International Progress Report

IPR-00-05

Äspö Hard Rock Laboratory

First True Stage

Pilot Resin Experiment

Background information

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March 2000

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Foreword

This report provides the background information related to the Pilot Resin Experiment. The main results from the Pilot Resin Experiment are described in a stand alone report, *[Birgersson et al, 2000]*.

The Pilot Resin experiment has been carried out in order to develop and test techniques for characterization of the connected pore space of a selected target volume for tracer experimentation using resin injection, subsequent excavation, and analysis.

The Pilot Resin Experiment is one component of the First TRUE Stage.

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1 Resin properties

The fluid and physical properties of the resin will determine how much of the fracture plane that can be impregnated. Several resins have been considered, but EPO-TEK 301 was selected for use since it has earlier been used in similar applications and is available more or less world-wide.

An information sheet illustrating the resin properties is found in Figure 1-1.

epoxy technology inc.

EPO·TEK®
301
Spectrally Transparent Epoxy

SC0402

Rev. I
1/94

SPECIFICATIONS

NUMBER OF COMPONENTS .... Two

MIXING RATIO PARTS BY WEIGHT
Part "A" 20
Part "B" (hardener) 5
Maximum recommended mixed quantity should not exceed .... 25 grams

CURE SCHEDULE (Bond line temperatures - use any one of the following)
65°C .... 1 hour
Room temperature .... Overnight

OPTICAL PROPERTIES (Adhesive film thickness - 0.0035")
Greater than 97% transmission 3200 - 9000 Å
Greater than 80% transmission 9100 Å - 2.6μ

INDEX OF REFRACTION .... 1.538 - 1.540

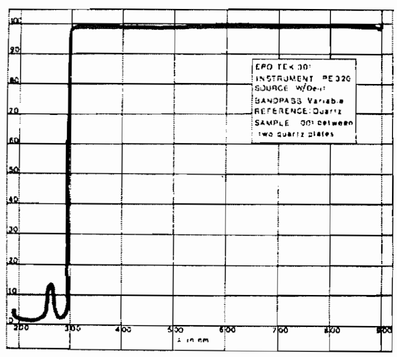
PHYSICAL PROPERTIES
Lap Shear Strength .... 1700 psi (aluminum to aluminum)
Specific Gravity (A & B mixed) 1.09
Part "A" 1.15
Part "B" 0.87
Shore D Hardness 81
Glass Transition Temperature (Tg) (Cured @ 65°C/1 hour) .... 48°C
Coefficient of Thermal Expansion
Below Tg: 50×10^{-6} in/in/°C
Above Tg: 125×10^{-6} in/in/°C

OUTGASSING PROFILE FOR AEROSPACE ENVIRONMENT
Total weight loss by weight (%) 1.08
VCM (volatile condensable materials) % by weight 0

VISCOSITY (25°C)
Parts "A" & "B" mixed .... 100 cps

POT LIFE
100 gram sample .... 30 min.
25 gram sample .... 50 min.

SHELF LIFE
One year when stored at room temperature.
Keep containers closed when not in use.
REFRIGERATION NOT REQUIRED



EPO-TEK 301 is a two component, room temperature curing, epoxy adhesive featuring very low viscosity, good pot life, good handling characteristics and excellent optical properties.

Although designed primarily for optical filters, EPO-TEK 301 has found wide usage in many instrumentation applications. It is also recommended for bonding glass and plastic fiber optics.

EPO-TEK 301 has good adhesion to many different types of substrates including glass, quartz, metals and most plastics.

Based on outgassing test results by NASA, EPO-TEK 301 is approved for space flight programs.

NONTOXIC - complies with USP Class VI Biocompatability standards

AVAILABILITY: 8 oz. trial evaluation kit, price on request, FOB Billerica, Mass. Production price schedule available on request.

EPOXY TECHNOLOGY, INC. 14 FORTUNE DRIVE, BILLERICA, MA 01821-3972 USA (508) 667- 3805
1-800-227-2201 (in USA) FAX: (508) 663-9782

Figure 1-1 Resin information sheet from the resin supplier.

1.1 Viscosity

The viscosity of the resin together with the properties of the fracture will determine how far it will penetrate into the fracture plane, for a given injection pressure. A low viscosity, very fluid, resin is preferred. However, the resin must set at temperatures of 10-15 °C and give a rigid, glassy, cured set. Experience has shown that adding thinners to resins, to decrease viscosity and increase setting times, generally reduces the rigidity of the resin set.

EPO-TEK 301 has a viscosity of 0.1 Ns/m^2 (100 cp), which is quite low for a resin but still 100 times larger than for water (10^{-3} Ns/m^2 = 1 cp).

1.2 Density

Nearly all of the commercially available resins have a density that is higher than water and can be classified as DNAPLS. Resins with a density close to water are preferred. Most of the laboratory experiments have been conducted in fracture planes that are horizontal at the time the resin was injected.

EPO-TEK 301 has a density of 1.09 g/cm^3, which is somewhat higher than the density of water, 1.0 g/cm^3.

1.3 Temperature dependence

The temperature in the rock at the Äspö HRL is 10-15 °C, which is considerably lower than in most laboratories on ground surface. This will induce a slightly longer curing time than what has been seen in laboratory experiments. This is an advantage when injecting the resin since it will be possible to inject over a longer time period, but it may be a drawback when sampling the target structure as the curing will take longer and may delay the start of the sampling. However, laboratory experiments have been conducted at temperatures as low as 6 °C and no major problems with the curing time or the rigidity of the resin after curing were noticed in these experiments.

1.4 Sensitivity to salinity

We do not know if the salinity of the water in the fracture plane will create any problems. However, most of the saline water will be flushed from the test fracture since the resin injections were preceded by injection of iso-propanol.

1.5 Longevity of cured resin

The time lag between injection and sampling must be at least 24 to 48 hours in a field experiment to ensure that the resin is well cured. Curing times in the laboratory under wet and cold conditions have generally been less than 24 hrs.

It should be possible to take additional samples from the target structure once the first samples have been excavated, monitored and evaluated. It is therefore essential that the resin should have a longevity of year(s) to enable additional sampling. Resin impregnated laboratory samples have been stored under laboratory conditions for up to 10 years with no apparent degradation.

2 Equipment for resin injection

2.1 Design criteria

The equipment to be used for the resin injection had to fulfill specifications related to:

- Working pressure.
- Flow rate.
- Mixing ratio and mixing procedure.

2.1.1 Pressure

The water pressure in the boreholes that were drilled for the Pilot Resin Experiment was found to be up to about 22 bars. For comparison, the water pressures in the target structure for TRUE-1 are about 35-45 bars.

The injection pressure for the resin has to be above the water pressure. Thus, the resin injection equipment had to be able to withstand a pressure of at least 60 bars.

2.1.2 Flow rate

It should be possible to adjust the flow rate within a wide range. Initially, the liquid (iso-propanol) in the injection section had to be replaced by resin. This should be carried out as quickly as possible giving that a high flow rate (1000 ml´s per hour) should be used. The flow rate during the resin injection should be adjustable at any time and as low as a few ml´s per hour at the end of the resin injection. The resin injection should be continuos.

2.1.3 Mixing ratio and mixing procedure

The mixing ratio for EPO-TEK 301 between the resin and the hardener should be 4:1. The mixing should take place in-line and close to the injection section in order to be able to keep the injection going on as long as possible.

2.2 Resin injection equipment

The designed resin injection system was based on usage of a stepper motor for simultaneously driving two parallel 2-way pistons. The dimensions of the pistons were chosen in order to achieve the 4:1 mixing ratio between the resin and the hardener. A illustration of the flow schematic is given in Figure 2-1.

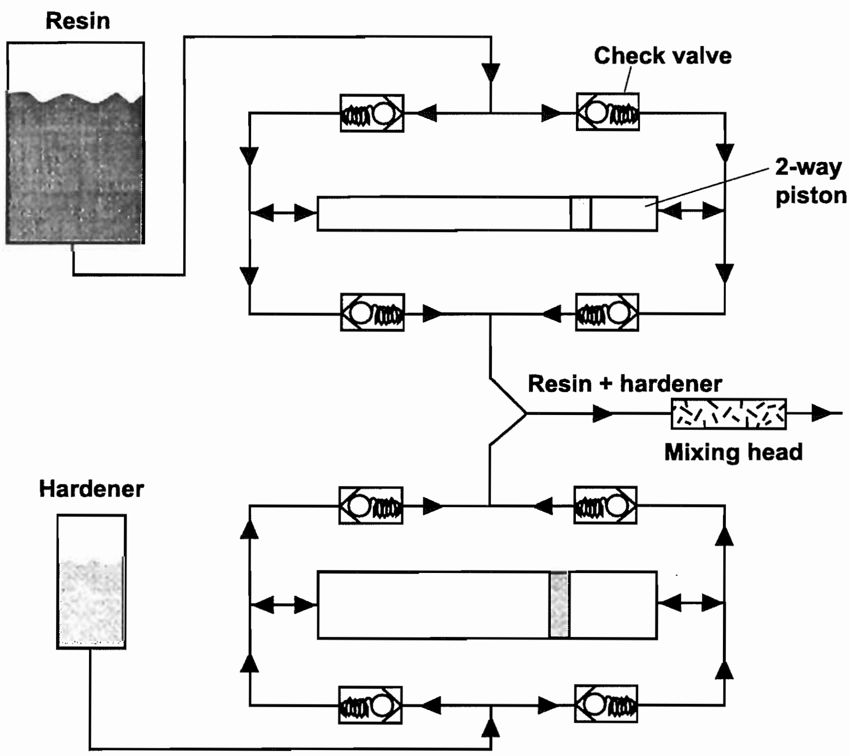


Figure 2-1 Schematic illustration of the resin injection system.

