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Äspö Hard Rock Laboratory

Prototype Repository

Instrumentation for resistivity measurements in buffer, backfill and rock in Section II

T. Rothfuchs
L. Hartwig
M. Komischke
R. Miehe
K. Wieczorek

GRS

September 2003

Svensk Kärnbränslehantering AB

Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel +46 8 459 84 00
Fax +46 8 661 57 19



**Äspö Hard Rock
Laboratory**

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Author	Date
T. Rothfuchs, L. Hartwig, M Komischke, R. Mieke, K. Wieczorek	2003-09-01
Checked by	Date
T. Rothfuchs, Christer Svemar	
Approved	Date
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This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the author(s) and do not necessarily coincide with those of the client.

PROTOTYPE REPOSITORY

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Instrumentation for Resistivity Measurements in Buffer, Backfill and Rock in Section II

T. Rothfuchs,
L. Hartwig,
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Abstract

Within the frame of research activities in the Prototype Repository at Äspö GRS will employ measurements of electrical resistivity to monitor water uptake in the borehole buffer, the drift backfill and desaturation effects in the rock between deposition boreholes 5 and 6.

This document contains a description of the arrangement and installation of the measuring arrays in the Section II of the Prototype Repository.

Sammanfattning

I Prototypförvarets forskningsprogram arbetar GRS med mätning av elektrisk resistivitet för övervakning av bentonitbuffertens och tunnelåterfyllningens vattenmättnadsförlopp samt av bergets förändring av vattenmättnadsgrad mellan deponeringshål 5 och 6.

Denna rapport beskriver arrangemanget och installationen av mätslingorna i Prototypförvarets sektion II.

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1 Introduction

Within the framework of the Prototype Repository Project performed by the Svensk Kärnbränslehantering AB (SKB) at the Aespoe Hard Rock Laboratory (HRL) in Sweden six copper casks containing electrical heaters have been emplaced in deposition boreholes drilled into the floor of a drift at 460 m depth below ground. The gap between the casks and the granitic rock has been filled with Na-bentonite buffer. The drift above the deposition boreholes has been backfilled, too with a mixture consisting of 30 % bentonite and 70 % crushed rock.

The rock, buffer and backfill has been instrumented by SKB for recording temperatures, swelling and water pressures. In addition to that, multi-electrode arrays has been installed by the Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) at top of one deposition borehole, in the drift above the deposition boreholes, and in the rock between two deposition boreholes in order to determine by geoelectrical measurements water uptake in buffer and backfill and desaturation of the rock.

In the following, information is given about the arrangement and the installation of the electrode arrays in section II of the Prototype Repository. Theoretical principles of DC-geoelectrics and field measurements techniques, as well as a summary of laboratory calibrations which are necessary for further interpretation of the field measurement results are described in a separate report (Rothfuchs et al. 2001).

2 Instrumentation

2.1 Instrumentation plan

Three areas have been instrumented in the Prototype Repository (Figure 2-1):

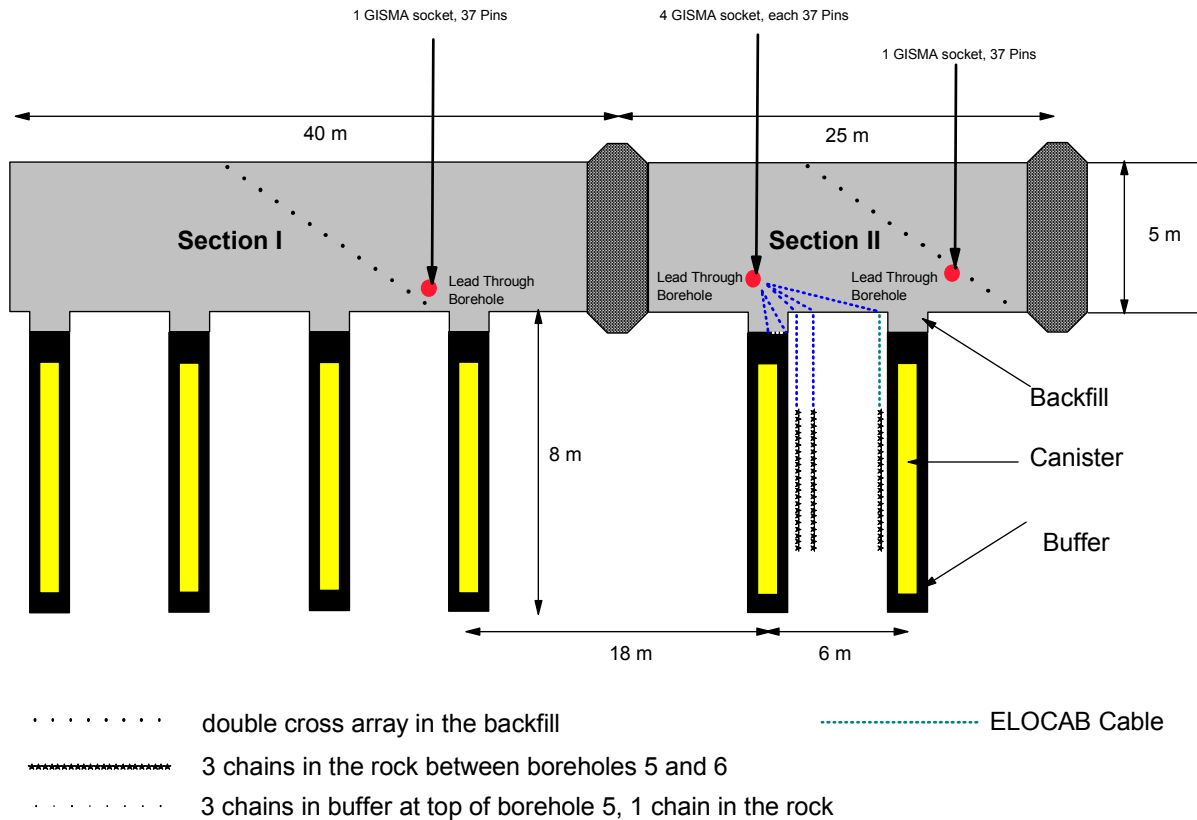


Figure 2-1: Overview of electrode arrangements in the Prototype Repository

2.1.1 Backfill

A double cross array (Figure 2-2) consisting of 36 single electrodes each with a spacing of 0.5 m has been installed on a 35° inclined backfill ramp above borehole 3 in section I and above deposition borehole 6 in section II. These arrays will monitor the resistivity distribution in the backfill.

