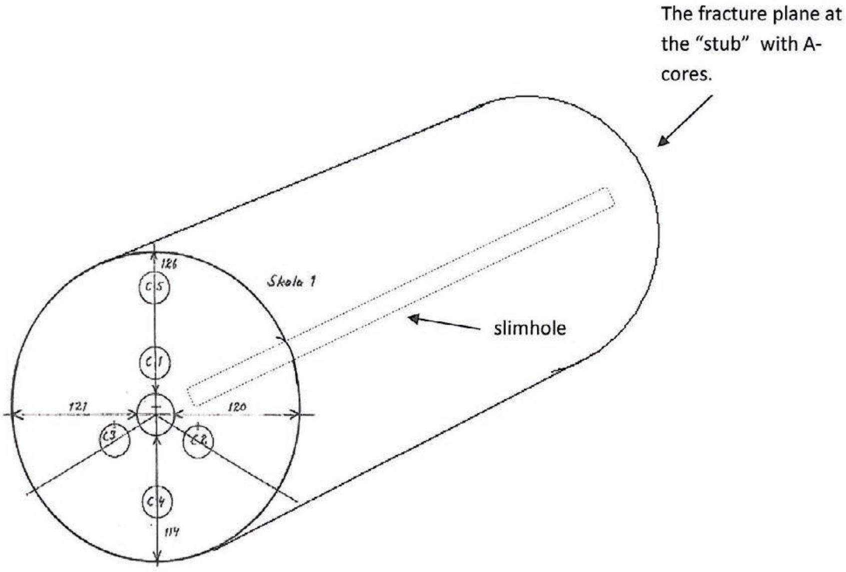

Figure 5-2. Position of the C-cores at the drill core (the over-cored rock cylinder); i.e. the five C-cores are drilled on the opposite side of the drill core compared to the A-cores.

5.2 Results

The full results of the geological characterisation with photos of the cores are presented in Appendix 14.

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Winberg A, Andersson P, Byegård J, Poteri A, Cvetkovic V, Dershowitz W, Doe T, Hermanson J, Jaime Gómez Hernández J, Hautojärvi A, Billaux D, Tullborg E L, Holton D, Meier P, Medina A, 2003a. Final report of the TRUE Block Scale project. 4. Synthesis of flow, transport and retention in the block scale. SKB TR-02-16, Svensk Kärnbränslehantering AB.

Winberg A, Hermanson J, Tullborg E-L, Staub I, 2003b. Äspö Hard Rock Laboratory. Long-Term Diffusion Experiment. Structural model of the LTDE site and detailed description of the characteristics of the experimental volume including target structure and intact rock section. SKB IPR-03-51, Svensk Kärnbränslehantering AB.

Appendix 1

Schematic of circulation set-up in experimental container (C1)

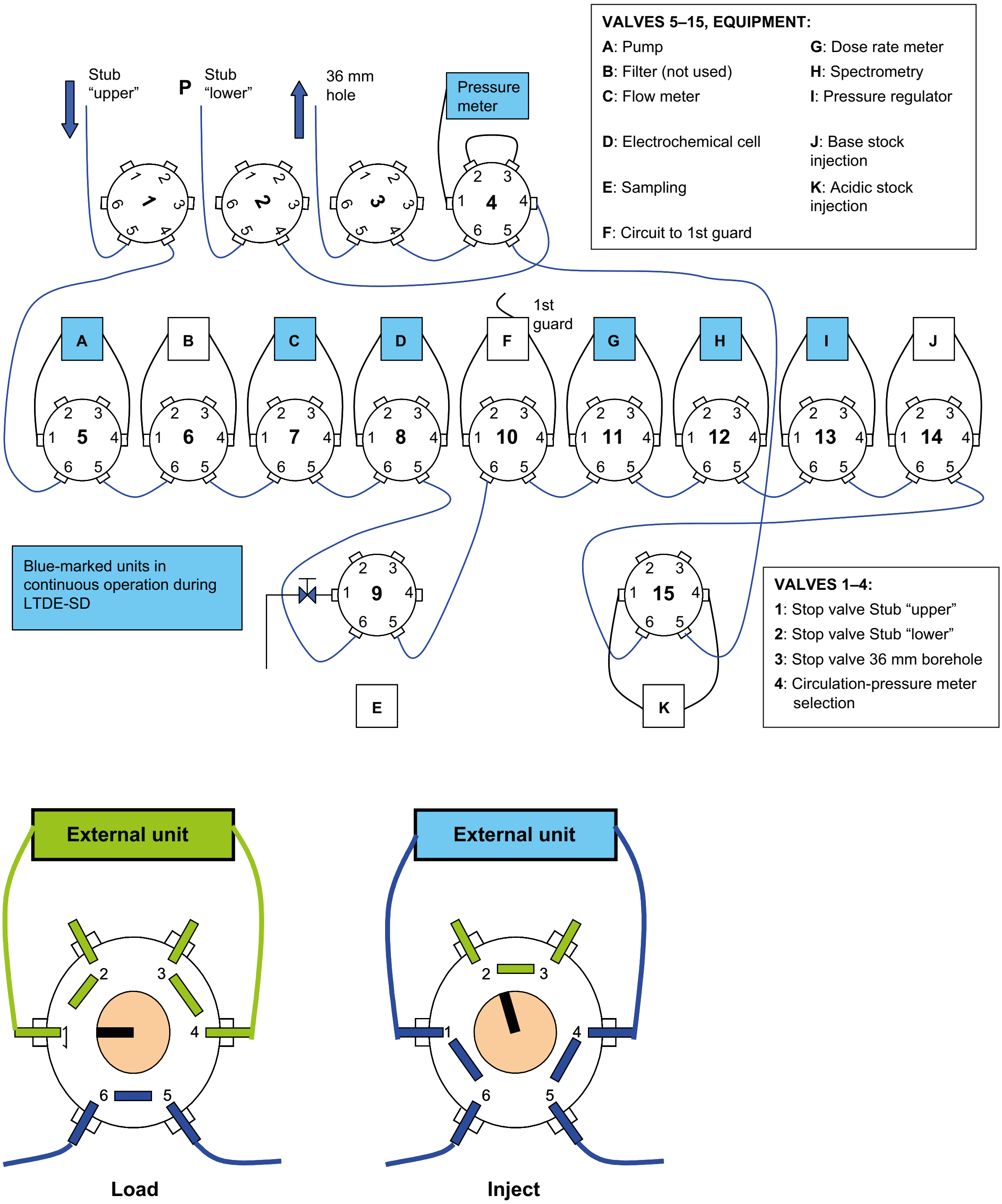


Figure A1-1. Schematic diagram of the circulation set-up during the tests (top) and connection diagram of the 6-port valves used for connections of equipment to the circulation line (bottom).

Appendix 2

Procedure for changing test section groundwater to isopropyl alcohol

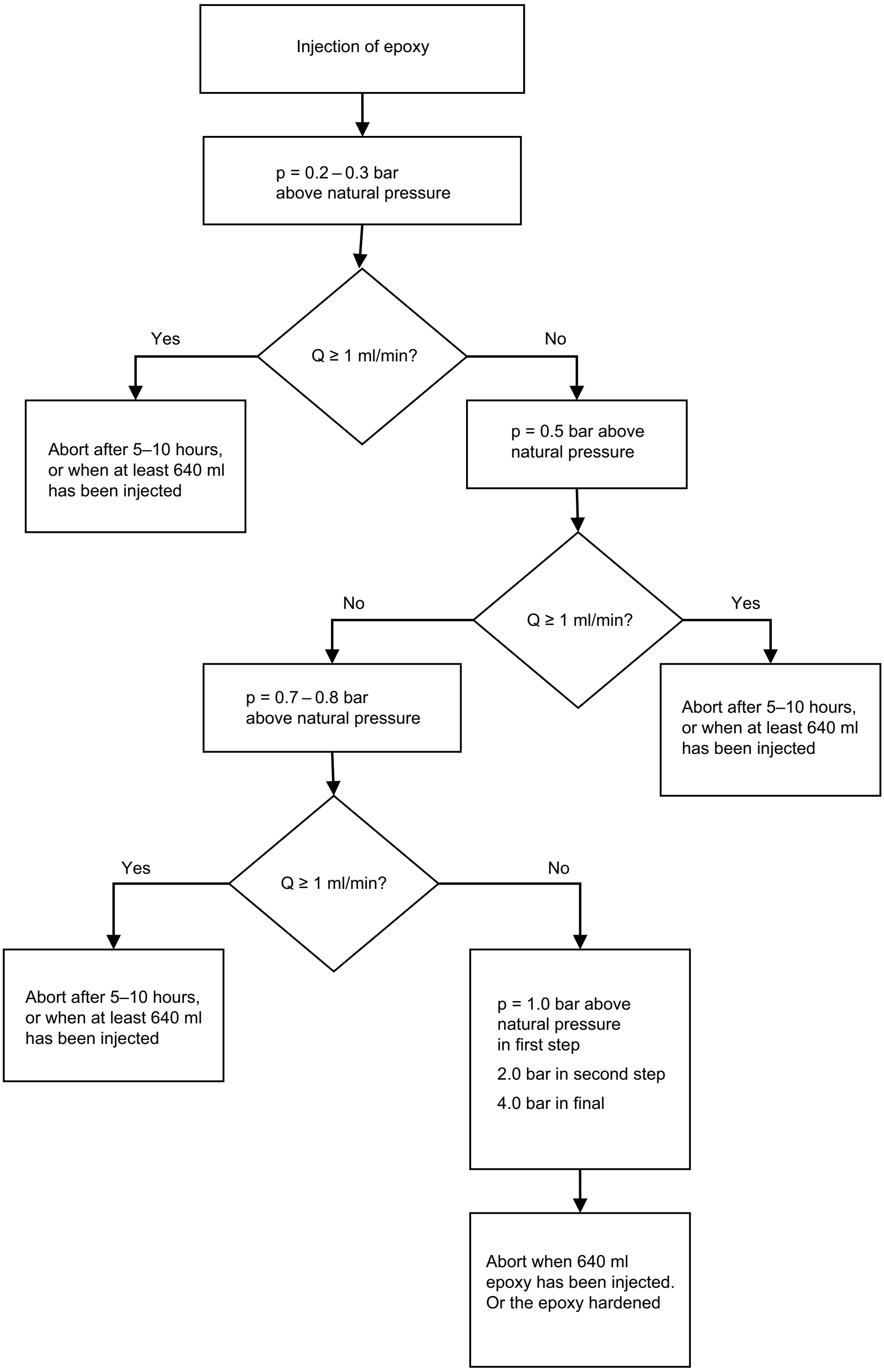
1. Increase the pressure in the isopropanol tank to a level slightly (0.2 bar) above the natural pressure in the borehole test section.
2. Open the outflow valve on the isopropanol tank and the injection valve (port 4 on valve No15) in the experimental set-up.
3. Open the sampling valve (port 1 on valve No 15) in the experimental set-up gently to exchange the groundwater to isopropanol. The withdraw flow rate will be within 5 – 25 ml/min. During this moment the pressure in the borehole section will decrease slightly but it is imperative that it does not fall below the natural pressure in the borehole test section.
4. Change position on valve No 4 between inject and load so that isopropanol injection will alternate between lower part of core stub and inner part of 36 mm extension borehole.
5. The radionuclide content and radioactivity in the extracted liquid are continuously measured on the HPGe and RNI detectors in the present experimental set-up.
6. When c 500 ml liquid has been extracted from the sampling valve, the sampling valve will be closed. A new 0.5 l bottle will be put to the valve. The valve is opened and another 500 ml of liquid is extracted.
7. When 5 000 ml liquid has been extracted the exchange is completed, which shall be verified by the HPGe and RNI measurements, and the sampling valve (port 1 on valve No 15) is closed.
8. If there is still radioactivity in the extracted liquid, flushing with isopropanol has to be continued until radioactivity is under 5.5E5 Bq/l., i.e. 99 % exchange from the radionuclide labelled groundwater to isopropanol.
9. Close the outflow valve on the isopropanol tank and the injection valve (port 4 on valve No 15) in the experimental set-up. Set valve No 15 to load position.

Procedure for changing isopropyl alcohol to Epoxy resin

1. The outflow tube from the test section (stub upper) and the inflow tube to the 36 mm extension borehole (36 mm hole) shall both be plugged at borehole collar by a specially designed throttle screw (hose clamp).
2. The outflow tube and the inflow tube shall be cut outside the plug. Steel connector with junction from 1/8″ to 6/4 mm tubing and valve are mounted on the outflow and inflow tube.
3. The pressure connection tube (stub lower) shall be plugged at borehole collar by a specially designed throttle screw (hose clamp).
4. The pressure connection tube shall be cut outside the plug. Steel connector with junction from 1/8″ to 6/4 mm tubing and valve are mounted on the pressure connection tube.
5. A high-resolution pressure gauge will be connected to the pressure connection tube for control of pressure during epoxy injection.
6. The epoxy resin and isopropanol injection equipment is connected to the valve on the 1/8″ inflow tube. Care has to be taken to avoid any air entering the injection line and inflow tube.
7. The tank with epoxy will be connected to the gas tank (with the turn of the 3-way valve on top of the two tanks).
8. The pressure in the test section will be regulated to 0.2 bar above the natural pressure.
9. The 3-way valve below the epoxy tank and the valve on the inflow tube will be opened.
10. The valve on the pressure connecting tube will be opened.
11. The valve on the outflow tube will be opened gently to inject epoxy and exchange the isopropanol to epoxy. During this moment the pressure in the borehole section will initially decrease slightly but it is imperative that it does not fall much below the natural pressure in the borehole test section.
12. The epoxy injection flow rate will be directed by the pressure in the test section as described in Appendix 4.
13. When c 500 ml liquid has been extracted from the outflow tube, the valve will be closed. A new 0.5 l bottle will be put to the valve. The valve is opened and another 500 ml of liquid is extracted.
14. When 640 ml epoxy has been injected (and 640 ml isopropanol and epoxy has been extracted) the injection is completed and the valve on the outflow tube is closed.
15. Close the 3-way outflow valve below the epoxy tank and the valves on the inflow tube and pressure connection tube.

Appendix 4

Flow versus pressure governed injection scheme for epoxy resin



Appendix 5

Procedure for removal and dismantling borehole equipment in KA3065A03

The epoxy resin may have adhered to the PEEK-disc and special care has to be taken when the PEEK-disc is removed so that the epoxy resin injected in the space between the core stub and the PEEK-disc will not loosen from the fracture surface on the core stub.

