International
Progress Report

IPR-07-15

Äspö Hard Rock Laboratory

Alternative Buffer Material

Installation report

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July 2007

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Report no.	No.
IPR-07-15	F125K
Author	Date
Anders Eng	July 2007
Checked by	Date
Roland Pusch	October 2007
Approved	Date
Anders Sjöland	2008-06-09

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Keywords: Buffer, Alternative, Material, ABM, Bentonite, Rock, Temperature, Test, Measurements, Swelling, LOT, In-situ, Packages, Artificial, Saturation, Steel, Block, Storage, Granulate

Abstract

Project Alternative Buffer Material (ABM) aims at investigating a number of different buffer materials under controlled and identical conditions. Eleven different bentonite materials have been chosen for the study.

The experiment is carried out in so called “LOT scale”; experiment packages with outer diameter of 280 mm are deposited in 300 mm deposit holes. In this case the holes are 3 meters deep. After installation the packages are heated to the goal temperature of 130 °C. Throughout the experiment the temperature is monitored using a computer data logging system.

The experiment consists of three packages in which all of the different clay materials are represented in each. The packages will be in operation for different time periods. The first package is expected to be retrieved for analysis after one year, the second after three years and the third after five years operation. This will give information of how the buffer develops with time.

One experiment package consists of buffer rings, a heater pipe, heaters, sensors and pipes for the artificial saturation system. The buffer rings are threaded onto the heater pipe in a previously determined pattern to achieve maximum mixture of the materials. At five different levels in the package three temperature sensors are installed in the buffer. Increasing distance between the sensors and the heater pipe will give information about the temperature distribution. On the outer edge of the package the saturation pipes are attached to which natural Äspö water is connected. The purpose of the saturation system is to speed up the saturation process of the buffer.

When the package assembly is completed the package is lowered into the deposit hole. To further increase the water distribution along the package sand is used to fill the small slot between the rock and the package.

To hold the package in position during the experiment a concrete plate is cast on top of the package. The concrete plate is also secured by steel bars bolted to the rock floor.

This report describes the work with the assembly and installation of the three experiment packages. The Report also contains detailed information of the block manufacturing, sensors, heater and other parts of the system.

Sammanfattning

Projekt Alternativa buffertmaterial syftar till att undersöka ett flertal olika buffertmaterial under kontrollerade och likvärdiga förhållanden. 11 stycken olika bentonitmaterial (varav en lersten) har valts ut att ingå i studien.

Studien genomförs i så kallad ”LOT-skala”, vilket innebär att försökspaket med diametern 280 millimeter installeras i deponeringshål med diameter 300 mm. I detta fall är deponeringshålen 3 meter djupa. Efter installation värms paketen upp till en tänkt måltemperatur av 130 grader. Under drifttiden övervakas temperaturutvecklingen i paketen kontinuerligt via ett dataloggningssystem

Alternativa buffertmaterial består av tre stycken försökspaket där samtliga varianter av materialen finns representerade i vart och ett. De olika paketen ska vara i drift under olika lång tid. Det första paketet beräknas tas upp för analys efter 1 år, det andra efter ca 3 år och det tredje efter ca 5 år. Detta ger en bild av hur bufferten påverkas över tid.

Ett försökspaket består av buffert, värmarrör, värmare, givare och bevätningssystem. Buffertringarna träs på värmarröret enligt ett förutbestämt mönster med mål att uppnå maximal blandning mellan materialen. På fem olika platser i paketen installeras 3 stycken temperaturgivare i bufferten. Dessa givare sitter på olika avstånd från värmarröret för att en god bild av temperaturspridningen ska uppnås. Utanpå det färdiga paketet sitter också bevätningsrör till vilka naturligt Äspö vatten kopplas. Bevätningssystemets syfte är att simulera vattenförande sprickor i det omgivande berget och att påskynda buffertens vattenmättnadsprocess.

När paketet är färdigbyggt sänks det ner i sitt deponeringshål. För att ytterligare sprida vattnet från bevätningssystemet, men även det naturligt inflödande vattnat i deponeringshålen, fylls spalten mellan berg och buffert med sand.

För att motverka buffertens svällkraft uppåt och hålla paketet på plats under försöket gjuts en betongplatta ovanför det installerade försökspaketet. Betongplattan säkras också med stålbalkar förankrade i berget.

Denna rapport beskriver arbetet med montering och installation av försökspaketen. Rapporten innehåller också och detaljerad information om blocktillverkning, givare, givarplacering, värmarrör och övriga beståndsdelar i försökspaketen.

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1 Introduction

MX80 bentonite from American Colloid Co (Wyoming) has long been the reference for buffer material in the Swedish KBS-3 concept. Extending the knowledge base of alternative buffer materials will make it possible to optimize regarding safety, availability and cost. For this reason the field experiment Alternative Buffer Material was started at Äspö Hard Rock Laboratory during 2006.

One of the main purposes of the experiment is to study differences on long-term buffer behavior and stability between different bentonite buffer material. Examples on behavior parameters to study are both in general terms of swelling and movement of dissolvable minerals and the stability of both the smectite minerals and the accessory minerals. To accomplish this study eleven different clays (including one clay stone / argillite) with differences in the amount of swelling clay minerals, smectite counter ions, total amount of iron and various accessory minerals have earlier been chosen. Also MX80 granulate with and without additional quartz are included. Some of the clays have previously been characterized by SKB, TR-06-30.

The use of an iron heater also makes it possible to look at the interaction of metallic iron with the buffer which is a very important part of the experiment. The amount of instrumentation is kept at a minimum to minimize the disturbance of the experiment, which means that the main results will be captured first after the packages have been excavated. The clays that have been included in the experiment are either ones that have been recognized as possibly very good buffer materials or they have been included for more scientific reasons such as extremely low iron content etc.

Alternative Buffer Experiment is an SKB project with several international partners, collaborating in the part of laboratory experiments and analysis. There is no strict procedure how the different organizations will contribute or how the analyses will be done. A test setup has been constructed to help in organizing and planning the work within and between the organizations. It is possible for one organization to analyze all materials or only the ones they find most interesting. For comparison between the clays it would be good if one organization analyze all materials using a specific method. But there are also possible benefits with organizations looking at their own material for the reason that they have more background in analyzing the specific material. Hopefully the more results that comes from the experiment, the more we will learn.

The experiment consists of three packages, number one will be excavated after one to two years, and number two after more than three years and the third will be excavated after more than five years.

This report aims at giving a description of how the packages are assembled and installed in the deposit holes. The description can be used when planning the upcoming retrieval and disassembly of the packages. The report does not contain any expectations or calculations regarding the experiment process.

2 Experiment description

Experiment layout is similar to the Swedish KBS-3 concept with a metal canister surrounded by clay situated in crystalline bedrock at approximately 500 m depth. The differences are mainly the scale, which is smaller, and that the canister is of iron instead of copper. This experiment is similar to the LOT experiment; the bore holes have the same diameter, 30 cm, but the depth is somewhat shorter, 3 m instead of 4 m as in LOT.

The experiment consists of three packages in three separate boreholes that will be excavated after about 1, 3 and 5 years (commonly referred to as the first, second and third package throughout this document). The different clays are compacted to rings, penetrated by a steel pipe, and positioned on top of each other. Figure 1 shows the basic layout of the packages with the heater pipe, the buffer blocks and the backfill simulator-the concrete block. The level of monitoring is at a minimum in order not to disturb the experiment. The 1 year and the 5 year package will be heated from the start and the 3 year package will be heated when fully water saturated. Because the heating of the 3 year package will start at saturation (according to monitoring) the saturation and heating processes are decoupled, which might give some interesting results. Buffer goal temperature is 130°C. The packages are wetted by natural water from fractures in the rock and optionally also artificially from the installed wetting system.

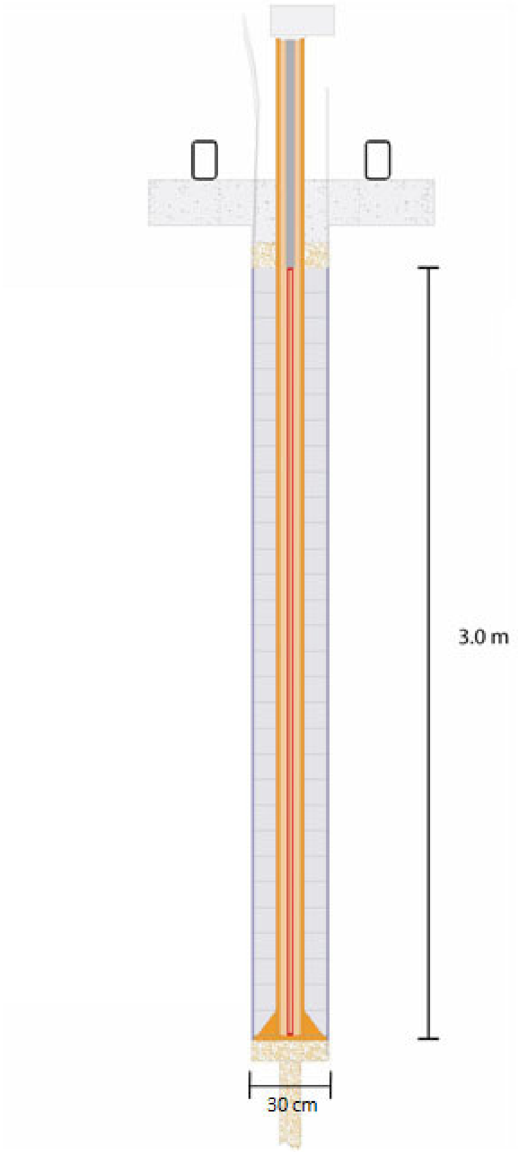


Figure 1. *The experiment package basic layout. Buffer rings are penetrated by a steel pipe which contains electrical heaters. The package is held in place by a concrete plate at the top, simulating the backfill.*

The parts of the system are described in detail in following chapters.

3 Experiment site

The Alternative Buffer Experiment is located at the -450 meter level in the Äspö facility. A new niche was excavated in the TASQ tunnel to host the experiment, the location is marked in Figure 2. Selection of the site was done considering numerous parameters, both experiment requests and Äspö facility requirements. The excavated niche is named NASQ. The main parameters that were important for the experiment to consider were that the depth of the site was similar to repository depth and that the site was reasonable dry. Other than that the goal was to find a site that had much in common with the LOT experiment which would make the experiment data easier to compare.

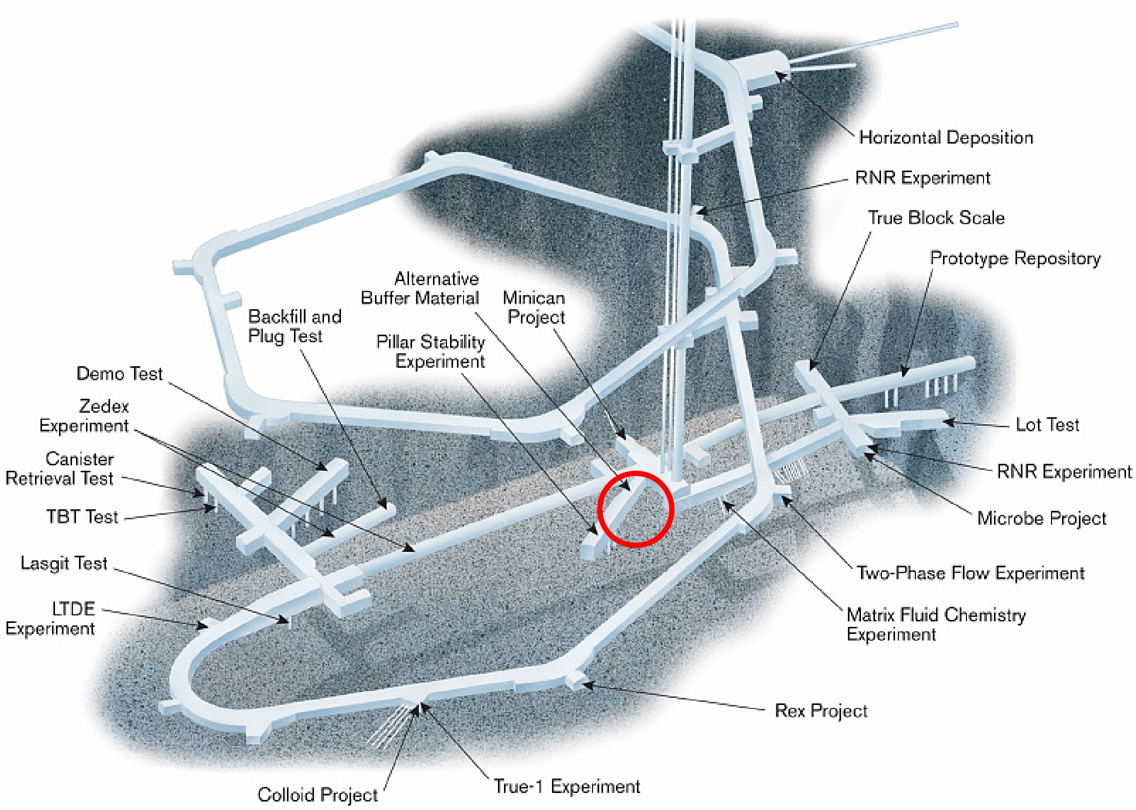


Figure 2. *The Alternative Buffer Experiment location is in the TASQ tunnel at the Äspö facility.*

Excavation was performed with “careful blasting” technique which was conducted in the spring of 2006. The tunnel TASQ holds quite many water bearing fractures further in the tunnel. Since the niche is located only half way in the tunnel these fractures are avoided as much as possible.