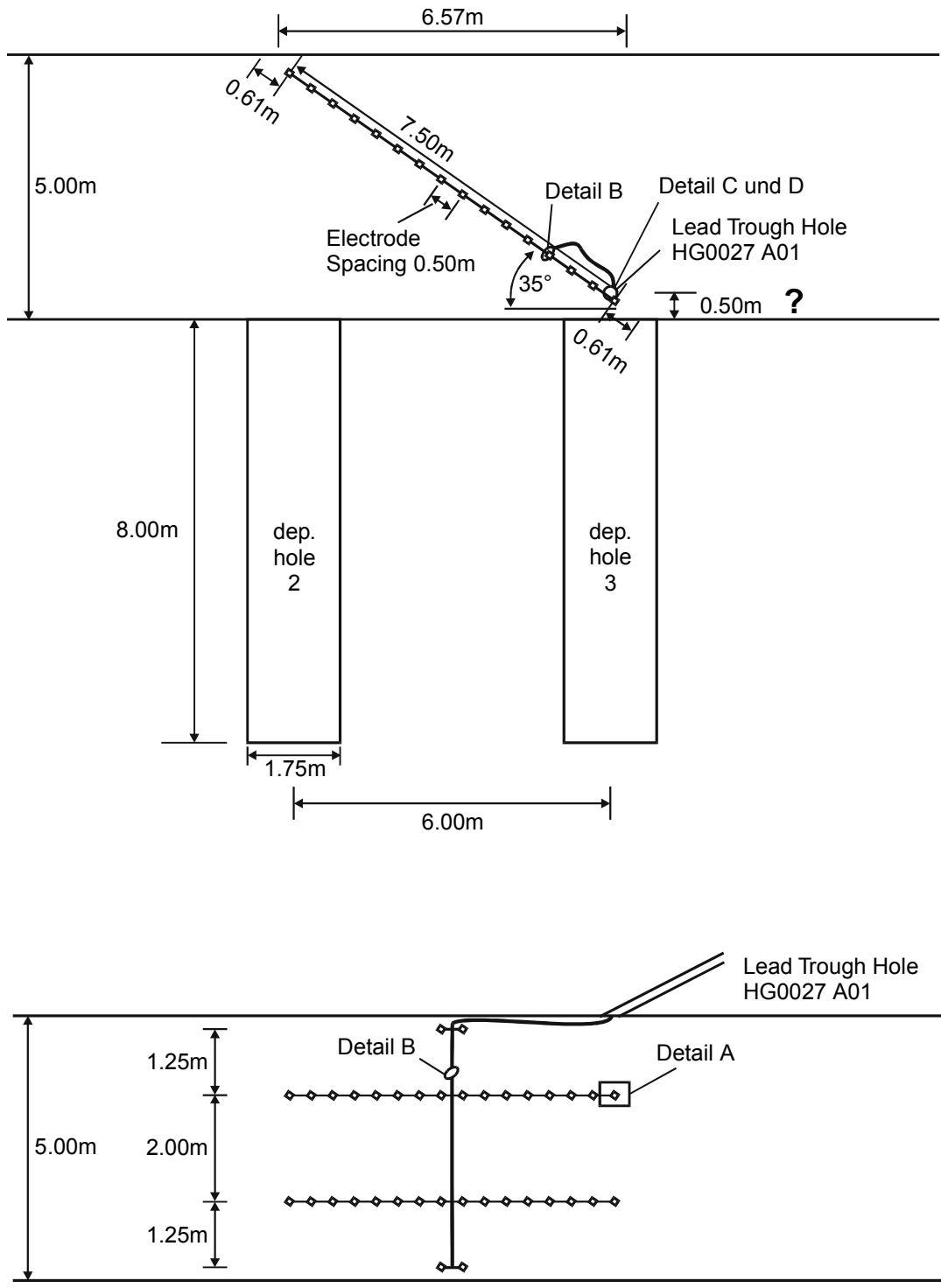


Figure 2-2: Double cross electrode arrangement in the backfill

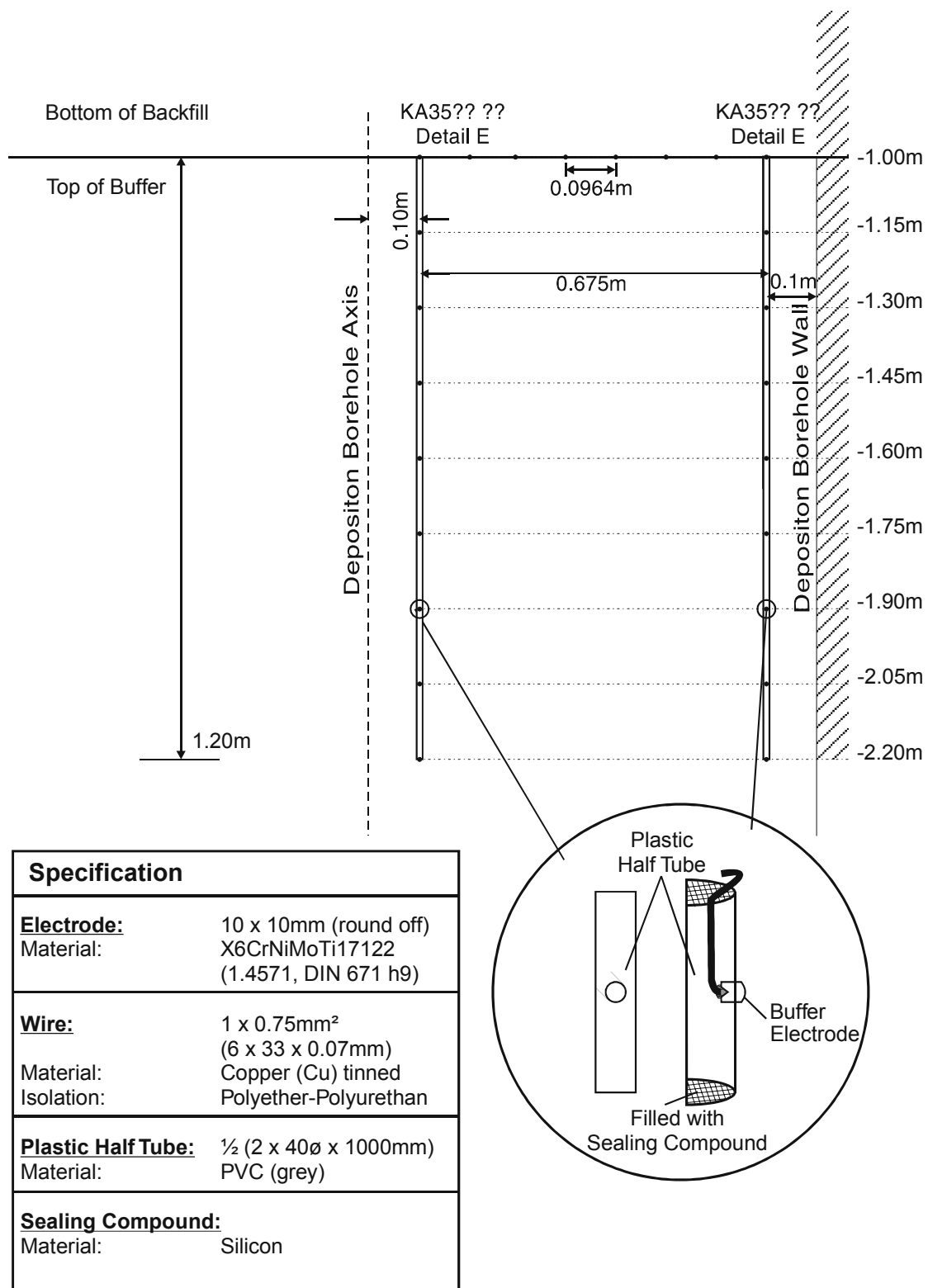


Figure 2-3: Electrode chains in the buffer at top of borehole 5

2.1.2 Buffer

The resistivity distribution in the buffer at top of deposition borehole 5 in section II (Figure 2-3) will be determined in a plane between one horizontal electrode chain installed on the surface of the buffer and two vertical measuring chains one installed in the centre of the buffer and another one about 10 cm from the borehole wall. A third vertical chain outside of the borehole in the rock at 30 cm distance from the borehole wall together with the latter buffer chain enables determination of resistivity in the rock adjacent to the buffer. The selected spacing of electrodes is 0.1 m at the top of the buffer and 0.15 m in the vertical measuring chains.

2.1.3 Rock

The resistivity distribution in the immediate vicinity of two of the deposition boreholes will be monitored with electrode chains installed in three vertical boreholes in the rock between deposition boreholes 5 and 6 (Figure 2-4).

2.2 Design of electrodes and electrode chains

Differently sized electrodes were manufactured for the different measurement arrays in the Prototype Repository. According to a recommendation of the Swedish Corrosion Institute the electrode material is a stainless steel type AISI 316 (also called SS2343).

2.2.1 Electrodes

The electrodes were manufactured according to Figure 2-5 with diameters of 10 and 30 mm, respectively with an accuracy of ± 0.1 mm.

Each electrode has a drillhole of 2 - 4 mm diameter and 5 – 10 mm depth in its neck in which the measuring wire is fastened by silver soldering. The transition from the electrode to the cable is pasted with epoxy resin and sealed with a plastic sealing which is screwed onto the electrode's neck.

2.2.2 Electrode chains

All electrode chains are of the same principle design shown in Figure 2-6. The multi-wire part of the ELOCAB-cable reaches from the GISMA-plug to a seal from which onwards the single wires are cut to different lengths forming a chain. At each end of the single wire an electrode is fixed as described above.

The ELOCAB multi-wire cable consists of 37 insulated wires each filled with a swelling filler preventing migration of moisture inside the insulation sheathing (Figure 2-7). The cables are tight against a water pressure of 10 MPa perpendicular to the cable axis and 6 MPa along the cable axis.