The manufactured injection equipment can withstand pressures well above 60 bars. The maximum pressure that could be applied is limited to about 60 bars by the nylon tubing that was used.

The injection flow rate is controlled by the speed of the stepper motor and can be adjusted from a few ml´s per hour up to several 1000 ml´s per hour. The injection flow rate is possible to adjust anytime during the injection.

The mixing between the resin and the hardener was carried out in-line in the mixing head. The mixing head consists of an about 0.2 m long section where the liquids have to travel in a screw mixer in order to achieve a good mixing.

2.2.1 Experience from the Pilot Experiment

The mixing of the two components that constitute the resin was carried out continuously based on mixing the two fluids emerging from the cylinders. It was however not possible to maintain the constant mixing ratio (4:1) during the entire injections. This was probably due to leakage in the check valves. The injection system should therefore be rebuilt and carefully tested before being used again.

The injection system was used for a wide range of flow rates and with pressures up to about 55 bars without any problems.

3 Water inflow measurements

Hydraulic testing was carried out in the KXTP boreholes in order to identify sections in the boreholes that had high water inflow rates. The testing programme included:

- Flow logging.
- Measurement of hydraulic pressure.
- Interference tests.

The main results from the hydraulic testing programme of the boreholes (flow logging, measurement of hydraulic pressure and interference tests) are found in *[Birgersson et al, 2000]*. Detailed information from the flow logging is given below.

3.1 Flow logging

Prior to the tests, all holes were sealed off using a single mechanical packer located fairly close to the start of the borehole. The tests were carried out by opening one hole to atmospheric pressure at the time and monitor the water inflow rate. The flow logging was carried out in such a way that it was possible to identify the water inflow rate into 5 cm sections. Flow logging was not carried out in boreholes KXTP5, -6 and -7 due to very low water inflow rates into these boreholes.

The test sequence for the flow logging was:

- Install a single mechanical packer, located fairly close to the start of the borehole, in all boreholes.
- Close all holes.
- Monitor the water inflow into one hole:
  - Open the hole (test section)
  - Wait 30 minutes for the water inflow to stabilize.
  - Monitor the water inflow rate.
  - Move the packer in order to identify “all” water inflow. Repeat this until “all” water inflow into the hole has been accounted for.
- Close the hole.
- Wait at least 1 hour until the next hole is monitored.

3.2 Water inflow measurements in borehole KXTP1

The flow rates for different packer positions in borehole KXTP1 are illustrated in Table 3-1 and Figure 3-1.

Table 3-1 Water inflow rates in borehole KXTP1 for different packer positions.

Depth [m]	Flow rate [l/min]
1.745	0.062
1.975	0.062
2.015	0.072
2.065	0.06
2.125	0.037
2.175	0.033
2.355	0.0165
2.465	0.016
2.615	0.016
2.665	0.016
2.885	0.013
2.945	0.0125

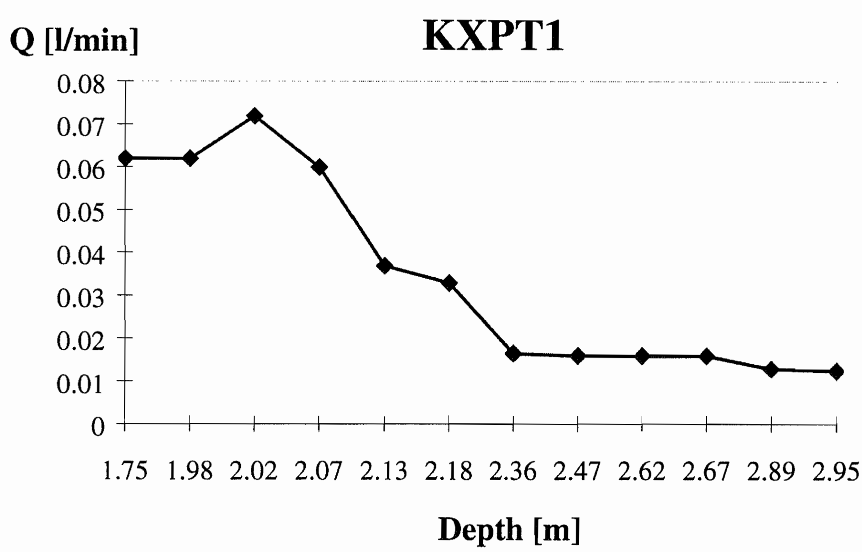


Figure 3-1 KXTP1. Water inflow as function of packer position.

The total water inflow into borehole KXTP1 was 0.062 l/min. 37 % (0.023 l/min) of the total flow was found in the section 2.065 - 2.125 m. 27 % (0.0165 l/min) was found in the section 2.175 - 2.355 m. These findings correspond well with structure I" that was interpreted to intersect KXTP1 at 1.98 – 2.16 m, see *[Birgersson et al, 2000]*.

3.3 Water inflow measurements in borehole KXTP2

The flow rates for different packer positions in borehole KXTP2 are illustrated in Table 3-2 and Figure 3-2.

Table 3-2 Water inflow rates in borehole KXTP2 for different packer positions.

Depth [m]	Flow rate [l/min]
2.525	0.063
2.575	0.057
2.775	0.057
2.825	0.025
2.875	0.016

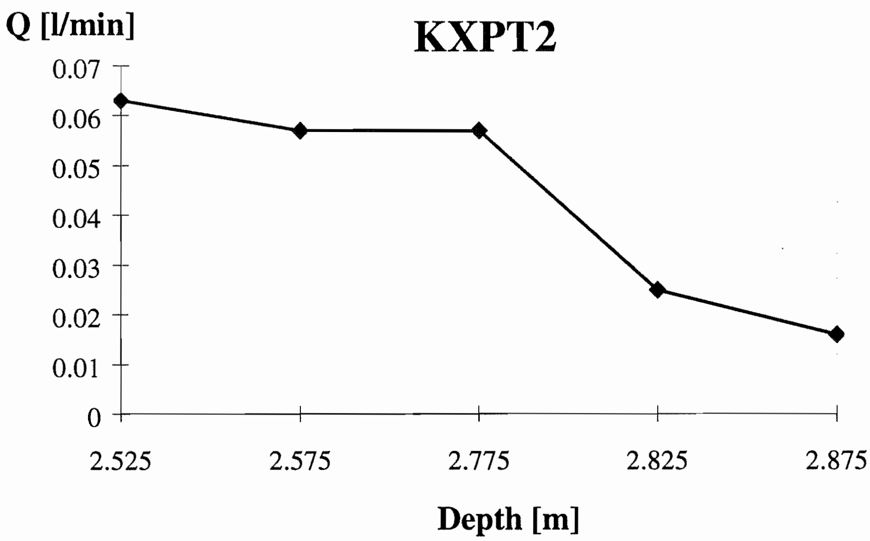


Figure 3-2 KXTP2. Water inflow as function of packer position.

The total water inflow into borehole KXTP2 was 0.0735 l/min. 44 % (0.032 l/min) of the total flow was found in the section 2.775 - 2.825 m. 12 % (0.009 l/min) was found in the section 2.825 - 2.875 m. These findings correspond well with structure I’ that was interpreted to intersect KXTP2 at 2.67 – 2.90 m, see *[Birgersson et al, 2000]*

3.4 Water inflow measurements in borehole KXTP3

The flow rates for different packer positions in borehole KXTP3 are illustrated in Table 3-3 and Figure 3-3.

Table 3-3 Water inflow rates in borehole KXTP3 for different packer positions.