1. First action is to decrease the pressure in the first guard section to 1.0 bar below ambient background pressure.
2. Loosen the nuts at the pull rods for the centre pipe.
3. Pull carefully by hand the centre pipe outwards 20–30 mm. It may be necessary to revolve the pipe a few degrees back and forth.

After the PEEK-disc has been removed from the core stub the removal of the entire packer system will start.

1. Decrease the hydraulic pressure in the borehole by: 1) open the valve on the sampling and pressure connecting tube from the second guard section; 2) open the valve on the circulation and sampling tube from the first guard section; 3) open the valve on the sampling and pressure connecting tube from the third guard section and 4) open the valve on the sampling and pressure connecting tube from the fourth (outermost) guard section.
2. The water flowing from the borehole shall be collected into an open tank or container for measurement of radioactivity before it can be lead further to the tunnel drainage system. It is not allowed letting water flow out on the ground.
3. Deflate the hydraulic packers.
4. Unfasten the mechanical packer by loosen the nut on the middle pipe.
5. Fully open the valves on the tubes emanating from the first guard section.
6. Loosen the piston-pipe locking device.
7. Loosen the outer seal and packer anchor device.
8. Loosen the bolts holding the lid at collar.
9. Check that all water emanating from the borehole is collected in a container and measured for radioactivity and sampled before it is further poured into the tunnel drainage system.

At this stage the equipment is ready to be removed from the borehole and dismantled.

1. Fasten the packer system to a wire winch and carefully pull the entire packer system outwards and prop up the equipment that comes out from the borehole on the installation rack. It may be necessary to aid pulling by the use of a tractor.
2. The equipment consists of four main blocks that are joined together. The blocks shall be separated and dismantled as they comes out of the borehole and are lying on the installation rack. The outermost block consist of steel connecting tubes (inner, middle, outer) and has a length of about 3.4 m. Block no 2 consists of outer hydraulic packer and steel connecting tubes and has a length of about 1.6 m. Block no 3 consists of steel connecting tubes and has a length of about 3.2 m, and the fourth and innermost block consists of inner hydraulic packer, mechanical packer, PEEK disc and steel tubes connecting the different parts. It has a length of about 3.0 m.
3. All borehole equipment parts are to be stored on tarps or plastic for later inspection by radiation safety personnel. Depending on the outcome of the inspection, the equipment is either to be stored in the SKB storehouse Verkstad 14 in Oskarshamn or taken to Clab for destruction or decontamination, following a decision from the SKB project leader.
4. When all equipment is removed, the borehole is plugged to prevent water from flowing into the tunnel. This is done by using a prepared cap attached to the casing.

Photographs of removal and dismantling borehole equipment in KA3065A03

Figure A6-1. *Disconnecting circulation tubes in glove box in experimental container (C1) before removal and dismantling of borehole equipment.*

Figure A6-2. *Tubes and fittings being disconnected before the lid at KA3065A03 borehole collar is removed.*

***Figure A6-3.** Lid at borehole collar removed and packer system is hauled out of borehole KA3065A03. Container beneath borehole collar, where water was sampled and monitored for γ-radiation, is also shown in the photo.*

***Figure A6-4.** First phase of hauling is coming to final. Special protective clothing is used due to potential risk of contamination from radionuclides used in the experiment.*

Figure A6-5. Hydraulic packer being disconnected from outer pipe.

Appendix 7

Photographs of over-core drilling KA3065A03

Figure A7-1. *System for handling backwashing water. Degasser (cyclone) on top of sedimentation container 1.*

Figure A7-2. *Check of installation at sedimentation container 1. Low dose scintillation meter attached to container wall for continuous measurement of radioactivity in the backwashing water.*

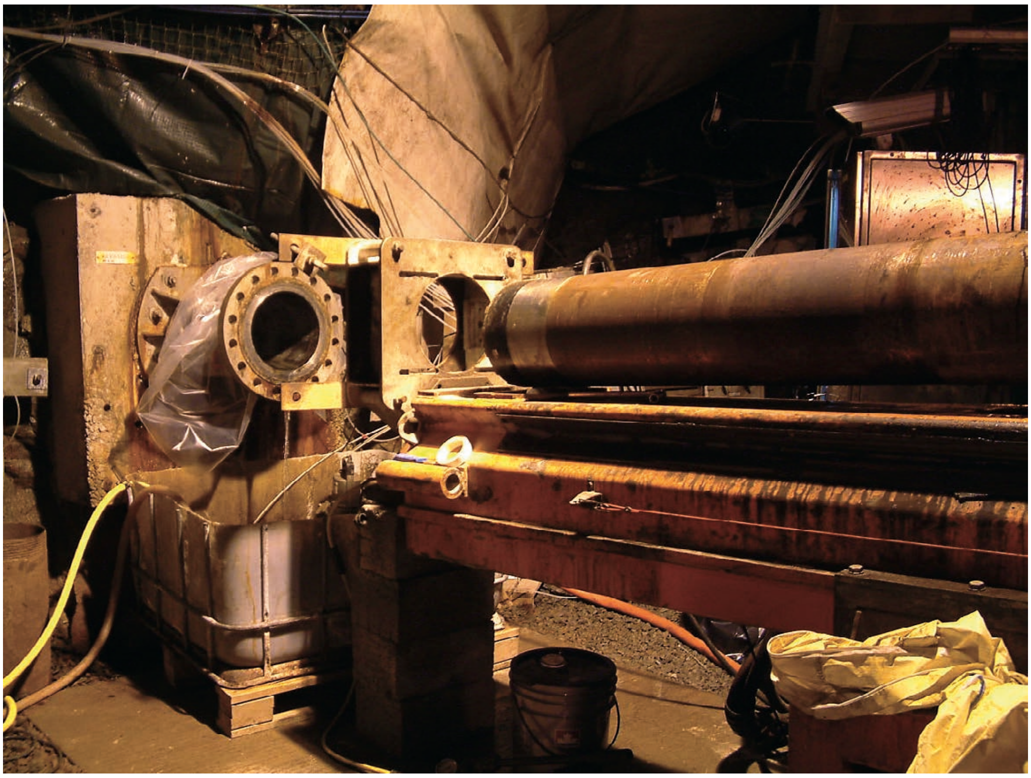


Figure A7-3. *Drill bit and core barrel attached and ready for over-core drilling KA3065A03.*

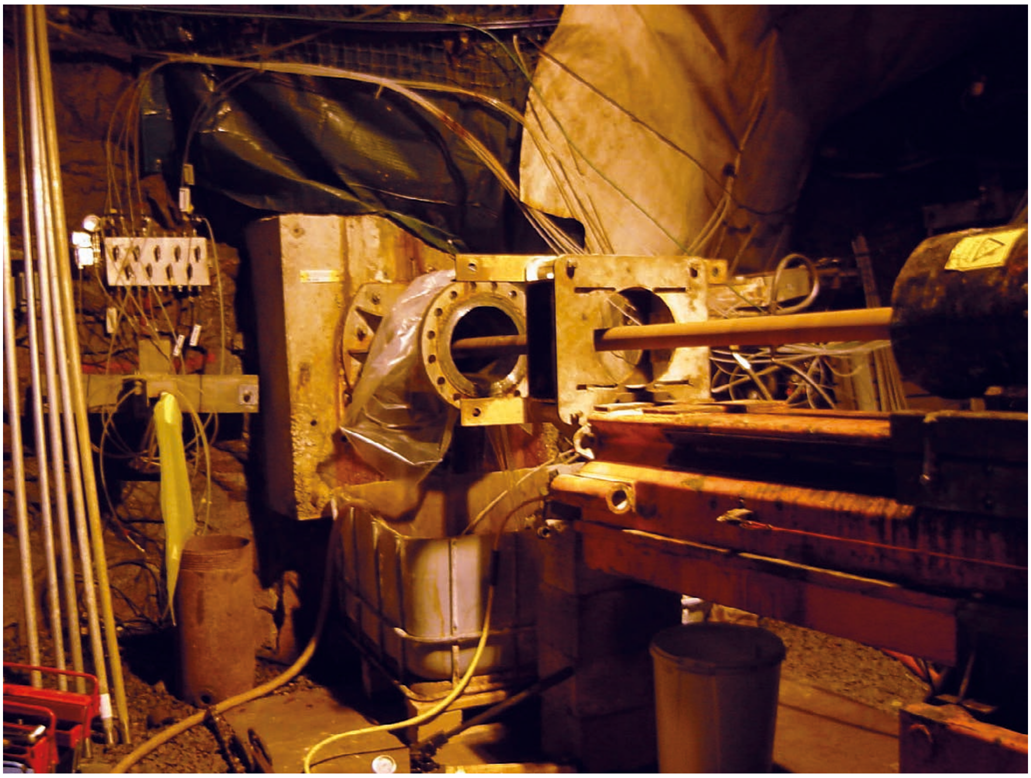


Figure A7-4. *Ongoing over-core drilling. Drill pipe and drilling machine.*

Figure A7-5. *Ongoing over-core drilling. Backwashing water with drilling debris flowing into container beneath borehole collar.*

Figure A7-6. *Supervising drilling.*

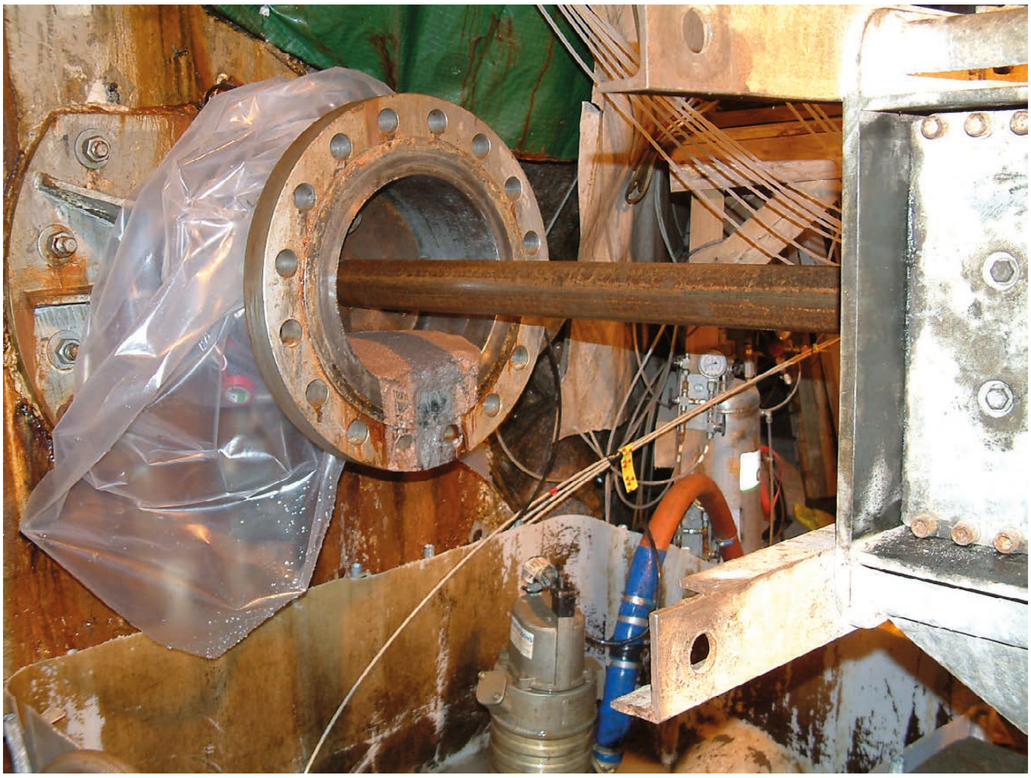


Figure A7-7. *Drill bit and core barrel hauled after completion of drill phase 1, chainage 9.67 to 10.3 m. Drilling debris laying on borehole invert is scraped out of borehole by core barrel.*

Figure A7-8. *Core barrel coming out of borehole.*

Figure A7-9. *The over-core of drill phase 1, chainage 9.67 to 10.3 m.*

Figure A7-10. *The over-core of drill phase 1, chainage 9.68 to 10.3 m. Core pieces are joined to re-create a hollow cylinder.*

Figure A7-11. *Core retrieval of drill phase 1, chainage 10.3 to 10.8 m. Fracture at 10.74 m, facing towards the drill bit, is ending the core.*

Figure A7-12. *Core retrieval of drill phase 1, chainage 10.3 to 10.8 m. Fracture at 10.74 m, facing towards the drill bit, is ending the core. Cf Figure A7-11, photo from another visual angle.*

Figure A7-13. The over-core of drill phase 1, chainage 10.3 to 10.8 m.

Figure A7-14. The over-core of drill phase 1, chainage 10.3 to 10.8 m.

Figure A7-15. *The over-core of drill phase 1, chainage 10.3 to 10.8 m. Core pieces are joined to re-create a hollow cylinder. The fracture at 10.74 m, ending the core, is facing upwards.*

Figure A7-16. *Borehole is drained by suction pump and inspected before start of drill phase 2.*

Figure A7-17. *Borehole is drained by suction pump and inspected with borehole camera before start of drill phase 2.*

***Figure A7-18.** Core barrel containing retrieved core from drill phase 2 is removed from the drilling machine.*

***Figure A7-19.** Over-core 10.74 m to 11.82 m pulled out of core barrel. Target fracture at 10.74 m is facing towards the core barrel.*

***Figure A7-20.** Over-core 10.74 m to 11.82 m. Target fracture at 10.74 m with the 177 mm diameter core stub inside the cylindrical PU sealing, where radionuclide tracers were circulated.*

***Figure A7-21.** Over-core 10.74 m to 11.82 m. Breached end at 11.82 m, 36 mm borehole with parts of the special packer used to restrict the slim hole test section is seen in centre of core.*

Appendix 8

Notes from over-core drilling KA3065A03

24 April 2007

Drilling machine ONRAM 1000 is established at the borehole.

Borehole is opened at 13:00 hours to facilitate alignment of drilling machine to the borehole strike and dip.

Smear testing of borehole invert by Clab radiation safety personnel.

Inflow to borehole, and thus outflow from casing about 8.0 L/min.

The sedimentation basins are filled with water from borehole HD0025A.

25 April 2007

Drilling machine is prepared for drilling.

The system for handling drilling flushing water and potentially contaminated backwashing water and drilling debris is ready to use.

For orientation the core was marked by means of a hammer blow on a pinch bar inserted along the invert of the hole.

Borehole has been open since 24 April at 13:00 hours.