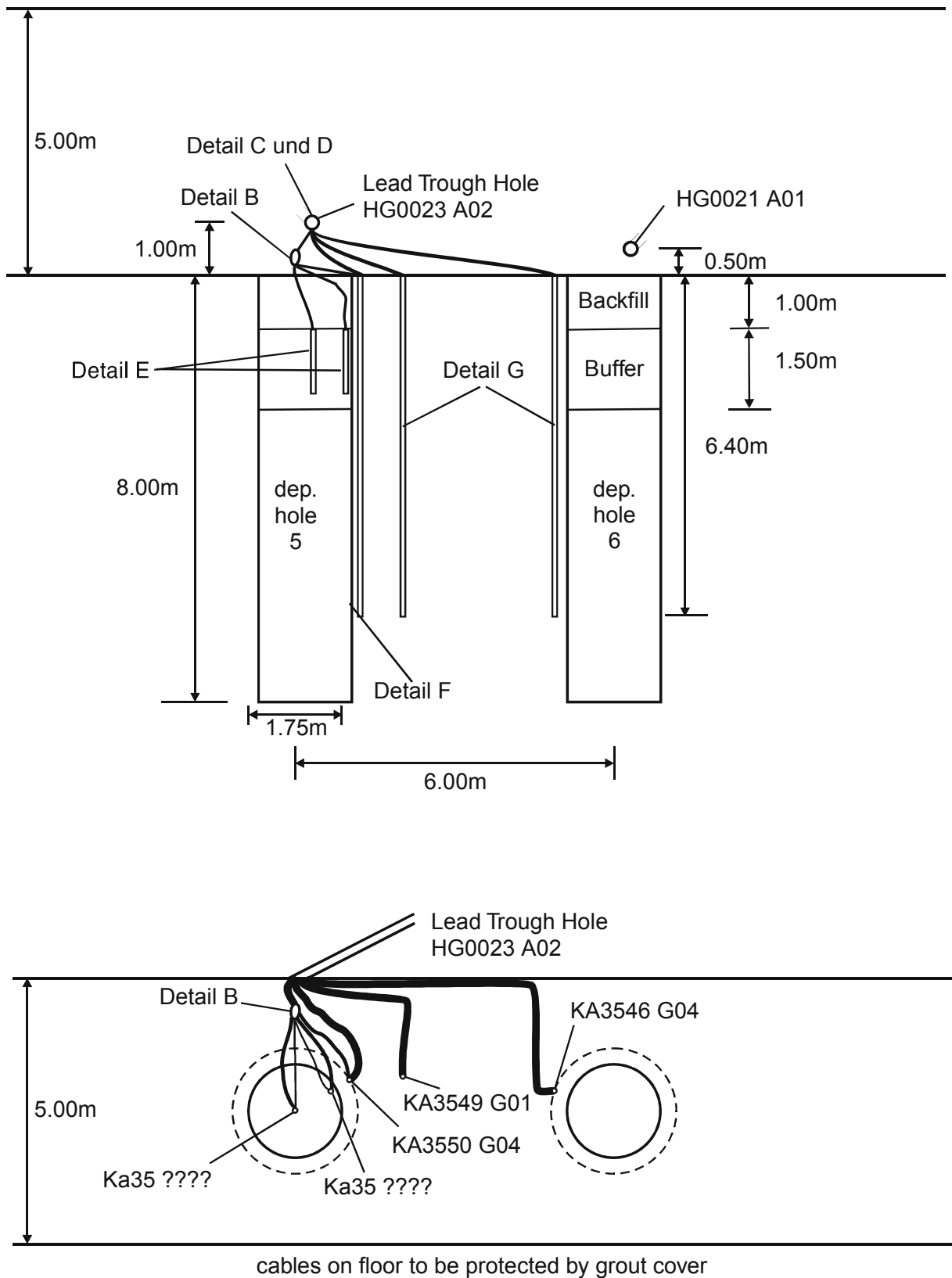


Figure 2-4: Electrodes in the rock between deposition boreholes 5 and 6

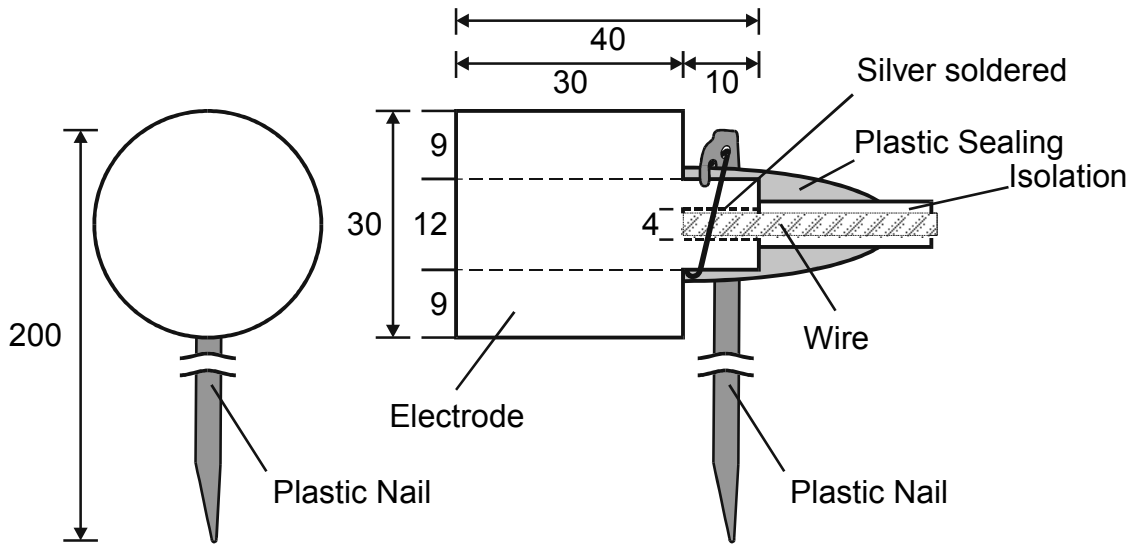
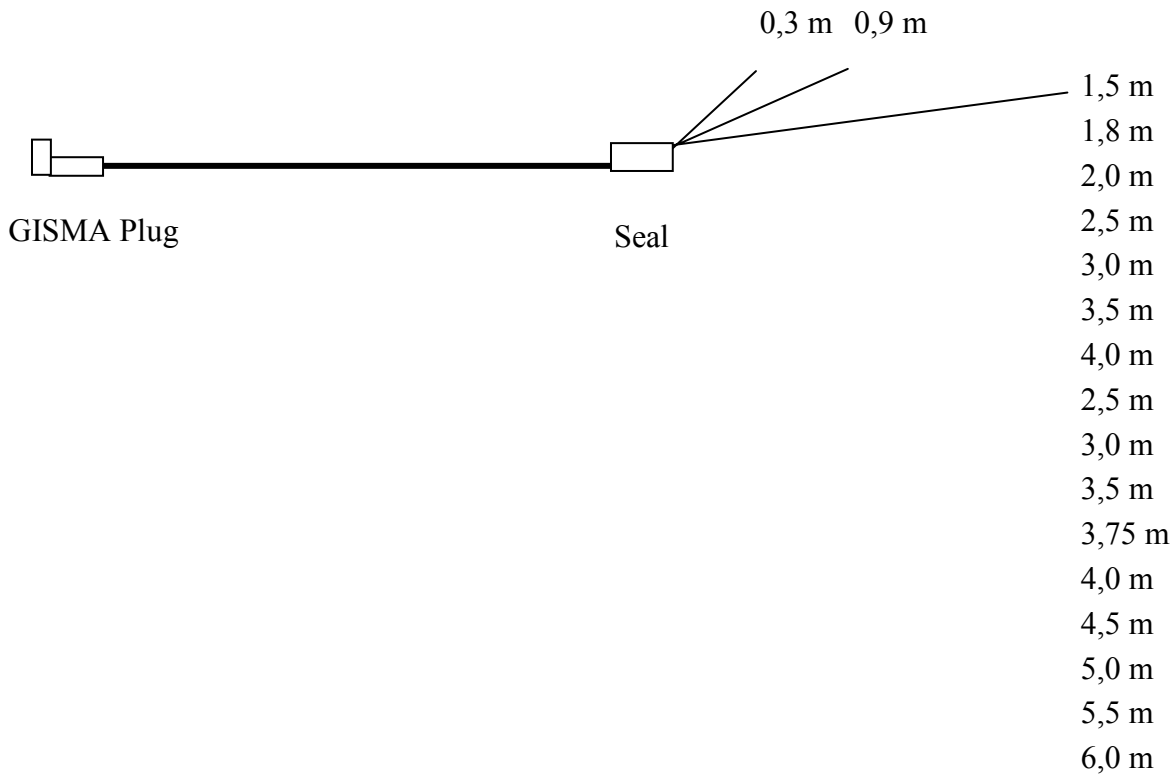