Depth [m]	Flow rate [l/min]
1.425	0.018
1.515	0.016
1.565	0.0155
1.615	0.016
1.805	0.016
1.915	0.016
2.115	0.015
2.215	0.015
2.265	0.008
2.315	0.007
2.365	0.004
2.415	0.005

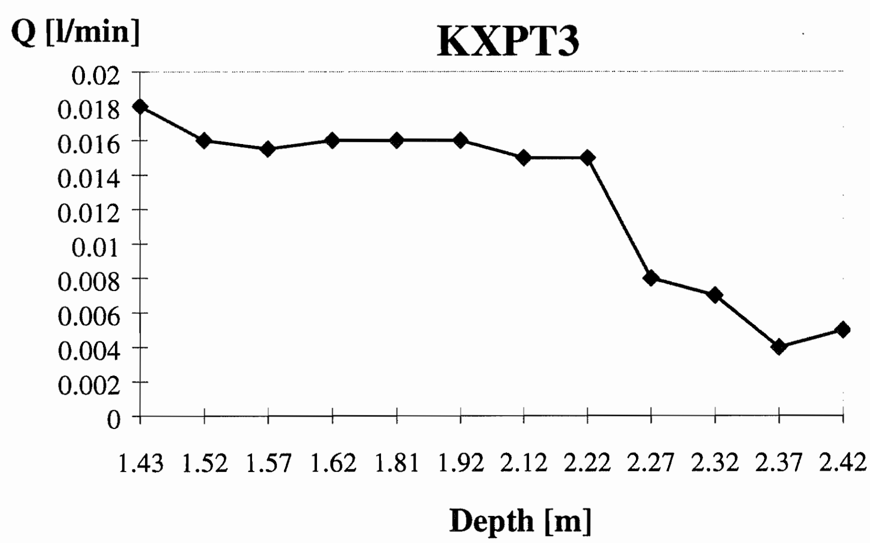


Figure 3-3 KXTP3. Water inflow as function of packer position.

The total water inflow into borehole KXTP3 was 0.018 l/min. 39 % (0.007 l/min) of the total flow was found in the section 2.215 - 2.265 m. 17 % (0.003 l/min) was found in the section 2.315 - 2.365 m. These findings correspond well with structure III that was interpreted to intersect KXTP3 at 2.12 – 2.28 m, see *[Birgersson et al, 2000]*.

3.5 Water inflow measurements in borehole KXTP4

The flow rates for different packer positions in borehole KXTP4 are illustrated in Table 3-4 and Figure 3-4.

Table 3-4 Water inflow rates in borehole KXTP4 for different packer positions.

Depth [m]	Flow rate [l/min]
2.23	0.016
2.4	0.016
2.52	0.0155
2.57	0.0003
2.62	0

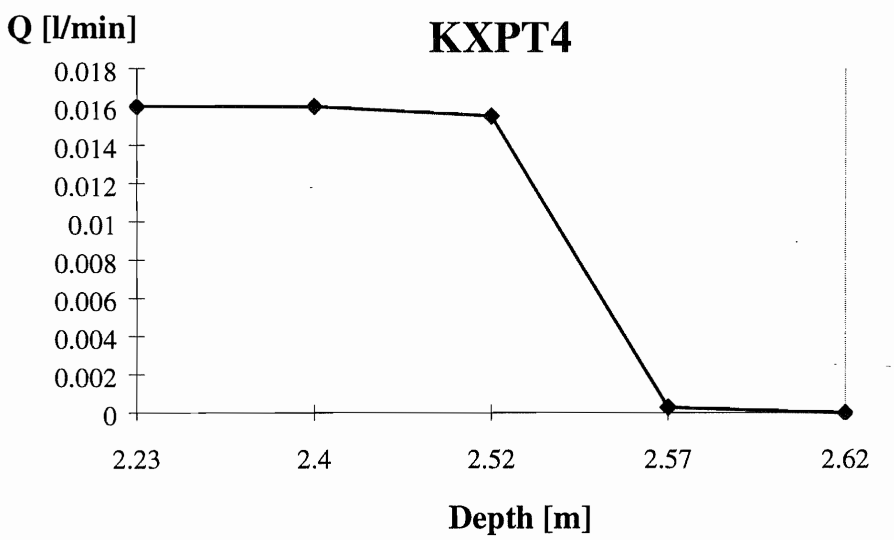


Figure 3-4 KXTP4. Water inflow as function of packer position.

The total water inflow into borehole KXTP4 was 0.016 l/min. 95 % (0.0152 l/min) of the total flow was found in the section 2.52 - 2.57 m. This correspond rather well with structure III that was interpreted to intersect KXTP4 at 2.25 – 2.42 m, see *[Birgersson et al, 2000]*.

3.6 Water inflow measurements in borehole KXTP8

The flow rates for different packer positions in borehole KXTP8 are illustrated in Table 3-5 and Figure 3-5. Water inflow measurements were carried out at two occasions, see below.

Table 3-5 Water inflow rates in borehole KXTP8 for different packer positions.

Depth [m]	Flow rate [l/min]	Date
1.11	0.006	7-8/2, 1996
1.5	0.006	7-8/2
1.55	0.006	7-8/2
0.8	0.0095	19/2, 1996
0.95	0.0085	19/2
1	0.003	19/2
1.05	0.002	19/2
1.55	0.003	19/2

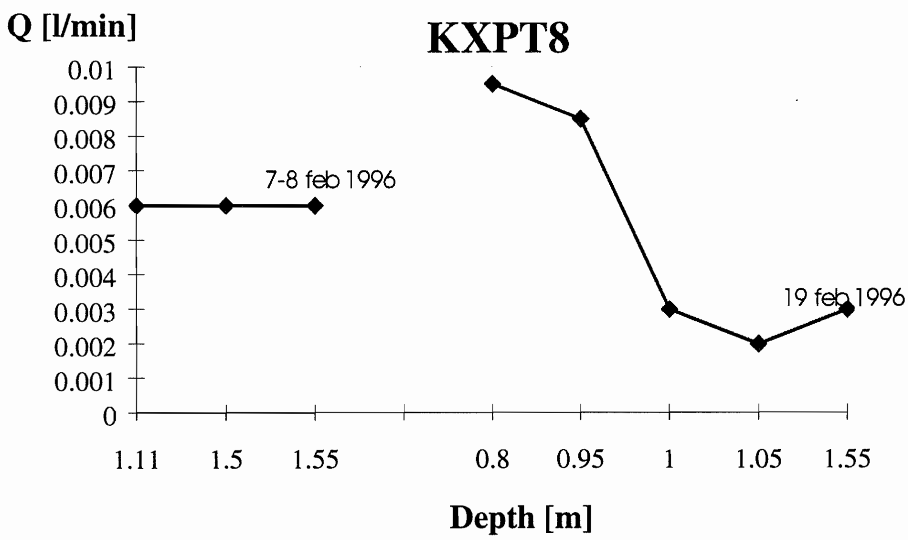


Figure 3-5 KXTP8. Water inflow as function of packer position.

The total water inflow into borehole KXTP8 was 0.0095 l/min. 58 % (0.0055 l/min) of the total flow was found in the section 0.95 – 1.00 m. 11 % (0.001 l/min) was found in sections 0.8 – 0.95 m and 1.00 – 1.05 m. These findings correspond well with structure IV that was interpreted to intersect KXTP8 at 0.96 – 0.99 m, see *[Birgersson et al, 2000]*.

3.7 Water inflow measurements in borehole KXTP9

The flow rates for different packer positions in borehole KXTP9 are illustrated in Table 3-6 and Figure 3-6.

Table 3-6 Water inflow rates in borehole KXTP9 for different packer positions.

Depth [m]	Flow rate [l/min]
0.955	0.072
1.875	0.07
1.925	0.0005
1.975	0.0005
2.065	0.001
2.275	0.0005

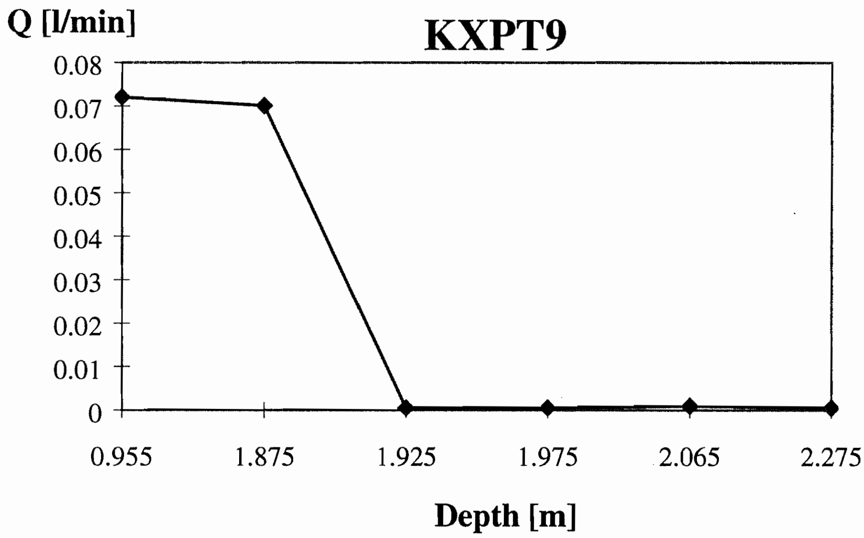


Figure 3-6 KXTP9. Water inflow as function of packer position.