26 April 2007

Clab radiation safety personnel inspecting the site and drilling set up. The smear testing of borehole invert on 24 April showed radioactivity somewhat above background. However, it was only due to daughters of naturally occurring radon, i.e. not from the tracers used in the experiment.

Drilling start at about 14:00 hours. At 18:35 hours the first part of phase 1 has been drilled, i.e. from 9.7 m to 10.3 m.

The retrieved core was broken into pieces by drilling, the appearance being similar to core disking which occur during rock stress measurements with the over-coring method. The pieces were 5 cm thick slices, like half a circle or a quarter of a circle. The end pieces, i.e. close to 9.7 and 10.3 m are larger.

The pressure in all sections of borehole KA3065A02 dropped when the drill bit breached the fracture zone at 10.08 – 10.28 m borehole length in KA3065A03. The flow into the borehole is now about 21 L/min.

Pressure in KA3065A03 during passage of 10.08–10.28 m fracture zone in KA3065A03 at over-core drilling

Section in KA3065A02	1	2	3	4
Pressure (kPa) before breach, c 16:30 hours	3534	3487	3449	2890
Pressure (kPa) after breach, c 21:00 hours	3424	3343	3151	2739

During drilling flushing water is about 40 L/min.

No increased level of radioactivity was monitored in backwashing water or on the retrieved core pieces.

Borehole has been open since 24 April at 13:00 hours.

27 April 2007

The today drilling starts at about 07:20 hours.

At 10:00 hours the second core retrieval from the 10.3 – 10.8 m drilling is out of the borehole. A core ending at the target fracture at about 10.74 m is retrieved. The pieces nearest the fracture are quite unbroken. Photos are taken.

A borehole camera is lowered in the borehole to inspect the target fracture and the 177 mm diameter core stub, sealed by a PEEKlid and a cylindrical PU sealing. The PEEK lid with the epoxy resin (injected in the gap between the stub surface and the PEEK lid) have loosened from the core stub and are lying in front of the core stub. An attempt is made to retrieve the PEEK lid with attached epoxy by means of the camera steering rod and the pipe string for the suction pump (used to drain the borehole). This was done without success and a second attempt was made using the drill bit and core barrel by lowering to the target fracture at a very slow rotation speed. The PEEKlid with attached epoxy was successfully retrieved. It was checked with a scintillation detector, showing high radiation. The PEEK lid with attached epoxy is inserted in double plastic bags and temporarily stored behind the experimental container (C1) with the epoxy surface facing towards the tunnel wall.

For orientation, the large core stub resulting from the 300 mm diameter over-coring was marked by means of two hammer blows on a pinch bar inserted along the invert of the hole using a 33 mm outer diameter aluminium pipe string.

Actions are taken to prepare drilling of the 10.8 – 11.4 m section, which may be extended to 11.75 or 11.95 m. The aim is drilling to 11.95 m borehole length and let the core break beyond the 10.93 – 11.23 m section, at one of the natural fractures at 11.4, 11.75 or 11.95 m.

Drilling was started at about 13:00 hours. At about 18:45 hours the drilling machine, which was fastened in a concrete slab in front of borehole collar, jumped backwards and drew the concrete slab about 0.15 m away from the borehole. At this moment the drill bit was at 11.19 – 11.26 m borehole length. This length is somewhat uncertain due to the unexpectedly movement of the drilling machine. From top of borehole casing to drill pipe steering device on drilling machine the distance was 1.02 m before the “jump” and 1.17 m afterwards. The concrete slab had moved upwards and backwards. Drilling can’t continue until the drilling machine has been lowered, adjusted and fastened.

To check if there was a loose core inside the borehole it was decided to take the drill pipe string and drill bit with core barrel out of the borehole. As the drilling machine had changed position it was not possible to get the drill bit with core barrel through the steering device without loosen it from the drilling machine. A crane is required for this heavy work and at about 22:00 hours the drill bit with core barrel can pass the steering device and be taken out of the borehole. The core barrel is empty, except for two small pieces of rock, about one cm size. This result is interpreted as a core stub 10.74 – 11.19 m is still fastened and undamaged in the borehole.

Drill penetration had been so incredibly slow that the question was raised whether there was anything wrong with the drilling equipment or the technique used. It took 5.5 hours to drill 0.5 m, from which the last 0.1 m took half of that time. The new drill bit may not be suited for drilling this particular rock. The drill bit seemed to be dilapidated on the width but not on depth. Is the steel too stiff, not allowing the diamonds to be exposed to the rock? The drilling charge-man knocked the drill bit with a file after which drill penetration was acceptable for 0.15 m. Thereafter the penetration was as slow as before this action. The drill pipe pressure was raised to 4 500 kg, although the drill pipe was hitting the invert of the borehole.

Frequent sampling for HPGe and Scintillation measurement of the water in the collection vessel beneath the borehole collar, as well as check of dose rate on the first sedimentation container, was done during the entire drilling from 10.8 m and onwards. No radioactivity above background values was measured with scintillation and dose rate detectors, even though HPGe measurement of water samples showed occasional radionuclides from the experiment in the water flowing out of the borehole. It was decided to drain the borehole, by using the suction pump, in order to keep the core stub with adsorbed radionuclides dry and thereby preventing them from diffuse into water and further out of the borehole.

28 April 2007

The drillers are lowering, adjusting and fastening the drilling machine. Water flow rates are checked and radiological controls made. No raised radioactivity is measured in the water. The drain pumping with suction pump is working well.

29 April 2007

The drilling machine was adjusted, fastened and ready for drilling at about 15:00 hours. Drilling can however not commence until staff from Clab radiation protection organisation and project coordinator are at site. Thus drilling has to wait until Monday 30 April.

A drill pipe pressure of 4 000 – 5 000 kg is normal for a drilling diameter of 300 mm according to the drilling engineer. Based on experience from the last drilling at Äspö HRL with 300 mm diameter, when they had to pry loose every second drill teeth to get the drill bit to work, this drill bit have much more space between the teeth's and should be suited for the rock at this site. However, the drill bit has to be sharpened very often e.g. every 0.1 m drilling, by knocking with a file to get the diamonds to be exposed.

30 April 2007

The drill bit has been sharpened and at 08:14 hours the drill is inserted in the borehole to start drilling from 11.19 m borehole length to 11.4 m. Check of core retrieval after drilling to 11.4 m. The core barrel was empty. Drill bit sharpened and drilling continued to next potential fracture at 11.75 m, where a new check was done resulting in no core in the barrel. This result is interpreted as a core stub 10.74 – 11.75 m is still fastened and undamaged in the borehole. The drill bit is sharpened and a short brake is taken at 11:20 hours. Drilling continues and at 14:10 hours the drill bit has reached 11.955 m. Drilling is stopped and a decision is taken to break the core. A core-breaking device is inserted in the borehole, but the device will not slip in the gap between core and borehole invert in the sub-horizontal borehole. The core seems to be hanging slightly downwards. This situation is confirmed by a check with the borehole PearPoint camera. At 16:30 hours it is decided that core break is postponed until 2 May, when staff from Clab radiation protection organisation can be on site.

The suction pump does not have capacity enough to keep the core stub dry. It is therefore decided to stop pumping and put the lid on the borehole collar. At 17:30 hours the lid is in place. There is a small leakage through the gasket, a few droplets per second, but this is not of importance.

The situation with the core still fasten in the borehole is discussed. New devices for core breaking are under construction. The drilling engineer idea is to insert the new device on the side of the core, instead of in under. However, since it is of outmost importance to retrieve an undamaged core from 10.7 to 11.3 m the core-breaking device must be inserted beyond 11.3 m borehole length.

2 May 2007

The borehole is opened and an attempt to break the core with the new device is done, but without success. It is decided to resume drilling, heading for 12.1 m borehole length.

Because the experimental borehole is close to the exploration pilot borehole KA3065A02, and the boreholes are sub-parallel directed towards each other it is of importance to check if the over-coring of KA3065A03 will intersect KA3065A02. The distance between the perimeter of KA3065A02 and the experimental borehole KA3065A03 was calculated based on data from The Äspö HRL Rock Visualisation System (RVS) and SICADA. KA3065A02 is scaled with Maxibor and KA3065A03 only with the strike and dip at drill start.

Distance from perimeter to perimeter of boreholes KA3065A02 and KA3065A03 as a function of borehole length in KA3065A03

Borehole length (m) in KA3065A03	Distance KA3065A03 – KA3065A02 centre – centre (m)	Distance KA3065A03 – KA3065A02 perimeter – perimeter (m)
10.8	0.430	0.242
11.8	0.405	0.217

The distances perimeter – perimeter are calculated based on a borehole diameter of 76 mm in KA3065A02 and 300 mm in KA3065A03.

According to the core mapping data in SICADA there are fractures at 9.85, 10.3, 10.5, 12.6 and 12.9 metres in KA3065A02. The maximum drilling depth, using the existing drill bit and core barrel, is 12.4 m. Thus, is not possible to drill further in order to intersect a fracture where the core will break, but further drilling will make better chance for core to break because of its own weight.

Drilling is stopped at 12.1 m. An attempt is made to break the core. By means of a special “barrel” the core-breaking device is inserted on top of the core, far beyond the minimum acceptable borehole length 11.35 m. At 16:10 hours the core is breached and at 16:25 hours an undamaged core is retrieved in the core barrel. In the bottom of the core some equipment parts in the slim hole can be seen. It is interpreted being the lower end of the extension borehole equipment, indicating a core about 10.74 – 11.82 m has been retrieved. A closer look can be taken on 3 May, i.e. next time when staff from Clab radiation protection organisation can be on site.

3 May 2007

At 11:00 hours an undamaged complete core 10.74 – 11.82 m has been taken out of the core barrel. Photos are taken. Using a scintillation detector a dose rate of 80 µS/h is measured at the core stub that has been exposed to test section groundwater the course of the experiment. The radiation protection personnel in charge decide the geological mapping has to be done at Clab and that the core has to be transported to Clab as soon as possible. Some complementary dose rate measurements were done with the dose rate meter that was fixed to the first sedimentation container during the over-core drilling.

Dose rate measurements on the 278 mm diameter over-core and PEEK lid with adhered epoxy

Dose rate (µS/h)	Point measured
65 – 70	0.02 m from the surface of the core stub
3 – 4	1.00 m from the surface of the core stub
1	0.01 m from the envelope surface of the 278 mm diameter core
13 – 15	0.02 m from the epoxy surface on the PEEK lid with adhered epoxy

The 300 mm diameter drilling was stopped at 12.11 m borehole length. The 278 mm diameter core was breached at 11.82 m, leaving a 0.29 m core stub in the borehole.

The drilling machine is dismantled and after equipment parts have been tested by smear tests and approved for transportation from the restricted area by the radiation protection personnel in charge, the complete machine is moved to the TRUE-1 site.

4 May 2007

The undamaged and complete 278 mm diameter core, section 10.74 – 11.82 m is placed in a wooden transport box. The hollow core (in pieces), section 9.7 – 11.74 m is placed in another wooden transport box. Both are transported to Clab, gate 888.

The PEEK lid with attached epoxy, placed in double plastic bags, will still be temporarily stored behind the experimental container (C1) with the epoxy surface facing towards the tunnel wall.

5 May 2007

The cores (transport boxes 1 and 2) have been removed from Clab, gate 888 to the filter hall at Clab.

Appendix 9

Timeline of Core Handling

Table A9-1. Information on dates for events with potential impact on results after the termination of the in situ experimental phase, until analysis of the sliced rock samples.

Date	Event	Comments
2007-04-12	Termination of in-diffusion phase	Exchange of radionuclides in water for isopropyl alcohol
2007-04-12	Epoxy injection	Protection from flushing away radionuclides and mechanical damage during over coring
2007-04-27	PEEK lid loosened and left borehole left open with stub exposed for about 3 hours. After that, the borehole was drained using a suction pump.	Water flushing may have caused desorption of radionuclides from the surface. During the drying phase, the surface of the stub may hade dried. Thereafter the PEEK lid was handled separately.
2007-04-30	The pumping was stopped, and instead the lid was put on, covering the borehole collar.	The suction pump did not have the capacity enough to keep the stub dry.
2007-04-30 to 2007-05-02	Over core drilling of the experiment section	After removal and dismantling of the borehole equipment
2007-05-03	Core totally covered in cellophane plastic and heavy plastic foil.	For prevention of drying.
2007-05-04	Core transported to Clab/Simpevarp	
2008-08-03	Epoxy coating of the core	Performed to avoid cross-contamination and to increase the mechanical stabiliy.
2008-08-06	Cutting of the core	Performed to facilitate drilling of the core samples
2007-08-08	Drilling of core samples	D1/D2, D9/D10, D5/D6, D13/D14 and D3/D4. All rock cores placed in plastic bags, see Figure A15-1 below.
2007-08-09	Drilling of core samples	D11/D12, D7/D8, D15/D16, A16, A10, A4 and A17
2007-08-10	Drilling of core samples	A5, A9, A11, A15, A3, A8, A14, A2, A6
2007-08-13	Drilling of core samples	A1, A18, A12, A13, A7, A19, A20, A21
2007-08-14	Drilling of epoxy covered PEEK lid samples	B15
2007-08-15	Drilling of epoxy covered PEEK lid samples	B15, B8, B14 and B9
2007-08-20	Drilling of epoxy covered PEEK lid samples	B3
2007-08-22	Drilling of epoxy covered PEEK lid samples	B2 and B16
2007-09-04	Drilling of epoxy covered PEEK lid samples	B7, B4, B10, B17, B5, B11, B6, B18, B1, B12 and B13
2007-10-25 to 2007-10-26	Slicing 1–10 mm	Performed at Helsinki University; A3, A7
2007-11-01	Slicing 1–10 mm	D10
2007-11-02	Slicing 1–10 mm	D9
2007-11-08	Slicing 1–10 mm	D1, D2
2007-11-15	Slicing 1–10 mm	D3, D4
2007-11-16	Slicing 1–10 mm	D5
2007-11-20	Square-cut 3 cm pieces	A2, A9
2007-11-21	Square-cut 3 cm pieces	A1, A11
2007-11-22	Slicing 1–10 mm	A12
2007-11-25	Slicing 1–10 mm	A3
2007-11-27	Slicing 1–10 mm	A5
2007-12	Square-cut 3 cm pieces	A13, A14, A15, A16, A17, D8, D11, D13, D14, D16
2007-12	Slicing 1–10 mm	
2007-12-04	Square-cut 3 cm pieces	A4
2007-12-05	Square-cut 3 cm pieces	A6
2007-12-09	Slicing 1–10 mm	A10
2007-12-10	Square-cut 3 cm pieces	A8, D6, D12
2007-12-10	Slicing 1–10 mm	A18
2007-12-11	Slicing 1–10 mm	D7
2008-01-05	Square-cut 3 cm pieces	D15
2008-02 to 2008-03	Slicing 1–10 mm	A1, A2, A4, A6, A8, A9, A11, A13, A14, A15, A16, A17, D6, D8, D11, D12, D13, D14, D15, D16
2008-10-24 to 2010-04-16	HPGe and LSC analyses of rock samples	Performed at Baslab/Clab/Simpevarp

***Figure A9-1.** Rock core samples contained in thin plastic bags, mainly to avoid cross-contamination during cutting, drilling and storage of rock core samples. Plastic bags were not primarily used to prevent drying of the pore water and air was not evacuated from them during storage.*

Appendix 10

Photographs of dry and wet drill core

Photographs of dry core. The core is rotated in such way that each photo faces the letters A to H, respectively.

