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IPR-04-10

Äspö Hard Rock Laboratory

TRUE-1 Continuation project

Fault rock zones characterisation

Overcoring (300mm) of impregnated fault rock zones at chainages 2/430, 2/545, 2/163 and 1/600m

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May 2004

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Keywords: Epoxy, fault rock zones, mapping, overcoring, pore space

Abstract

Seven overcoring drillings were performed of previously existing pilot borholes where epoxy resin had been injected into identified fault rock zones. The overcoring was made with a diameter of 300 mm, using the existing 76 mm boreholes as pilots, and producing 277 mm cores. A predefined protocol for the overcoring and retrieval of cores was employed. Four of the seven holes produced cores of high integrity while the remaining three produced poor results in conjunction with thee identified target sections. The latter was attributed to poor resin invasion (low permeability) resulting in poor cohesion. The successfully retrieved cores provide results which will form a good platform for analysis of pore space geometry and subsequent revisit of existing conceptual models of porespace geometry in, and adjacent to, fault rock zones

Sammanfattning

Överborrning har genomförts av sju borrhål i vilka konduktiva deformationszoner injekterats med epoxi. Överborrningen gjordes med en diameter av 300 mm med utnyttjande av de existerande 76 mm hålen som piloter, och resulterande i kärnor med en diameter av 277 mm. En upprättad metodik för överborrning och uttag av borrkärna ur borrhålet utnyttjades. Fyra av de sju hålen producerade kärnor av en hög grad av integritet medan resterande tre visade sämre resultat med mycket låg integritet i de injekterade zonerna. Det senare tillskrevs en sämre inträngning av resin på grund av en lägre hydraulisk konduktivitet. De fyra kärnorna av god integritet visar en god palett av portyper och porstorlekar och kommer att utgöra en viktig komponent för analysen av porvolymer och efterföljande uppdatering av konceptuella modeller för porstruktur i och i anslutning till konduktiva deformationszoner.

Contents

1 Introduction

The Fault Rock Zones Characterisation Project aims to improve conceptualisation and quantification of the pore space which provide immobile zones that effectively retard migration of radionuclides in fractured rock.

Four target fault and fracture zones have been selected in the access tunnel to the Äspö Hard Rock Laboratory at chainages 1/600, 2/163, 2/430 and 2/545. The four target structures and zones have been modelled generically at the four locations in the tunnel. A brief description and RVS site models in 3D of target structures are presented and illustrated in Stigsson et al., 2003.

In order to establish the suitability of these structures for the purpose of the characterisation, 16 pilot core drillings with a borehole diameter of 76 mm were carried out at these 4 target locations. The boreholes are subhorizontal and their locations along the tunnel wall, bearings, and lengths were defined in order to drill through the four fault and fracture zones in a suitable geometry. Subsequently, the holes were logged using the BIPS borehole imaging method in order to determine the orientation of fractures, thin veins and other structures. The indications of structures in the cores were used to confirm and update the target structures. These activities are reported by Hansen et al, 2003.

Each of the 16 pilot holes was equipped with a mechanical packer system which included a massive 74 mm diameter plastic dummy in the packed-off part of the borehole in order to minimise epoxy consumption, and a pipe through the dummy such that the hole can be filled with resin from the bottom (cf Figure 1-1). An inner rod is fixed to the packer by means of a threaded coupling. Another, outer rod slide along the inner rod, being pressed by means of a nut on the threaded exposed end of the inner rod against the packer, thus expanding the rubber coils of the packer (cf *Appendix 3*). Hydraulic tests were carried out by means of water injection at selected excess head, the results of which showed that epoxy injection would be possible in seven holes only, distributed over the four sites. One site, however, at chainage 2/545, was deemed inadequate for the purpose or the project, but was used for initial testing of the developed work procedure.

The target faults or fracture zones were grouted with epoxy resin with a fluorescent additive (uranine). Subsequently, 300 mm overcoring was carried out to enable study of the appearance of epoxy filling, including the 3D nature of the connected pore space. The overcoring activities comprise the following drill holes: KA1596A02, KA1596A04, KA2169A01, KA2169A02, KA2169A03, KA2423A03, and KA2549A01. Borehole-specific data and evaluated epoxy take are provided in Table 1-1. The packer position for each hole is indicated in Appendix 2.

The activities were carried out in accordance with the developed activity Plan (AP) (cf Section 2.1) with possible modifications introduced for each hole, as described in Chapter 3.

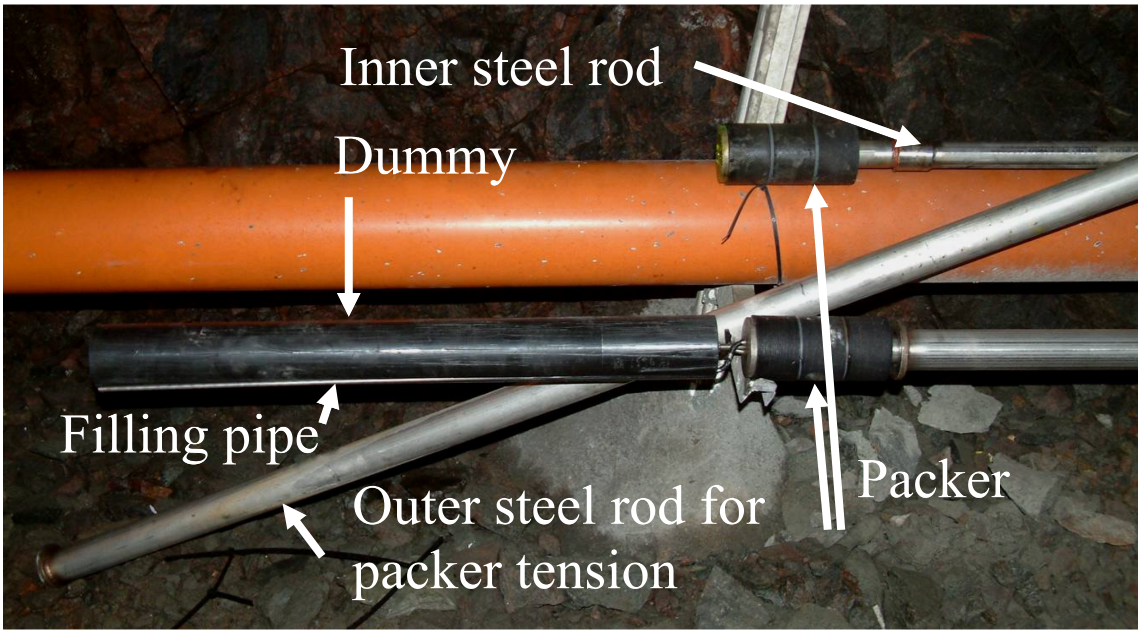


Figure 1-1. *Mechanical packers with plastic dummy.*

Table 1-1. Borehole-specific data for the seven injection holes which have been overcored (length unit: metre).