The total water inflow into borehole KXTP9 was 0.070 l/min. Almost 100 % of the flow was found in the section 1.875 - 1.925 m. This correspond well with structure I' that was interpreted to intersect KXTP9 at 1.81 – 1.87 m, see *[Birgersson et al, 2000]*.

4 Field notes from the resin injections

This section gives detailed information, based on field notes, from the resin injections. A compilation of the resin injections is given in *[Birgersson et al, 2000]*.

4.1 Resin injection in KXTP7

August 19 – 21, 1996: Injection of dye-labelled water was carried out simultaneously in borehole KXTP2 (2 heads) and borehole KXTP3 (1 head). The other KXTP-boreholes were closed. The total injected volume was 150 l during 1 day 21 hours and 45 minutes. This gives an average flow rate of 3.28 l/h (about 2.43 l/h into KXTP2 and about 0.85 l/h into KXTP3). On August 20, dye was observed to emerge into the drift from the target structure, the lower 200 mm sampling hole in the target structure, from a fracture about 50 cm to the right (downward in the F-tunnel) of the starting points of the KXTP-boreholes and some from the outer part of borehole KXTP2. On August 21, dye was as well observed from another point at the drift wall. The distance from the injection sections to the location in the drift where dye breakthrough was observed is in the order of 1-3 m.

August 21 – 22, 1996: Injection of dye-labelled iso-propanol was carried out simultaneously in borehole KXTP2 (2 heads) and borehole KXTP3 (1 head). The other KXTP-boreholes were closed. The total injected volume was 24 l during 20 hours and 35 minutes. This gives an average flow rate of 1.17 l/h (about 0.89 l/h into KXTP2 and about 0.28 l/h into KXTP3). On August 22, alcohol and dye was observed to emerge into the drift from the target structure and the fracture located about 50 cm to the right (downward in the F-tunnel) of the starting points of the KXTP-boreholes. The distance from the injection sections to the location in the drift where dye breakthrough was observed is in the order of 1-3 m.

August 22, 1996: Injection of dye-labelled iso-propanol in borehole KXTP7. The other KXTP-boreholes were closed. About 500 ml dye-labelled iso-propanol was injected during 47 minutes. Resin injection into borehole KXTP7. The volume injected into the structure has been estimated at a few 100´s ml´s.

4.1.1 Field notes from August 19, 1996

The injection of water + dye was started.

Mixed 190 l water (from the sump at the underground pump station) and 25 g Rhodamine B, which gives a concentration of 132 ppm. The injections were carried out using a piston pump with 3 heads. The injection capacity was about 1 l/h per head. The flow rates are given in per cent of the maximum possible flow rate (1 l/h) for each head.

15^{30}: Started the injection. 2 heads connected to KXTP2, 1 head to KXTP3. Injection flow rate: 2*40 % / 40 %. This correspond to an injection flow rate of about 0.4 + 0.4 l/h into borehole KXTP2 and 0.4 l/h into KXTP3.

15^{35}: Injection flow rate: 2*80 % / 80 %.

15^{40}: Injection flow rate: 2*100 % / 100 %.

15^{50}: Injection flow rate: 2*100 % / 70 %.

16^{05}: No observations of dye in the drift.

16^{05}: Changed the pressure scanning interval from fast to slow.

Table 4-1 Pressure readings August 19, 1996.

Hole	Time/Pressure (bar) 15^{30}	16^{00}
KXTP1	19.5	23
KXTP2	19.5	23
KXTP3	8.5	16.5-17
KXTP4	8.5	16.5-17
KXTP5	4	5
KXTP6	8	16
KXTP7	4	6
KXTP8	0 (open)	7
KXTP9	20	23.5

The following sequence describe how to change the resin injection flow rate:
- EDIT
- PROG
- 1 (ENTER)
- VE xx (2 places) and GH-xx (1 place)
- ESC
- YES
- RUN
- PRG1 (ENTER)

- ESC => Stop

A velocity setting of VE 0.2 was found to result in a flow rate of 100 ml in about 15 minutes => 400 ml/h.

4.1.2 Field notes from August 20, 1996

Photographs were taken to show where the dyed water was entering into the drift.

11^{00}: Observations of dye emerging from the target structure, the lower sampling hole in the target structure, from the fracture immediately to the right of the starting points of our boreholes and some coming out from KXTP2.

125 l tracer-solution remains.

15^{30}: No further observations of dyes.

115 l tracer-solution remains => Tracer injected so far: 75 l in 24 h.

Table 4-2 Pressure readings August 20, 1996.

Hole	**Time/Pressure (bar)**			
	August 19		August 20	
	15^{30}	16^{00}	11^{00}	15^{30}
KXTP1	19.5	23	23.5	23.5
KXTP2	19.5	23	23.5	24
KXTP3	8.5	16.5-17	19	19.5
KXTP4	8.5	16.5-17	19	19.5
KXTP5	4	5	6.5	6.5
KXTP6	8	16	18	18.5
KXTP7	4	6	6.5	6.5
KXTP8	0 (open)	7	6	6
KXTP9	20	23.5	24	24

4.1.3 Field notes from August 21, 1996

The dye tracer injection was terminated and the alcohol (iso-propanol) + dye injection was started.

Mixed 29 l iso-propanol and 5.85 g Rhodamine B, which gives a concentration of 200 ppm.

9^{15}: Observations of dyes at the same locations as on August 20 plus from borehole KXTP2, from a point on the drift wall, from a fracture plane about 0.5 m up-right from the start of borehole KXTP2 and a weak sign of tracer from the target structure.

9^{30}: 50 l dye tracer-solution remains

12^{25}: Changed the pressure scanning interval from slow to fast.

12^{40}: 40 l tracer-solution remains.

12^{45}: Stopped the injection of water + dye. 150 l of water + dye has been injected during 1 day 21 hours 45 minutes. This gives an average flow rate of 3.28 l/h.

Opened KXTP8. The water that emerged was red!!

15^{30}: Monitored the flow rate from KXTP8. 67 ml in 15 minutes => 268 ml/h.

15^{35}: Closed hole KXTP8.

16^{25}: Started the injection of iso-propanol and dye. Flowrates: 2*50 % / 35 %

16^{50}: Flowrates: 2*40 % / 25 %.

16^{55}: Changed the pressure scanning interval from fast to slow.

Table 4-3 Pressure readings August 21, 1996.

Hole	Time/Pressure (bar)						
	August 19		August 20		August 21		
	15^{30}	16^{00}	11^{00}	15^{30}	9^{15}	12^{40}	16^{20}
KXTP1	19.5	23	23.5	23.5	23.5	24	16
KXTP2	19.5	23	23.5	24	23.5	24	16.5
KXTP3	8.5	16.5-17	19	19.5	19.5	19	9
KXTP4	8.5	16.5-17	19	19.5	20	19.5	9
KXTP5	4	5	6.5	6.5	6.5	6.5	3.5
KXTP6	8	16	18	18.5	19	18.5	8.5
KXTP7	4	6	6.5	6.5	6.5	6.5	3
KXTP8	0 (open)	7	6	6	6	6	1
KXTP9	20	23.5	24	24	24	24	16.5

4.1.4 Field notes from August 22, 1996

Resin injection in KXTP7.

9^{30}: 9.5 l tracer-solution remains. Flowrates: 2*45 % / 30 %.

Alcohol breakthrough in the target fracture and in another nearby fracture. Some minor observations of alcohol at other locations where dye + water earlier had emerged.

13^{00}: Injection stopped. 5 l tracer-solution left. 24 l of iso-propanol + dye has been injected during 20 h 35 m => 1.17 l/h.

13^{10}: KXTP7 opened. 60 bar manometer installed, pressure transducer disconnected.

13^{15}: Started to pump iso-propanol into KXTP7 (kept open). Flow rate 2000 ml/h.

13^{25}: Strong smell of alcohol from the hole. Hole closed and flow rate decreased to 250 ml/h.

13^{30}: Flow rate 400 ml/h.

13^{35}: Flow rate 500 ml/h.

13^{40}: Flow rate 600 ml/h.

13^{45}: Flow rate 750 ml/h.

14^{12}: Injection stopped.

14^{17}: Started the injection of resin in KXTP7. The hole was being bled as the pressure builds up. The resin was labelled with a blue dye and Uranin.

15^{14}: Opened KXTP6 (draining hole).