3.1 Deposit holes

Boring of the 300 mm diameter deposit holes was conducted shortly after the blasting was completed. The holes were mapped and the data inserted into the Äspö geological mapping database, Appendix 5 shows the fracture mapping of the three holes. Water inflow measurements were also conducted. Results are similar between the three holes; 3.6 l/ hour was measured (equivalent to 0.06 l/min). Inflow positions in the boreholes was not identified, this mainly because sand between the package and rock wall is be used to distribute the water from the inflow positions to as much of the package as possible and also from the artificial saturation system.

The deposit holes are named KQ0032G01, KQ0036G01 and KQ0040G01 is the SKB bore hole ID system. To accomplish a flat surface on the bottom of the holes gravel was used.

The first package, short term, is installed in the borehole KQ0032G01. Package two, 2-4 years running time, is installed in borehole KQ0036G01. The long term package, more than 5 years, is installed in borehole KQ0040G01.

4 Buffer materials

This section describes the buffer block manufacturing process. The blocks were manufactured by Clay Technology in Lund.

4.1 Initial experiments

At the delivery of the different clay materials measurement of the water content was made. The results are shown in Table 1. Extreme materials are Asha 505 with high water content and the milled Callovo-Oxfordian. The Callovo-Oxfordian material was processed into a grain size of max 5 mm from the original rock shards. The processing was done with sledge hammer to max size 50 mm and then by using a jaw crusher and a roller mill to reach the final size.

Table 1. Water content of the different clays when delivered.

Material	Water content	Abbreviation
Ikosorb	14,53%	IKO
Deponit CA-N	18,80%	CAN
Ibeco Seal M-90	14,76%	IBE
Friedland	5,89%	FRI
Asha 505	26,60%	ASH
Calcigel	6,61%	CAL
Febex	14,41%	FEB
Kunigel V1	7,86%	JNB
Callovo Oxfordian, milled	2,50%	COB
Rokle	9,65%	ROK
MX-80	13,5%	LOT

Compaction tests were made with different water content and pressure to determine suitable pressure and resulting density. In Figure 3 the resulting dry density is shown as a function of water ratio for each material for an applied total pressure of 100 MPa. Since the difference between minimum and initial water content values are small (except Asha 505) the blocks were compacted at initial values. The Asha 505 material was air dried to about 13% water content before pressing. In Table 2 the density for the chosen water ratio values is presented.

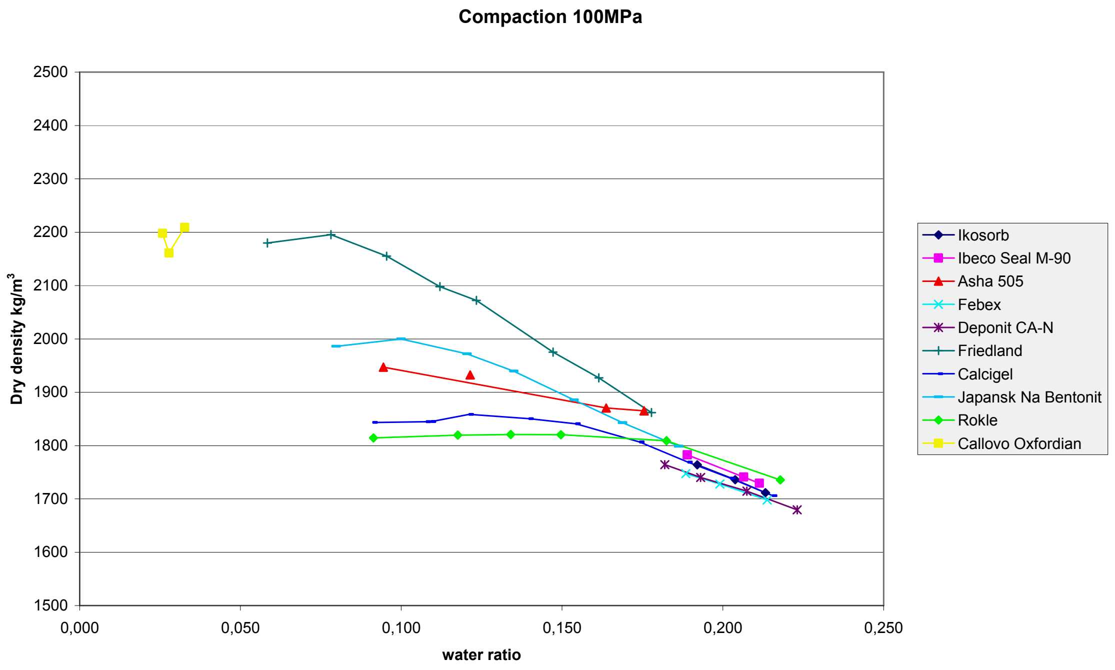


Figure 3. *Compaction curves for applied pressure 100 MPa.*

Table 2. Target density and water ratio for the different blocks (compaction pressure100 MPa).

Material	**Bulk density kg/dm³**	**Water ratio %**	**Dry density kg/dm³**	**Void ratio**
Ikosorb	2,12	14,0	1,86	0,59
Deponit CA-N	2,08	18,6	1,75	0,58
Ibeco Seal M-90	2,11	14,9	1,84	0,60
Friedland	2,30	5,7	2,18	0,28
Asha 505	2,15	13,7	1,89	0,44
Calcigel	2,12	7,2	1,98	0,51
Febex	2,05	14,4	1,79	0,57
Kunigel V1	2,15	8,6	1,96	0,40
Callovo Oxfordian milled	2,25	2,7	2,15	0,26
Rokle	1,98	9,0	1,82	0,53
Mx-80	2,09	13,5	1,84	0,63

In Appendix 1 all compaction results are presented.

4.2 Block production

The blocks were made with the same mould and routines as the blocks in the ”LOT” tests. The required amount of material was determined from the size of the mould and the results from the compaction tests. The mould was coated with a thin layer of grease to reduce friction and facilitate the demoulding. The material was poured into the mould and was distributed evenly. Washers were placed before the piston was inserted and the whole equipment was placed in the press. The mould was connected to a vacuum pump to evacuate trapped air in the material and the clay was pressed with 100 MPa. When finished the block was demoulded. In some cases the block got stuck in the mould and had to be pressed out, see below. Dimensions and weight of the block were measured directly after demoulding. The block was placed in a marked plastic bag for storing. Material samples from each moulding were taken for water content determination and then stored for subsequent analyses.

Outer diameter of the blocks is 280 mm, inner diameter is 110 mm and the height is 100mm. The weight of the blocks varies with buffer material, but within the range of 10.0 to 11.7 kg.

4.3 Results

All materials could be compacted to blocks. Some minor damages took place during demoulding of some blocks when the block was pressed out from the mould. Materials with a grain size of 1 mm and courser were fairly easy to press with the exception of Callovo-Oxfordian (a clay stone material) which expanded and got stuck after the pressure was released. Fine powder materials such as Rokle, Deponit CA-N and Japan Na Bentonite (Kunigel V1) leaked through some washer, leading to parts of the mould to get stuck. These materials were initially also voluminous and had to be pre compacted by hand in the mould before normal routines started. The filters to the vacuum pump also tended to get clogged fast and had to be cleaned.

Detailed block data are reported in Appendix 2.

5 Heater system

As in many experiments in the Äspö HRL electrical heaters are used to simulate the residual heat from spent fuel. This section describes the heater system used in this installation.

5.1 Steel pipes

Steel pipes are used as the base for the experiment packages. The pipes are also used to house the heaters. The reason for not using a copper pipe, as in most of the experiments at Äspö, is to be able to study the effects of rusting steel in close contact with the buffer material.

The steel pipe material is common carbon steel, P235TR1. Outer diameter of the pipe is 108 mm. The length of the pipes is roughly four meters.

To be able to hold the buffer rings during package assembly and installation a bottom plate was welded to each pipe. The plates are also carbon steel, S355J2G3, and 5 cm thick. Outer diameter of the plate is the same as the outer diameter of the buffer rings, 280 mm.

Helium leakage testing was executed to verify that the welding between the pipe and the bottom plate is completely tight. Rust preventing paint was also used at the bottom plate to reduce the risk of eventual leakage due to corrosion in the welds during the experiment. The uppermost part of the pipes was also painted to avoid rust.

A picture on a heater pipe can be seen in Figure 14 on page 35.

5.2 Heaters

As in many other experiments in the Äspö facility electrical heaters are used to simulate residual heat from spent fuel. In each experiment package three electrical heaters are installed. A main heater runs along the entire package length. Two additional heaters are installed, one at the bottom and one at the top. Using two additional heaters in each package, one at the top and one at the bottom will compensate for the temperature loss at the top and bottom and give a more homogenous temperature distribution throughout the package length. The goal is to give the buffer blocks similar conditions during the experiment regardless of position within the package. Table 3 gives the data for the heaters. All packages are equipped with identical heater setup.

Table 3. Heater data. The heater setup is identical for all three packages.

Heater	**Maximum heater power**	**Heater length**	**Inactive length (measured from top)**
Main	1000 W / 230 V	3100 mm	100 mm
Top	500 W / 230 V	1100 mm	100 mm
Bottom	500 W / 230 V	3100 mm	2100 mm

The heaters are connected to thyristors for power control. The power to the heaters can also be remotely controlled via SKB network for quick adjustment if needed.

6 Sensors

Three types of sensors are used in the experiment monitor system; two online types and one offline type. Online sensors measures temperature and relative humidity and are connected to a computer logging the current values. The offline sensors are temperature indicators and can only be read once the experiment packages are retrieved and disassembled. This chapter describes the sensors used and their positions in the packages.

6.1 Thermocouples

20 thermocouples are installed in each package. All sensors are connected to the monitor system and gives continuous data about the temperature in the packages. The sensors are thermocouples type K. The shield of the sensors is cupronickel which will ensure that they will withstand the rough environment in the boreholes.

Thermocouple sensors are mounted at five levels in the packages. Package 1 and 3 have se sensors mounted in blocks number 3, 9, 15, 21 and 27, counting from the bottom and up. Package number 2 has sensor mounted on blocks number 3, 9, 15, 22 and 28. A sketch of the sensor positions is shown in Figure 5. At each level 4 sensors are placed, three in the buffer and one inside the heater pipe. The three sensors in the buffer are placed at different distances from the heater pipe. The most inner sensor is placed as close to the heater pipe as possible, typically 0 to 0,5 cm. One sensor is positioned half way between the inner and outer edge of the blocks. The outer sensor is placed 2-3 cm from the outer edge. The exact distances are given in the sensor installation protocol. All sensors are inserted approximately 3 cm into the buffer blocks in a pre-drilled hole. Figure 5 also shows the positions of the sensors within each sensor level. A small notch on the buffer block top is also made for each sensor so that there are no gaps between the buffer blocks. Figure 6 shows how the sensors are installed in the notches made in the buffer blocks.

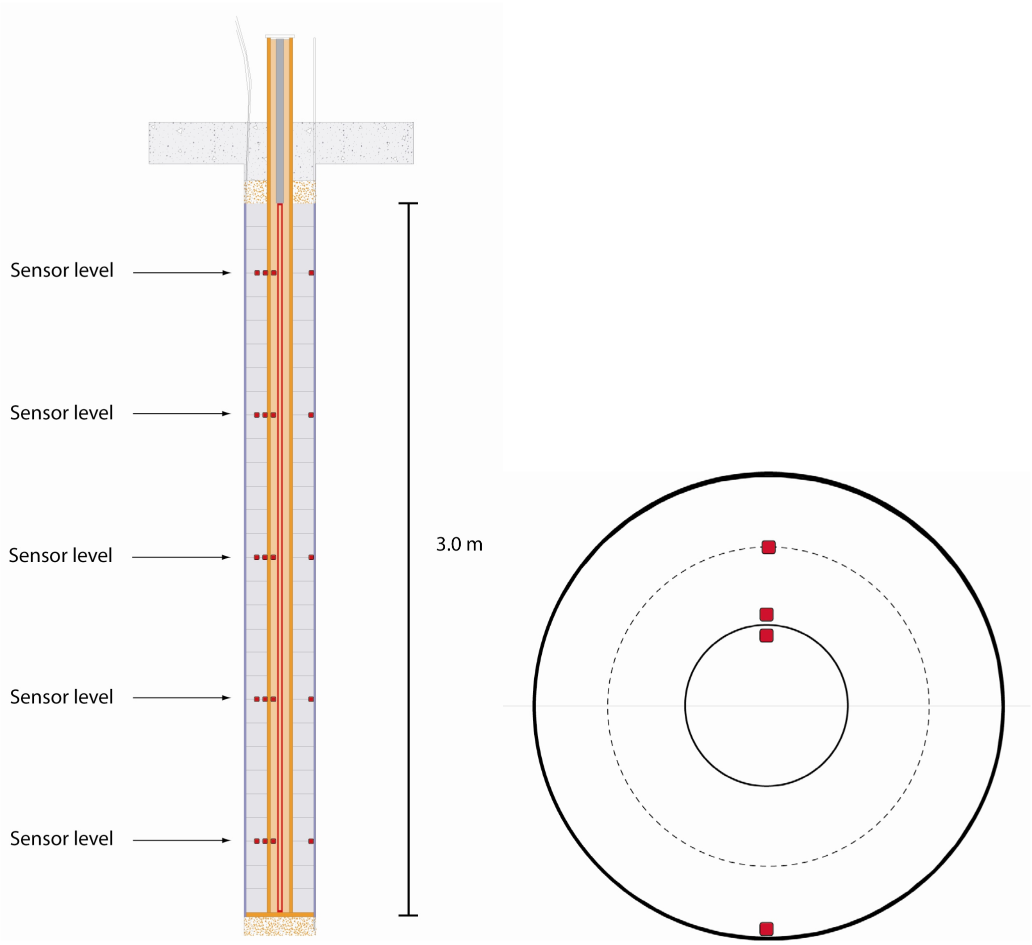


Figure 4. *Thermocouple sensor layout. The left image is an overview of the sensor level position. The right image shows the sensor layout within each level. The sensor levels are located on top of block number 3, 9, 15, 21 and 27, counting from the bottom and up.*

Figure 5. *Installation of thermocouple sensors. The left image shows the notches made to house the sensor shields. In the right image two sensors are installed. (The code 3:21 represents package 3, block 21.) The yellow stickers are temperature indicators, described in section 6.3.*

6.2 Relative humidity sensors

Relative humidity sensors (RH) are only installed in package number two. Heaters in package number two should not be activated until the buffer is completely saturated. For this reason the sensors are needed. The second package should be in operation for 2-4 years.