Hole ID	Pilot length	Target Zone position	Packer position	Grouted length	Grout take [litres]	Specif. grout take [l/m]	Over-coring length	Target core length
KA1596A02	5.62	4.32-5.00	3.45-3.63	1.99	0.1214	0.06	6.15	4.3-6.15
KA1596A04	4.1	2.05-3.05	1.10-1.28	2.82	0,1387	0.05	3.2	1.9-3.2
KA2169A01	3.62	2.30-2.65	1.90-2.08	1.54	1,054	0.68	3.6	1.9-2.6
KA2169A02	4.32	2.70-3.35	2.60-2.78	1.54	0,44	0.29	4.4	No core
KA2169A03	4.28	3.70-4.20	3.50-3.68	0.6	0,26	0.43	4.4	3.55-4.4
KA2423A03	2.93	2.20-2.65	1.80-1.98	0.95	0,5635	0.59	3.1	1.9-3.1
KA2549A01	3.69	1.67-2.24	1.35-1.53	2.16	0,690	0.32	2.4	1.3-2.4

2 Equipment and methods

2.1 Core Drilling

Drilling was, when applicable carried out in accordance with the method described in the AP, The following description of a typical work sequence is slighty abbreviated and modified.

1) Removal of outer piping and hoses (and possibly the mechanical packer).
2) Removal of 76 mm massive PET cylinder and 6 mm injection pipe by means of cutting (excavation by drilling, full face drill bit) until 10 cm before target zone (cf Table 1-1). Should the packer equipment and/or the plastic dummy assembly start to rotate, it was to be removed.
3) Overcoring down to ca 10 cm before target zone with a single 300 mm core barrel with of 76 cm length (Figure 2-1). The core diameter is 277 mm (in the following, all cores referred to has this diameter, unless for cores from the 76 mm pilot boreholes which have a diameter of 56 mm). Each drill round varied in length generally between 65 and 75 cm..
4) In many cases, the core would break due to an existing natural fracture, but if required, core breakage was to be induced by means of a double steel plate, expanded by means of hydraulic oil in the annular slot between the core and the borehole wall some 40 cm from the bottom of each drill round,. The in-situ core was acting as a lever to break (itself) at its base inside the drill hole (Figure 2-2 and Figure 2-3).
5) Drilling of each 75 cm round was to be followed by careful recovery of core by means of a specific core recovery tool (Figure 2-4).
6) The target zone recovery was defined from 10 cm before target zone to 50 cm beyond it, the latter to avoid excessive stress on the target zone during application of the breakage tool. The target recovery was drilled with a single core barrel of 225 cm length, aiming to recover the remaining core including the target zone in one single piece (Figure 2-1). Breakage, if required and recovery was aimed to be carried out using the same method as for the shorter drill rounds.*
7) Core orientation and labelling and sawing into manageable pieces.

*Two alternatives for overcoring of the target recovery were foreseen:

- Case 1: In case of loosened plastic dummy, the pilot hole should be stabilised by means of epoxy reinforced with a metal pipe or rod along the target recovery before drilling. A plug was to be used at the end of the target zone in order to avoid reinforcement of the breakage point.
- Case 2. Plastic dummy left in the target zone should be cut away until end of target recovery and afterwhich the pilot borehole should be reinforced

Due to the large core diameter, giving a weight of 150-170 kg per metre of core, handling had to be done with a tractor equipped with a crane beam (Figure 2-5).

Figure 2-1. *300 mm Core barrels with space for 76 cm and 225 cm core length, respectively*

Figure 2-2. *Tools for core breakage.*

Figure 2-3. *Insertion of tool for core breakage.*

Figure 2-4. *Core recovery tool.*

Figure 2-5. *Core lifting.*

Figure 2-6. *Core logging desk.*

2.2 Core orientation and core logging

Before drilling, the outer core face at the tunnel wall was marked with a suite of 5 mm drill holes at top and bottom, connected with a vertical arrow pointing up, and at the extreme left and right, connected by a horizontal line in order to fix the orientation of the first core recovery.

For core logging purpose, a desk with four pairs of 70 mm rotating cylinders was used. The desk was inclined to fit with the drill hole plunge, 2º to 5º downwards from horizontal. On the desk, the first core recovery was placed with its axis parallel to the cylinders. Following rotation of the core to its original orientation with aid of the markings, a scaled line was drawn on top of core, along its axis. Then, the next core recovery was placed on the desk, and rotated individually relative to the first core, so the core ends could be aligned to match (Figure 2-6). This procedure was repeated for all subsequent core recoveries.

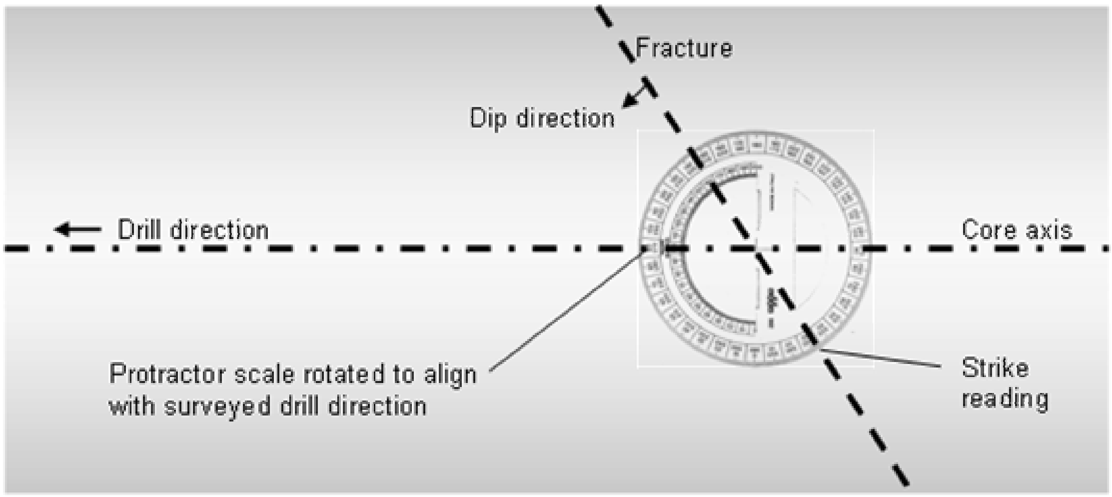


Figure 2-7. *Measurement of strike by means of a protractor placed on top of drill core.*

Strike determination by means of a compass was disturbed by magnetic matter in the rotating cylinders and in pipes and cables in the tunnel. Instead, strike was measured with a protractor, placed on the top of core. The protractor was placed with the surveyed drill direction on the protractor scale aligned with the core axis, and strike (right hand rule) was read on the protractor scale (Figure 2-7). Fracture dip was measured by means of a clinometer with a bubble vial adjustable relatively to a protractor scale (Figure 2-8).