15^{16}: Opened KXTP5 (draining hole).

15^{30}: Resin breakthrough from the inner part of the lowest sampling hole in the target structure.

17^{50}: Flow rate from KXTP6: 55 ml in 5 minutes => 660 ml/h.

23^{10}: Stopped the injection (after 8 h 53 m).

The resin as well as the hardener levels were monitored manually during the entire injection period, see Table 4-4. A difference in level with 1 cm corresponds to a volume of 62.5 ml. The ratio between resin and hardener should be 4.0, if the mixing is perfect.

Table 4-4 Resin injection into KXTP7.

Time	Resin level [cm]	Hardener level [cm]	Ratio since start of injection	Comment
13:59	39	16.8		Flushing the hole
14:00	38	16.6		
14:01	37.1	16.4		
14:05	36	16.1		
14:08	34.5	16.6		
14:12	33.3	15.3		
14:17	26	14.8		Start injection
14:18	20	14.3		
14:28	20	12.8		
14:33	26	12.5		
14:56	24.7	12.2		
15:00	24	12		
15:02	25	12		
15:09	24.6	12		
15:17	24.2	12		
15:25	23.5	11.9		
15:31	23	11.85		
15:34	22.7	11.8		
15:50	20.9	11.1		
16:08	20.2	10.9		
16:15	21.1	10.9	4.9/3.9=1.3	
16:32	19.8	10.9		
16:46	19.8	10.9		
17:34	19.1	10.85		
18:35	18.2	10.85		
19:15	17.6	10.85		
20:00	16	10.7		
23:05 0	10.8	10.6	15.2/4.2=3.6	Injected volume: 1212 ml (19.4 cm) Stop injection

The injected volume was 1212 ml (19.4 cm). A large quantity was however bled off to reduce the pressure build-up. A large quantity was as well emerging into the 200 mm sampling hole in the target structure. The volume injected into the structure has been estimated at a few 100´s ml´s. The overall mixing ratio was good. However, to much hardener in the beginning and to much resin at the end.

4.2 Resin injection in KXTP2 and KXTP3

4.2.1 Field notes from August 23, 1996

Resin injection in KXTP3, and for a short period into KXTP2 before the packer burst.

The volume injected into the structure from KXTP3 has been estimated at 1000-2000 ml. The mixing ratio was very good during the entire injection. About 1000 ml resin was injected from KXTP2 before the packer failure.

8^{20}: Closed KXTP5 and KXTP6.

10^{00}: Alcohol injected into KXTP3 with the hole opened. Flow rate 2500 ml/h.

10^{20}: KXTP3 closed. Injection flow rate 400 ml/h.

12^{05}: Injection stopped.

12^{12}: Started to flush/fill KXTP3 with resin.

12^{24}: Resin started to come out from the hole.

12^{25}: Started the resin injection into KXTP3. Velocity, VE 0.5. The resin was labelled with a red dye and Uranin.

12^{32}: Injection flow rate: 24 ml in 1 min (=> almost 1500 ml/h).

12^{48}: Opened hole 4. Resin showing up quickly.

12^{53}: Flow rate into KXTP4: 30 ml in 1 min (partly resin and partly water)

13^{07}: KXTP4 closed.

13^{07}: Injection stopped to refill cylinders. Level in resin tube increased to 8.35 cm.

13^{18}: Injection started.

13^{22}: Injection stopped since the packer in KXTP4 began to move!

13^{30}: Injection restarted with a velocity of VE 0.3.

13^{45}: Opened KXTP8.

13^{50}: Injection velocity adjusted to VE 0.2.

14^{30}: Injection velocity adjusted to VE 0.15.

14^{50}: Injection velocity adjusted to VE 0.1.

14^{57}: Injection velocity adjusted to VE 0.05.

15^{15}: Flow rate from KXTP8: 37 ml in 20 min => 111 ml/h (268 ml/h 21 aug!).

16^{07}: Injection in KXTP3 stopped.

16^{20}: Opened KXTP2.

16^{35}: Started inject iso-propanol in KXTP2. Flow rate 2500 ml/h.

16^{58}: Stopped the iso-propanol injection.

17^{02}: Started to flush KXTP2 with resin.

17^{08}: Started to inject resin in KXTP2. Velocity VE 5. The resin was labelled with a blue dye and a yellow dye to give it a green colour. Uranin was as well added.

17^{10}: Injection velocity adjusted to VE 3.

17^{21}: Packer failure in KXTP2. Stopped injection. Hocked up KXTP9 to begin injection. Removed packer from KXTP2. Tried to remove packer from KXTP8 and put into KXTP2, could however not remove the packer. Resin stopped flowing, was injecting hardener only. Stopped injection, cleaned lines and checked valves on pump system (the check valves seemed to cause the problem).

19^{10}: Restarted the system. Check valves still not working properly. Replaced hardener valves with 1 psi (6.9 kPa) check valves. Found a packer which was installed in KXTP2. The dummy from the inflatable packer was installed as well.

20^{30}: Not enough resin and hardener left for a meaningful injection. Still low pressure in KXTP2.

The resin as well as the hardener levels were monitored manually during the entire injection period, see Table 4-5. A difference in level with 1 cm corresponds to a volume of 62.5 ml. The ratio between resin and hardener should be 4.0, if the mixing is perfect.

Table 4-5 Resin injection into KXTP3.

Time	Resin level [cm]	Hardener level [cm]	Ratio since start of injection	Comment
11:45	53	22.5		Flushing the hole
12:12	31.5	17.7		
12:13	28.5	7.65		
12:15	24.5	16.45		
12:22	19.6	13.8		
12:23	18.5	13.7	13/4=3.25 (since 11:45)	Start injection 12:25
12:31	17.9	13.15		
12:45	12.7	12.2		
12:49	11.0	11.7		
12:55	8.7	11.05		
12:58	7.3	10.6		
13:07	*4.2*	*9.5*	*14.3/4.2=3.40 (since 12:23)*	*Stopped to refill. Injected volume: 1160 ml (18.5 cm)*
13:18	*34.5*	*9.7*		*Injection restarted*
13:34	31.5	8.9		
13:58	28.4	7.8		
14:30	23.6	6.5	10.9/3.2=3.41 (since 13:18)	
15:35	22.0	6.0		
16:03	21.6	5.8	12.9/3.9=3.31 (since 13:18)	Injected volume: 2210 ml (18.5+16.8 cm)
16:07				Injection stopped

The injected volume was 2210 ml (18.5+16.8 cm). A small quantity was bled off to reduce the pressure build-up. A unknown quantity of resin migrated into KXTP4. Resin did not emerge into the drift. The volume injected into the structure has been estimated at one or a few 1000´s ml´s. The mixing ratio was very good during the entire injection.

Table 4-6 Resin injection into KXTP2.

Time	Resin level [cm]	Hardener level [cm]	Ratio since start of injection	Comment
17:02	53	24.9		
17:07	47	23.7		Start injection 17:08
17:14	35.5	17.7		
17:15	34.5	17.1		
17:17	33.0	15.1		
17:18.5	31.8	14.3	15.2/9.4=1.62	
17:21				Packer failure in hole 2. Injected volume: 1540 ml (24.6 cm).

The injected volume was 1540 ml (24.6 cm). No resin was bled off. Resin did not emerge into the drift. An unknown amount of resin migrated back to KXTP2 when the pressure decreased. The volume injected into the structure was estimated at about 1000 ml. However, resin was not injected long enough to allow a proper setting. Furthermore, the mixing ratio was quite bad.

4.3 Resin injection in KXTP1

September 5: Injection of dye-labelled water was carried out in borehole KXTP1. The total injected volume was 10 l during 6 h 35 m. This gives a flow rate of 1.5 l/h. The other KXTP-boreholes were closed. No observation of dye emerging into the drift.

September 5 - 6: Injection of dye-labelled iso-propanol in borehole KXTP1. About 7.2 l dye-labelled iso-propanol was injected during 17 h 18 m. This gives a total flow rate of 0.42 l/h. The other KXTP-boreholes were closed. Injection of resin into KXTP1.

4.3.1 Field notes from September 5, 1996

Injection of water + dye and iso-propanol +dye in KXTP1. It was not possible to use KXTP9 as injection hole since the tube to the bottom of the hole was tight due to the resin injection in August. Mixed yellow and blue dye to get a green color. Added Uranin.

09^{05}: Started the injection of water + dye in order to replace the water in the hole with water + dye. Injection flow rate: 2*125 %.

09^{30}: Started the injection in KXTP1. Injection flow rate: 2*75 %.

09^{40}: Pressure in KXTP1 = 17.5 bar.

16^{05}: Stopped the water injection. Started the injection of iso-propanol + dye. Injection flow rate: 2*40 %.

16^{50}: Volume of iso-propanol 22 l.