RH sensors are positioned according to Figure 8 below. One block only contains one sensor, either positioned in the left or right position. The sensors are installed on block number 3, 9, 22 and 28, these levels are the same as the thermocouples are mounted on with the exception of block number 15. Sensors are installed in pre drilled holes in the block, approximately 5 cm down. Distance between the sensor and the test block inner edge is 3 cm.

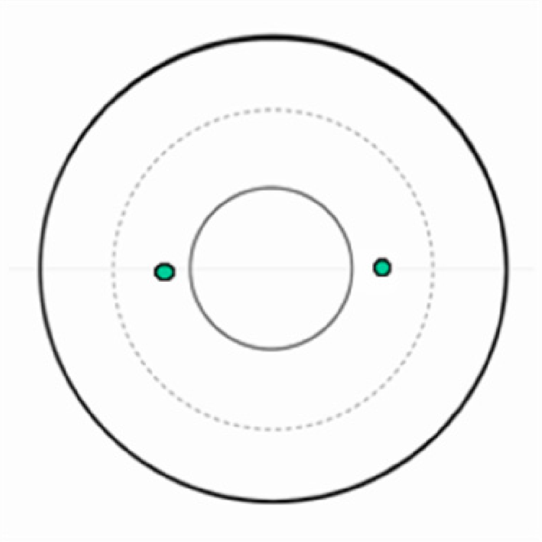


Figure 6. *Relative humidity sensor positions. The distance between the inner edge of the test block and the sensor is 3 cm. One block only contains one sensor, either positioned in the left or right position.*

The RH sensor is quite high and has a relatively large cable shield. To be able to install the sensor tip in the middle of a buffer block it was needed to put the sensor through the buffer block above. For that reason the sensor cable notch as well as a hole is made in the buffer block above the block that the sensor is installed in, Figure 7. The hole and notch are filled with bentonite powder of the same type as the buffer block after the sensor is installed, also shown in Figure 8

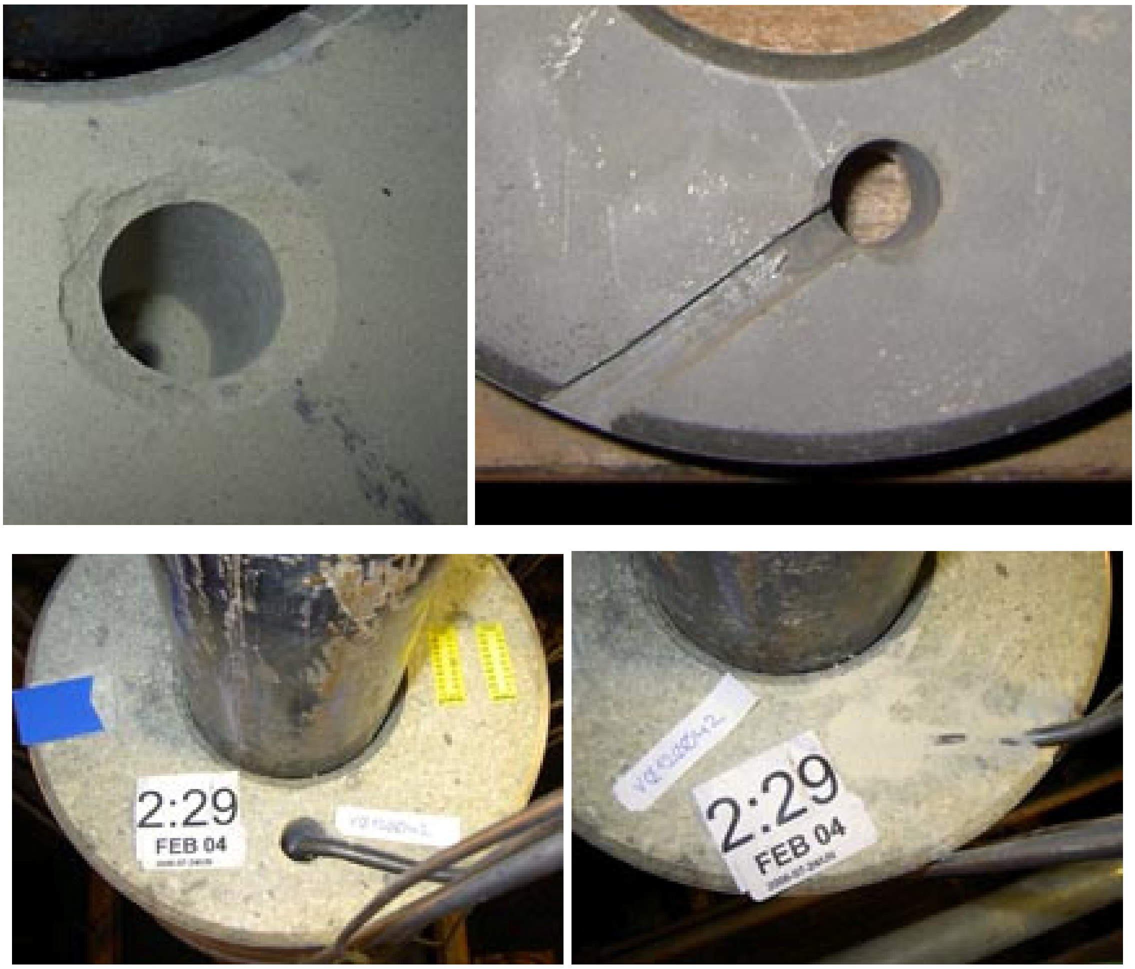


Figure 7. *Installation of a RH sensor. Upper left image shows the hole the sensor is installed in. Upper right is the hole and cable notch in the buffer block above the sensor block. Lower left shows a RH sensor installed in the blocks and finally the lower right image shows the completed installation after the hole and notch are filled with bentonite powder.*

6.3 Temperature indicators

The temperature indicators are offline type. This means that the sensors can only be read after the packages have been retrieved and disassembled. The sensors indicate the highest temperature that they have been exposed to. Two sensors are installed on top of each buffer block. The two sensors have different temperature interval, the inner sensor can indicate temperatures between 121 and 160°C in 8 steps. The outer sensors have an interval between 77 and 116°C, also with eight increments.

Distance from the inner edge to the first indicator is 3 cm. Distance between the outer edge of the test block and the second indicator is 3 cm. This also makes the distance between the sensors approximately 3 cm. Sensor positioning is shown in Figure 9. Indicators with the high temperature interval are placed closest to the heater pipe, Figure 10.

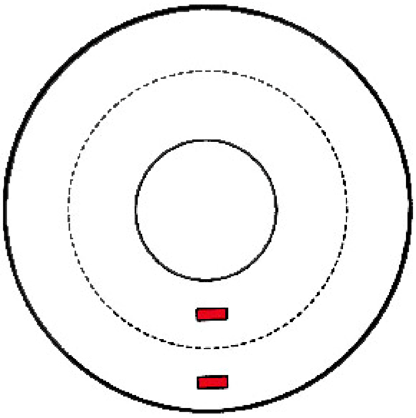


Figure 8. *The position and orientation of the temperature indicators located between each block. The inner indicator can indicate temperatures between 121 and 160°C and the outer temperatures between 77 and 116°C in eight steps. Two indicators are placed on all buffer block. A few indicators are also placed on the heater pipes and on granulate holding baskets.*

The use of the offline sensors are an interesting addition to the online sensors. Hopefully they will give good information about the temperature distribution throughout the experiment package length. This can of course also be shown with the online temperature sensors, but since the indicators are cheap and maintenance free we can easily use a large number of them to trace the temperature throughout the experiment packages with small distances between the measuring positions. The use of the indicators are regarded as a test, there are no guarantees that the sensors will endure the conditions they are exposed to during the experiment.

Indicators are also placed strategically on the heater pipes and on granulate holding baskets, Figure 9.

Figure 9. *Left: Temperature indicators in position on a buffer block. Two different ranges are used on the sensors. 77 to 116°C and 121 to 160°C. The higher range indicator is located closer to the heater pipe. Right: Indicators are also placed on the frame of the granulate holding cage as well as on the granulate.*

6.4 Sensor identification and orientation

Each online sensor is given a unique SKB number depending on package number, buffer block number and sensor position within the block. The ID codes are built from the template ”PXAxxxxxS”. Where P implies a singular point, XA represents the Alternative Buffer material project, “xxxxx” gives the sensor position within the packages and S indicates sensor type (T for temperature or M for relative Humidity (moisture)). Note that the temperature indicators are not given sensor ID codes.

A typical sensor ID code looks like this: PXA109:3T, where the PXA code is static, 109:3 is broken down to 1= package one, 09= buffer block 09, and :3 is the sensor position within the sensor level (in this case on the outer edge of the buffer block). Finally the T indicates that the sensor measures temperature. The SKB sensor ID code should not be mistaken for the manufacturer sensor ID code.

The online sensors are oriented identically in all packages. Figure 11 shows how the packages are oriented within the boreholes and experiment tunnel.

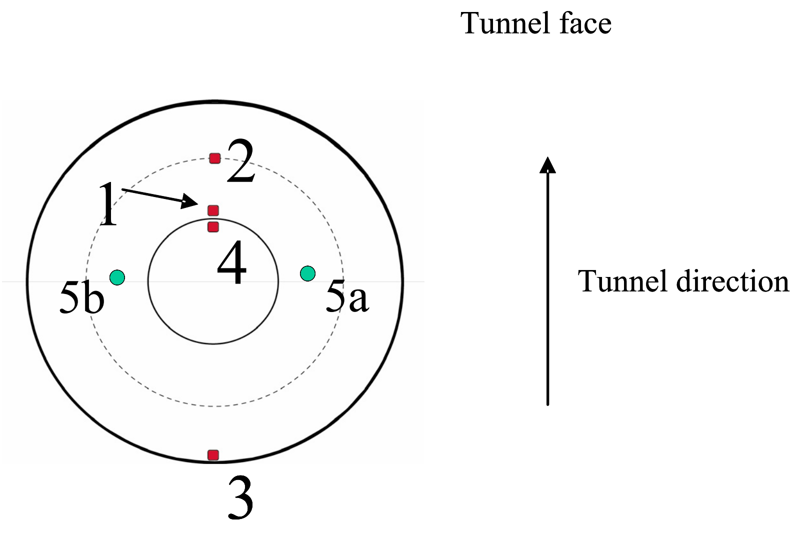


Figure 10. *Orientation of the sensors in the experiment tunnel, TASQ.*

Sensor ID codes, both SKB and manufacturer specific, are found in Appendix 3.

6.5 Monitor system

All online sensors and heaters are connected to the monitoring system. The system is logging data from all sensors. During the beginning of the experiment the log rate is set to once every 30 minutes to record the temperature increase period. The log rate will most likely be set to a longer time period, 1 to 2 hours between samples, when the system reaches steady state.

7 Saturation system

The saturation system aims at simulating water bearing fractures in the rock wall. This is done by installing four pipes along the outer edge of each package. The pipes are connected to a water tank at the experiment site. At the location of the simulated fractures small holes are drilled in the pipes, allowing water to leak onto the buffer blocks. Pipes are installed in all three packages even if the second package according to the plans should not be artificially saturated. This because of the apparent difficulties to, if needed, install a saturation system after the package is completely installed.

Two different variations in the hole drilling pattern are installed, mainly because of the different test times for the packages. Package number one, the short term package, has holes in the pipes every 10 cm. This will allow for quick saturation of the buffer. Package two and three have only three simulated fractures along the package, these are placed 1.0 m apart with the centre one at the mid height of the package.

Four pipes are used to lead water down to the package. They are connected two and two underneath the bottom buffer block, Figure 12. This makes it possible to "flush" the system is needed.

The pipes are titanium to withstand the harsh environment during the experiment. To avoid sand to enter the small holes and clog the "fracture" a perforated plastic "sock" is pulled over the pipes, Figure 12.

Äspö natural water is used in the saturation system.