Figure 2-8. *Measurement of dip by means of a clinometer with a rotating bubble vial.*

3 Applied drilling procedure

Overcoring of the holes is reported in the same order as drilled. Before overcoring, the steel rods were removed from the packer (cf Figure 1-1). Experience from each hole was used to successively optimise the overcoring routine to be used for the subsequent holes. For the initial overcoring rounds, down to the target recovery zone, the planned method, as described in Section 2.1, was followed. Planned overcoring lengths and target core lengths are shown in Table 1-1.

3.1 KA2549A01

Overcoring was carried out in agreement with the AP, down to 130 cm with a single core barrel of 76 cm length (cf Section1 and 2.1). The last core recovery was drilled down to the bottom of the hole, with a core barrel of 225 cm length, aiming to recover the remaining core including the target zone in one piece, without removal of the dummy, a deviation from the default method, and hereinafter called Method A.

At 255cm of depth, drilling was blocked, due to core wedging, and the barrel was recovered, containing core from 130 to 240 cm, including the target zone, and half of the dummy, which had broken at an unexepected joint in the dummy material at 245 cm.

Although the planned drill length had not been achieved, the entire target zone had been recovered with a shorter drill length, due to the joint. It was decided to investigate whether or not dummy joints could be expected to occur in subsequent holes, at favourable lengths so that unnecessary drilling, and long recoveries could be avoided. This was, however, found not to be the case and it was decided to continue with Method A for the next hole, KA2169A01.

3.2 KA2169A01

Overcoring was carried out in agreement with the AP, down to 190 cm with a single core barrel of 76 cm length. The last core recovery was drilled with a core barrel of 225 cm length, using Method A as described in Section 3.1.

Drilling continued down to the end of the hole at 360 cm, and the barrel was recovered, containing core from 190 to 335 cm, including the entire target zone, and all of the dummy material, 25 cm of which was fully visible, as the core had broken along a fracture at 335 cm, leaving a core butt at the bottom of the drill hole.

As the core had been retrieved during removal of the core barrel from the hole, no artificial breakage of the target recovery had to be applied.

Although the planned core length had not been achieved, the deviation was regarded favourable as the target zone had been recovered. It was decided to continue using Method A for the next hole, KA2169A02.

3.3 KA2169A02

Overcoring was carried out in agreement with the AP, down to 250 cm with a single core barrel of 76 cm length. The last core recovery was drilled with a core barrel of 225 cm length, aiming to recover the remaining core in one piece. Drilling continued as designed down to the end of the hole at 440 cm, and the core barrel was retrieved, but no core was in it. The barrel was inserted again and recovered with the same negative result.

An attempt was made to insert the breakage tool into the annular slot between core and hole wall, but failed to pass more than a few cm from the outer face of core remaining in the hole.

It was then decided to drill a little further, in order to pass more natural fractures. However, the barrel was blocked when entering the target zone (cf Table 1-1). On retrieval, the target zone was destroyed (i.e. fell apart) but the core with the packer was retrieved. In a second attempt, part of the target zone was recovered in pieces, as gravel and cobble.

It was decided on site to continue with Method A for the next hole, KA2169A03, but also to devise a new breakage tool, with a thinner double plate in order to be able to pass into the annular slot.

3.4 KA2169A03

Overcoring was carried out in agreement with the AP, down to 355 cm with a single core barrel of 76 cm length. The last core recovery was drilled with a core barrel of 225 cm length, aiming to recover the remaining core in one piece.

Drilling continued as designed to 440 cm, and the core barrel was retrieved, containing core from 355 to 440 cm, including the target zone, with the entire packer and dummy. No breakage of the core was required. The core was easily removed from the barrel.

It was decided on site to continue with Method A for the next hole, KA2423A03.

3.5 KA2423A03

The outer packer rod was removed without any obstacle, but during the attempt to unthread the inner rod from the packer, the packer started to rotate, loosened, and was retrieved together with the rod (cf Figure 1-1).

Overcoring was carried out in agreement with the AP down to 190 cm with a single core barrel of 76 cm length. The last core recovery was drilled with a core barrel of 225 cm length, aiming to recover the remaining core in one piece. Drilling continued as designed down to 310 cm, and the core barrel was retrieved, but without the core. Another attempt to recover the core failed, but with no signs of any obstacles, showing that the core was fixed at the bottom of the borehole.

The new breakage tool with a thinner double plate was inserted beneath the core, into the annular slot and pushed to the bottom of the hole, and then pulled back again some 20 cm. A hydraulic oil pressure was applied on the tool, and the core was broken at the bottom of the hole according to design. At breakage, the outer end of the core hit the ceiling of the hole, indicating a potential risk of breaking a long target core.

An attempt was made to recover the core by means of a core recovery barrel designed particularly for this purpose (cf Figure 2-4), but with a negative result. Finally, the core was successfully recovered using the core barrel as used for drilling. The core was easily retrieved from the barrel.

3.6 KA1596A02

It was decided on site to use a modified Method A for borehole KA1596A02, cutting away the outer part of the dummy down to 430 cm, in order to reduce the length of the target core (cf Table 1-1 and Appendix 2). Dummy material was left for the entire length of the target recovery.

The packer was retrieved by means of pulling the inner rod. Attempts were made to remove the dummy, firstly by means of a purpose-designed cutter bit, then by using hard-metal and standard diamond core drill bits, all of which failed. Finally, the dummy was cut down to 430 cm by means of core drilling with a coarse diamond core drill bit.

Overcoring 300 mm was carried out in agreement with the AP down to 430 cm with a single core barrel of 76 cm length.

The last core recovery was drilled with a core barrel of 225 cm length, aiming to recover the remaining core in one piece. This was not successful. The barrel was stuck at 465 cm, and the recovery (430-450 cm) revealed fault gouge and breccia making up the core of the target zone in pieces of 0-100 mm of size, with very little epoxy in the rock material, suggesting either that epoxy grouting had failed, or that the pore space of the clayey fault gouge simply may be too small to allow entry of any measurable amounts of epoxy. The conclusion was that fault gouge material had disintegrated during drilling; pieces had then fastened between the core and the core barrel, resulting in further core damage.

Drilling continued down to 615 cm, in order to pass more natural fractures and the barrel was recovered, but without core. The new breakage tool was pushed into the annular slot down to 520 cm. A hydraulic oil pressure was applied on the tool, and the core was broken at the bottom of the hole according to AP. The core was then recovered using the core barrel used for drilling, as previously practised for borehole KA2423A03.

Some of the fault gouge was found to be in place, from the perimeter of the pilot borehole and out some 2-3 cm, and contained some epoxy along cleavage surfaces. Epoxy was also present at the 277 mm core surface in a very thin (< 0.5 mm) fracture near (but not within) the target zone, showing that epoxy grouting had been successful in more porous parts of the rock. Therefore it is concluded that recovery of loose fault materials was not due to poor epoxy grouting procedure, but is an indication that the gouge material is impermeable to epoxy impregnation under the pressures used, as indicated by the grout take (cf Table 1-1).