18^{20}: Pressure in KXTP1 = 20 bar. Reduced the injection flow rate to 2*25 %.

Table 4-7 Pressure readings September 5, 1996.

Hole	Time/Pressure (bar)		
	08^{55}	13^{30}	17^{00}
KXTP1	15.5	19	18.5
KXTP2	15.5	18	18
KXTP3	-	-	-
KXTP4	14	14.5	14.5
KXTP5	2	2	2
KXTP6	1	1	1
KXTP7	-	-	-
KXTP8	3.5	3.5	3.5
KXTP9	15.5	18	18

4.3.2 Field notes from September 6, 1996

Stopped the injection of iso-propanol +dye in KXTP1. Injected resin in KXTP1. The resin was labelled with a yellow and a blue dye to get a green colour. Uranin was as well added. The volume injected into the structure was estimated at about 1000 – 1500 ml.

8^{40}: Increased flow rate (iso-propanol + dye) to 2*40 %.

9^{23}: Stopped the injection of alcohol. Remaining volume is 14.8 l. This mean that 7.2 l of iso-propanol + dye has been injected during 17 h 18 min => 0.42 l/h.

9^{48}: Start to circulate resin in KXTP1. Kept the hole pressurized during the replacement of alcohol with resin. This probably reduced the water inflow (dilution) during the replacement.

10^{17}: Start injection of resin into KXTP1. The injection was most of the time carried out manually. Resin was injected until the pressure reached about 40-45 bar. The injection was stopped until the pressure had decreased to about 30 bar. Then resin was injected for a short time until the pressure reached 40-45 bar etc. This procedure worked fine!

10^{23}: The pressure in KXTP1 was 44 bar.

10^{25}: The pressure in KXTP1 was 46 bar.

10^{33}: Stopped the pump program. Running the pump manually for the rest of the injection.

10^{46}: The pressure in KXTP1 was 42 bar.

10^{48}: Opened KXTP2.

11^{10}: Opened KXTP9.

11^{14}: The flow rate from KXTP2 was 43 ml/min.

11^{15}: The flow rate from KXTP9 was 4 ml/min.

11^{28}: The flow rate from KXTP2 was 40 ml/min. Some smell of alcohol.

12^{07}: The flow rate from KXTP2 was 40 ml/min.

12^{19}: The flow rate from KXTP2 was 38 ml/min.

12^{29}: The flow rate from KXTP2 was 36 ml/min.

13^{20}: Resin breakthrough in KXTP2!.

13^{27}: Closed KXTP2.

13^{34}: The flow rate from KXTP9 was 38 ml/min.

13^{43}: Injection stopped - refilling the system.

14^{04}: The flow rate from KXTP9 was 28 ml/min. P_{inj} = 12 bar.

14^{06}: The injection was restarted.

14^{08}: The flow rate from KXTP9 was 30 ml/min. P_{inj} = 40 bar.

14^{10}: The flow rate from KXTP9 was 22 ml/min. P_{inj} = 36 bar.

14^{17}: The flow rate from KXTP9 was 20 ml/min. P_{inj} = 28 bar.

14^{30}: The flow rate from KXTP9 was 22 ml/min. P_{inj} = 30-40 bar.

14^{45}: The flow rate from KXTP9 was 20 ml/min. P_{inj} = 38 bar.

15^{15}: The flow rate from KXTP9 was 13 ml/min. P_{inj} = 39 bar.

15^{25}: The flow rate from KXTP9 was 12 ml/min. P_{inj} = 41 bar.

15^{33}: The flow rate from KXTP9 was 12 ml/min. P_{inj} = 44 bar.

15^{49}: The flow rate from KXTP9 was 9 ml/min. P_{inj} = 41 bar.

15^{59}: The flow rate from KXTP9 was 9 ml/min. P_{inj} = 40 bar.

16^{04}: The pressure in KXTP2 was 13 bar.

16^{06}: The flow rate from KXTP9 was 12 ml/min. P_{inj} = 45.5 bar.

16^{35}: The pressure in KXTP2 was 10 bar.

17^{00}: Injection stopped.

Table 4-8 Resin injection into KXTP1.

Time	Resin level [cm]	Hardener level [cm]	Ratio since start of injection	Comment
09:30	41	19		
09:55	30.6	17		
10:10	17.8	12.7		
10:20	18.7	10.8	22.3/8.2=2.72 (since 9:30)	Start injection
10:25	16.8	10.2		
10:35	14.7	9.2		
10:45	13.3	8.7		
11:00	12.0	8.0	6.7/2.8=2.39	
11:20	11.4	7.2		
11:27	9.8	7.0		
11:40	8.8	6.6	9.9/4.2=2.36	
11:45	8.3	6.2		
12:10	6.7	5.0		
12:30	6.5	4.7		
13:43	*3.0*	*3.5*	*15.7/7.3=2.15 (since 10:20)*	*Stopped to refill. Injected volume 1440 ml (23 cm)*
17:18.5	31.8	14.3	15.2/9.4=1.62	
17:21				Packer failure in hole 2. Injected volume: 1540 ml (24.6 cm).

The injected volume was 1540 ml (24.6 cm). Resin did not emerge to the drift. Resin breakthrough was observed in KXTP2. The volume injected into the structure was estimated at about 1000 – 1500 ml. The mixing ratio was a little low, but acceptable.

Table 4-9 Pressure readings September 5–6, 1996.

Hole	Time/Pressure (bar)			
	September 5			September 6
	08^{55}	13^{30}	17^{00}	8^{35}
KXTP1	15.5	19	18.5	21
KXTP2	15.5	18	18	18
KXTP3	-	-	-	-
KXTP4	14	14.5	14.5	15.5
KXTP5	2	2	2	2
KXTP6	1	1	1	1
KXTP7	-	-	-	-
KXTP8	3.5	3.5	3.5	4
KXTP9	15.5	18	18	18

5 Description of dye/resin observations

5.1 Resin and dye observations in the KXTRI and KXTE cores

The KXTRI boreholes were drilled in order to characterize the resin spread. The information from these boreholes was incorporated in a 3-D CAD-model in order to guide the drilling of the large diameter boreholes. Ten 56 mm boreholes were drilled according to the plans, i.e. about 4 m in length. The drilling of another two boreholes was terminated after a short distance, 1-2 m, due to technical problems. The resin and dye observations in the KXTRI cores are compiled in Table 5-1.

The KXTE holes were drilled in order to sample the structures at the site for quantitative resin studies. The core samples that were used for the resin thickness analysis originated from these cores. The resin and dye observations in the KXTE cores are compiled in Table 5-2.

It was very hard to distinguish between the different colours. The description of the color of the resin and the dye found in Tables 5-1 and 5-2 might therefore be associated with errors.

Table 5-1 Resin and dye observations in the KXTRI boreholes.

Borehole	Depth [m]	Resin observations	Comments
KXTRI1 Length : 3.59 m	2.92-2.95	Red resin.	A "flake" with red resin. The flake is about 1.5*3 cm in size. It seems that a fracture has touched the core. The resin was loose (not stuck to the core).
KXTRI2 Length : 3.74 m	1.26	Red/violet resin.	The resin covers about 60 % of the fracture surface. The fracture was opened during the drilling.
	1.81, 1.83 and 1.85	Red/violet resin on all three fractures.	The fracture at 1.85 m was opened during the drilling, the other closed. The coverage varies between about 20 % (1.83 m) to about 90 % (1.81 m).
KXTRI3 Length : 3.66 m	1.75	Red resin.	Fracture opened during drilling. About 90 % coverage.
	1.84	Red resin.	Fracture not opened during drilling. More than 90 % coverage. Mix of red and violet resin that seems to have the same origin.
	2.67	Resin! Could be red, could be blue!	25 % coverage. No observation of dye!
	2.71	Probably blue resin!	25 % coverage. No observation of dye!

Borehole	Depth [m]	Resin observations	Comments
	2.81	Probably blue resin!	25 % coverage. No observation of dye!
	2.84	Probably blue resin!	25 % coverage. No observation of dye!
	2.97	Probably blue resin!	25 % coverage. No observation of dye!
KXTRI4 Length : 4.23 m	0.40	No resin.	Some red/violet dye.
KXTRI5 Length : 3.12 m	1.20	Red colour. Probably resin.	30-40 % coverage.
	1.43	Red and/or blue resin.	Fracture not opened during drilling. 100 % coverage.
KXTRI6 Length : 3.91 m	1.43	No resin.	Red or violet colour.
	2.54	Blue resin.	Fracture not opened during drilling. Two almost parallel fractures. Coverage about 30 %.
KXTRI7 Length : 4.25 m	0.20	No resin.	Red dye.
	1.24, 1.28, 1.32, 1.38 and 1.48	Red resin.	Five fractures connected in a network. The 1.48 m fracture seems to be the base in the network. This fracture has red resin with 100 % coverage. The other fractures have 50-100 % coverage.
	1.65	Red resin.	Red dye and resin. 80-90 % coverage.
KXTRI8 Length : 4.25 m	0.15, 0.25 and 0.65	No resin.	Red dye.
KXTRI9 Length : 2.21 m	0.20	Probably not any resin.	Red/violet dye.
KXTRI9B Length : 3.95 m	0.35, 0.43 and 0.55	Probably not any resin.	Red/violet dye.
	3.11	Blue resin.	No dye.
KXTRI10 Length : 4.35 m	0.27	No resin.	Red dye.
	0.99	Red dye and/or resin. As well some black (?) resin!?	Red dye and/or resin.
KXTRI10B Length : 0.84 m	0.32	Red dye and/or resin.	Red dye and/or resin.