A

B

C

D

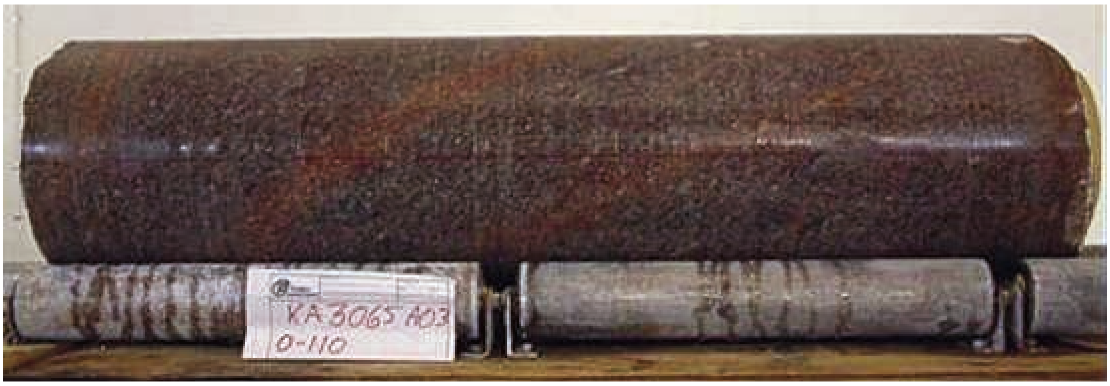
E

F

G

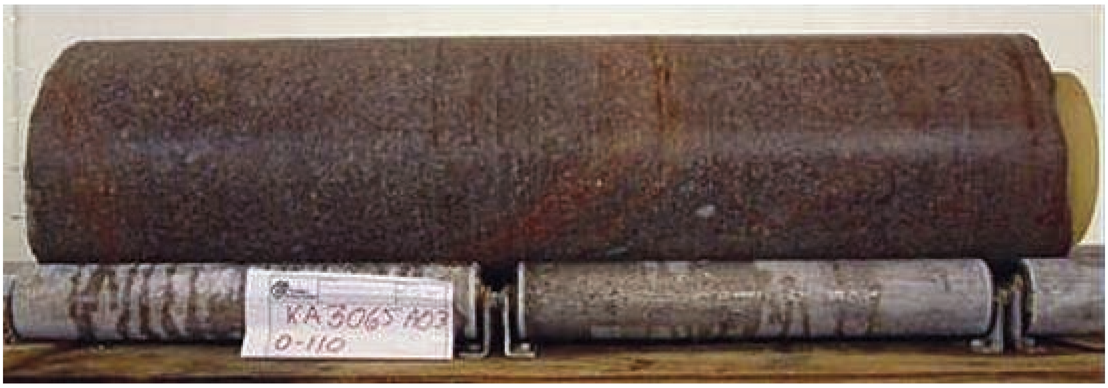
H

Photographs of wet core. The core is rotated in such way that each photo faces the letters A to H, respectively.



A

B



C

D


KA 3065 A03
0-110

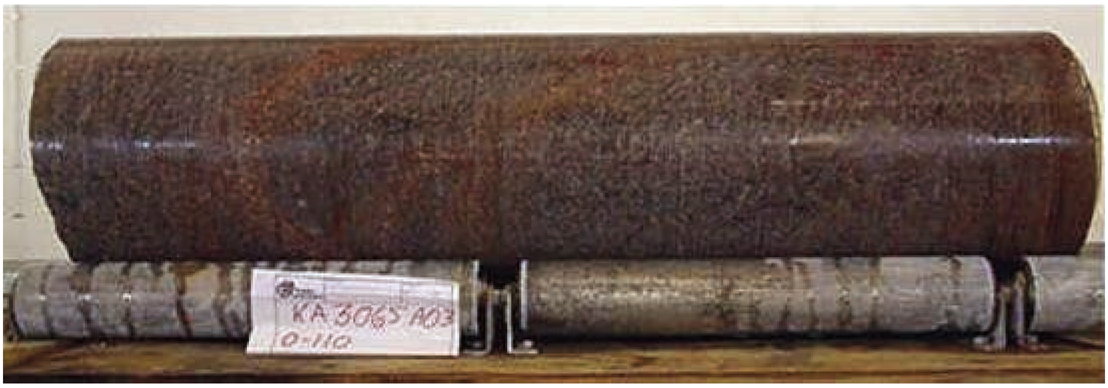
E


KA 3065 A03
0-110

F


KA 3065 A03
0-110

G


KA 3065 A03
0-110

H

Appendix 11

Photographs and drawings from orientation and scaling

Figure A11-1. *Target fracture at 10.74 m with the 177 mm diameter core stub inside the cylindrical PU sealing. The core is rotated to show the orientation in the borehole, i.e. the core low side is down. The photo is taken immediately after core extraction at the experimental site NASA3067A in the Äspö HRL, cf Figure A7-20.*

Figure A11-2. *Target fracture at 10.74 m with the 177 mm diameter core stub inside the cylindrical PU sealing. The core is rotated to show the orientation in the borehole, i.e the core low side is down. The photo is taken at Clab in connection with the first marking of the core. See Section 3.1 and Figure 3-4.*

Figure A11-3. *Target fracture at 10.74 m with the 177 mm diameter core stub inside the cylindrical PU sealing. The photo is taken at Clab in connection with the first marking of the core. See Section 3.1. Remains of the loosened yellow epoxy resin can be seen on the fracture surface.*

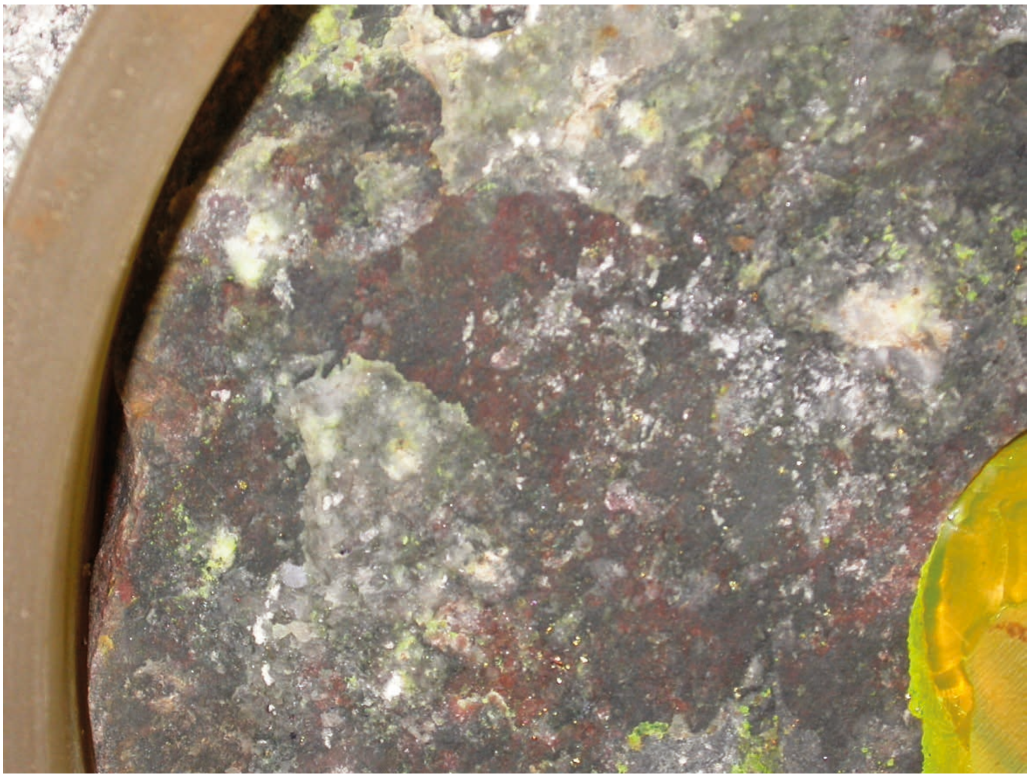
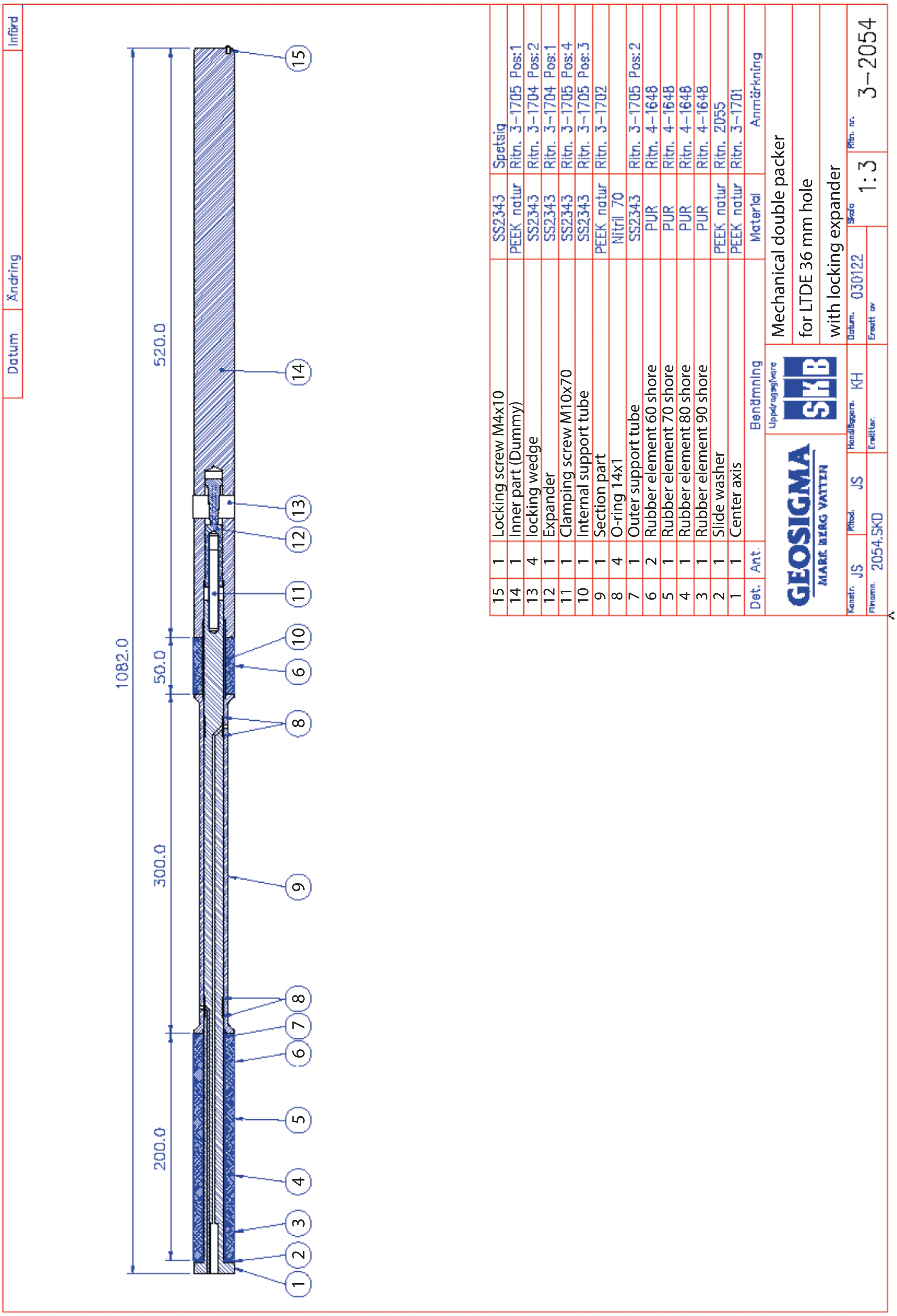


Figure A11-4. *Close up of target fracture at 10.74 m with the 177 mm diameter core stub inside the cylindrical PU sealing.*



Det.	Ant.	Benämning	Material	Anmärkning
15	1	Locking screw M4x10	SS2343	Spetsig
14	1	Inner part (Dummy)	PEEK natur	Ritn. 3-1705 Pos:1
13	4	locking wedge	SS2343	Ritn. 3-1704 Pos:2
12	1	Expander	SS2343	Ritn. 3-1704 Pos:1
11	1	Clamping screw M10x70	SS2343	Ritn. 3-1705 Pos:4
10	1	Internal support tube	SS2343	Ritn. 3-1705 Pos:3
9	1	Section part	PEEK natur	Ritn. 3-1702
8	4	O-ring 14x1	Nitril 70	
7	1	Outer support tube	SS2343	Ritn. 3-1705 Pos:2
6	2	Rubber element 60 shore	PUR	Ritn. 4-1648
5	1	Rubber element 70 shore	PUR	Ritn. 4-1648
4	1	Rubber element 80 shore	PUR	Ritn. 4-1648
3	1	Rubber element 90 shore	PUR	Ritn. 4-1648
2	1	Slide washer	PEEK natur	Ritn. 2055
1	1	Center axis	PEEK natur	Ritn. 3-1701

***Figure A11-5.** Equipment for the LTDE-SD 36 mm diameter extension borehole, the 300 mm long test section with dummy and devices for circulation of tracer spiked groundwater.*