3.7 KA1596A04

The packer was removed by means of pulling the packer rod. As the pilot core had revealed dense fracturing, the packer was placed far from the target zone. As this would have resulted in a too long target zone recovery, the dummy material was cut down to the bottom of the pilot drill hole, as for the previous hole. A plug was placed at 315 cm, and a 126 cm long 72 mm drill rod was cemented in the pilot from 188 to 314 cm, using a secondary epoxy, in order to stabilise the core (cf Section 2.1, #7, Case 2).

Overcoring 300 mm was carried out in agreement with the AP, down to 190 cm using a single core barrel of 76 cm length. The last core recovery was drilled with a core barrel of 225 cm length of core, with the aim to recover the remaining core, 190-320 cm in one piece. The core was retrieved successfully. However, the fault gouge disintegrated during retrieval of core from the core barrel. The recovery (430-450 cm) showed fault gouge and breccia in pieces 0-100 mm of size, usually with very little epoxy in the gouge and breccia material, while epoxy was abundant in nearby fractures, as for KA1596A02 (cf grout take in Table 1-1).

With respect to drilling method, it may be concluded, that using a single core barrel is a risky and unsuccessful method when dealing with a dense clayey fault gouge, while more open fractures are more prone to impregnation and result in an "intact" core that will withstand retrieval from the core barrel. The risk for core damage during drilling is high (KA2169A02 and KA1596A02) but not delimiting. The core from the overcored borehole KA1596A04 was successfully recovered from the hole but was damaged during retrieval from core barrel. One of three suggested methods may solve the problem:

1. Use of a double core barrel, the inner barrel being divided in two half-barrels.
2. The single core barrel (and probably also the drill bit) is cleft in halves, subsequently used for core storage. In this way, the core barrel will be lost, and probably also the drill bit
3. Unthread the core barrel from drill bit and place core in a plastic half barrel with an inner diameter greater than the outer diameter of the core barrel, then pulling off the core barrel. The stuck drill bit will stay with the core until further cutting of the core in order to avoid core damage.

4 Results and conclusions

4.1 Core documentation

Four cores, KA2169A01, KA2169A03, KA2423A03, and KA2549A01 were recovered with complete or almost complete success. Fractures in or near the target zones had been filled with epoxy and the cores were intact (KA2169A01, KA2169A03, and KA2423A03) or almost intact (KA2549A01). These cores, including the target structure/-s, were mapped in detail by covering the cylindrical envelope surface of the core with a transparant drawing film. Cataclastic structures, were indicated with ink on the film, fractures (black), quartz fillings (orange), mylonitic foliation (green). Likewise, epoxy infillings were marked (red). By this method, a 1:1 scale drawing of the entire cylindrical envelope surface of target zone and adjacent core could be made. The drawings are shown in reduced scale in Appendix 1.

In addition, the entire core from each hole was logged in scale 1:10, with respect to fracture position, fracture orientation, fracture wall alteration, fracture mineral fill and/or coating and epoxy filling. Core logs are shown in two dimensions: a fracture intersection with the core will form an ellipse. The long axes of all fractures are shown in the same plane, regardless of fracture orientation. The drawings are shown in Appendix 2.

One core, KA2169A02 was so severely damaged at the target zone that it was regarded as being of no benefit to log it in detail. Two cores, KA1596A02 and KA1596A04 were damaged too much to log in detail, but the target zones were logged in two dimensions in scale 1:4, and merged into the 1:10 scale core logs.

The cores were also photographed using a digital camera. Epoxy grouted zones were, in addition photographed in UV light, with a wavelength spectrum of approximately 315-400 nm, enabling enhanced visualisation/identification of resin-filled pore spaces.

4.2 KA2549A01

Pilot: The original target zone was not identified by pilot drilling as a zone. Individual fractures occurred, but could not be made to fit with two subsequent intercepts in boreholes (KA2549A02 and KA2549A03) at this site (Hansen et al., 2003).

However, another zone, almost perpendicular to the original target zone appeared in the pilot core as four fractures crossing at approximately 200 cm, two with an angle to core axis of approximately 10º and two of approximately 30º. Subsequent BIPS camera logging inside the hole did only detect three of them (probably due to dimmed water) and determined their orientations to N78W/47N, N69W/44N and N64W/56N, in accordance with both core logs and tunnel mapping. The zone was interpreted as consisting of 4 individual fractures. A fourth pilot hole, KA2548A01 was drilled in order to pass 1 metre beyond this zone, but did not encounter it at all.

Overcoring (Figure 4-1): At the target zone at ca 200 cm of depth, two epoxy filled fractures were observed with an orientation of 268/62. The dip was measured in situ by aiming with the clinometer at the core stub in the hole, before overcoring, and the angle was subsequently used for core orientation. The two fractures diverge into four, with an orientation of 292/50 (one such divergence can be seen in Figure 4-2). A few fractures at 150-170 cm, with an orientation of 136/85º are also filled with epoxy, and also minor randomly oriented fractures were filled up well with epoxy (Figure 4-3).

Conclusions: The bend of the structure explains why it was not encountered by the fourth pilot hole, KA2548A01. The larger core gives a more detailed picture of the structure, being a system of sub-parallel fractures which diverge and merge, instead of the interpreted four individual subparallel fractures.

Figure 4-1. *KA2549A01. Core recovery with target zone, and outline of Figure 4-2.*