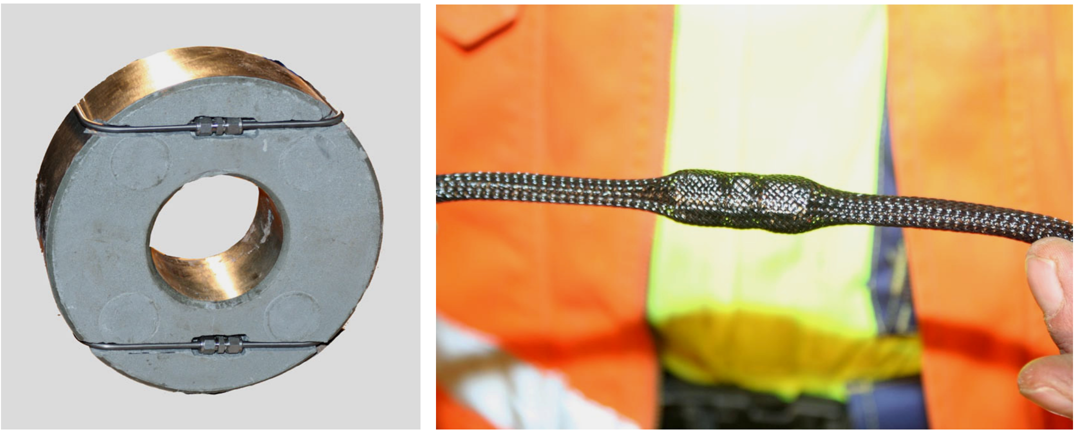


Figure 11. *Left: The pipes connect underneath the bottom buffer block. This allows the pipes to be flushed is needed. Right: A perforated plastic "sock" covers the pipes in order to prevent sand from clogging the water holes in the pipes.*

8 Granulate cage

As mentioned earlier not only buffer blocks are installed, but granulate as well. The experiment packages was assembled in the tunnel and then installed in the 300 mm deposit holes. To successful be able to install granulate “buffer blocks” some type of container or holding device was needed. A cage to hold the granulate was developed to fulfil the basic demands; hold the granulate in position during package assembly and installation, not introduce additional materials in the experiment package, the cage should also be as “invisible” as possible after installation and during the experiment, i.e. allow water flow and bentonite interaction etc. Long term life of the cage was not considered.

The solution was a steel frame wrapped with a fibre cloth. The steel frame will hold the weight of the buffer blocks above the cage and the cloth hold the granulates within the cage. The cage is open both at the top and bottom, the buffer block below the cage acts as floor for the granulates. The cage is shown in Figure 13. The steel frame of the cage is black steel, not corrosion protected by any means. The cloth was fastened to the steel frame using a thin steel wire.

The outer dimensions of the cages are the same as the bentonite buffer blocks, 10 cm high and a diameter of 28 cm.

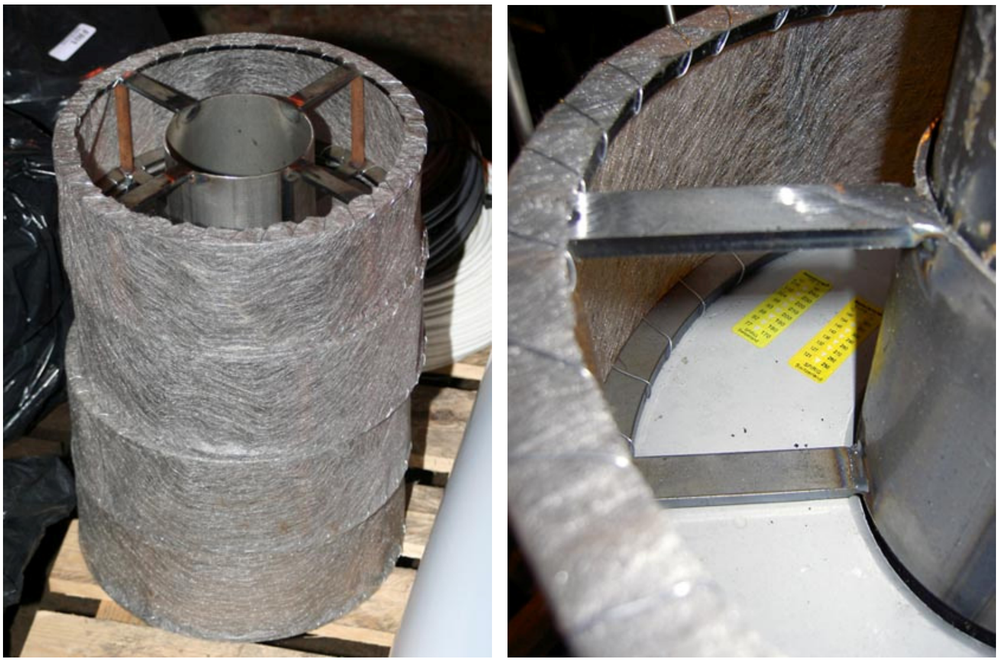


Figure 12. *The granulate cages consist of a steel frame wrapped with a fibre cloth. The steel frame holds the weight of the blocks placed above the granulate during installation, and the cloth prevents the granulate from falling out during package assembly. Left image shows four cages on top of each other. The right image shows a detailed view of an empty cage in position in the package. The top of the buffer block underneath act as floor of the cage.*

A cage filled with granulate is shown in Figure 17 on page 37.

9 Installation

This section describes the work conducted to completely assemble and install one experiment package. The same procedure was used on all three packages.

9.1 Preparation

A small amount of gravel was poured into the deposit hole. This was done to adjust the hole depth and even out the hole bottom to make a flat and stable surface for the steel pipe construction to rest on.

Since the backfill above the experiment package is simulated by a concrete block, a mould was constructed around the deposit hole, Figure 13. Four threaded steel rods were also fastened into the rock. The rods will be used to fasten the steel bars that will support the concrete block holding the package in position. A platform was mounted on top of the hole using the threaded bars. The steel pipe to be used was fastened right above the deposit hole. Figure 14. This makes the installation in the hole easy since the package only will need to be lifted straight up to remove the steel plate and then lowered into the hole.

Figure 13. *The steel pipe mounted above the deposit hole. The pipe is secured on top of a steel plate. The wooden construction around the deposit hole is the mould for the concrete block that will hold the package in position during the experiment.*

To protect the buffer blocks from the moist conditions in the tunnel the blocks were transported to the experiment site just before the assembly work was started. Only the blocks to be used in the current package were transported into the tunnel. The remaining blocks were left in the storage room. This means that the blocks that are kept as reference blocks in storage never have been down at the experiment site.

9.2 Package assembly

The artificial saturation system pipes are connected underneath the bottom block in the package. Therefore the first thing prepared were notches in the buffer block that the saturation system pipes can run in. With completed notches the block was threaded onto the pipe and placed together with the saturation pipes on its position. Figure 14 shows the notches done in the bottom block as well as the saturation pipes that run through the block.

Figure 14. *Notches for the saturation system pipes are being prepared in the first block to be mounted in the steel pipe. The notches are cut using a router, left image. The right image shows the completed result with the saturation pipes in position (though without the sand protector around the pipes).*

Through all assembly work effort was made to ensure that all notches made are deep and wide enough to house pipes and cable shields. If the notches are to narrow there would be gaps between the buffer blocks. The gaps leads water but also make the forces on the blocks from above uneven and the blocks might fracture. Block fracturing is mostly important to avoid in the assembly and installation work since fracturing can lead to material loss in the blocks.

Assembly of the buffer blocks are straightforward. The blocks are threaded onto the steel pipe in accordance with the buffer material table, Table 4 on page 41. A small plastic indicator is also placed between the blocks that are not separated with sensor cables, this will ease the block identification at the package disassembly, Figure 16. Temperature indicators and other sensors, if any, are installed and photographed. Each block is photographed and the block identification number noted in an installation record. One installation record is filled for each block and each on-line sensor installed.

Figure 15. *A small blue plastic plate is placed between each block, to the right in the image This will help identify the blocks during the package disassembly. The picture shows the eleventh block in the first experiment package, this is a MX80 block (ID code LOT 03). To the left the two temperature indicators can be seen.*

In case of the "block" being granulate, the cage is threaded onto the pipe and filled with granulate, Figure 17. The granulate are compacted using only hand force. When the container is completely full, the total weight of the installed granulate is noted in the installation record.

Figure 16. *The cage is filled with granulate, left. A completed cage to the right.*

When all blocks were in position the sensor cables and saturation pipes were aligned along the package and secured at the top, Figure 18. Since the gap between the package and the deposit hole wall is narrow, it was important no to have any sensor cables crossing each other. That would make the package wider and more difficult to install with an increased risk of damaging the sensors.

To protect the package from moist during installation and also during the time from finishing the assembly to the actual installation in the deposit hole (typically over night) plastic was used. A plastic tube, more commonly used to lead air in temporary ventilation systems, was used for the first assembled package. Since the tube was somewhat difficult to work with plastic film was used for the following packages. The plastic film was found to be a very good solution to protect the package, easy to apply and easy to remove.

All sensor shields were also painted with corrosion protection from the uppermost buffer block and approximately 50 cm upwards, this to prevent corrosion at the section where the concrete will be in contact with the cable shields.

Figure 17. *Left: Package two thirds finished, wrapped in plastic. Right: Finalizing the second package assembly with sensors cable aligning and plastic wrapping.*

9.3 Package installation

Installation of the package was done the day after the assembly. All three packages took one day for assembly and one day for installation each. The work was planned in order to be able to install a package in the deposit hole the day after the assembly was finished. This to avoid the buffer blocks to be affected of the moist conditions in the tunnel during a weekend.

All three packages were installed in the same way. Only minor changes were done in the procedure between the packages.

A winch was mounted in the tunnel roof above the package and a chain fastened at the top of the heater pipe. The package was then lifted somewhat to allow for the plate covering the deposit hole and serving as assembly support for the package to be removed. The package was then carefully lowered into the deposit hole while removing the covering plastic.

With the package entirely lowered into the deposit hole the 10 mm slot between the rock and package was filled with sand. The sand acts as water distribution material. For the first package unsorted sand was used. The sand was poured into the hole from the top using a hose. This showed to be a difficult task since the sand got stuck in the hose and lumps was formed in the slot hindering the sand from falling down to the bottom. This made the sand filling time consuming and the risk of forming air pockets significant. To avoid this problem sand with a specific grain size was used to fill the slots during installation of the second and third package, Figure 19. To further dry the rock wall prior installation (package two and three) a dry air blower was used together with the pump removing the water from the holes. Filling of the slot was significantly easier with the new sand and the dryer walls.

Figure 18. *The sand used to fill the slot between the package and rock wall during installation of the second and third package. The sand contains grains of only one size which reduces the risk of lumps forming during the work. The sand will distribute water from both the saturation system and the natural fractures along the packages.*

Instead of sand, granulate was poured into the slot at the uppermost 10 cm of all packages, Figure 20. The purpose of the granulate is to quickly get a seal stopping water from leaking into the hole from the tunnel floor.

Figure 19. *The uppermost 10 cm of the slot in all three packages were filled with granulate instead of sand. The granulate will quickly seal the package from water leaking into the hole from the tunnel. A small amount of granulate was also placed on top of the package*

Concrete was then poured into the mould surrounding the deposit hole. The concrete used is armed using fibre and not ordinary concrete armour steel. Since the packages will be retrieved by drilling a slot around the package ordinary armour would be in the way.

Once the concrete hardened the mould could be removed and the steel bars on top of the concrete plate installed. Two steel bars are used at each package to hold the concrete plate in position,

Figure 20. *Left: Casting of the concrete block holding the package in place. Right: The concrete block is completed and the two supporting bars are in position. The package installation is completed.*

10 Buffer block installation order

The order in which the blocks are mounted in the packages is derived in such a way that one material type should not be positioned next to another type at more than one position throughout the packages. This maximizes the different material interaction possibilities. The puzzle was completed with only a few duplicates in block neighbours. Additional MX-80 blocks are installed at both top and bottom of the packages to serve as both temperature and water insulators. The complete block order for all three packages is given in Table 4. A corresponding table with block ID numbers can be found in Appendix 4.

Table 4. The block order in each of the three packages. The positions with "Callovo Oxfordian discs" represent two discs.

Block number	Package 1	Package 2	Package 3
31	Not installed	MX80	MX80
30	MX80	MX80	MX80
29	MX80	Febex	Ibeco Seal
28	Ikosorb	Ikosorb	Rokle
27	Deponit	MX80 granulate	Febex
26	Ibeco Seal	Deponit	MX80
25	Friedland	MX80 granulate +quartz	Friedland
24	Asha 505	Rokle	Callovo-Oxfordian discs
23	Calcigel	Friedland	Callovo-Oxfordian
22	Callovo-Oxfordian	Kunigel V1	Kunigel V1
21	Febex	Asha 505	Deponit
20	MX80 granulate	Callovo-Oxfordian discs	Calcigel
19	MX80 granulate +quartz	Callovo-Oxfordian	MX80 granulate
18	MX80	Calcigel	Asha 505
17	Kunigel V1	MX80	Ikosorb
16	Rokle	Callovo-Oxfordian	MX80 granulate +quartz
15	Deponit	Ibeco Seal	Friedland
14	Asha 505	MX80 granulate +quartz	MX80 granulate
13	Rokle	Kunigel V1	Ibeco Seal
12	Callovo-Oxfordian	Ikosorb	Kunigel V1
11	MX80	Ibeco Seal	Febex
10	Ikosorb	Asha 505	Deponit
9	Friedland	Febex	Callovo-Oxfordian
8	Febex	MX80 granulate	Ikosorb
7	MX80 granulate +quartz	Rokle	Rokle
6	Ibeco Seal	MX80	Calcigel
5	Calcigel	Deponit	MX80 granulate +quartz
4	Kunigel V1	Friedland	Asha 505
3	MX80 granulate	Calcigel	MX80
2	MX80	MX80	MX80
1	MX80	MX80	MX80

11 Observations

Some observations have been made during both the assembly, installation work and the first period of the test.