Figure 2-5: Design of a drift electrode

multi-wire cable (36 single cables)

Length of single cables from seal:



each length two times
totals 36 single cables

Figure 2-6: Principle design of an electrode chain in the drift

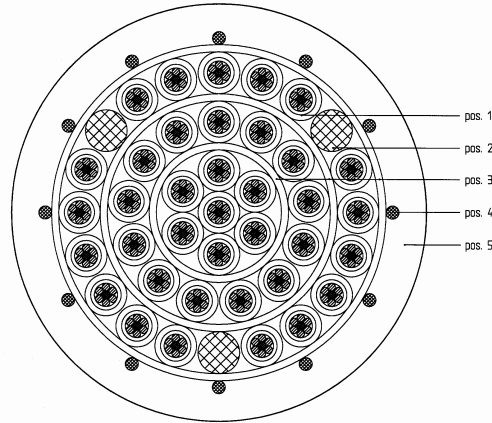
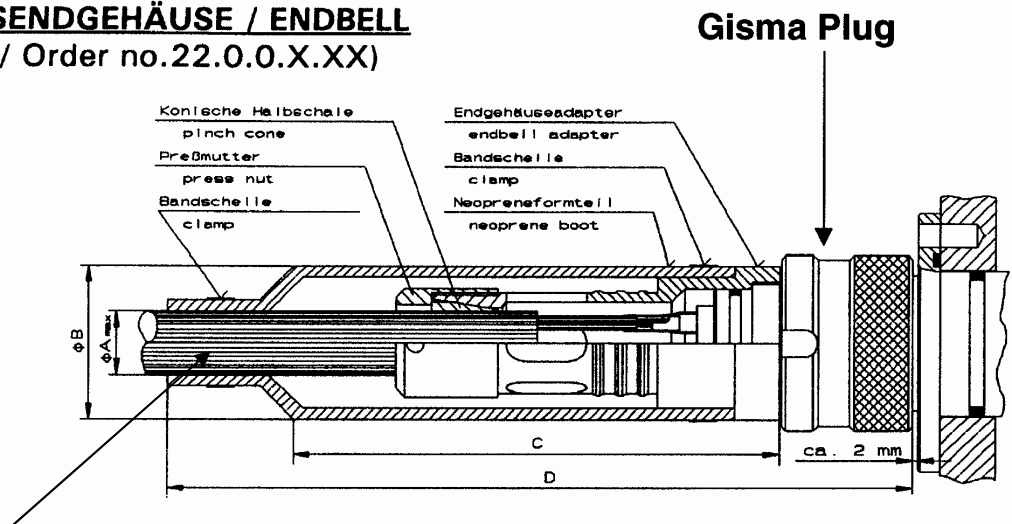


Figure 2-7: Design of an ELOCAB-cable (diameter of multi-wire cable: 27.5 mm, diameter of single wire: 2.7 mm)

2.2.3 GISMA plugs

The ELOCAB-cables are connected pressure tight to a GISMA-plug developed in submarine techniques (Figure 2-8). The GISMA-plugs are pressure tight, too up to water pressures of 10 MPa.

VERGUSSENDGEHÄUSE / ENDBELL (Best.Nr. / Order no.22.0.0.X.XX)



ELOCAB Multi-wire Cable ERK 7673 (37 pins)

Figure 2-8: GISMA-plug

2.3 Installation

2.3.1 Backfill electrodes

In the drift the chains consist simply of an ELOCAB-cable with a multi-wire part reaching from the GISMA-plug to a seal from which onwards the single wires are cut to different lengths forming a chain (Fig. 2-6). At each end of the single wire an electrode is fixed as described above. The backfill electrodes in section II were installed on 11 June 2003. The installation was prepared by SKB by mounting an installation stencil which was provided by GRS.

Checking of the position of the installation stencil by GRS resulted deviations from the position given in the GRS-Installation Instruction of 6 November 2001, drawing sheet 2 of 9. The distance between the long electrode chains (200 cm planned) and those to the side walls (125 cm planned) were correct. The distance to the roof was 70 cm instead of 61 cm. The arrangement was not corrected because of the high effort needed for such an action. The situation given (Figure 2-9) was accepted by GRS.

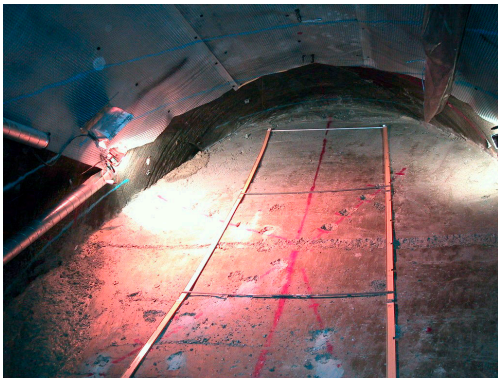


Figure 2-9: Installation stencil mounted at the backfill ramp in section II



Figure 2-10: Cable and electrode fixation in the backfill

The electrode cables were fixed to the backfill by plastic nails (Figure 2-10). Subsequently, the slots were covered by slightly moistened fine bentonite powder (Figure 2-11).

The results of the initial measurement performed on June 18, 2003 are shown in Figure 2-12. While the resistivity in the centre of the backfill ranges around 10 Ωm , there are pronounced low resistivity areas on the left and right sides close to the wall. This is in agreement with the observations during installation of the electrodes. It was found that the tunnel around the cross section of the electrode array was considerably wetter than in section 1 of the Prototype Repository, which resulted in higher moisture contents of the backfill right from the beginning.