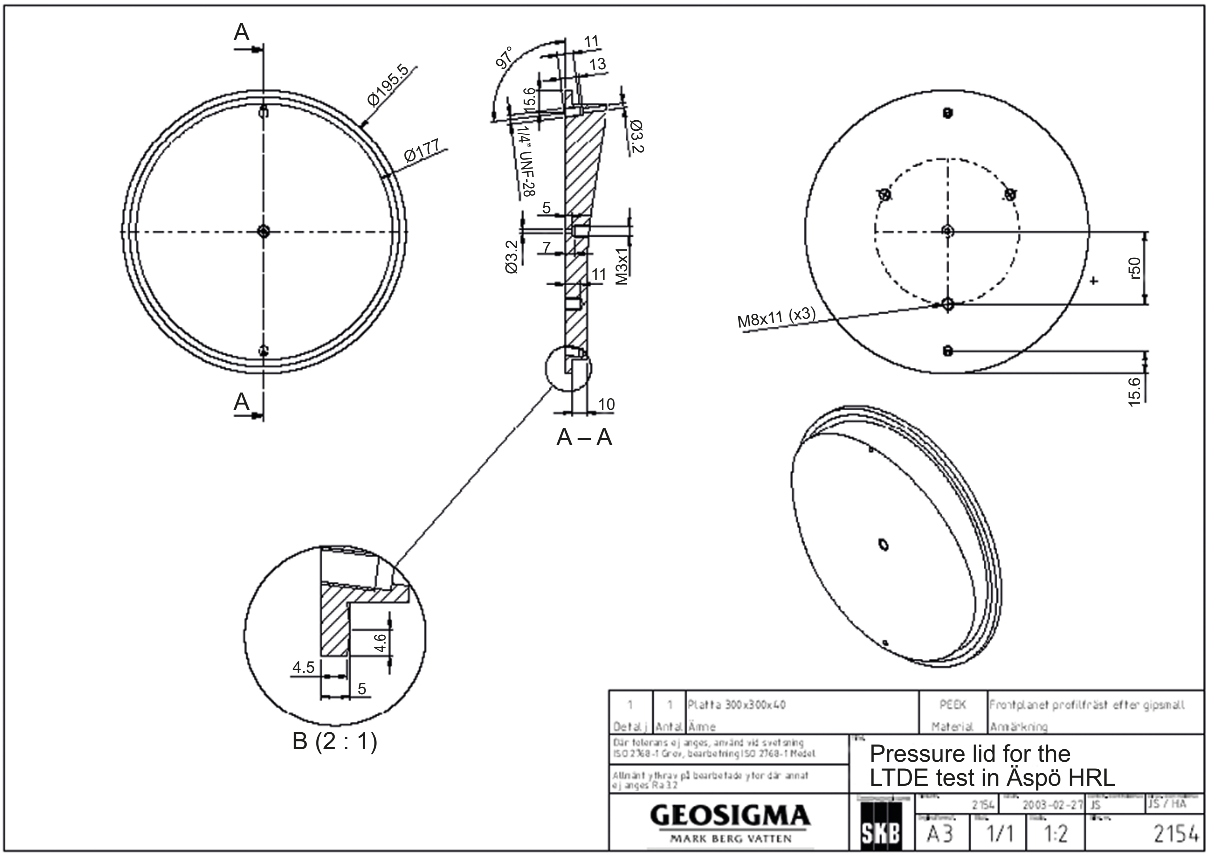


Figure A11-6. *The PEEK plastic lid used on top of the cylindrical PU sealing in order to seal the test section at the natural fracture (target fracture) core stub.*

Photographs of core samples drilling

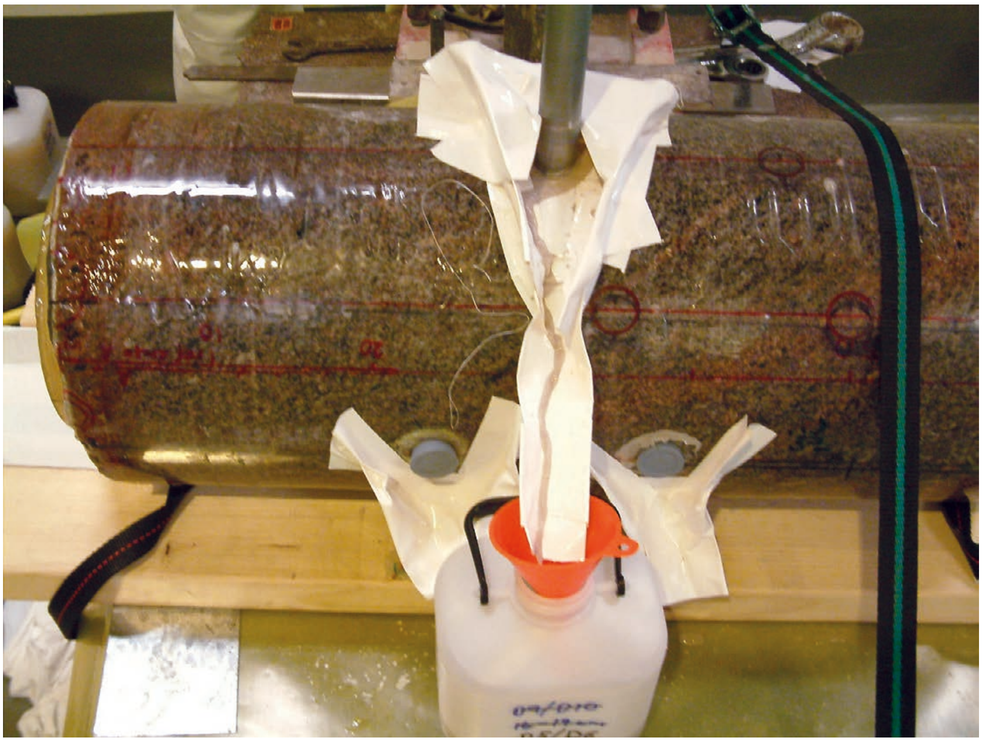


Figure A12-1. *Drilling of a D-core sample. Drilling debris and flushing water is collected to enable investigation of any potential contamination and/or loss of radionuclide tracers.*

Figure A12-2. *Fastening of over-core before drilling of A-core samples.*

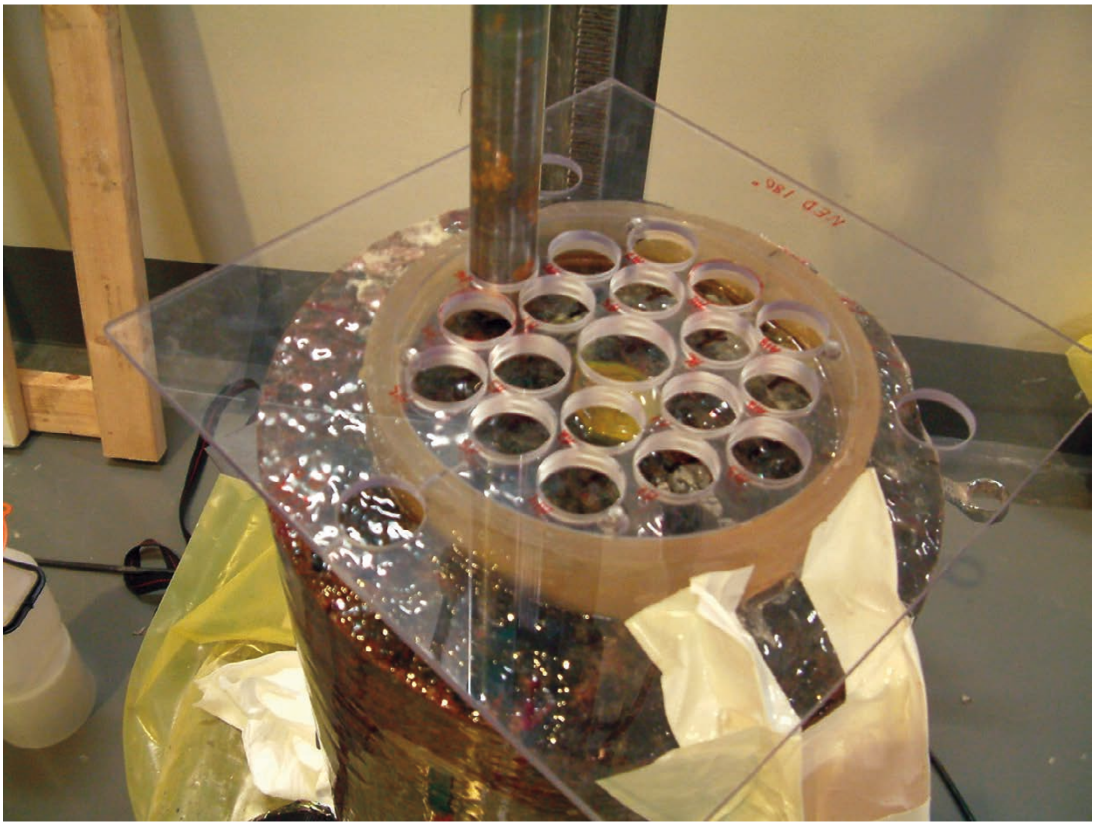


Figure A12-3. *Jig used to achieve the correct positioning of the A-core samples. Drilling of core sample A-16 is to be started.*

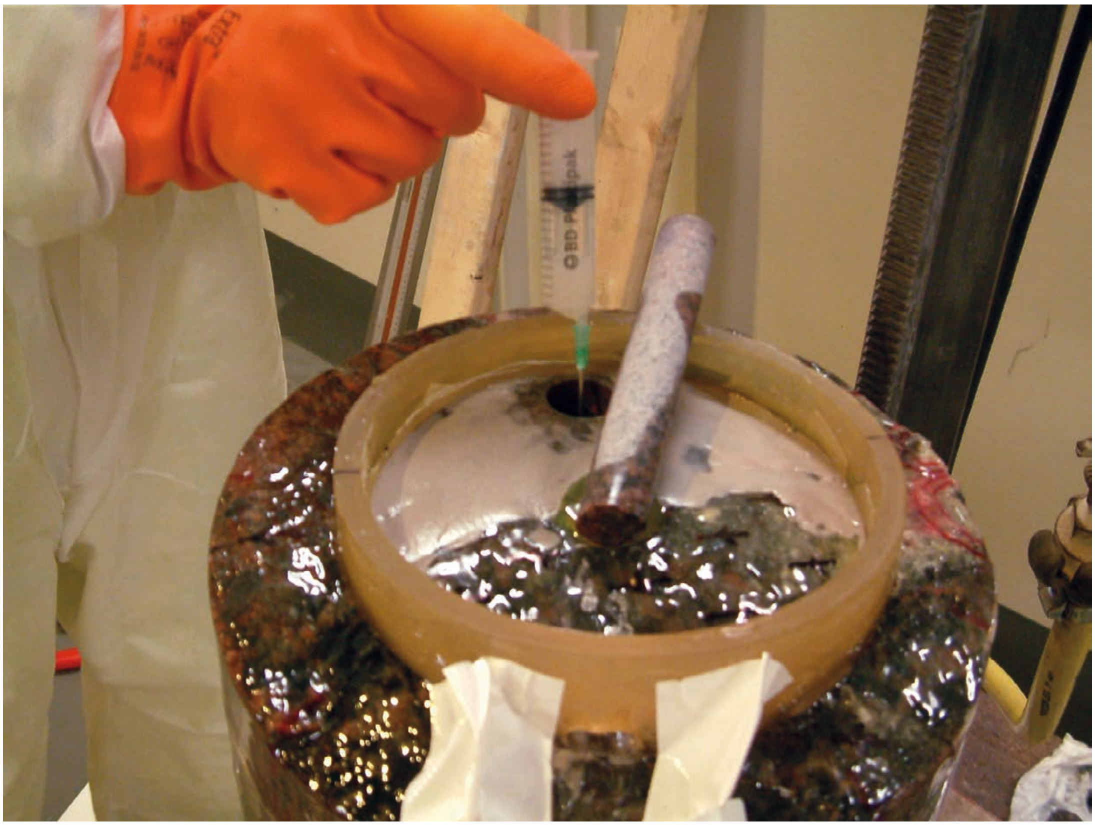


Figure A12-4. *Drill hole of sample A-16 is emptied from drilling water, before plugged by rubber cork.*

***Figure A12-5.** Core breaking and retrieval of sample A-4. Drill holes of samples A-12, 6, 5, 10, 18, 11, and A-17 are plugged by rubber corks.*

***Figure A12-6.** Drilling of a C-core sample.*

Appendix 13

Notes from drilling of core samples

Core sample	Date	Drill start	Drill stop	Comment
KA3065A03	2007-08-06	15:19	15:24	Diamond sawing for cutting the large 270 mm diameter core. Consumption: 11.5 litres sawing water and 4.5 litres of flushing water.
D1/D2	2007-08-08	09:25	09:50	
D9/D10		11:05	11:14	Drilling water is flowing out of D1/D2 when drill bit is passing core centre hole, the epoxy injected in centre hole do not seal completely. Drilling is stopped for plugging the borehole. From now on boreholes are plugged.
		13:20	13:28	Drilling D10
D5/D6		16:13	16:24	
D13/D14		17:16	17:42	
D3/D4		18:26	18:34	
D11/D12	2007-08-09	07:39	07:52	
D7/D8		08:22	08:32	Orientation of D7 based on geology, the epoxy with marking loosened during drilling.
D15/D16		09:52	10:06	
A16	2007-08-09	13:17	13:23	
A10		14:01	14:08	
A4		14:27	14:35	
A17		14:49	14:55	
A5	2007-08-10	07:43	07:47	
A9	2007-08-10	08:00	08:10	Main part of the drilling debris enters the right vessel, but some remain on the stub surface. From now on the stub surface will be flushed after every core sample drilled. Extra water samples are taken.
A11		08:33	08:49	Stub surface is flushed, but 2 cm interval sample is missed. Interval now is 0–1, 1–3, 3–5 etc. Extra water samples.
A15		09:56	10:02	
A3		10:17	10:21	
A8		10:31	10:37	
A14		10:53	10:57	
A2		11:06	11:10	
A6		11:30	11:35	
A1	2007-08-13	07:28	07:31	
A18		07:44	07:49	
A12		07:57	08:03	
A13		08:21	08:32	Extra water samples with flushing
A7		08:40	08:44	
A19		09:52	10:06	
A20		10:37	10:44	
A21		11:04	11:08	Broken at core retrieval
C1	2007-08-13	13:39	13:45	Partially cracking
C5		14:14	14:18	Break at fracture. Core is retrieved and drilling continues. Bottom part of core somewhat oval due to the break of the upper part.
C3	2007-08-13	14:55	14:59	Breached at fracture. Core is retrieved and drilling continues. Bottom part of core somewhat oval due to the break of the upper part.
C4		15:30	15:35	
C2		16:00	16:10	Breached at fracture. Drilling continues for a while before upper part of core is retrieved.