During the assembly work the block order was somewhat changed. At one position a Callovo-oxfordian remoulded block was supposed to house on line sensors. Since those blocks were difficult to process and fragile it was decided not to drill the holes for the sensors. Instead the position of the block was changed. For that reason no Callovo-oxfordian blocks are equipped with on line sensors.

Several Calcigel buffer blocks showed damage at the end of the day of assembly. The surface of the blocks was fractured and pieces had fallen off. In Figure 22 an example of a undamaged block prior installation and the same block at the end of the assembly work of the first package is shown. Damages can be due to the compressive force from the blocks above, the moist conditions at the experiment site, or both.

Figure 21. *Left: A Calcigel block prior installation (block 1:05). Right: The same Calcigel block as to the left is showing damages shortly after the completion of the first package assembly. The surface was fractured and pieces had fallen off the block.*

To minimize the risk for buffer erosion the saturation system was not started until after about one month after the installation was completed. After the system was activated it was observed that a large amount of water was inserted in the packages. It was concluded that the water inserted into the system had to disappear through fractures in the rock wall. To further minimize the possibilities of buffer erosion the saturation system was stopped. The system will be activated later when the buffer have had a chance to seal the fractures.

A couple of months after the installation was finished fractures was beginning to show on the concrete blocks holding packages number two and three in position. The supporting bars also showed some buckling. The bars were exchanges to more heavy duty bars and the fractures grouted to seal the fractures. After another two months more fractures was visible on the concrete blocks. The new fractures have not been grouted since no bentonite leakage has been observed neither around the concrete blocks of in any fractures. The need for further grouting is limited since the main purpose of the block is to hold the packages in position and not to seal the deposit hole.

Appendix

Appendix 1

Result from compaction tests with the compaction pressure of 100 MPa

Material	Sample	D(par) kg/m³	w	Sr	e	D(dry) kg/m³
Ikosorb	IKO18	2102	0,192	0,926	0,58	1763
	IKO20	2090	0,204	0,942	0,60	1736
	IKO22	2077	0,213	0,950	0,62	1712
Deponit CAN	CAN19	2085	0,182	0,878	0,58	1764
	CAN21	2076	0,193	0,898	0,60	1740
	CAN23	2070	0,207	0,928	0,62	1715
	CAN25	2054	0,223	0,947	0,66	1679
Ibeco Seal M-90	IBE19	2119	0,189	1,043	0,56	1782
	IBE21	2100	0,206	1,069	0,60	1741
	IBE23	2095	0,211	1,075	0,61	1730
Friedland	FRI06	2307	0,058	0,655	0,28	2180
	FRI08	2367	0,078	0,906	0,27	2196
	FRI10	2361	0,095	1,017	0,29	2156
	FRI12	2333	0,112	1,064	0,33	2098
	FRI14	2328	0,123	1,116	0,34	2073
	FRI16	2266	0,147	1,116	0,41	1976
	FRI18	2238	0,161	1,126	0,44	1928
	FRI20	2193	0,178	1,114	0,49	1862
Asha 505	ASH01	2131	0,094	0,614	0,43	1948
	ASH02	2177	0,164	0,936	0,49	1870
	ASH03	2193	0,176	0,995	0,49	1865
	ASH00	2167	0,121	0,770	0,44	1933
Calcigel	CAL07	2012	0,091	0,499	0,51	1844
	CAL09	2044	0,108	0,591	0,51	1845
	CAL11	2047	0,109	0,600	0,51	1846
	CAL13	2084	0,121	0,679	0,50	1859
	CAL15	2109	0,140	0,773	0,50	1850
	CAL17	2125	0,154	0,841	0,51	1840
	CAL19	2121	0,174	0,898	0,54	1806
	CAL21	2103	0,189	0,920	0,57	1769
	CAL23	2091	0,202	0,940	0,60	1739
	CAL25	2074	0,215	0,952	0,63	1706

Material	**Sample**	**D(par) kg/m³**	**w**	**Sr**	**e**	**D(dry) kg/m³**
Febex	FEB017	2077	0,188	0,887	0,59	1747
	FEB019	2072	0,199	0,909	0,61	1728
	FEB021	2061	0,214	0,932	0,64	1698
Kunigel V1	JNB08	2144	0,080	0,555	0,40	1986
	JNB10	2200	0,100	0,712	0,39	2000
	JNB12	2210	0,120	0,817	0,41	1972
	JNB14	2201	0,135	0,866	0,43	1939
	JNB16	2176	0,154	0,901	0,47	1886
	JNB18	2154	0,169	0,923	0,51	1843
	JNB20	2134	0,186	0,950	0,55	1799
Callovo Oxfordian	COB	2254	0,026	0,270	0,26	2198
Rokle	ROK10	1980	0,091	0,477	0,53	1814
	ROK12	2033	0,118	0,619	0,53	1819
	ROK14	2065	0,134	0,707	0,53	1821
	ROK16	2093	0,150	0,789	0,53	1820
	ROK20	2139	0,182	0,945	0,54	1809
	ROK24	2114	0,218	1,006	0,60	1736

Explanation: 1) Sample name, name of the sample tested, 2) density after compaction measured with paraffin method, 3) water ration measured after 24 h in 105°C, 4) calculated saturation ratio, 5) calculated void ratio, 6) calculated dry density.

Appendix 2

Block measurements

Quality Control at manufacturing of ALBUM-block 2006
Measurements made after demoulding
Date 06-07-19 - 06-08-01
Responsible UN

Block	m	dy	Dy	Di	h1	h2	h3	note	Volume	Volume calc	Density
	g	mm	mm	mm	mm	mm	mm		mm³	mm³	g/cm³
IKO1	10681,0	275,8	279,4	110,0	99,4	99,1	99,4	Minor damage	5066,370	5029,314	2,124
IKO2	10693,0	275,8	279,1	109,6	99,6	99,7	99,8		5086,051	5048,995	2,118
IKO3	10710,0	275,8	279,5	110,1	99,8	100,0	99,7		5094,032	5056,976	2,118
IKO4	10733,0	276,2	279,5	109,9	99,9	99,4	99,7		5097,669	5060,613	2,121
IKO5	10706,0	276,2	279,1	110,1	99,4	99,5	99,4		5072,772	5035,716	2,126
IKO6	10711,0	276,2	279,8	110,1	99,3	99,4	99,1		5081,138	5044,082	2,123
IKO7	10716,0	276,0	279,9	110,1	99,0	99,1	99,1		5067,882	5030,825	2,130
IKO8	10710,0	276,4	279,8	110,2	99,5	100,0	99,9		5110,207	5073,151	2,111
IKO9	10707,0	276,3	280,0	110,2	99,6	100,1	100,2		5120,071	5083,015	2,106
CAN1	10561,0	276,7	279,1	110,1	101,1	101,0	101,2	block stuck	5170,567	5133,510	2,057
CAN2	10582,0	276,1	279,4	109,9	102,1	102,3	102,1	Cracks	5221,079	5184,023	2,041
CAN3	10529,0	275,0	279,2	110,1	104,2	104,6	104,8	Cracks	5308,802	5271,745	1,997
CAN4	10523,0	275,6	279,1	110,0	101,4	101,7	101,5		5169,253	5132,197	2,050
CAN5	10064,0	275,7	279,6	110,0	102,8	102,7	102,8		5245,483	5208,427	1,932
CAN6	10590,0	275,2	279,0	109,7	102,1	102,6	102,4		5205,835	5168,778	2,049
CAN7								Total loss			
CAN8	10584,0	275,4	279,1	110,1	102,3	102,1	102,3		5198,671	5161,615	2,051
CAN9	10600,0	275,7	279,7	109,9	101,9	102,4	101,9		5213,742	5176,686	2,048
CAN10	10590,0	275,5	279,7	109,9	104,0	104,1	104,1	Cracks	5311,367	5274,311	2,008
IBE1	10736,0	276,0	279,6	110,1	100,0	99,9	99,9	Cracks	5105,674	5068,618	2,118
IBE2	10776,0	276,4	280,0	110,2	100,1	100,2	100,2		5133,359	5096,302	2,114
IBE3	10776,0	275,6	279,6	110,0	100,8	100,9	100,8		5144,602	5107,546	2,110
IBE4	10767,0	276,5	280,0	110,1	100,3	100,2	99,8		5133,861	5096,805	2,112
IBE5	10759,0	276,4	279,6	109,9	100,2	100,2	100,4		5134,923	5097,867	2,110

Block	**m**	**dy**	**Dy**	**Di**	**h1**	**h2**	**h3**	**note**	**Volume**	**Volume calc**	**Density**
	g	**mm**	**mm**	**mm**	**mm**	**mm**	**mm**		**mm³**	**mm³**	**g/cm³**
IBE6	10752,0	276,3	280,1	110,1	101,1	100,6	100,7		5166,459	5129,403	2,096
IBE7	10772,0	277,0	280,0	110,2				Broken			
IBE8	10750,0	276,0	279,9	110,0	99,8	100,1	100,0		5115,650	5078,594	2,117
IBE9	10722,0	276,0	280,1	110,3	100,2	100,1	100,2	Piece of at the rim	5123,114	5086,057	2,108
IBE10	10781,0	276,3	280,0	110,2	100,5	100,6	100,6		5151,661	5114,605	2,108
FRI1	11709,0	276,5	280,6	110,2	101,0	101,1	101,0	Minor damage	5192,380	5155,323	2,271
FRI2	11716,0	276,2	280,5	110,5	100,6	100,5	100,7	Minor damage	5156,931	5119,875	2,288
FRI3	11717,0	276,4	280,0	110,3	100,1	100,2	100,1		5129,916	5092,860	2,301
FRI4	11731,0	276,8	280,4	110,2	101,2	100,8	101,0		5193,733	5156,677	2,275
FRI5	11714,0	277,6	280,1	110,3	100,5	100,8	100,3	Minor damage	5178,998	5141,942	2,278
FRI6	11424,0	276,8	280,5	110,3	98,0	98,1	98,3		5046,768	5009,712	2,280
FRI7	11680,0	276,8	280,1	110,6	100,1	100,1	100,9		5147,616	5110,560	2,285
FRI8	11733,0	276,5	280,4	110,1	100,4	100,4	100,9		5166,590	5129,533	2,287
FRI9	11733,0	276,9	280,3	110,2	100,8	100,8	100,4		5177,473	5140,417	2,282
ASH1	11023,0	276,7	280,2	110,1	100,7	100,6	100,7		5171,727	5134,671	2,147
ASH2	10945,0	276,5	280,4	110,0	100,7	100,7	100,7	Minor damage	5175,180	5138,124	2,130
ASH3	11010,0	277,5	280,4	110,3	100,4	100,6	100,6	Minor damage	5183,402	5146,346	2,139
ASH4	11024,0	276,7	280,4	110,3	100,4	100,5	100,5		5162,369	5125,313	2,151
ASH5	10992,0	276,7	280,3	110,4	100,8	101,1	100,9	Minor damage	5182,391	5145,335	2,136
ASH6	10963,0	276,5	280,4	110,3	100,9	100,4	100,4	Minor damage	5163,108	5126,052	2,139
ASH7	11024,0	276,8	280,4	110,1	100,9	100,8	100,9		5188,622	5151,565	2,140
ASH8	11007,0	276,7	280,3	110,0	100,7	100,8	100,9	Minor damage	5182,524	5145,468	2,139
ASH9	11022,0	276,6	280,6	110,3	100,8	101,1	101,0		5190,270	5153,214	2,139
CAL1	10043,0	277,0	282,5	110,3	101,4	101,4	101,4	Minor damage	5263,683	5226,626	1,922
CAL2	10189,0	276,8	280,4	110,6	99,8	99,7	100,3	Minor damage	5131,949	5094,893	2,000
CAL3	10230,0	276,4	280,0	110,4	98,1	98,6	98,8		5044,532	5007,476	2,043
CAL4	10183,0	276,3	281,0	110,5	100,1	100,4	100,6		5158,142	5121,086	1,988
CAL5	10250,0	276,0	280,5	110,6	9,4	99,9	99,6		3565,272	3528,216	2,905
CAL6	10166,0	276,7	280,5	109,5	100,8	100,6	100,5		5187,033	5149,977	1,974
CAL7	10187,0	277,4	281,2	110,3	101,6	101,5	101,6		5252,266	5215,210	1,953
CAL8	10202,0	276,7	280,7	110,4	99,8	99,9	99,6	Minor damage	5131,221	5094,164	2,003
CAL9	10199,0	277,3	281,1	110,6	98,5	98,6	98,9		5092,837	5055,780	2,017