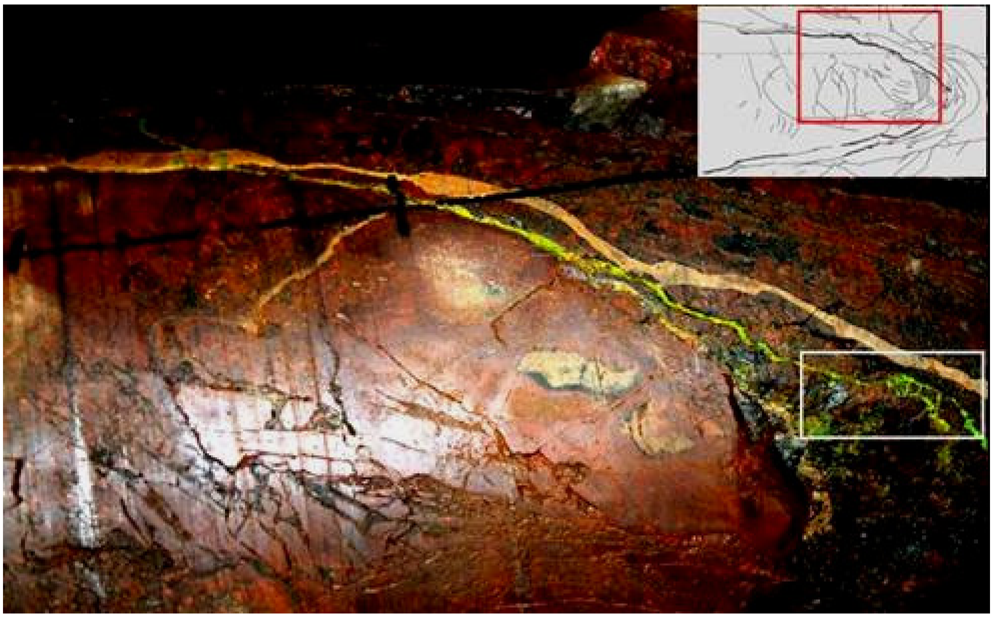


Figure 4-2. *KA2549A01. Target zone with diverging fracture zone with epoxy fill, and approximate outline white box of Figure 4-3. Miniature in upper right-hand corner shows approximate coverage of figure in relation to the corresponding envelope drawing in Appendix 1.*

Figure 4-3. *KA2549A01. Epoxy fill detail, c.f. Figure 4-2 for relative position.*

4.3 KA2169A01

Pilot: The target structure at 250 cm is a fracture with a width of 2-3 mm filled with breccia, appearing potentially water conducting, and with an angle of 40º to the core axis. BIPS logging showed an orientation of 164/37. Nearby, another two fractures oriented 169/87 and 165/85 occur at 210 and 220 cm.

Overcoring: Overcoring showed that the target fracture is connected with adjacent subparallel fractures (Figure 4-4). There is no visible epoxy in the zone. But three fractures at 210-235 cm are epoxy filled, two oriented 340/70 and one 130/78 with a sub system of splays (Figure 4-5). No connection with the target zone is visible in the core, but fracture orientations indicate that they will intersect or merge.

Figure 4-4. *KA2169A01. Core recovery with target zone at 250 cm, with no visible epoxy grout. Hidden under the drill bit (far right) are epoxy filled fractures at 210-235 (Figure 4-5).*

Conclusions: The target structure consists of a few sub-parallel converging master fractures. It is regarded as containing clay minerals which has obstructed epoxy intrusion. Instead three fractures striking NW-SE, two 340/70 and one 130/78, were filled well with epoxy as well as adjacent minor splay fractures (Figure 4-6). This is in accordance with the noted epoxy take (cf Table 1-1)

Figure 4-5. *KA2169A01. Core recovery with epoxy filled fractures at 215-235 cm.*

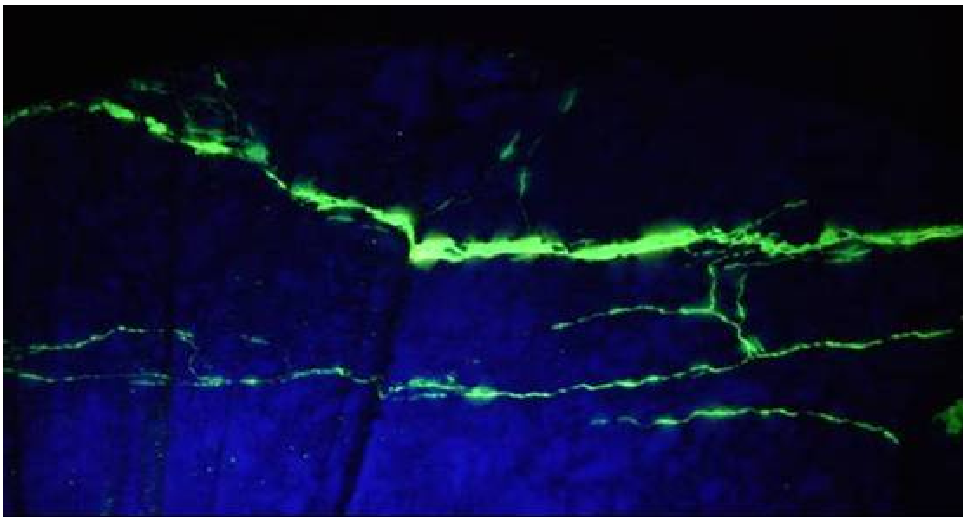


Figure 4-6. *KA2169A01. Epoxy filled fractures on a surface cut across the core at 220 cm in UV light. Approximate 1:1 scale.*

4.4 KA2169A02

Pilot: The pilot drill core showed a 5 cm thick structure with fault crush at 300 cm, with a 30º angle to the core axis. The BIPS log indicated an orientation of 308/89, in accordance with angle to core and tunnel appearance.

Overcoring: The core was damaged during drilling. Only debris with patches of epoxy was recovered from the target zone, and no direction data could be measured (Figure 4-7).

Conclusions: Clayey infilling has obstructed epoxy intrusion and also resulted in bad cohesion of the fault gouge and breccia material.

Figure 4-7. *KA2169A02. Epoxy patches on fracture surfaces.*

Figure 4-8. *KA2169A03. Core recovery with target zone at 390 cm, with plenty of epoxy grout (yellow along the diagonal fracture). The area above the 400 mark is shown in Figure 4-9.*

4.5 KA2169A03

Pilot: The pilot core showed a 2 cm thick structure with fault crush at ca 400 cm, with a 30º angle to the core axis. The BIPS logs indicated an orientation of 310/80º, in accordance with tunnel and core data.

Overcoring: The target structure appeared as an up to 5 cm wide zone with mylonitic foliation, (foliation caused by shearing, common in fault zones) with an orientation of 300-315/80º, and with sub-parallel, converging and diverving epoxy filled master faults, with orientations of 300-315/80º, and also epoxy filled cavities and minor splay fractures (Figure 4-8 and Figure 4-9).

Conclusions: The structure appeared as projected and has a structure similar to that observed in the pilot borehole. The overcore is filled well with epoxy (cf epoxy take in Table 1-1) both in NW-SE striking master faults and in splays (Figure 4-9), preserving the rock material, and resulting in excellent core recovery.