Core sample	Date	Drill start	Drill stop	Comment
B15	2007-08-14	11:44	11:56	Diamond drill with water flushing. Got stuck in the PEEK plastic.
		16:00	16:01	Hole saw (Bahco). Weld together with the diamond drill core barrel. Vibrates too much, cannot be used.
	2007-08-15	08:10	08:11	Hole saw (Jula). Sawing in the PEEK plastic. The PEEK plastic becomes extremely hot.
B8	2007-08-15	08:26	08:28	Hole saw (Jula). Unbroken epoxy/PEEK plastic core
B14		08:34	08:38	Hole saw (Jula). Core breached in centre
B9		08:51	08:57	Hole saw (Jula). Core breached in centre
B3	2007-08-20	10:30	10:36	Hole saw (Starret). The yellow marked epoxy is broken into splinters.
		10:45	10:53	Hole saw (Starret). Got stuck in the PEEK plastic. Hole saw broken.
B2	2007-08-22	14:44	14:50	Hole saw (Bahco special). The epoxy/PEEK plastic core is broken.
		15:28	15:33	Hole saw (Bahco special). Drilling in the PEEK plastic
B16	2007-08-22	15:52	16:15	Hole saw (Bahco special). Low drilling rate and high rotation speed. The epoxy and PEEK plastics starts to melt. The chips melts and are squeezed stuck in the plastic core. Lower rotation speed is used but still plastic gets very warm.
B7	2007-09-04	10:46	10:53	Difficult to break the core to loosen from the bottom of the PEEK lid.
B4		13:17	13.21	
B10		13.30	13.34	
B17		13:41	13:43	
B5		14:15	14:18	The two epoxy layers (yellow marked and natural) loosen from each other.
B11		14.38	14:40	
B6		14:49	14:52	
B18		14:59	15:01	
B1		15:06	15:10	Part of the epoxy cracked and was crushed.
B12		15:18	15:21	The core is breached to loosen from the bottom of the PEEK lid, 2007-09-05 kl 15:47
B13		15.27	15:31	The core is breached to loosen from the bottom of the PEEK lid, 2007-09-05 kl 15:47

Appendix 14

Photographs of epoxy/PEEK plastic core samples drilling

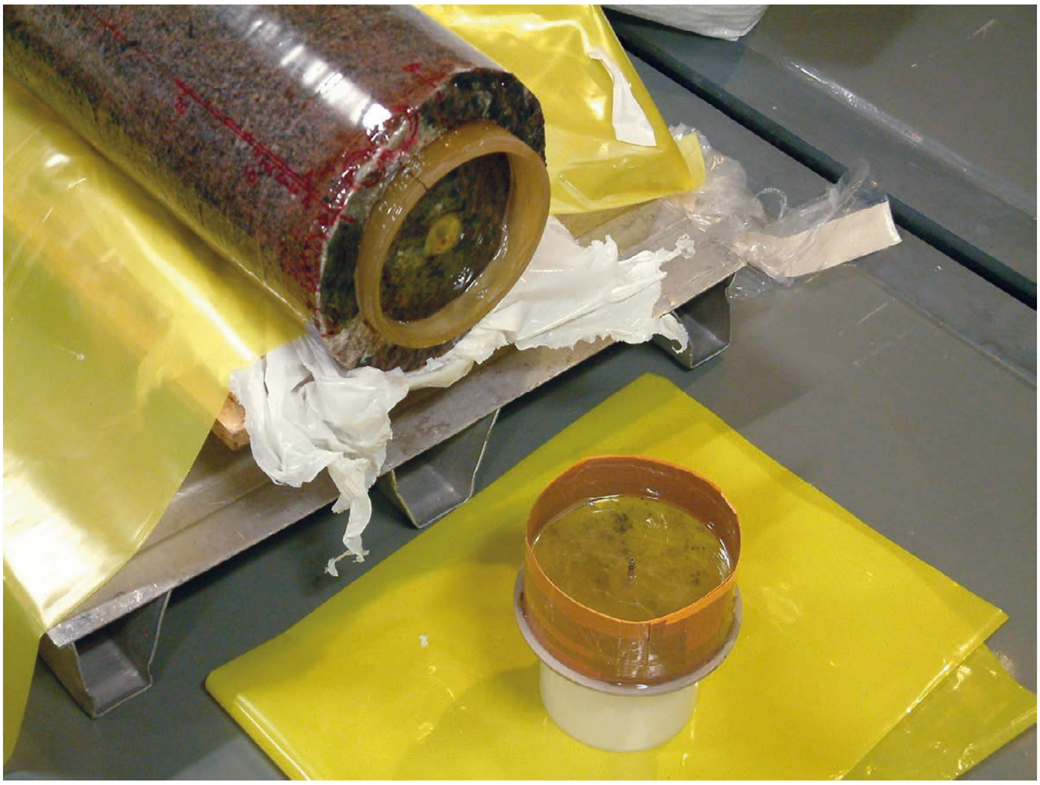


Figure A14-1. Protective colourless epoxy (EpoTec 302) cast on top of yellow marked epoxy and PEEK lid.

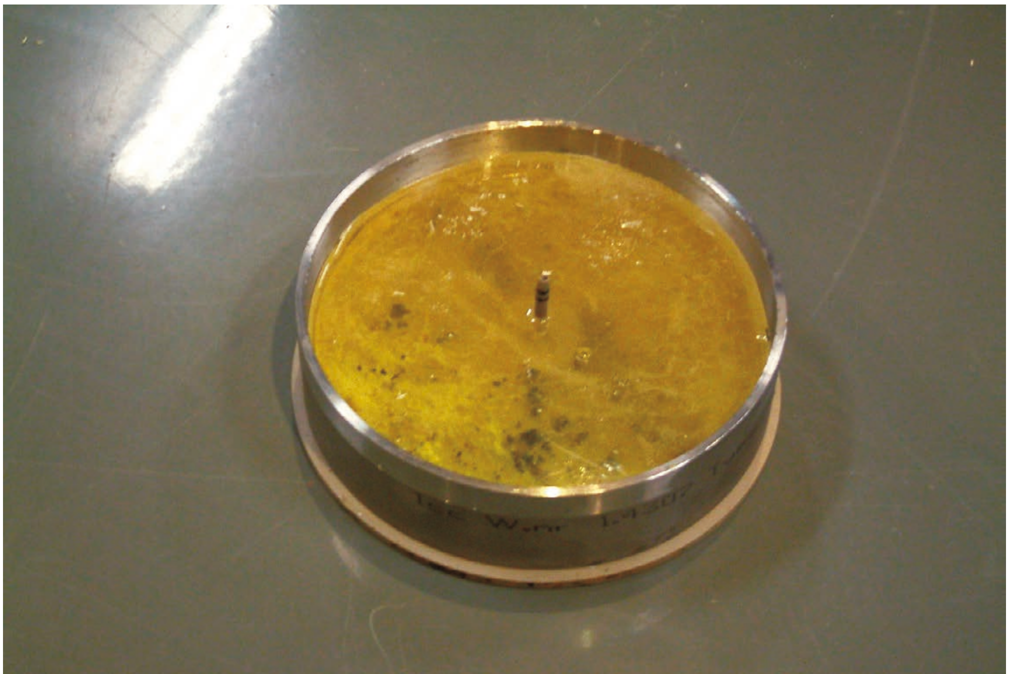


Figure A14-2. Casting mould replaced by stainless steel ring to support the drilling jig.

Figure A14-3. *PEEK lid with (injected) yellow marked epoxy and protective coating of colourless epoxy is fastened to a stiff plate before drilling of the B-core samples.*

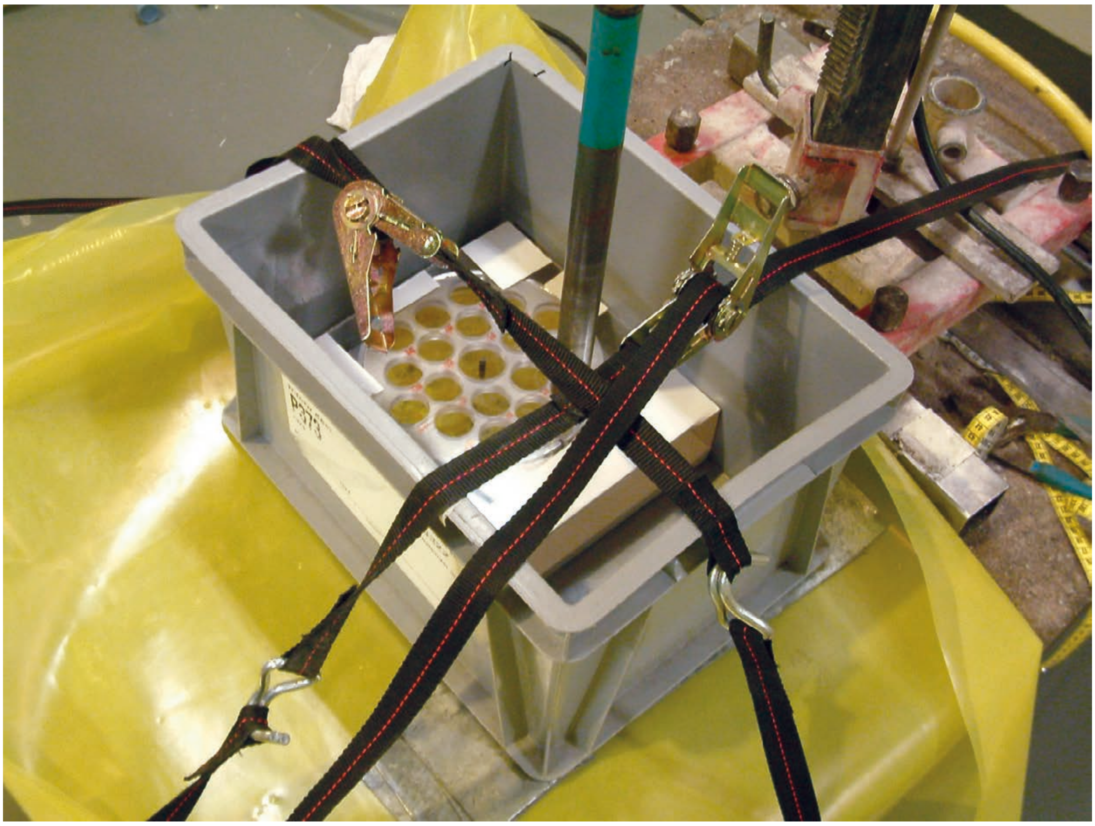


Figure A14-4. *Drilling of a B-core sample.*

Appendix 15

Geological characterisation of core samples

A1

General:

Remaining epoxy on the fracture surface, c 80 %.

Partially, 0–1 mm width between the epoxy and the fracture surface.

About 50 % coverage of fracture minerals, with a thickness of ≤ 0.5 mm.

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite. Titanite is probably hematite stained, visible as rusty colour around some of the mineral grains.

Fracture surface coating (A): Chlorite and possibly calcite.

Fracture fillings, sealed fractures: chlorite and/or calcite.

Fractures:

a) Increasing amount of microfractures, mainly sealed, from about 4 cm and towards the fracture surface (A). The last cm = a fine-meshed network of very thin sealed and partly open microfractures

b) At about 10.5 cm core length, two thin sealed fractures (≤ 1 mm width) with surrounding oxidation at an angle of approximately 45° to the borehole axis.

Wall rock alteration:

Red staining as well as weak albitization, are visible with decreasing intensity from the fracture surface and inwards, about 11.5 cm. In microscope, weak degree of alteration is discernible throughout the whole core.

A2

General:

Fracture surface covered with epoxy (100 %).

Fracture coating only indicated as a white rim at single points. Approximately ≤ 20 % coverage, with a thickness of ≤ 0.5 mm.

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite. Titanite is probably hematite stained, visible as rusty colour around some of the mineral grains.

Fracture surface coating (A): calcite ± quartz.

Fracture mineralogy, sealed fractures: calcite ± chlorite and epidote.

Fractures:

a) Close to the fracture surface, (2–3 mm distance) 1 sealed fracture with calcite/chlorite.
b) Sealed fracture about 1 cm from the surface.
c) Small microfractures in network (but less than for core sample A1).
d) Single microfractures, possibly partly opened, throughout the whole core. No dominating orientation. Nevertheless, microfractures close to A (the surface) are more parallel to the fracture surface than the microfractures at distance.

Wall rock alteration:

Red staining, faint to medium degree, increasing towards fracture surface.

Sometimes just like a rust-coloured grain boundary.

A3

General:

Epoxy covers 100 % of the fracture surface.

About 50 % of thin fracture coating at the fracture surface (A).

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite. Titanite is probably hematite stained, visible as rusty colour around some of the mineral grains.

Fracture surface coating: Chlorite.

Fractures:

One relatively long (7 cm) microfracture, partly open.

Wall rock alteration:

Red-staining from faint (B) to medium (A).

A4

General:

Remaining epoxy on the fracture surface, 100 %.

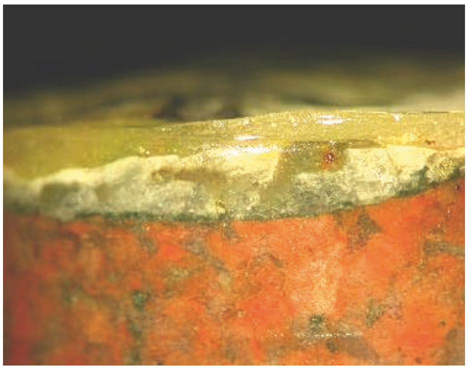
A 0–2 mm thick fracture coating covers approximately 70 % of the fracture surface.

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite. Titanite is probably hematite stained, visible as rusty colour around some of the mineral grains.

Fracture surface coating (A): chlorite, calcite, chalcopyrite ± pyrite ± epidote (see photo below).