Figure 2-11: Backfill ramp above deposition borehole 6. The electrodes being covered by slightly moistened bentonite powder

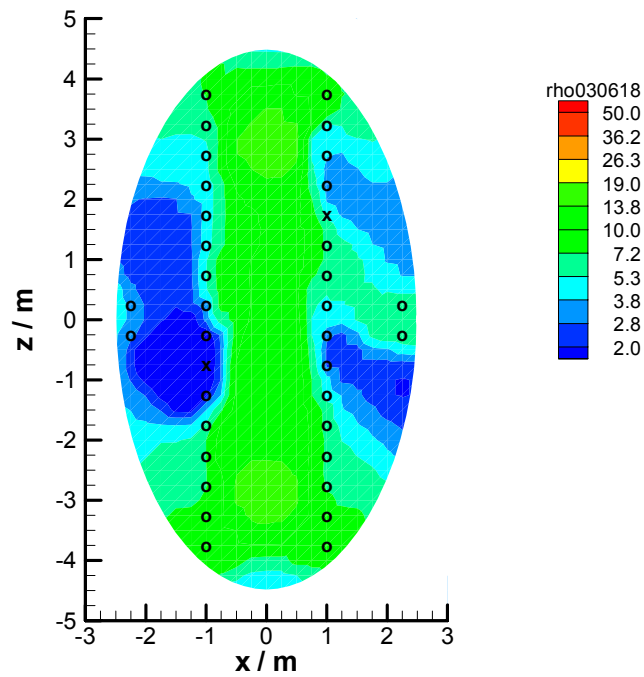
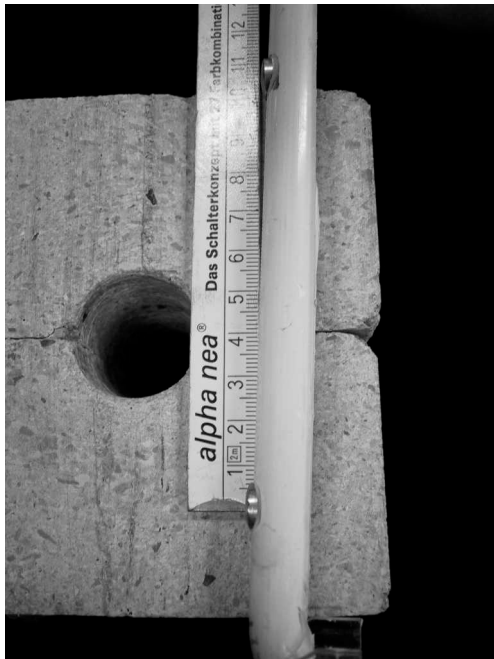


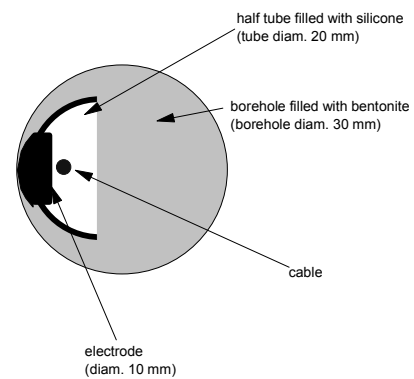
Figure 2-12: Resistivity tomogram of the backfill one week after installation of the electrodes

2.3.2 Buffer electrodes

The electrode chains in the buffer boreholes (Figure 2-3 and Figure 2-4) consist of an ELOCAB cable with the single wires soldered to 10 mm electrodes which are fixed in the wall of a Plexiglas® half tube (Figure 2-13). The single wires connected to the electrodes are sealed in the half tube with silicone and guided vertically upwards out of the buffer.



a) Test block of bentonite and mock up electrode chain



b) Horizontal cross section through buffer borehole

Figure 2-13: Design of electrode chain in the buffer

Buffer electrode installation was done on 10 and 11 April 2003. Checking of the location of the electrode boreholes drilled by Clay Technology in the buffer resulted that the locations were not correct. In contrast to GRS-Installation Instruction of 6 November 2001, drawing sheet 8 of 9, the electrode boreholes were moved about 2 cm in direction of the deposition borehole wall. The depth of the electrode boreholes of 1.2 m was correct. The outer electrode borehole was not perfectly vertical and thus penetrated into the outer annulus between bentonite and rock at a depth of 1m. After discussion of the situation with GRS Braunschweig it was decided to use the boreholes as drilled. The most lower two electrodes of the outer electrode borehole, however, were to be cut off.

The first electrode chain was installed in the centre borehole (Figure2-14).



Figure 2-14: *Installation of electrode chain in the centre of buffer at top of deposition borehole #5*

The electrodes were pressed against the buffer by filling the remaining volume of the borehole with bentonite powder produced during drilling of the borehole and compacting the bentonite by stamping with a stick as far as achievable to the design density of 1.66 g/cm^3 . After installation in the buffer, the GISMA-plug of the cable was plugged into the respective GISMA socket at the head flange of the respective lead-through borehole in the drift wall.

The tomogram of May 27, 2003 (first measurement, Figure 2-15) shows the high resistivity (above $1000 \text{ } \Omega\text{m}$) of the rock on the right side and the low resistivity of the buffer (below $80 \text{ } \Omega\text{m}$). The picture is somewhat distorted by the fact that along the electrode chains the resistivity is increased compared to the undisturbed buffer. The increased resistivity along the electrode chains can be attributed to the refilling of the electrode boreholes with bentonite powder produced during borehole drilling. It is, however, expected that the difference will diminish with time, especially if the buffer takes up water.