Table 5-2 Resin and dye observations in the KXTE boreholes.

Borehole	Depth [m]	Resin observations	Comments
KXTE1 Length : 3.84 m	0.55	No resin.	Violet (red/blue) dye. Fracture orientation: α=17°, β=270°.
	1.95	No resin.	Violet/red dye. Fracture orientation: α=75°, β=120°.
	2.40	Red/violet resin.	The section 1.95-2.83 m seems to contain resin. The sample "KXTE1.b" that were analysed for resin aperture was taken from the section 2.30-2.52 m. Fracture orientation: α=14°, β=110°.
	2.83	Red/violet resin.	Fracture opened during the drilling.

Borehole	Depth [m]	Resin observations	Comments
			Fracture orientation: α=52°, β=300°.
	3.04	Red/violet resin.	Fracture opened during the drilling. The resin covers about 80-90 % of the fracture surface. Fracture orientation: α=70°, β=130°.
KXTE2 Length : 3.71 m	0.77	Red resin.	Opened during the drilling. Part of the fracture covered with a flakey red resin. Fracture orientation: α=45°, β=260°.
	1.90	Red/violet resin.	The fracture was opened during the drilling, but glued back together. This is sample "KXTE2.c". The section 1.5-1.9 m seems to contain resin. Fracture orientation: α=25°, β=240°.
KXTE3 Length : 4.17 m	0.86	Red/violet resin.	The entire section 0.86-1.55 m seems to contain resin. Fracture orientation: α=70°, β=90°.
	1.13	Red/violet resin.	Intact fracture. The sample "KXTE3.b" that were analysed for resin aperture was taken from the section 1.12-1.55 m. Fracture orientation: α=16°, β=90°.
	1.55	Violet resin in flakes.	Opened during the drilling. Fracture orientation: α=37°, β=260°.
KXTE4 Length : 3.35 m	0.91-1.05	No resin.	An intact section with a cluster of fractures. Red/violet dye can be observed, but no resin. Fracture orientations: 0.91 m : α=75°, β=160°. 0.93 m : α=20°, β=260°. 1.05 m : α=30°, β=360°.
	1.38	Red resin.	Fracture opened during the drilling. The resin has very bad bonding to the fracture surfaces. Fracture orientation: α=45°, β=260°.
KXTE5 Length : 3.52 m	2.03	Fractures that might contain blue (?) resin.	Intact section. Fracture orientation: α=60°, β=30°.
KXTE6 Length : 3.32 m	0.65	Blue resin/dye in flakes.	Core break. Fracture orientation: α=65°, β=270° (uncertain due to core rotation).
	0.90	Possibly small amounts of resin.	Violet dye. Fracture orientation: α=60°. Not possible to estimate β due to core rotation.

The definitions of α- and β-angles are illustrated in Figure 5-1.

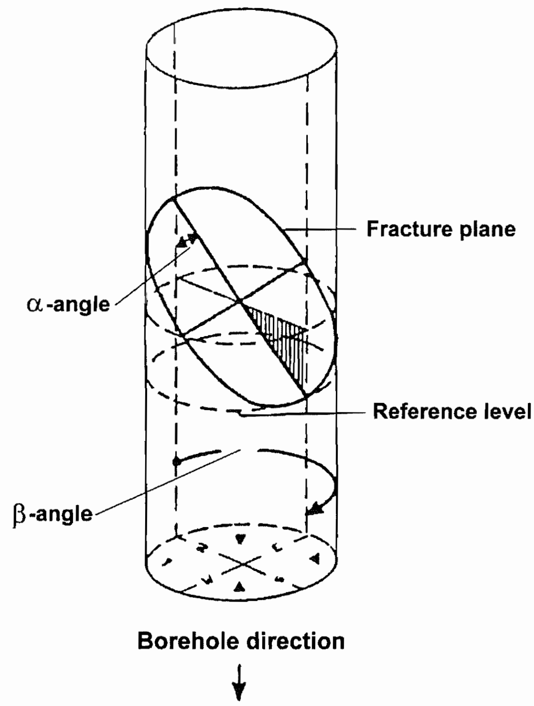


Figure 5-1 Definition of α- and β-angles.

5.2 Sum-up of resin observations in the KXTE cores

The resin thickness analysis was focused on cores from the first drilling campaign, i.e. KXTE1-3. These cores seem to contain resin in the following intact sections:

- KXTE1 1.95-2.83 m = 0.88 m. Probably resin.
- KXTE2 1.50-1.95 m = 0.45 m. Probably resin.
- KXTE3 0.86-1.55 m = 0.69 m. Resin.

Total: 1.96 m of the KXTE1-3 cores seems to contain resin. This corresponds to about 20 % of the total core length.

The resin thickness analysis was based on two samples taken from KXTE1 and KXTE3. The total length of these samples is about 0.45 m.

The following intact sections in KXTE4-6 seem to contain resin:

- KXTE4 No candidates.
- KXTE5 1.7-1.9 m = 0.2 m. May contain resin.
- KXTE6 1.7-2.0 m = 0.3 m. May contain resin.

Total assessment: 0.5 m of the KXTE4-6 cores seems to contain resin. This corresponds to about 5 % of the total core length.

6 Borehole coordinates

The results from the surveying of borehole collars in the pilot resin injection site are presented in Table 2-1. The boreholes are located on the north side of the F-tunnel, 450 meters below ground surface. Locations of the boreholes are given in the local Äspö coordinate system. Borehole direction is given relative to Äspö Local North. This reference direction is also used for the orientation (strike) of fractures in this report. The same datum has been used for the different logs.

Table 6-1 Surveying of collars of boreholes KXTP1-9

Borehole	Length (m)	Northing	Easting	Elevation	Bearing	Inclination
KXTP1	3.94	7297.690	1987.980	-450.070	304.560	-14.000
KXTP2	3.70	7297.779	1987.923	-449.742	305.534	-3.068
KXTP3	3.31	7297.637	1987.384	-449.961	302.293	-21.473
KXTP4	3.05	7297.616	1987.472	-449.806	305.260	-6.425
KXTP5	2.92	7297.629	1987.417	-449.539	303.037	5.627
KXTP6	1.94	7297.562	1986.884	-449.720	306.815	-25.269
KXTP7	2.10	7297.533	1986.965	-449.581	301.285	-4.223
KXTP8	2.20	7297.468	1986.402	-450.660	338.507	-7.226
KXTP9	2.92	7297.498	1986.661	-448.504	339.232	-3.633

Table 6-2 Surveying of collars of boreholes KXTRI1-10

Borehole	Length (m)	Northing	Easting	Elevation	Bearing	Inclination
KXTRI1	3.59	7297.636	1987.570	-449.869	306.100	-5.600
KXTRI2	3.74	7297.630	1987.427	-449.857	300.500	-14.800
KXTRI3	3.66	7297.593	1987.360	-450.036	301.900	-19.100
KXTRI4	4.23	7297.676	1987.694	-450.016	306.700	-1.000
KXTRI5	3.12	7297.631	1987.265	-449.557	300.600	3.000
KXTRI6	3.91	7297.676	1987.761	-449.630	303.500	5.300
KXTRI7	4.25	7297.656	1987.761	-450.023	314.600	-3.800
KXTRI8	4.25	7297.746	1987.829	-449.790	310.500	-2.000
KXTRI9	2.21	7297.570	1987.367	-450.294	312.100	-15.800
KXTRI9B	3.95	7297.662	1987.681	-450.072	305.600	-13.700
KXTRI10	4.35	7297.519	1987.456	-450.264	341.200	-5.100
KXTRI10B	0.84	7297.559	1987.376	-450.216	341.100	-4.900

Table 6-3 Surveying of collars of boreholes KXTE1-6

Borehole	Length (m)	Northing	Easting	Elevation	Bearing	Inclination
KXTE1	3.84	7297.622	1987.623	-449.990	302.595	-16.973
KXTE2	3.71	7297.460	1986.604	-450.706	339.099	-6.895
KXTE3	4.17	7297.358	1985.852	-449.850	355.670	8.965
KXTE4	3.51	7297.541	1987.126	-450.073	300.669	-17.673
KXTE5	3.50	7297.416	1986.951	-450.512	339.408	-7.168
KXTE6	3.32	7297.408	1986.049	-449.149	355.669	-5.080

7 Description and evaluation of techniques for drilling of large diameter sampling boreholes

This chapter is based on an unpublished Technical Note by Gunnar Ramqvist, SKB/Äspö HRL, and describes the activities and different techniques used during drilling of the large diameter holes.