Fractures:

Two varieties of fractures:

a) Sealed, more or less parallel with the fracture surface (A). The largest one 3 cm from the fracture surface (A). These fractures form a circle around the core, but do not close the ends (see photo a) below). Red coloured according to small hematite grains in calcite.

b) Very thin sealed or partly open microfractures. Can be seen anywhere and at different orientations at the rock core (see photo b) below).

a)

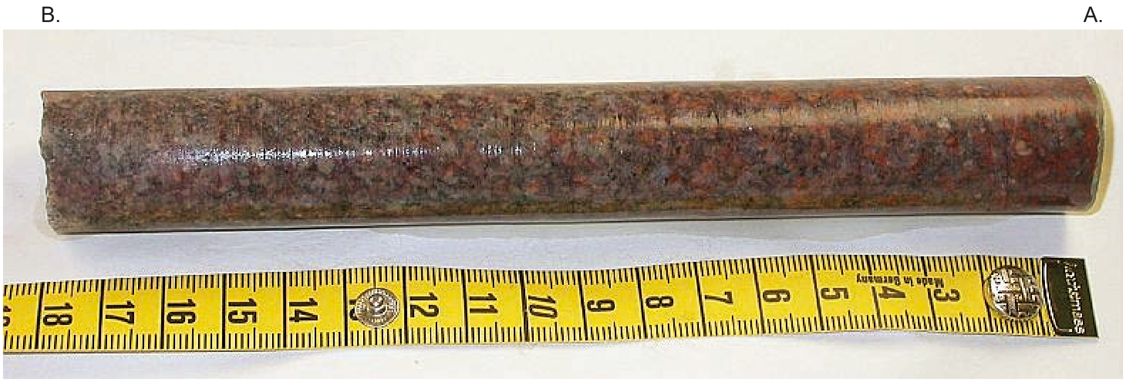
b)

Wall rock alteration:

Faint to medium degree of red staining, increasing towards the fracture surface (A).

When faint degree, merely a rust-coloured grain boundary.

A5



General:

Fracture surface covered with epoxy (100 %).

Approximately 50 % of the fracture surface has a thin (≤ 0.5 mm) fracture coating.

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite. Titanite is probably hematite stained, visible as rusty colour around some of the mineral grains.

Fracture surface coating (A): minor amount of chlorite that is overlaid by calcite and/or quartz.

Fracture mineralogy, sealed fractures: calcite, hematite ± laumontite.

Fractures:

a) Sealed fracture 2 cm from, and parallel with, fracture surface (A). Forms a circle, which does not close the ends (as illustrated for rock core A4).
b) Sealed fracture 5.5 cm from (A) but at angle to the borehole axis.
c) Small microfractures close to the fracture surface (A).

Wall rock alteration:

Red staining, faint to medium. Faint degree, irregular at the second part of the rock core (towards B).

A6

General:

Epoxy covers 100 % of the fracture surface.

The fracture surface coating is 0–2 mm thick and covers c 95 % of the surface.

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite. Titanite is probably hematite stained, visible as rusty colour around some of the mineral grains.

Fracture surface coating: Calcite, chlorite, epidote and minor amount of chalcopyrite, ± quartz.

Fracture fillings, sealed fractures: Calcite.

Fractures:

a) Sealed fractures, 0.5 and 1 cm from fracture surface (A).
b) 2 fractures c 45° to the borehole axis between the “0.5” and “1 cm fractures” described in a). Not visible round the whole core.
c) Very thin microfractures at c 8 cm distance from the fracture surface (A). No specific orientation.

Wall rock alteration:

Faint to medium (possibly strong) degree of oxidation, i.e. red staining.

A7

General:

Epoxy covers 100 % of the fracture surface.

Fracture coating at about 75 % of the surface (A).

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite. Titanite is probably hematite stained, visible as rusty colour around some of the mineral grains.

Fracture surface coating (A): Chlorite.

Fractures:

a) Sealed fracture at 0–1 cm distance from the fracture surface (A), i.e. not parallel to the fracture surface.
b) Minor amount of microfractures except from a couple of thin and short partly open fractures around the described fracture above.

Wall rock alteration:

Varying degree from A to B (see figure above); the first 6 cm = medium, 6–11 cm = weak, 11–13 cm = faint, 13–16.5 cm = no alteration.

A8

General:

Epoxy covers 100 % of the fracture surface.

The fracture coating is thin (≤ 0.2 mm) and covers about 70 % of the surface area.

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite. Titanite is probably hematite stained, visible as rusty colour around some of the mineral grains.

Fracture surface coating (A): Chlorite ± epidote.

Fracture fillings, sealed fractures: Calcite.

Fractures:

a) Sealed fracture at about 2.5 cm distance from fracture surface (A).
b) Thin, sealed microfractures sporadic over the core. No specific orientation although.

Wall rock alteration:

Faint to medium oxidation, i.e. red staining.

A9

General:

Epoxy covers 100 % of the fracture surface.

50 % of the fracture surface has a thin (≤ 0.5 mm) fracture coating.

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite. Titanite is probably hematite stained, visible as rusty colour around some of the mineral grains.

Fracture surface coating (A): calcite, minor amounts of chlorite ± epidote.

Fractures:

a) Sealed fracture with calcite, red coloured due to small hematite grains at a distance of c 3 cm from the fracture surface (A). At 70° to the borehole axis.
b) Several short (0.5 to 1 cm) microfractures parallel with a).

Wall rock alteration:

Red staining, faint to medium degree, increasing towards fracture surface (A).

A10

General:

Epoxy covers 100 % of the fracture surface.

The fracture coating covers 100 % of the fracture surface and is relatively thick (0.5–2 mm) at c 75 % of the area. At the remaining 25 % of the surface the coating is thin (≤ 0.5 mm).

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite. Titanite is probably hematite stained, visible as rusty colour around some of the mineral grains.

Fracture surface coating (A): calcite, chlorite, chalcopyrite, epidote.

Fracture mineralogy, sealed fractures: calcite, quartz, chlorite, chalcopyrite ± oxidized walls.

Fractures:

a) Sealed fracture, 0.5–1 mm thick at 2.7 cm.
b) Several microfractures at 0–3 cm.
c) Diagonal (45°) sealed/partly opened fracture at 7 cm.

Wall rock alteration:

Weak to strong red staining with increasing intensity towards the fracture surface (A).

A11

General:

Epoxy covers 100 % of the fracture surface. Generally thin (≤ 0.5 mm), but irregular, fracture coating is observed at about 60 % of the fracture surface (A). Remaining 40 % seems to be without fracture coating.

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite. Titanite is probably hematite stained, visible as rusty colour around some of the mineral grains.

Fracture surface coating (A): Calcite and chlorite.

Fracture mineralogy for sealed and partly opened fractures: calcite, hematite, small amounts of chlorite, ± quartz (see photo b) below).

Fractures:

a) Partly open fracture at about 1.5 cm from the fracture surface (see photo a) below). Parallel (or sub-parallel) to (A).

b) A few sealed microfractures close to the fracture surface (A). Diagonal relative to the borehole axis.

c) Sealed and thin calcite filled fracture at 45° relative to the borehole axis.

a)

b)

Wall rock alteration:

Red staining, from weak to medium the first 10 cm, i.e. closest to fracture surface (A) to no alteration towards (B).

A12

General:

Fracture surface covered with epoxy (100 %).

The fracture surface coating is very thin and covers about 30 %.

The core has been scratched during drilling.

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite. Titanite is probably hematite stained, visible as rusty colour around some of the mineral grains.

Fracture surface coating (A): chlorite and calcite ± epidote.

Fracture fillings (partly open fractures): chlorite and calcite.

Fractures:

a) Partly opened fracture at 0–1 cm distance from the fracture surface (A), not exactly parallel to the fracture surface but perpendicular to the borehole axis.

b) Partly opened fracture at about 6 to 8 cm from the fracture surface (A). Undulating.

Wall rock alteration:

Red staining, weak to strong degree, increasing towards fracture surface.

A13

General:

Epoxy covers 85 % of the fracture surface.

Fracture coating visible at about 45 % of the fracture surface, ≤ 0.2 mm thickness.

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite. Titanite is probably hematite stained, visible as rusty colour around some of the mineral grains.

Fracture surface coating: chlorite.

Fracture fillings (partly open fractures): chlorite and calcite.

Fractures:

a) 2 parallel to subparallel (to the fracture surface), partly open fractures at about 1 cm and 3 cm distance from the fracture surface (A).
b) 2 small partly open fractures cut approximately diagonal to the borehole axis at about 8 and 9 cm distance from the fracture surface (A).

Wall rock alteration:

Faint to medium degree of oxidation (red staining).

A14

General:

Epoxy covers 100 % of the fracture surface.

Fracture coating is visible at about 15 % of the fracture surface (A).

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite. Titanite is probably hematite stained, visible as rusty color around some of the mineral grains.

Fracture surface coating (A): Chlorite.

Fracture filling: calcite.

Fractures:

3 subparallel (with respect to the fracture surface) sealed fractures, at about 1, 1.3 and 2 cm distance.

Wall rock alteration:

Faint to weak/medium oxidation.

A15

General:

Epoxy covers 100 % of the fracture surface.

Mineral coating on approximately 35 % of the fracture surface (A).

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite. Titanite is probably hematite stained, visible as rusty colour around some of the mineral grains.

Fracture surface coating (A): chlorite ± epidote.

Fracture fillings in partly open fracture: chlorite and calcite.

Fractures:

a) One partly open fracture (parallel with the fracture surface (A)) at about 4 cm distance from the fracture surface (A).

b) Two thin partly open fractures (with calcite) cut approximately diagonal to the borehole axis at about 7 to 8 cm distance from the fracture surface (A).

Wall rock alteration:

Faint to weak/medium degree of oxidation (red staining).

A16

General:

100 % epoxy covers the fracture surface.

No visible fracture coating.

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite. Titanite is probably hematite stained, visible as rusty colour around some of the mineral grains.

Fracture surface coating (A): None.

Fracture filling: Calcite, hematite and possibly small amounts of chlorite ± laumontite.

Fractures:

a) One partly open fracture at about 4 cm distance from fracture surface (A).
b) A few microfractures close to, and subparallel to the fracture surface.

Wall rock alteration:

Faint to medium degree of oxidation (red staining).

A17

General:

100 % epoxy covers the fracture surface.

About 65 % of the fracture surface has a thin fracture coating, ≤ 0.5 mm. Remaining surface area (c 35 %) has a thicker coating, 0.5–1.5 mm (at 200°–300°).

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite. Titanite is probably hematite stained, visible as rusty colour around some of the mineral grains.

Fracture surface coating (A): calcite.

Fracture filling: Calcite, hematite and minor amounts of chlorite.

Fractures:

a) Several small subparallel fractures and microfractures close to the fracture surface (A).

b) 3 parallel sealed fractures at about 2, 2.5 and 4.5 cm distance from fracture surface (A), respectively.

Illustration of thick fracture coating (epoxy covered) as well as small chlorite/calcite filled fractures close to the fracture surface (A).

Wall rock alteration:

Weak to medium degree of oxidation (red staining) at A, gradually decreasing towards B where no visible alteration is seen.

A18

General:

Epoxy covers 100 % of the fracture surface.

Fracture coatings at 100 % of the surface area (A). Irregular thickness of the fracture coating, from 0 to 4 mm.

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite. Titanite is probably hematite stained, visible as rusty colour around some of the mineral grains.

Fracture surface coating (A): calcite, chalcopyrite and hematite.

Fracture filling: calcite and chlorite.

Fractures:

a) Several sealed thin fractures and microfractures which are close to, and sub-parallel to the fracture surface (A). Some of them in connection to the fracture surface.

b) 3 sealed fractures at approximately 2, 2.5 and 4.5 cm distance from fracture surface (A) respectively (parallel orientation with respect to (A)).

Illustration of the irregular fracture coating, mainly consisting of calcite, at (A) (epoxy covered). Small chlorite/calcite filled sealed fractures close to the fracture surface can be seen as well.

Wall rock alteration:

Faint to strong (at 5 mm close to the fracture surface (A)) degree of oxidation (red staining).

A19

General:

No epoxy on the fracture surface. This rock core is drilled outside the PU-cylinder, i.e. outside the experiment area.

No fracture coating at the surface (A).

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite. Titanite is probably hematite stained, visible as rusty colour around some of the mineral grains.

Fracture filling, sealed fractures: calcite and chlorite.

Fractures:

a) Several sealed microfractures close to the fracture surface (A).
b) 2 sealed fractures at approximately 0.5 and 0.6 cm distance from fracture surface (A), respectively. Parallel orientation with respect to (A).
c) 1 sealed fracture intersecting the borehole axis with an angel of c 30°. Stretching from 0.5 to 7.5 cm on the core.

Wall rock alteration:

Faint to medium degree of oxidation (red staining).

A20

General:

Epoxy covers 100 % of the fracture surface. This rock core is drilled outside the experiment area, i.e. outside the cylindrical PU sealing.

100 % fracture coating at the surface (A).

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite. Titanite is probably hematite stained, visible as rusty colour around some of the mineral grains.

Fracture surface (A): Chlorite and epidote is dominating the fracture coating. Calcite and quartz with single chalcopyrite grains dominate at c 0.5 cm distance from A as a second fracture filling layer. Epidote sealed cataclasitic rock is documented in between these two layers.

Fracture filling, sealed fractures: calcite, epidote and chlorite.

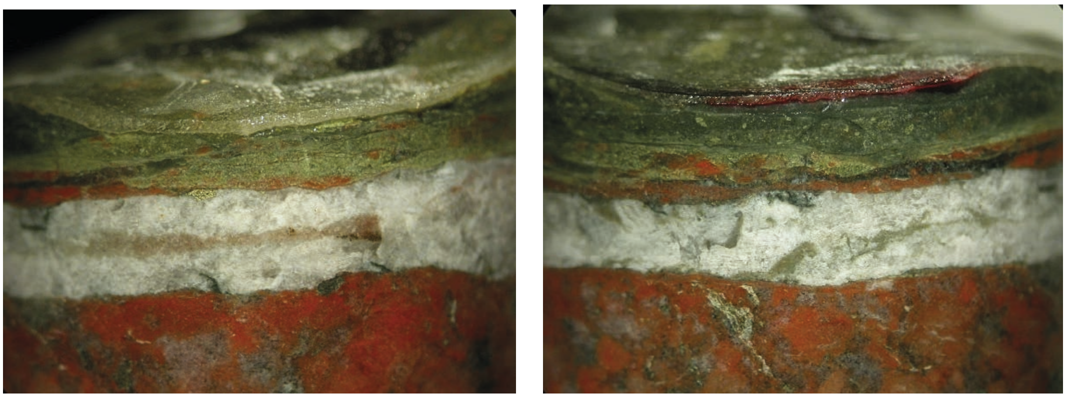


Illustration of fracture coatings at and close to the surface. Cataclasite is visible between the different layers of fracture coating.

Fractures:

a) Several sealed microfractures at 1 to 3 cm from the fracture surface (A).

b) One thick sealed fracture at approximately 0.5 cm distance from fracture surface (A) (see pictures above).

c) Two partly open, thin fractures at a distance of 4.5 to 5.5 cm from (A).

d) Several sealed and open microfractures over the whole core.