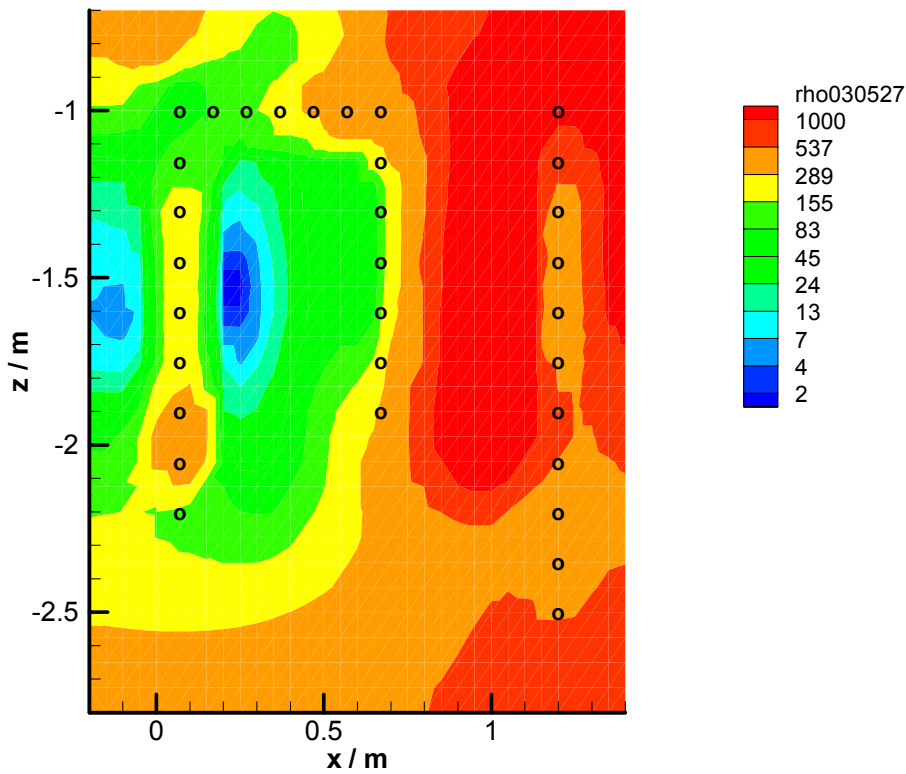


Figure 2-15: Resistivity tomogram of the buffer at top of deposition borehole #5 and of the adjacent rock

2.3.3 Rock electrodes

The electrode chains in the rock between deposition boreholes #5 and #6 (Figure 2-4 and Figure 2-16) consist also of an ELOCAB cable with the single wires soldered to 10 mm electrodes which are fixed to a plastic stick which is lowered into the borehole in the rock (Figure 2-17). To get proper contact of the electrodes to the rock the boreholes were to be grouted with a special cement/crushed rock mixture.

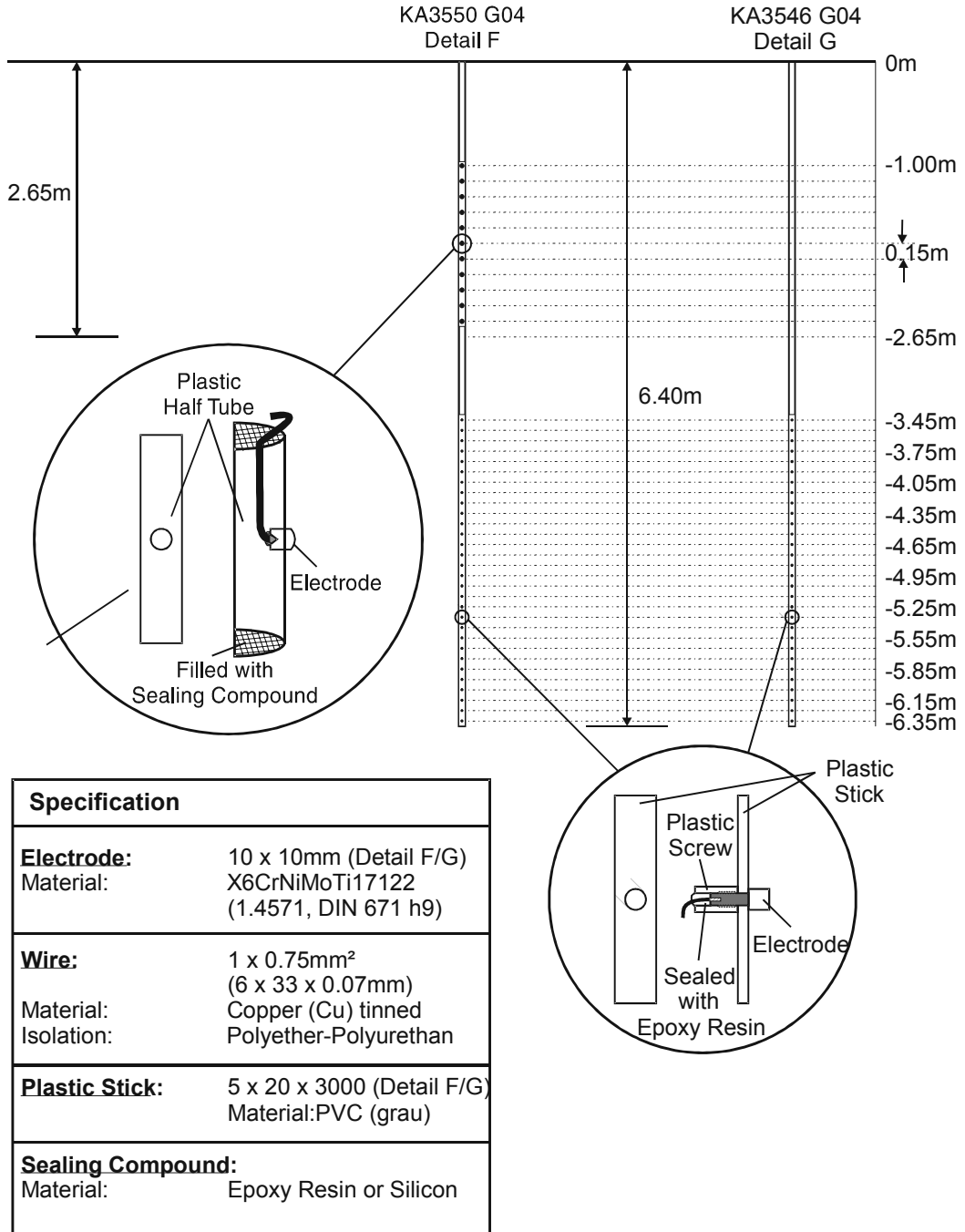


Figure 2-16: Design of electrode chains in the rock

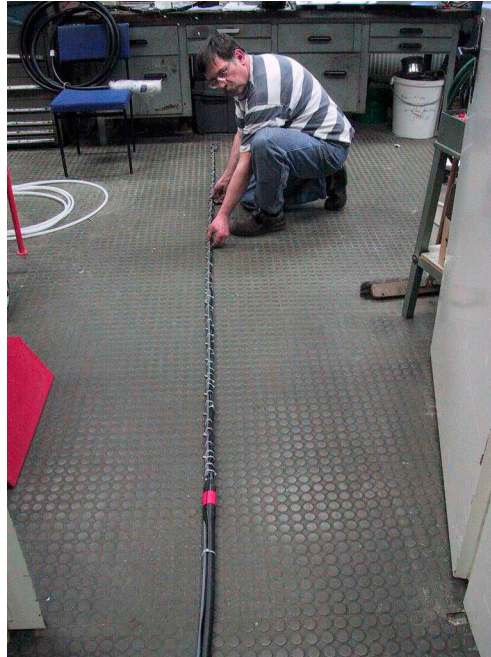


Figure 2-17: *Rock electrode chain*

Installation of the rock electrodes took place on 29 and 30 January 2002. Grouting of the boreholes was performed using an electric pump (Figure 2-18). After complete filling of the boreholes, the electrode multi-wire cable was fixed at the borehole mouth (Figure 2-19) and the cable was guided to the respective lead-through borehole in the drift wall.