7.1 Drilling procedures

A schematic illustration of the drilling arrangements is found in Figure 7-1.

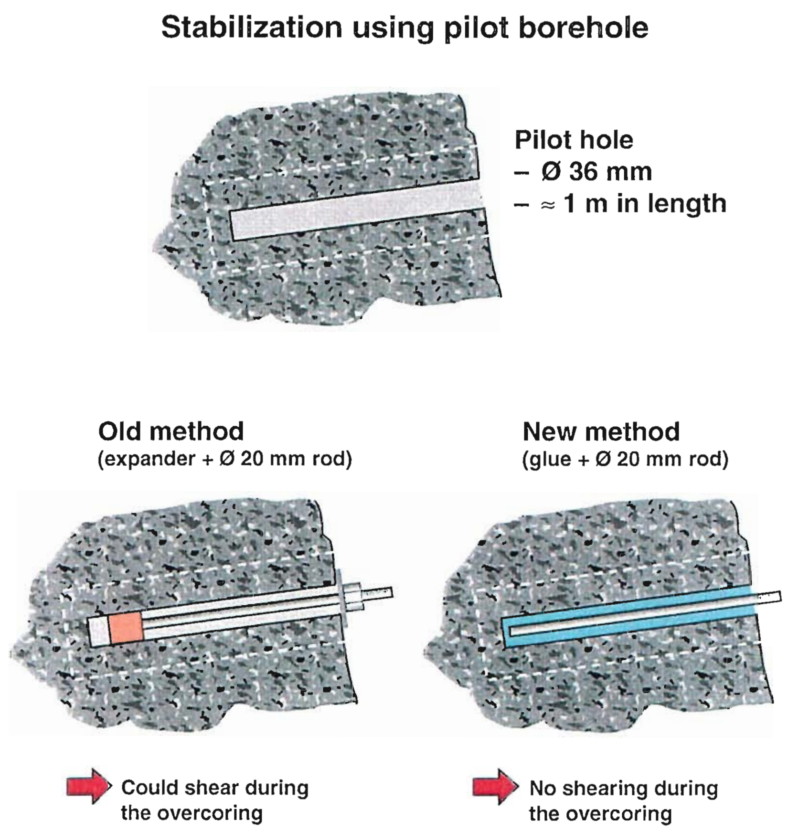


Figure 7-1 The drilling arrangements for large diameter core sampling of the site.

7.1.1 Drilling phase 1 (∅ 200 mm)

Drilling of the three first boreholes, KXTE1-3, was carried out using a HB 400 drill rig which is easy to handle due to its low weight. A disadvantage with this machine is that the pressure on the drill bit has to be operated manually.

A 36 mm core-drilled pilot hole was drilled in the centre position of the large hole in order to secure the core sample and to avoid breaks in weak sections of the core. Before the drilling of the large core started, a 20 mm threaded rod was installed with an anchorbolt fixed approximately 15 cm above the planned breaking point of the larger core. On the top of the core, a nut with a special made teflon-washer was tightened to keep the core in tension and in order to avoid break during the drilling.

For the drilling of the large core, a standard type 212 mm barrel, which is normally used for concrete-drilling, was used. Drilling of large cores has shown to be difficult, especially if the hole is to be longer than approximately two metres, due to problems to break the core and get the core out of the hole.

The technique for breaking the core was to insert a hydraulic flatjack into the six millimetre annular slot that was made by the drillbit. The hydraulic pressure on the flatjack was generated by a manually operated pump, outside of the hole.

The boreholes KXTE 1-3 were drilled with the above technique. The drilling arrangement is indicated as the “Old method” in Figure 7-1.

Several problems occurred during the drilling. One was related to inserting the flatjack into the slot without disturbing, or breaking the core. Another was the tightening of the nut and teflon-washer on the top of the core. If the fracture surface that was of interest was not in a perpendicular angle to the borehole axis, a shear force that could break the core could be generated if the nut was tightened too much.

Since the boreholes were orientated almost horizontally, problems occurred when the drilling was finished and the core barrel was removed from the hole. If the nut was to loose, the core broke due to the bending induced by gravity.

An unsuccessful test to secure the core using a large metal clamp over the core, before breaking the core at the base, was carried out. The annular space (slot) from the drill bit was too small for both the clamp and the flatjack.

The drilling records are presented at the end of this chapter.

7.1.2 Drilling phase 2 (∅146 mm)

Based on the experience from the first drilling phase, a discussion followed how to continue with the second phase. Several technical options were discussed such as drilling a larger number of holes using a considerably smaller diameter. However, it was in the end decided to drill a pilot hole and glue an aluminium pipe in place before the overcoring. Furthermore, it was decided to use a ONRAM 1000 drillrig and to drill

146 mm boreholes using a method called GEOBOR-S triple tube. The drilling arrangement is indicated as the “New method” in Figure 7-1.

With this triple tube method, the core is drilled out of the formation by the rotating bit, after which the core is slided into an inner non-rotating core lifter case and a plastic inner tub. This method is recommended for drilling in non-cohesive sedimentary rocks, as well as in very cohesive soil, but can also be used in hard rock formations whenever a good core recovery is desired. The standard core barrel has a diameter of 146 mm and the core will be 102 mm.

It was also decided that a pilot hole with a diameter of 36 mm should be drilled down the centre of the core as in the previous phase, but in this case the centre hole should be equipped with a rod, and the annular space of the hole filled with a epoxy or similar, to avoid movements along the fracture planes. The boreholes KXTE4-6 were drilled using this technique.

The main drawback of this technique is that a large drill rig with a high torque and pressure capacity has to be used. Furthermore, gluing the rod in the pilot hole was quite time-consuming. Therefore, this new drilling method was more time-consuming and expensive compared to the drilling method applied during phase one. In addition, the crossectional surface area of the obtained cores was significantly smaller.

The advantages of the technique are that the core is well protected in the inner non-rotating plastic tube, and the core can easily be transported in the tube for future analyses in the laboratory.

When the 36 mm pilot hole was drilled, a prefabricated glue paste (”Cembolt”) was placed in the hole, and the 20 mm aluminium-rod was installed. The normal hardening time for the paste is 6-8 hour. During the first test the paste was still not fully hardened after 12 hour. After the initial test, a two component epoxy INP 42 with a H24LS hardener was used. The epoxy was fully hardened after eight hours. The procedure had to be repeated for each core uptake, i.e. every $\approx$ 1 m.

Another problem was the low penetration rate, approximately 2 hours for drilling 1.5 m, even if the pressure on the drill bit was two tons.

The drilling records are presented at the end of this chapter.

7.2 Drilling records

Table 7-1 Drilling records for KXTE4.

Drilling start	Drilling stop	Length (m)	Diameter (mm)
970116 -----	--------- -----	0.0 - 0.65	36
970123 09:30	970123 09:40	0.65 - 1.35	36
970124 08:15	970124 10:35	0.0 - 1.50	146
970125 11:45	970125 11:45	1.50 - 2.35	36
970126 08:10	970126 09:20	1.50 - 2.51	146
970126 09:55	970126 10:10	2.51 - 3.36	36
970127 02:50	970127 05:05	2.51 - 3.51	146

Table 7-2 Drilling records for KXTE5.

Drilling start	Drilling stop	Length (m)	Diameter (mm)
970131 16:45	970131 17:15	0.0 - 1.40	36
970201 07:15	970201 10:35	0.0 - 1.45	146
970201 11:15	970201 11:30	1.45 - 2.45	36
970202 07:20	970202 09:30	1.45 - 2.50	146
970202 10:10	970202 12:15	2.50 - 3.50	146

Table 7-3 Drilling records for KXTE6.

Drilling start	Drilling stop	Length (m)	Diameter (mm)
970203 14:15	970203 15:10	0.0 - 0.50	146
970203 15:35	970203 15:55	0.50 - 1.40	36
970204 09:15	970204 11:30	0.50 - 1.53	146
970204 14:30	970204 17:15	1.53 - 2.45	146
970205 11:30	970205 14:55	2.45 - 3.32	146

8 Reference

Birgersson, L., Gale, J. and Hakami, E., First TRUE Stage – Pilot Resin Experiment – Summary Report, 2000.