Block	m	dy	Dy	Di	h1	h2	h3	note	Volume	Volume calc	Density
	g	mm	mm	mm	mm	mm	mm		mm^3	mm^3	g/cm^3
FEB1	10541,0	276,5	280,1	110,1	101,1	101,3	101,6	Minor damage	5199,330	5162,274	2,042
FEB2	10569,0	276,2	280,1	110,1	100,5	100,6	100,7		5155,109	5118,053	2,065
FEB3	10544,0	276,7	280,1	110,4	101,0	101,5	101,0	Minor damage	5189,091	5152,035	2,047
FEB4	10573,0	276,2	280,3	110,3	100,7	100,8	100,9		5166,956	5129,900	2,061
FEB5	10568,0	276,5	280,3	110,3	100,5	100,5	100,7		5160,909	5123,853	2,063
FEB6	10551,0	276,4	280,2	110,2	100,5	100,5	100,5	Minor damage	5154,834	5117,778	2,062
FEB7	10500,0	276,7	280,1	110,3	100,7	100,9	100,9	Minor damage	5174,594	5137,538	2,044
FEB8	10493,0	276,7	280,1	110,2	101,1	100,8	101,1	Minor damage	5184,896	5147,840	2,038
FEB9	10165,0	276,5	280,1	110,2	97,5	97,4	97,6		5000,958	4963,902	2,048
JNB1	10858,0	276,7	280,4	110,5	98,8	99,1	98,8		5078,437	5041,381	2,154
JNB2	10842,0	276,1	280,1	110,1	98,5	98,6	99,5		5064,127	5027,071	2,157
JNB3	10866,0	276,5	280,4	110,4	99,1	99,5	99,0		5091,224	5054,167	2,150
JNB4	10875,0	277,0	280,2	110,6	99,3	99,4	99,3		5101,137	5064,081	2,147
JNB5	10898,0	277,0	280,3	110,4	98,9	99,0	98,9		5086,195	5049,139	2,158
JNB6	10872,0	277,0	280,0	109,8	99,5	99,4	99,5		5117,407	5080,350	2,140
JNB7	10907,0	276,9	280,0	110,4	99,1	99,2	99,6		5096,356	5059,300	2,156
JNB8	10899,0	276,4	280,0	110,2	99,3	99,5	99,4		5094,068	5057,012	2,155
JNB9	10891,0	277,0	280,3	110,4	99,2	99,3	99,7	Minor damage	5110,187	5073,130	2,147
COB1	11455,0	276,7	280,2	110,3	102,0	102,2	102,1		5241,830	5204,773	2,201
COB2	11462,0	276,7	280,4	110,3	101,5	101,6	101,7		5219,748	5182,692	2,212
COB3	11460,0	276,7	280,4	110,1	101,6	101,6	101,7		5224,979	5187,922	2,209
COB4	11473,0	276,7	280,9	110,1	101,3	101,6	101,7		5230,946	5193,890	2,209
COB5	11213,0	276,6	283,6	110,3	100,7	100,4	100,3		5230,695	5193,638	2,159
COB6	11459,0	276,5	280,2	110,4	101,5	101,5	101,6		5206,537	5169,481	2,217
COB7	11157,0	276,5	280,7	110,5	101,5	101,1	101,1		5200,467	5163,411	2,161
COB8	11450,0	276,6	280,4	110,3	100,9	100,9	101,2		5187,564	5150,508	2,223
COB9	11463,0	276,7	280,5	110,0	101,0	101,0	101,1		5198,941	5161,885	2,221
ROK1	11706,0	276,4	281,2	110,0	116,8	116,6	116,7	Overweight	6015,330	5978,274	1,958
ROK2	10695,0	277,6	281,1	109,1	107,0	107,4	107,7	Damaged surface	5576,755	5539,699	1,931
ROK3	10688,0	277,0	280,8	110,3	105,2	105,1	105,4		5423,425	5386,368	1,984
ROK4	10695,0	277,5	281,2	110,1	106,2	106,2	106,1		5496,148	5459,092	1,959
ROK5	10734,0	277,2	281,2	110,5	106,4	106,5	106,4		5495,574	5458,517	1,966

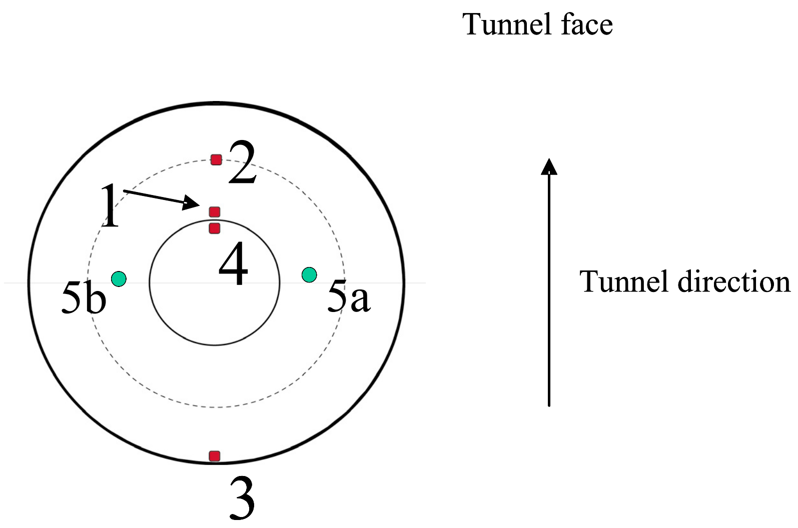
Block	m	dy	Dy	Di	h1	h2	h3	note	Volume	Volume calc	Density
	g	mm	mm	mm	mm	mm	mm		mm³	mm³	g/cm³
ROK6	10705,0	277,1	280,6	110,1	106,4	106,1	106,4		5479,749	5442,693	1,967
ROK7	10789,0	276,4	279,5	110,4	107,1	107,0	107,0		5469,866	5432,810	1,986
ROK8	10780,0	276,9	281,3	110,6	109,4	109,7	109,6		5650,653	5613,597	1,920
ROK9	10747,0	276,9	281,5	110,4	112,2	112,3	112,1		5795,276	5758,220	1,866
LOT1	10639,0	276,6	280,0	110,1	100,1	99,5	100,0		5124,077	5087,021	2,091
LOT2	10636,0	276,6	280,0	110,3	100,1	100,5	100,5		5146,257	5109,201	2,082
LOT3	10639,0	276,2	280,1	110,2	100,1	100,3	100,2		5132,878	5095,822	2,088
LOT4	10595,0	276,5	280,1	110,3	100,9	100,5	100,6		5161,639	5124,583	2,067
LOT5	10640,0	276,9	279,6	110,0	100,5	100,6	100,7		5161,244	5124,188	2,076
LOT6	10455,0	276,2	280,0	110,2	89,2	98,0	98,2		4871,253	4834,197	2,163
LOT7	10635,0	276,3	279,4	110,0	101,5	101,5	101,0		5181,164	5144,108	2,067
LOT8	10186,0	276,5	279,9	110,2	101,0	100,2	100,4	Damaged top	5152,150	5115,093	1,991
LOT9	10446,0	276,5		110,1				Damaged top			
LOT10	10650,0	276,1	280,0	110,1	99,1	99,2	98,9		5072,208	5035,152	2,115
LOT11	10653,0	276,1	280,1	110,2	99,3	99,2	99,3		5082,898	5045,842	2,111
LOT12	10637,0	277,2	280,2	110,2	99,9	99,9	99,8		5139,824	5102,768	2,085
LOT13	10635,0	276,6	279,9	110,2	99,6	99,6	99,8		5109,912	5072,856	2,096
LOT14	10628,0	276,3	279,8	110,0	99,4	99,6	99,8		5101,236	5064,180	2,099
LOT15	10642,0	276,3	279,9	110,2	100,1	100,1	100,3		5128,982	5091,926	2,090
LOT16	10644,0	276,3	280,1	110,2	100,3	100,5	100,3		5143,608	5106,552	2,084
LOT17	10638,0	276,3	279,7	110,2	100,6	100,6	100,1		5138,250	5101,194	2,085
LOT18	10630,0	276,3	280,0	110,2	99,4	99,4	99,2		5088,482	5051,425	2,104
LOT19	10583,0	276,3	280,3	110,2	99,5	99,5	99,6	Damaged bottom	5105,252	5068,196	2,088
LOT20	10639,0	276,7	280,0	110,2	99,9	99,9	99,9		5126,243	5089,186	2,091
LOT21	10640,0	276,0	280,1	110,1	100,0	99,9	100,0		5118,288	5081,231	2,094
LOT22	10631,0	276,3	280,2	110,0	99,6	99,7	99,8		5115,070	5078,014	2,094
LOT23	10634,0	276,5	280,2	110,1	100,4	100,7	100,7		5163,903	5126,847	2,074
LOT24	10637,0	276,1	280,2	110,2	100,4	100,6	100,7		5151,661	5114,605	2,080
LOT25	10568,0	276,7	280,2	110,2	100,2	100,1	100,1	Damaged bottom	5142,595	5105,539	2,070
LOT26	10638,0	276,5	280,2	110,2	101,0	101,0	100,8		5179,267	5142,211	2,069
LOT27	10644,0	276,4	280,3	110,2	100,7	100,4	100,8		5163,873	5126,816	2,076

Explanation: 1) block name combination of material and serial number, 2) mass of the block, 3) smallest diameter, 4) largest diameter, 5) diameter of the hole in the middle, 6) – 8) height of the block on three places, 9) comments, 10) volume of the block, 11) volume with compensations for washers, 12) calculated bulk density.

Appendix 3

This document describes the position, ID codes and Sicada ID codes of the sensors in the packages.

The sensors are numbered: Package number : block number : sensor number.
The sensor closest to the heater pipe is number 1, the sensor in the middle of the block number 2 and the outer sensor 3.
Example: The outer sensor in block 27 in package one is numbered 1:27:3.
Sensor number 4 is mounted inside the heater pipe.
Relative humidity (RH) sensors are installed in position 5, only present in package number two.



Package 1: Deposit hole KQ0032G01

Block	Position	Sensor ID	Sensornumber	Distance, heater pipe - sensor (cm). i = inside heater pipe.	SICADA ID
27	4	06341158	1:27:4	i	PXA127:4T
27	3	06341150	1:27:3	6	PXA127:3T
27	2	06341159	1:27:2	4	PXA127:2T
27	1	06341151	1:27:1	0,5	PXA127:1T
21	4	06341103	1:21:4	i	PXA121:4T
21	3	06341108	1:21:3	6	PXA121:3T
21	2	06341104	1:21:2	4	PXA121:2T
21	1	06341101	1:21:1	0	PXA121:1T
15	4	06341247	1:15:4	i	PXA115:4T
15	3	06341249	1:15:3	6,5	PXA115:3T
15	2	06341248	1:15:2	4	PXA115:2T
15	1	06341241	1:15:1	0	PXA115:1T
9	4	06341167	1:9:4	i	PXA109:4T
9	3	06341168	1:9:3	6	PXA109:3T
9	2	06341171	1:9:2	4	PXA109:2T
9	1	06341172	1:9:1	0	PXA109:1T
3	4	06341077	1:3:4	i	PXA103:4T
3	3	06341067	1:3:3	7	PXA103:3T
3	2	06341066	1:3:2	4	PXA103:2T
3	1	06341076	1:3:1	0	PXA103:1T

Package 2: Deposit hole KQ0036G01

Block	Position	Sensor ID	Sensornumber	Distance, heater pipe - sensor (cm). i = inside heater pipe.	SICADA ID
28	3	06341160	2:28:3	6	PXA228:3T
28	2	06341154	2:28:2	4	PXA228:2T
28	1	06341152	2:28:1	0	PXA228:1T
28	4	6341153	2:28:4	i	PXA228:4T
22	3	06341106	2:22:3	6	PXA222:3T
22	2	06341105	2:22:2	4	PXA222:2T
22	1	06341107	2:22:1	0	PXA222:1T
22	4	06341102	2:22:4	i	PXA222:4T
15	3	06341244	2:15:3	6,5	PXA215:3T
15	2	06341245	2:15:2	4	PXA215:2T
15	1	06341242	2:15:1	0	PXA215:1T
15	4	06341240	2:15:4	i	PXA215:4T
9	3	06341169	2:9:3	6	PXA209:3T
9	2	06341173	2:9:2	4	PXA209:2T
9	1	06341170	2:9:1	0	PXA209:1T
9	4	06341165	2:9:4	i	PXA209:4T
3	3	06341075	2:3:3	6	PXA203:3T
3	2	06341073	2:3:2	4	PXA203:2T
3	1	06341074	2:3:1	0	PXA203:1T
3		06341070	2:3:4	i	PXA203:4T
RH:					
28	5a	V0120042	2:28:5	3	PXA228:5M
22	5b	V0120023	2:22:5	3	PXA222:5M
9	5a	V0120052	2:9:5	3	PXA209:5M
3	5b	V0120022	2:3:5	3	PXA203:5M

Package 3: Deposit hole KQ0040G01

Block	Position	Sensor ID	Sensornumber	Distance, heater pipe - sensor (cm). i = inside heater pipe.	SICADA ID
27	4	06341157	3:27:4	i	PXA327:4T
27	3	06341155	3:27:3	6	PXA327:3T
27	2	06341161	3:27:2	4	PXA327:2T
27	1	06341156	3:27:1	0	PXA327:1T
21	4	06341100	3:21:4	i	PXA321:4T
21	3	06341109	3:21:3	6	PXA321:3T
21	2	06341098	3:21:2	4	PXA321:2T
21	1	06341099	3:21:1	0	PXA321:1T
15	4	06341238	3:15:4	i	PXA315:4T
15	3	06341243	3:15:3	6	PXA315:3T
15	2	06341239	3:15:2	4	PXA315:2T
15	1	06341246	3:15:1	0	PXA315:1T
9	4	06341162	3:9:4	i	PXA309:4T
9	3	06341163	3:9:3	6	PXA309:3T
9	2	06341166	3:9:2	4	PXA309:2T
9	1	06341164	3:9:1	0	PXA309:1T
3	4	06341072	3:3:4	i	PXA303:4T
3	3	06341068	3:3:3	6	PXA303:3T
3	2	06341069	3:3:2	4	PXA303:2T
3	1	06341071	3:3:1	0	PXA303:1T

Appendix 4

This appendix contains the buffer block installation order of the buffer blocks within the packages including the block ID codes.