Wall rock alteration:

Medium degree of oxidation (red staining) at (A) decreasing to no visible alteration at (B).

A21

General:

Epoxy covers 100 % of the fracture surface. This drillcore is placed outside the PU cylinder, i.e. outside the test area.

No fracture coating at the surface (A).

The core is broken at 5.5 cm (average distance) from (A), probably due to a partly open fracture.

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite. Titanite is probably hematite stained, visible as rusty colour around some of the mineral grains.

Fracture surface coating (A): None.

Fracture filling, sealed fractures: chlorite and calcite.

Fractures:

a) Partly open fracture (almost broken core) at c 0.6 cm from the fracture surface (A), at 90° angle to the borehole axis.
b) Single microfractures at 2 cm distance from (B).

Wall rock alteration:

Weak/medium degree of oxidation (red staining) at (A) decreasing to no visible alteration at (B).

C1

General:

The core is broken at c 3.5 and 5.5 cm, the position of discontinuous, partly open fractures. Mechanical damage of the core is visible in connection to these breaks.

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite.

Fracture filling, sealed fractures: calcite ± quartz ± hematite ± laumontite.

Fracture filling, open/partly open fractures: chlorite, calcite.

Fractures:

a) Open/partly open fractures at 3.5 cm and 5.5 cm from (A). Fracture filling to c 60 %.
b) Sealed fracture with an angle (α) of about 55° to the borehole axis, visible at c 0.4 to 3.6 cm from (A).

Wall rock alteration:

Weak to medium oxidation (red staining), 0–4 cm from (A).

C2

B. A.

General:

The core is broken during drilling at c 3.5 cm, i.e. the position of a discontinuous partly open fracture. The break at 7 cm is supposed to be a natural fracture as well.

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite.

Fracture filling, sealed fractures: calcite ± quartz ± hematite ± laumontite.

Fracture filling, open/partly open fractures: chlorite, calcite.

Fractures:

a) Open/partly open fractures in connection with the mechanical break 3.5 cm and 7 cm from (A).
b) Sealed fracture with an angle (α) of about 45° to the borehole axis, visible at c 0.6 to 7 cm from (A).
c) Microfractures occur around, and are parallel to, the sealed fracture described in b) as well as sporadically throughout the whole core. One microfracture is cross-cutting the sealed fracture b).

Wall rock alteration:

Weak to medium oxidation (red staining), 0–7 cm from (A). Faint oxidation in the last part of the core, 7–14 cm (towards B).

C3

B. A.

General:

Break at a natural fracture, 5.8 cm from (A), with adjacent drill induced damage at 6 to 8.5 cm.

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite.

Fracture filling, open fracture: chlorite.

Fractures:

a) Open fracture at the break at 5.8 cm.
b) One open/partly open microfracture in the second part of the broken rock core.

Wall rock alteration:

Faint oxidation/albitization at 0–3 cm from (A), but no visible alteration of the remaining rock core. Some rust colour in grain boundaries is visible in stereomicroscope.

C4

B. A.

General:

The core is broken at a natural fracture, 7 cm from (A).

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite.

Fracture filling, sealed fractures: calcite.

Fracture filling, open/partly open fractures: chlorite, calcite.

Fractures:

a) Open fracture at 7 cm from (A).
b) Sealed fracture with an angle (α) of about 60° to the borehole axis, visible at c 0–1 cm.
c) Partly open fracture at 4 cm, perpendicular to the borehole axis.

Wall rock alteration:

Faint to weak oxidation (red staining), 0–7 cm from (A). No alteration in the last part of the core, 7–14 cm.

C5

General:

The core is broken at c 4 cm, at the position of discontinuous partly open fracture.

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite.

Fracture filling, sealed fractures: calcite.

Fracture filling, open/partly open fractures: chlorite, calcite.

Fractures:

a) Sealed fracture with an angle (α) of about 50° to the borehole axis, at c 2.4 – 4.5 cm. Core rotation 180–360°.
b) Open/partly open fracture at 4 cm, crosscutting fracture a).

Wall rock alteration:

Faint to weak irregular oxidation (red staining), 0–4 cm from (A). No alteration to faint alteration in the last part of the core, 4–14 cm.

D1

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite. Titanite is probably hematite stained, visible as rusty colour around some of the mineral grains.

Fracture filling, sealed fracture: no clear visible minerals, probably small amounts quartz or calcite.

Fractures:

a) Sealed thin fracture (rotation 80° on core), subparallel with the borehole axis.
b) Signs of sealed fracture close to B, visible as red-staining.

Wall rock alteration:

Faint degree of oxidation (red-staining) at (B) quickly decreasing to no visible alteration at (A).

Partly rusty colour around titanite, hematite/magnetite and chlorite.

D2

B. A.

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite.

Fracture filling, quartz and/or calcite.

Fractures:

One partly open fracture (rotation 90–180° on core), the angle (α) is 45° to the borehole axis.

Wall rock alteration:

Weak to medium degree of alteration close to the slimhole (A), visible as albitization and rust colouring in grain boundaries. Bleached appearance with distinct demarcation (not so clear in the photo).

No visible alteration from 1.5 cm to 6 cm, changing to faint/weak oxidation at (B).

D3

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite.

Fractures:

No detected fractures.

Wall rock alteration:

No alteration, except for the last 2.5 cm (towards B) which has a medium degree of oxidation (red staining).

D4

Rock core D4 with orientation 0°–180° (upper picture) as well as orientation 180°–360° (lower picture).

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized i.e. altered to epidote, sericite and albite.

Fractures:

Red-staining around what is believed to be sealed fractures, with no detectable minerals at c 2.5, 4 and 9 cm respectively. The angle, with respect to the borehole axis, is perpendicular at 4 cm and approximately 60° at 2.5 and 9 cm.

Wall rock alteration:

Irregular red staining and albitization (see pictures above).

D5

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite.

Fractures:

No detectable.

Wall rock alteration:

Faint alteration.

D6

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite.

Fractures:

Thin sealed fractures (with irregular outshoots) at 2.5, 3.5 and 4.5 cm respectively, at an angle of 65° to the borehole axis.

Wall rock alteration:

Faint to weak alteration, 0–6 cm (i.e. near the slimhole).

D7

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite.

Fracture filling, sealed fracture: Calcite, hematite ± quartz ± laumontite.

Fractures:

a) Sealed fracture at about 6 cm distance from (A). The angle is approximately 20° to the borehole axis.
b) Small microfractures at 0.5–1 mm from the slimhole (A) when the core is rotated 160°. Possibly drill-induced microfractures.

Wall rock alteration:

No clear signs of alteration, except for small areas around sealed fractures.

D8

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite.

Fracture filling, sealed fracture: Calcite ± quartz.

Fractures:

a) Sealed fracture at about 3 cm distance from (A). The angle is approximately 20° to the borehole axis.

b) Several small microfractures at 0.5–1 mm from the slimhole (A). Possibly drill induced microfractures.

Wall rock alteration:

Faint to weak oxidation (red staining). Most of the red-staining probably originate from sealed fractures.

D9

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite.

Fracture filling, sealed fracture: Calcite and hematite.

Fractures:

a) Short (< 5 mm), sealed microfracture at about 7.5 cm distance from (A), visible at core rotation 240°.
b) Several small microfractures at 0.5–2 mm from the slimhole (A). Possibly drill-induced microfractures.

Wall rock alteration:

Faint to weak oxidation (red-staining). Most of the red staining probably originates from sealed fractures.

D10

General:

Minor amount of epoxy at the core mantle (yellow-green coloured); i.e. a contamination rest from the drilling process.

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite.

Fracture filling, sealed fractures: Calcite and hematite ± quartz ± laumontite.

Fractures (see pictures below):

a) 2 parallel sealed fractures, visible at the surface in the slimhole (A) and 3.5 cm inwards the core (rotation on core 120–295°), α-angle about 40°.

b) 1 sealed fracture intersecting the fractures described in a). At an angle (α) of about 70° to the borehole axis, visible from c 1 to 3 cm.

c) Sealed fracture at an angle of c 12° to the borehole axis. Intersects the fractures in a) at the core surface in the slimhole (A).

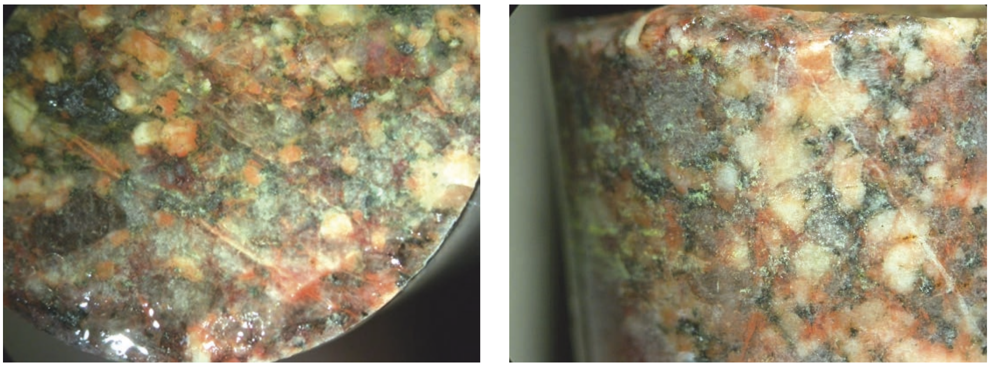


Illustration of the sealed fractures, described in a).

Wall rock alteration:

Weak to medium oxidation (red staining), 0–4.5 cm from the slimhole (A). Most of the red-staining is supposed to originate from sealed fractures.

Limited amount of rust colour is also documented along the whole core during microscopic investigation.

D11

General:

Epoxy at the surface towards slimhole (yellow).

Mineralogy:

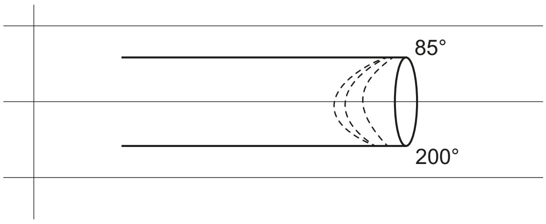
Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite.

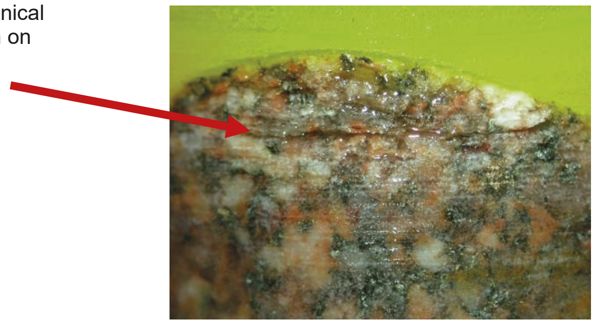
Fracture filling, sealed fractures: calcite and hematite ± quartz.

Fractures:

a) 3 parallel sealed fractures, visible at core rotation 85–200°, 1.5 cm from (A).



b) 1 open or partly open fracture (or mechanical break) 0.5 cm from the slimhole (rotation on core 90°). Subhorizontal.



Wall rock alteration:

Faint oxidation (red staining), 0–2 cm from the slimhole (A).

D12

General:

Minor amounts of remaining epoxy on the core at the surface towards the slimhole (A).

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite.

Fracture filling, sealed fractures: calcite and hematite ± quartz ± laumontite.

Wall rock alteration:

Nearly no signs of alteration. Single mineral grains are slightly red stained or albitized.

D13

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite.

Fracture filling, sealed fractures: calcite and hematite ± quartz and laumontite.

Fractures:

a) Open (or partly open) microfracture at the slimhole surface (A).
b) 2 sealed fractures with different orientations (cross cutting), visible in the upper part of the core (1–4 cm).
c) Microfractures around the fractures described in b).

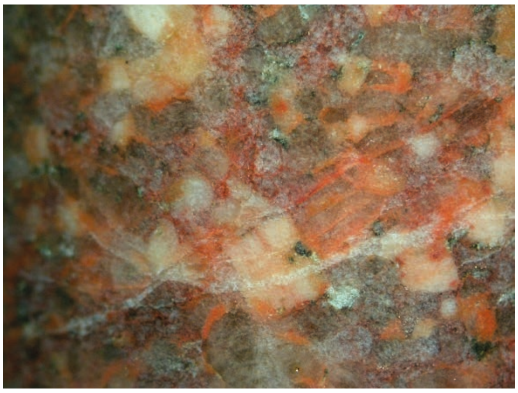


Illustration of the two sealed fractures described in b).

Wall rock alteration:

Red staining, only around sealed fractures.

D14

General:

Epoxy at the surface towards slimhole (yellow).

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite.

Fracture filling, sealed fractures: calcite and hematite ± quartz ± laumontite.

Fractures:

2 sealed fractures with different orientations (cross cutting), visible with core rotation 135–315° and 2.3 cm from (A). Both fractures split up and have small splays. α-angle is about 60–70°.

Wall rock alteration:

Faint to weak oxidation (red-staining) in the last part of rock core, from about 9 to 12 cm (close to B).

D15

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite.

Fracture filling, sealed fractures: calcite and hematite ± quartz ± laumontite.

Fractures:

a) Microfractures, parallel to subparallel to the slimhole surface (A). Primarily visible in quartz and feldspars.

b) Sealed fracture visible at approximately 2.5 cm from (A), when core is rotated 0–135°. Angle, c 60° to the borehole axis.

c) Partly open microfracture cuts the fracture described in b).

Wall rock alteration:

Faint to weak oxidation (red staining) in the last part of rock core, c 7–12 cm (towards B).

D16

B. A.

General:

Epoxy at the surface towards slimhole (yellow).

Mineralogy:

Quartz, k-feldspar, plagioclase, biotite, chlorite, titanite, hematite/magnetite and epidote.

K-feldspar to varying extent albitized, biotite partially altered to chlorite and plagioclase is partially saussuritized, i.e. altered to epidote, sericite and albite.

Fracture filling, sealed fractures: calcite and hematite ± quartz ± laumontite.

Fractures:

a) Partly open fracture at 6.5 cm from (A), perpendicular to the borehole axis.
b) Sealed fracture visible at approximately 0.5 cm from (B).

Wall rock alteration:

Faint oxidation (red staining) at the last part of rock core, c 7.5–13 cm (towards B).

Arkitektkopia AB, Bromma, 2022

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