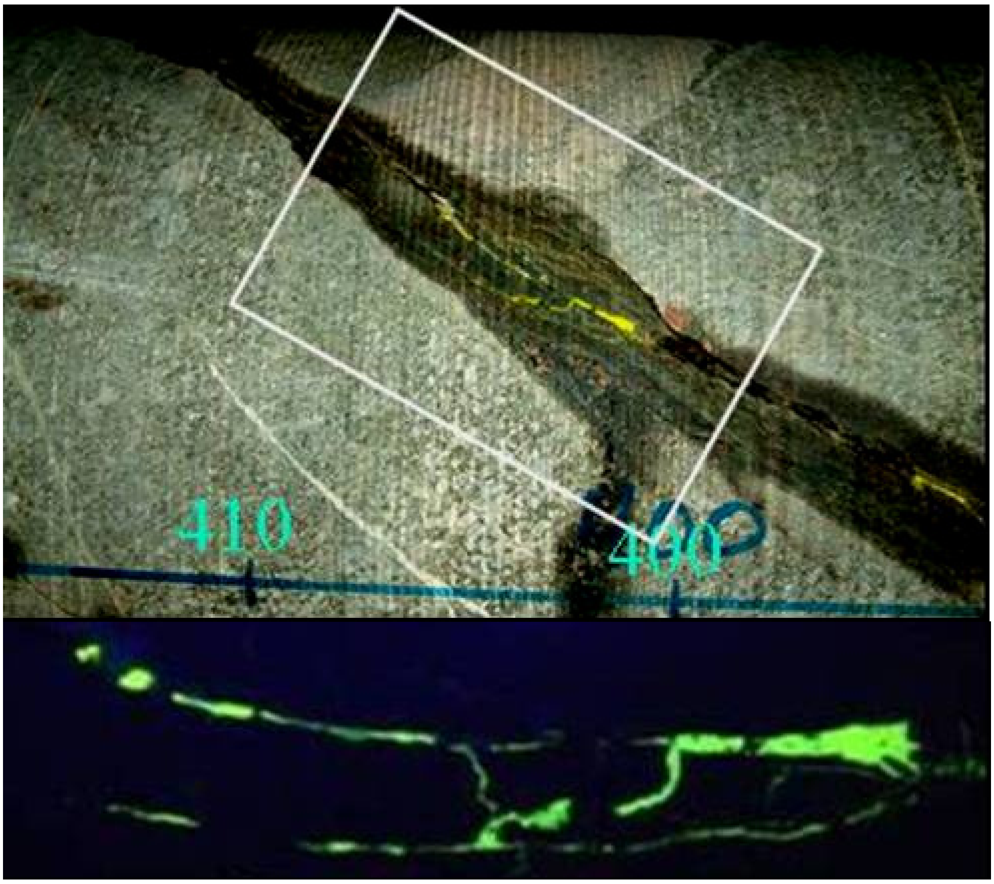


Figure 4-9. *KA2169A03, 390 cm. Above: Epoxy grouted structure flanked by mylonitic foliation. Below: detail in ultraviolet light (Approximate magnification = 3.5).*

4.6 KA2423A03

Pilot: The pilot borehole showed three 2 cm thick zones with fault crush at ca 240 cm, with a 40º angle to the core axis. BIPS logs indicated an orientation of 165-170/75º, in accordance with tunnel and core data.

Overcoring: An up to 10 cm wide zone with mylonitic foliation has an orientation of 150-160/80-85, approximately 50º to the core axis. This zone contains converging and diverving epoxy filled master faults with orientations of 150-160/80-85 but also abundant epoxy filled cavities and splay fractures. Also tight fractures can be observed (Figure 4-10).

Conclusions: The structure appeared as projected and has a structure similar to that observed in the pilot borehole (Hansen et al, 2003). It is filled well with epoxy, both in master fractures and splays, preserving the rock material and resulting in excellent core recovery.

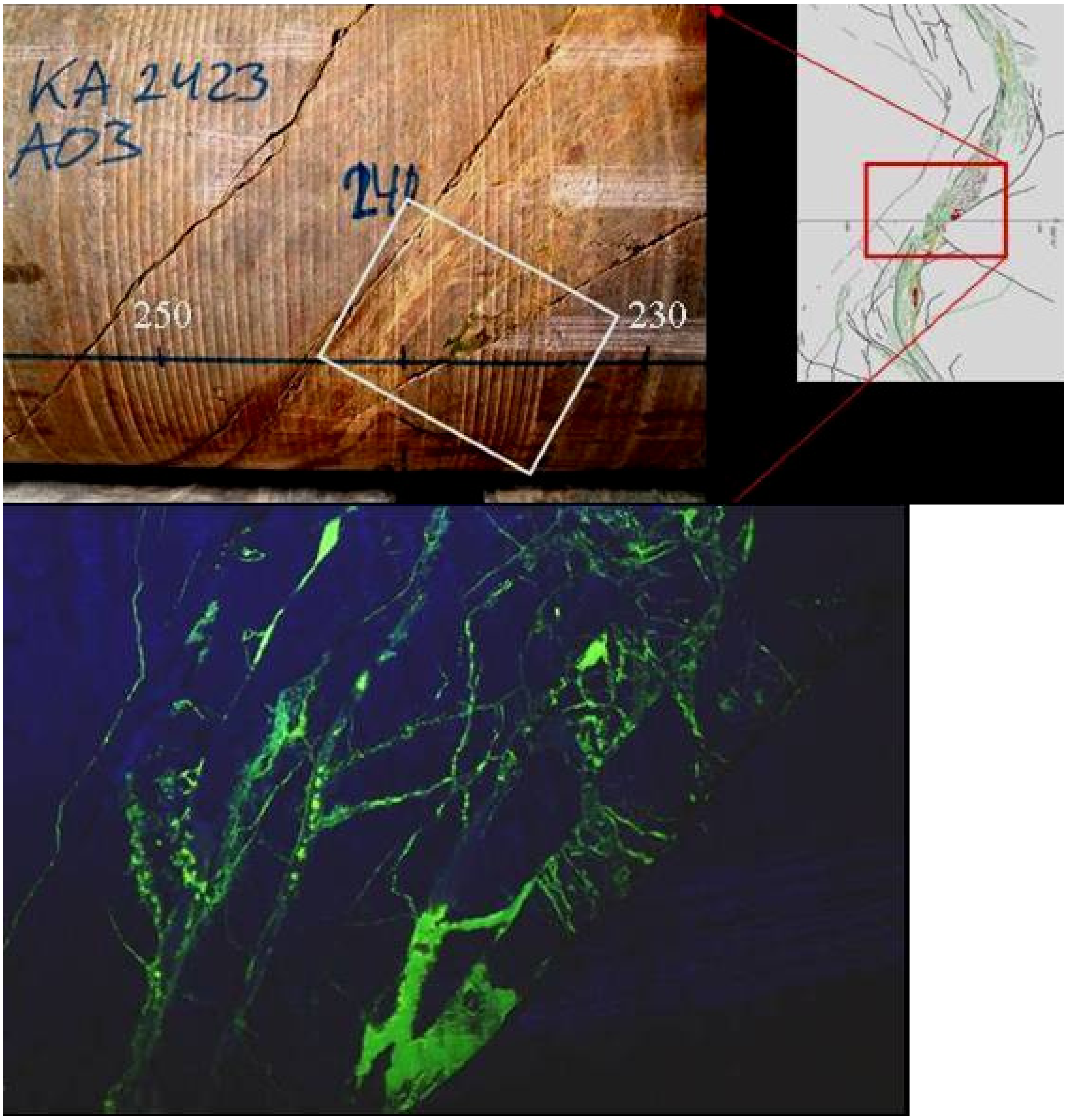


Figure 4-10. *KA2423A03, Core recovery with target zone at 240 cm, 50º to core axis, and with mylonitic foliation along the zone, and with epoxy grout (dark green in middle of rectangle indicating outline of UV picture) The pore spaces vary up to 1x2 cm (lower mid centre) and seem to be well connected. NB the cm-wide spaces in the lower part of the blow-up are assumed to be a result of the angle of the cutting plane to the pore, i.e. a likely geometrical effect to be substantiated by further analysis. NB Pore size mapped on core mantel surface is a function of the cutting surface relative to the geometry of the pore.*