Package 1 buffer block ID codes

Block number	Material	Block ID
30	MX80	LOT06
29	MX80	LOT05
28	Ikosorb	IKO02
27	Deponit	CAN02
26	Ibeco Seal	IBE02
25	Friedland	FRI2
24	Asha 505	Asha05
23	Calcigel	CAL03
22	Callovo-Oxfordian	COB02
21	Febex	FEB02
20	MX80 granulate	Granulate weight not measured
19	MX80 granulate +quartz	Granulate weight not measured
18	MX80	LOT04
17	Kunigel V1	JNB02
16	Rokle	ROK2
15	Deponit	CAN01
14	Asha 505	ASHA01
13	Rokle	ROK1
12	Callovo-Oxfordian	COB01
11	MX80	LOT03
10	Ikosorb	IKO1
9	Friedland	FRI1
8	Febex	FEB01
7	MX80 granulate +quartz	Granulate weight not measured
6	Ibeco Seal	IBE01
5	Calcigel	CAL02
4	Kunigel V1	JNB01
3	MX80 granulate	Granulate weight not measured
2	MX80	LOT02
1	MX80	LOT01

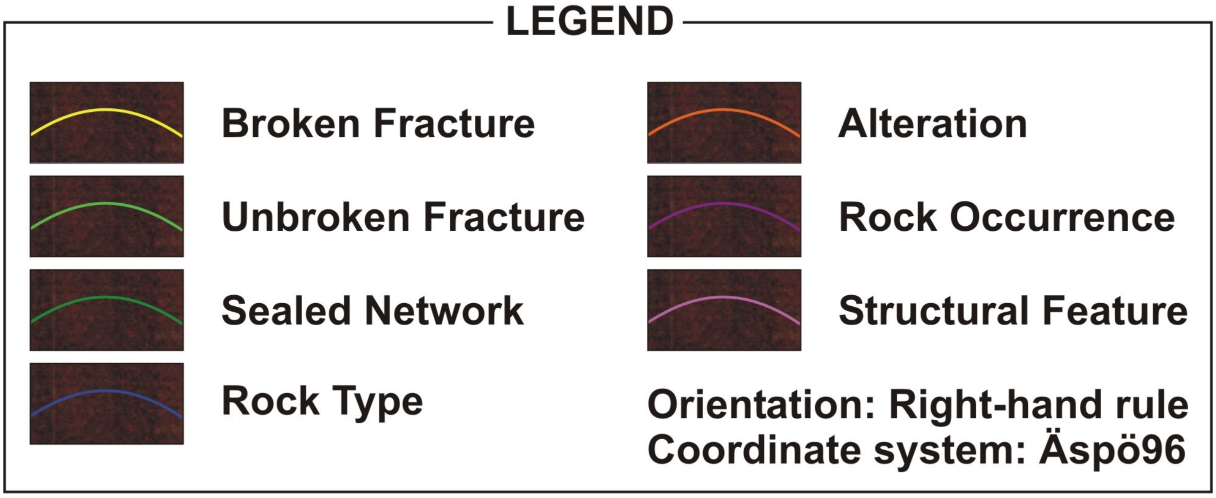
Package 2 buffer block ID codes

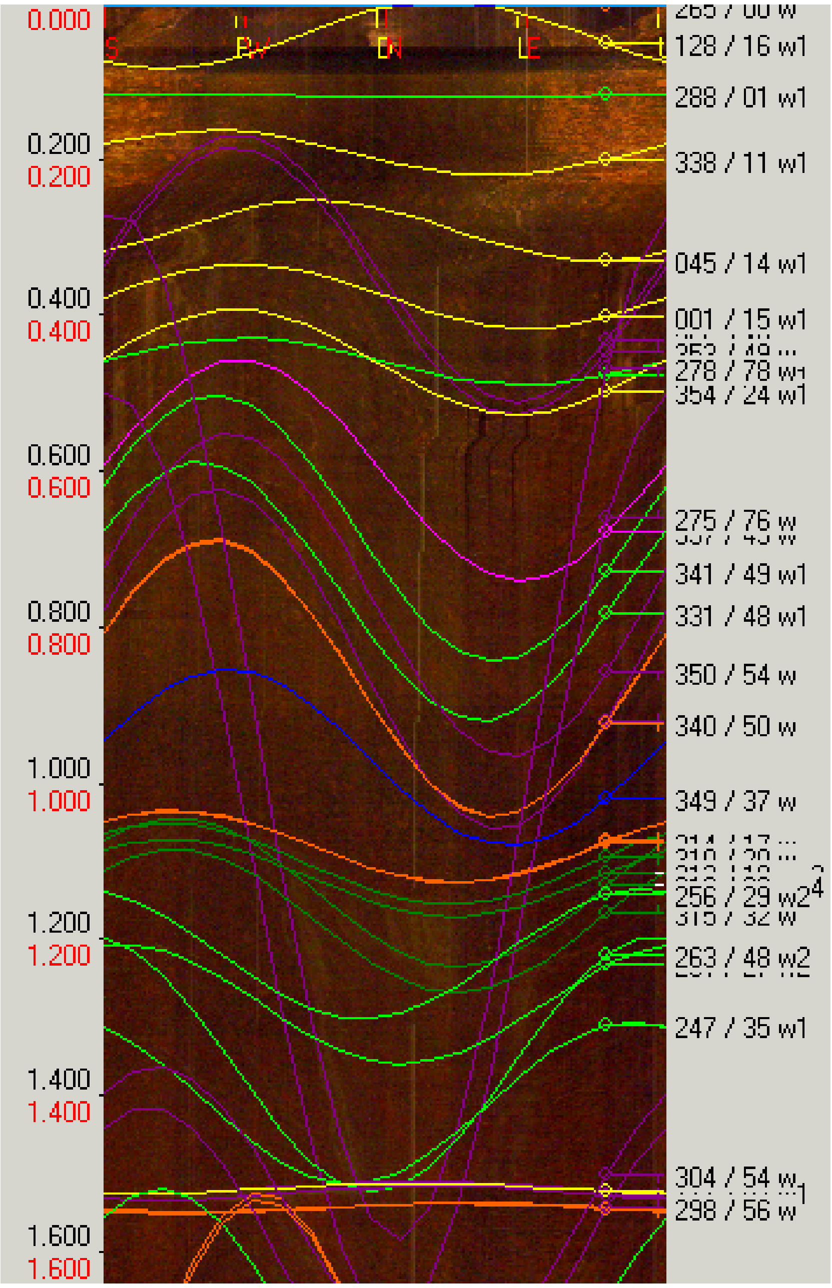
Block number	Material	Block ID
31	MX80	LOT14
30	MX80	LOT13
29	Febex	FEB04
28	Ikosorb	IKO04
27	MX80 granulate	Granulate weight 7112g
26	Deponit	CAN04
25	MX80 granulate +quartz	Granulate weight 7151g
24	Rokle	ROK4
23	Friedland	FRI4
22	Kunigel V1	JNB04
21	Asha 505	ASHA04
20b	Callovo-Oxfordian discs	F
20a	Callovo-Oxfordian discs	1
19	Callovo-Oxfordian	COB04
18	Calcigel	CAL05
17	MX80	LOT12
16	Callovo-Oxfordian	COB03
15	Ibeco Seal	IBE04
14	MX80 granulate +quartz	Granulate weight 7003g
13	Kunigel V1	JNB03
12	Ikosorb	IKO3
11	Ibeco Seal	IBE03
10	Asha 505	ASHA03
9	Febex	FEB03
8	MX80 granulate	Granulate weight 6913g
7	Rokle	ROK3
6	MX80	LOT11
5	Deponit	CAN03
4	Friedland	FRI3
3	Calcigel	CAL04
2	MX80	LOT10
1	MX80	LOT07

Package 3 buffer block ID codes

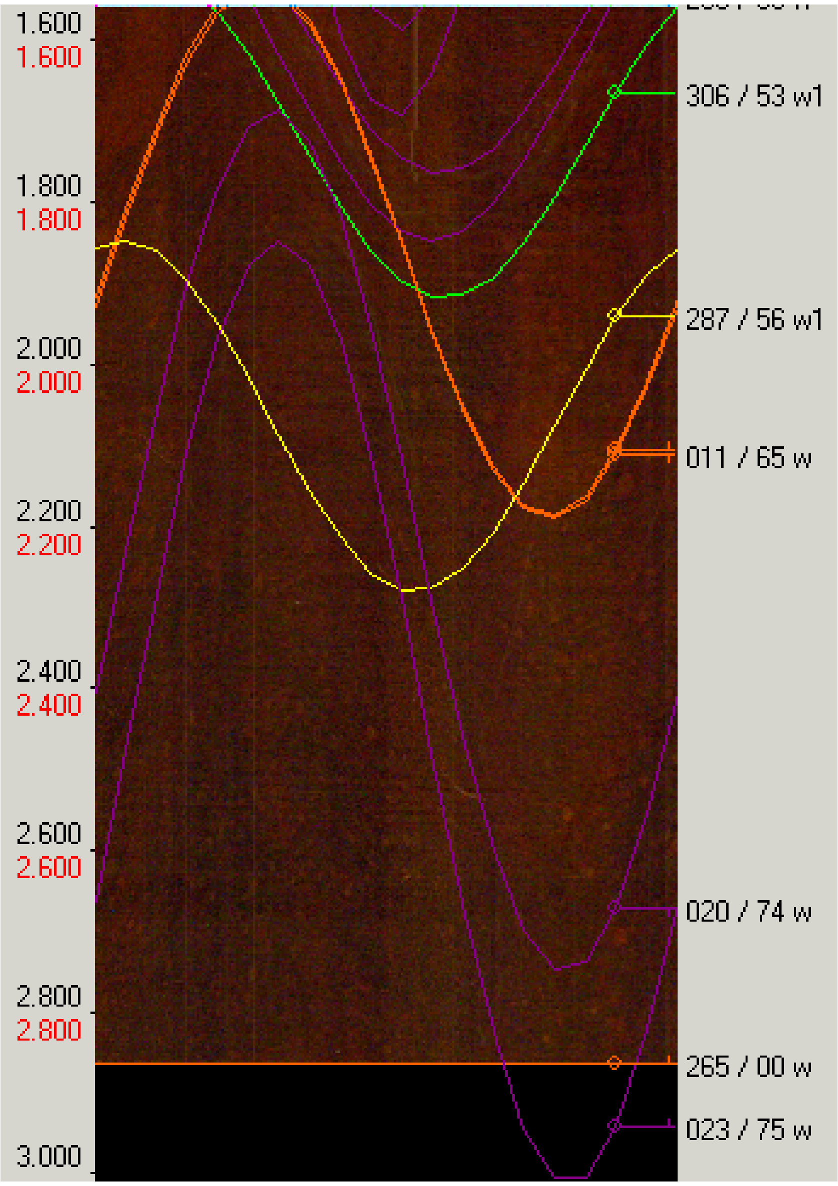
Block number	Material	Block ID
31	MX80	LOT20
30	MX80	LOT19
29	Ibeco Seal	IBE02
28	Rokle	ROK6
27	Febex	FEB06
26	MX80	LOT18
25	Friedland	FRI6
24b	Callovo-Oxfordian disc	C
24a	Callovo-Oxfordian disc	A
23	Callovo-Oxfordian	COB06
22	Kunigel V1	JNB06
21	Deponit	CAN06
20	Calcigel	CAL07
19	MX80 granulate	Granulate weight 6819g
18	Asha 505	ASHA06
17	Ikosorb	IKO06
16	MX80 granulate +quartz	Granulate weight 6765g
15	Friedland	FRI5
14	MX80 granulate	Granulate weight 6843g
13	Ibeco Seal	IBE05
12	Kunigel V1	JNB05
11	Febex	FEB05
10	Deponit	CAN05
9	Callovo-Oxfordian	COB05
8	Ikosorb	IKO05
7	Rokle	ROK5
6	Calcigel	CAL06
5	MX80 granulate +quartz	Granulate weight 7117g
4	Asha 505	ASHA05
3	MX80	LOT17
2	MX80	LOT16
1	MX80	LOT15