Figure 2-18: *Electric cement-pump*

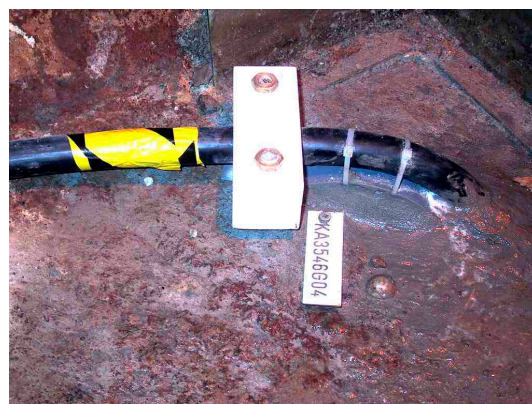


Figure 2-19: *Cable fixation and protection at borehole mouth*

The initial measurement in the rock could only be performed seven months later in late August 2002 after connection of the multi-wire cables to the monitoring system in May 2002 and a repair of a connecting plug in August 2002.

Figure 2-20 shows the resistivity distributions as determined by inverse modelling. The resistivity distributions along the three electrode chains installed in the rock are quite similar to each other. Close to the electrodes, the resistivity ranges around 200 Ωm . This value characterizes the water-saturated concrete used for backfilling the electrode boreholes. Further away from the boreholes, the resistivity rises to values of 2000 to 7000 Ωm which is characteristic for water-saturated granite.

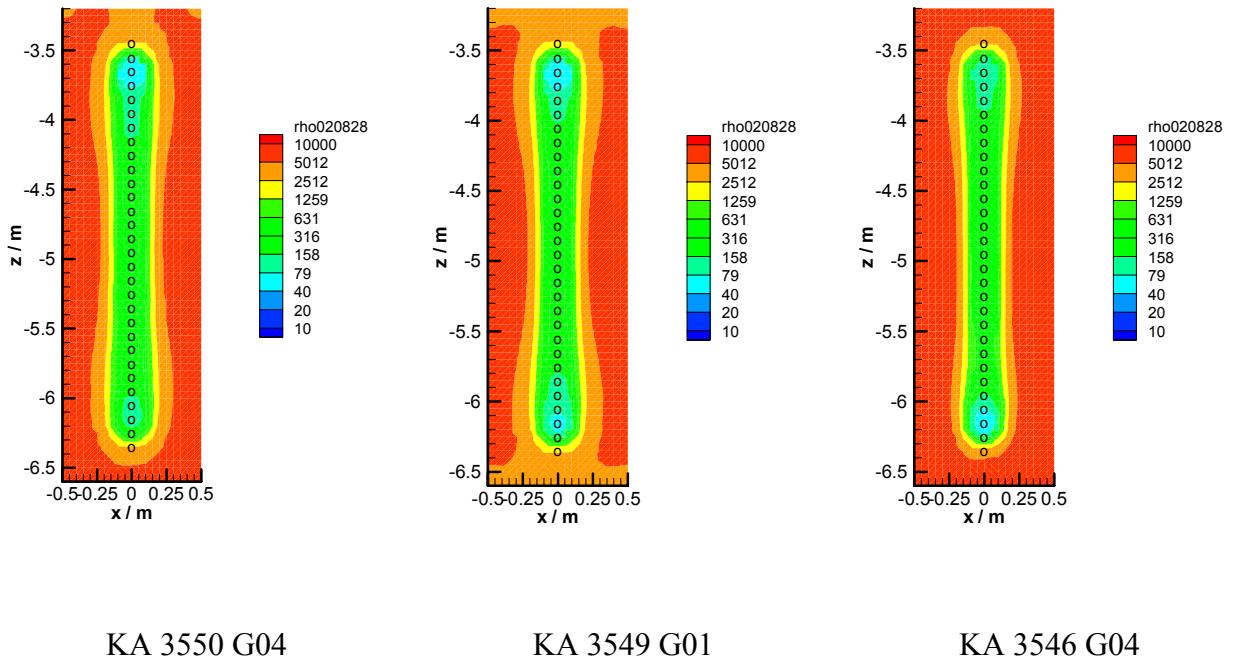


Figure 2-20: Resistivity distribution along the boreholes in the rock as measured on August 28, 2002

3 Summary and Conclusions

Three electrode arrays have been installed in the Prototype Repository at the Äspö Hard Rock Laboratory to monitor water uptake in the bentonite buffer in the deposition borehole 5, the crushed rock/bentonite backfill in the drift above the deposition borehole, and to monitor eventual de-saturation of the host rock between the deposition borehole 5 and 6.

Installation of the arrays took place between January 2002 (rock) and April (buffer) to June 2003 (backfill). Immediately after electrode installation, dipole-dipole measurements were performed to determine the initial resistivity distribution in the different materials.

The initial resistivity data agree fairly well with expected data, but show some unexpected effects as for instance an initial moisture content in the backfill close to the drift wall which is distinctly higher than that observed initially in the backfill in section I. This may be due to the water inflow at the drift wall observed during electrode installation.

The initial resistivities determined in the buffer and the rock represent normal values for the buffer having a starting water content of 17% and the initially fully saturated granite rock, respectively. The resistivity distributions, however, show also some deviating values resulting on one hand from the high resistivity gradient at the interface of buffer and rock and on the other hand on the resistivity difference between the grouting material in the rock boreholes and the rock itself.

It is expected that the different initial situations will change considerably during the saturation process in the buffer and the de-saturation process in the rock.

References

Rothfuchs, T., Komischke, M., Mieke, R., Moog, H., Wiczorek, K., 2001: Äspö Hard Rock Laboratory, Prototype Repository, Geoelectric Monitoring in Buffer, Backfill and Rock, International Progress Report, IRP-01-63, Svensk Kärnbränslehantering AB, Stockholm