4.7 KA1596A02

Pilot: The pilot core showed a 25 cm thick zone with fault gouge (rather chloritic phyllonite) at ca 470 cm, with an angle to the core axis of 40º. The BIPS log showed fractures in the fault gouge with orientations of 54/70º, 45/78º, 37/83º, and 23/86º, which are in accordance with tunnel and core data.

Overcoring: The core at the position of the target zone was severely damaged by drilling and only loose debris, presumably from the zone, was recovered. Some epoxy had intruded into the fault gouge, but only up to a few cm from pilot hole perimeter, and only sporadical epoxy was observed on the core surface. However epoxy was abundant in fractures at 370-390 cm with an orientation of 145/80º, approximately perpendicular to the zone (Figure 4-11), and parallel with the horizontal stress.

Conclusions: The structure appeared as expected and has a structure similar to that observed in the pilot borehole. Clayey infilling has obstructed epoxy impregnation of the fault gouge, but, as for KA2169A01 and KA2169A03, epoxy is abundant in steep fractures in the NW quadrant.

Figure 4-11. *KA1596A02. Core recovery with target zone at ca 460 cm.*

4.8 KA1596A04

Pilot: The pilot core indicated three 5 cm thick zones with fault gouge at approximately 230-280 cm, with a 30º angle to the core axis. The BIPS log indicated orientations of 49-52/60-80º, which are in accordance with core and tunnel data.

Overcoring: The core at the position of the target zone was heavily damaged by the removal from the core barrel, but loose debris could to some extent be identified with respect to position in core. Epoxy was abundant in 130/80-85º fractures at 210 cm and 270 cm and in one 0/63º fracture at 190 cm (Figure 4-12), and some epoxy had intruded into the fault gouge, but only up to a few cm from pilot, and no epoxy was observed on the core surface (Figure 4-13). Some pieces of intact fault gouge were also recovered and secured in sealed plastic bags and sent to the laboratory for further testing of porosity and other petrophysical parameters (Figure 4-14).

Conclusions: The structure appeared as projected and has a structure similar to that observed in the pilot drill hole. Clay fill has obstructed epoxy impregnation of the fault gouge but, as for KA2169A01, KA2169A02, and KA2169A03, epoxy is abundant in steep fractures in the NW quadrant, but also in one fracture oriented 0/63º.

Figure 4-12. *KA1596A04. Above: core recovery with epoxy at 190 cm and target zones at 230-320cm. Below: 0º/63º fracture with epoxy at 190 cm.*

Figure 4-13. *KA1596A04. Zone with epoxy at 190-300cm.*

Figure 4-14. *KA1596A04. Zone with fault gouge at 290 cm.*

4.9 General Results

Epoxy is abundant in steeply dipping fractures with a strike of 130-170º at all four sites 1600 - Model D, 2163 - Model C, 2430 - Model B, and 2545 - Model A (cf Appendix 2). Both single fractures and breccias appear to be epoxy filled. At 1600 very little epoxy has intruded in the NE striking target structure with clayey fault gouge in chloritic phyllonite (a mica or chlorite rich rock type formed by shear), and the epoxy has had difficulties reaching the surface of the 277 mm core. At 2545, the target structure striking E-W was filled well with epoxy. Epoxy intrusion appears to have been efficient, and epoxy has intruded into very narrow spacings, just visible by the unpowered eye.

5 Drilling methods - Conclusions and suggested improvements

- The 277 mm cores from drill holes KA2169A01, KA2169A03, KA2423A01, and 2549A01, in which the material was more brecciated rather than fine-grained clayey fault gouge, were filled well with epoxy and were all recovered in one piece, with epoxy acting as an efficient reinforcement.
- Retrieval of cores KA2169A01, KA1596A02 and KA1596A04 all of which contained clayey fault gouge with a thickness between 2 and 10 cm, were more or less problematic. The fault gouge material of the two former, was destroyed during drilling and was thus only recovered in pieces, the position of which in the core is more or less uncertain.
- KA1596A04 was recovered in the core barrel, but difficulties were encountered during removal of the core from barrel, and the fault gouge disintegrated during handling. However, it was to some extent possible to reinstate the disturbed material at their original position in the core.
- The customised core recovery barrel did not work properly. The core did not fasten in it and the core barrel used for drilling had to be used, instead. The recovery barrel needs modifications. It must be longer than the core to recover, and it must be equipped with a stopper to prevent the core from sliding out of the barrel, when being retrieved.
- For recovery of core from the barrel the following measures need to be taken: the drill bit must be removed before any attempt to recover the core is made. A half-pipe with an inner diameter larger than the outer diameter of the core barrel must be used to collect the core. In extreme cases, the core barrel and even the drill bit may need to be cleft along its axis.
- Storage in boxes appears not suitable for this core dimension, as cores have to be cut to fit the boxes. Instead it is recommended to use standard plastic sewer pipes, cut on site to fit the obtained core lengths. The pipes should be cleaved in halves, secured by adjustable straps, and stored on pallets. It may also be possible to obtain caps for closing the pipe ends.

References

Stigsson M, Hermanson J, Forsberg O, 2003. True 1 Continuation. Fault rock zones. Structural models of tentative experiment sites. SKB IPR-03-49

Hansen, L M, Hermanson, J, & Staub, I, 2003. Core drilling. Observations during drilling and a preliminary structural-geological description based on drillcore data and tunnel mapping. SKB IPR-03-50 (in prep,)

Appendices

Appendix 1. Drawings of envelope surfaces of KA2169A01, KA2169A03, KA2423A03, and KA2549A01.

Appendix 2. Two dimensional drawings of cores from KA1596A02, KA1596A04 KA2169A01, KA2169A02, KA2169A03, KA2423A03, and KA2549A01.

Appendix 3. Packer system used for epoxy grouting.