Appendix 5 Fracture mapping of the three boreholes

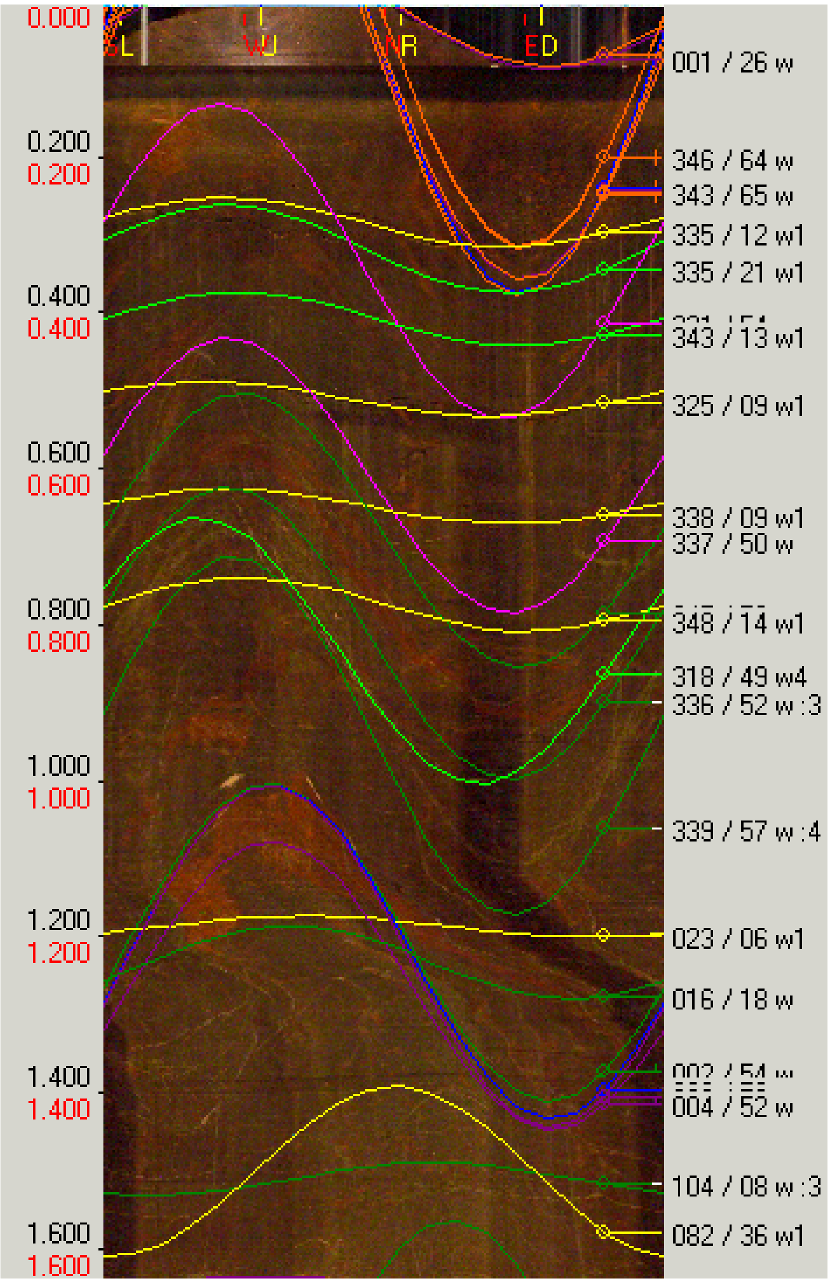




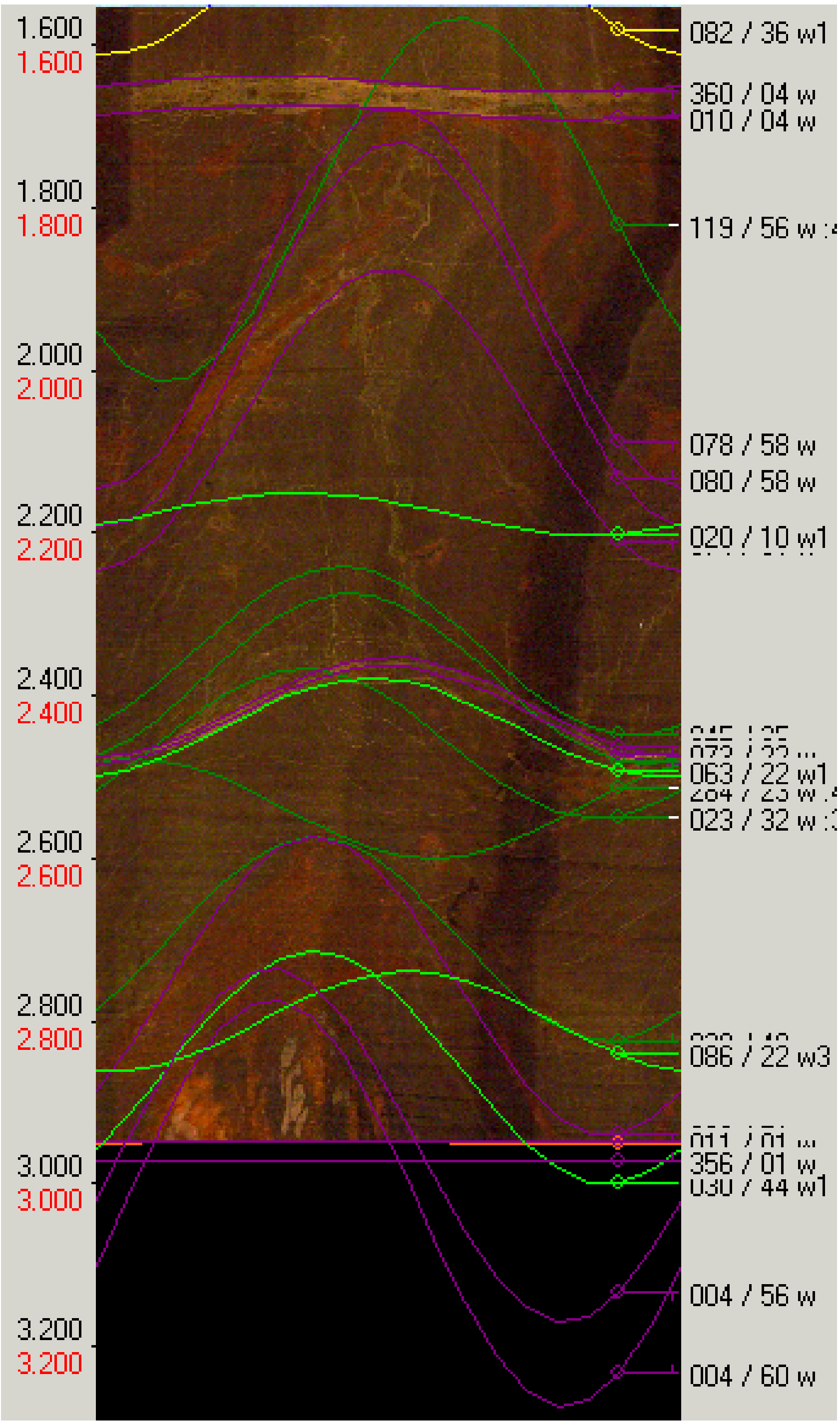
Figur 1. *Fracture mapping of KQ0032G01, upper part.*



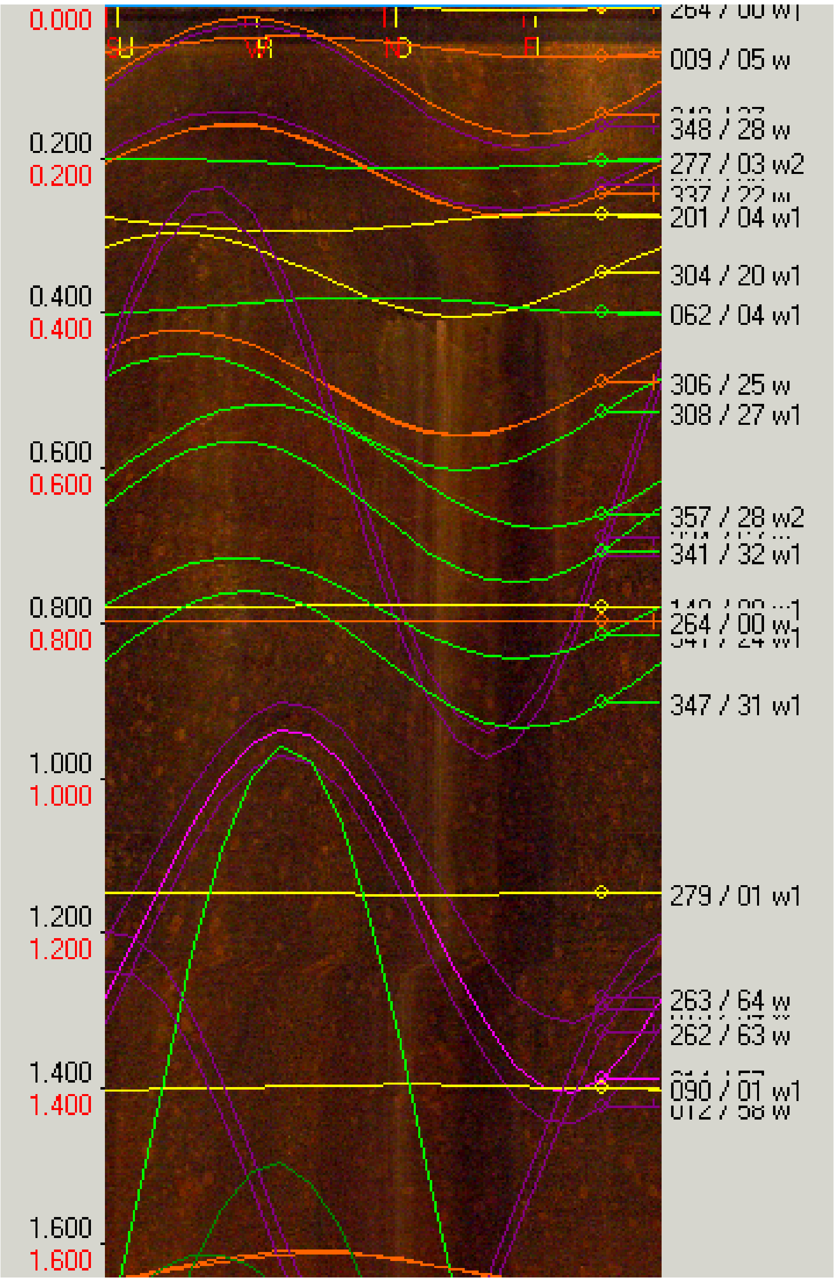
Figur 2. *Fracture mapping of KQ0032G01, lower part.*



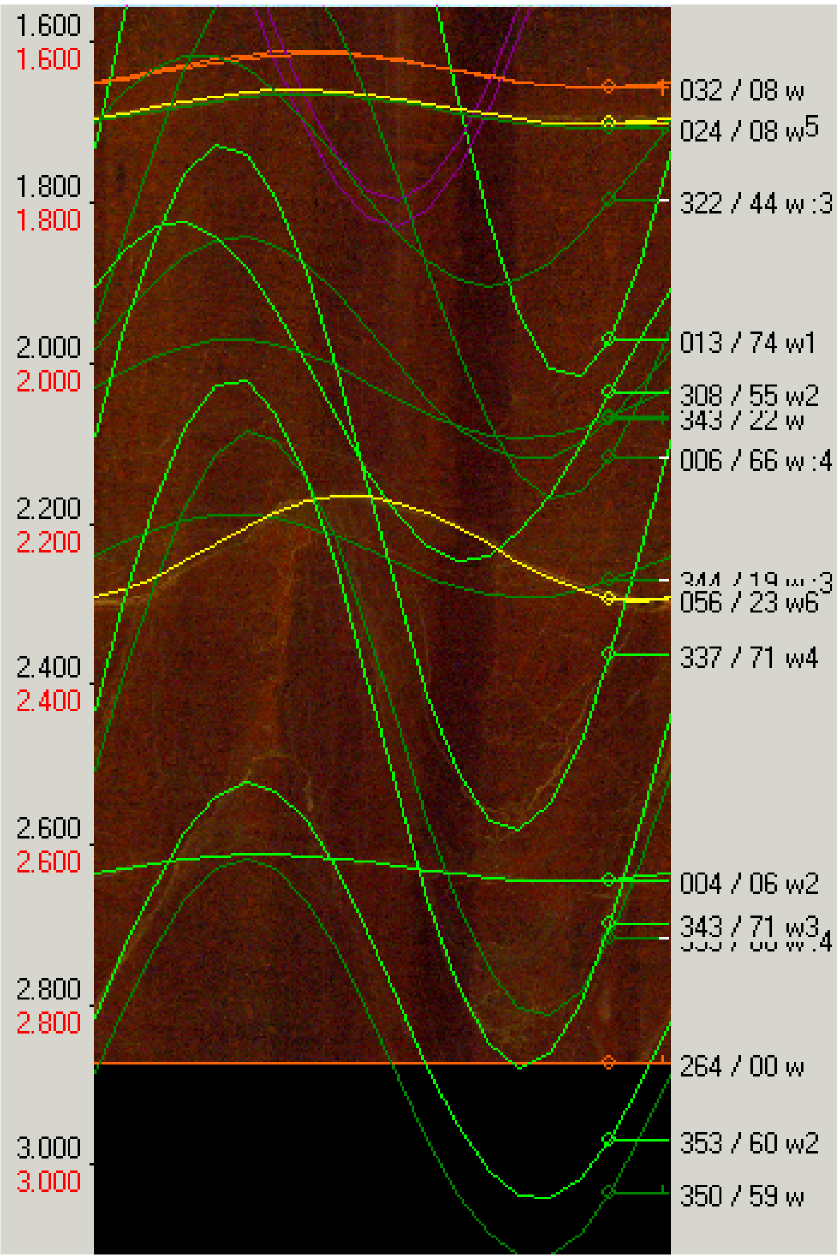
Figur 3. *Fracture mapping of KQ0036G01, upper part.*



Figur 4. *Fracture mapping of KQ0036G01, lower part.*



Figur 5. *Fracture mapping of KQ0040G01, upper part.*



Figur 6. *Fracture mapping of KQ0040G01, lower part.*