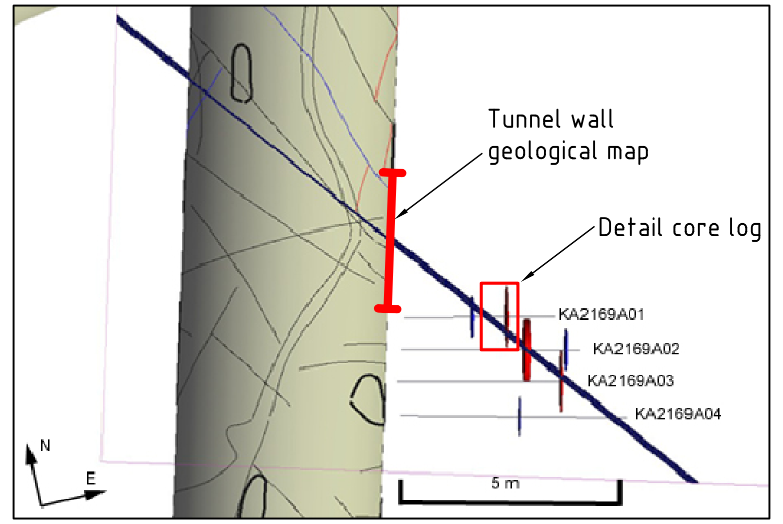
Golder Associates	TRUE-1 CONTINUATION PROJECT Characterisation of fault rock zones Overcoring 300 mm of investigation/grouting holes in the Äspö tunnel at chainages 2/430, 2/545, 2/163 and 1/600	Project No. 0370536	APPENDIX 1:1
		Scale 1:200	Object ID:
		Date March 2004	KA2169 A01

Project Manager: I. STAUB

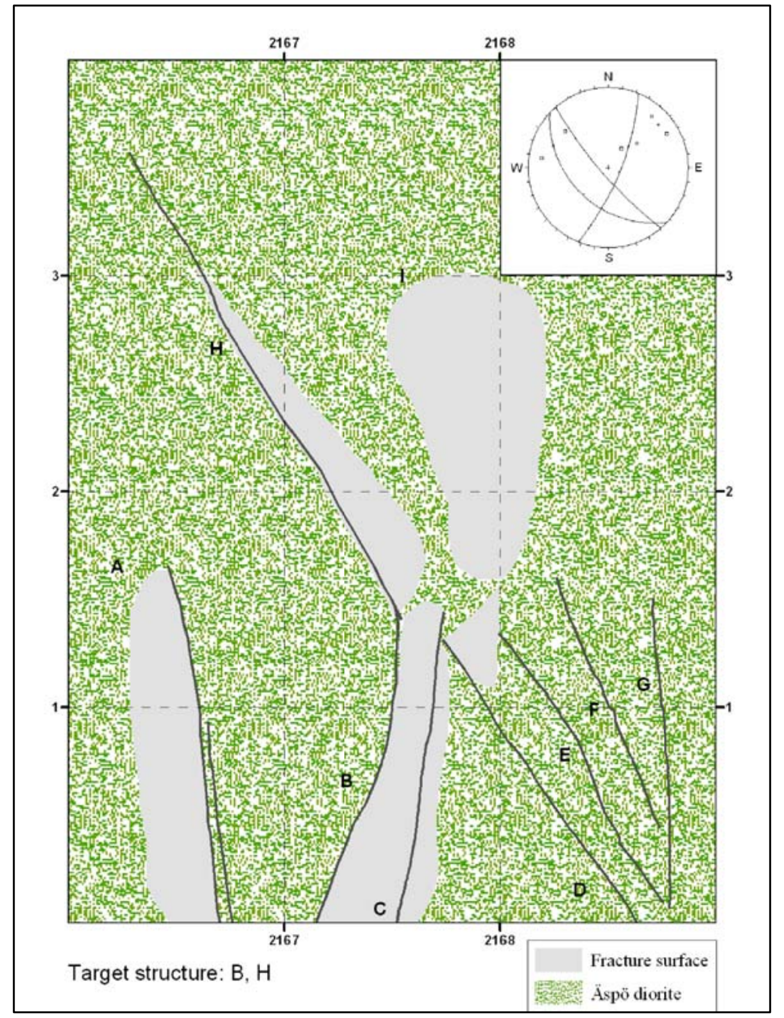
Person responsible: L. HANSEN

Drawn by: S. KOYI

Source: Golder Associates (field)



Model C, Chainage 2163

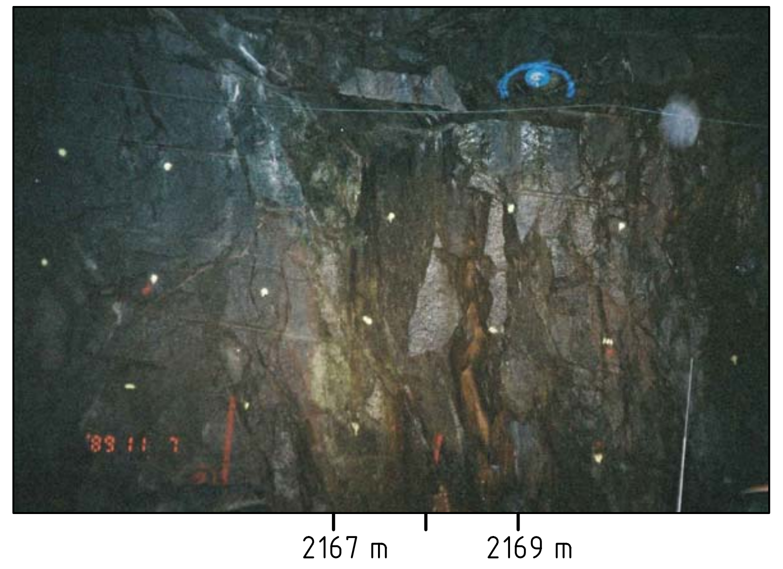


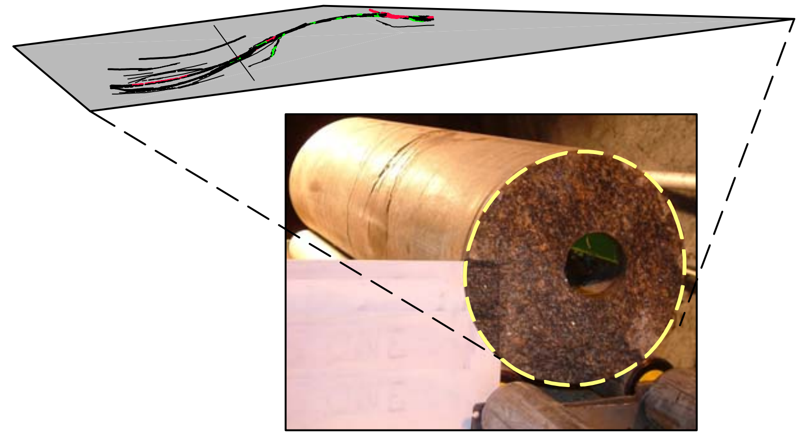
Tunnel wall geological map

LEGEND

FRACTURE, TIGHT

EPOXY FILLED FRACTURE

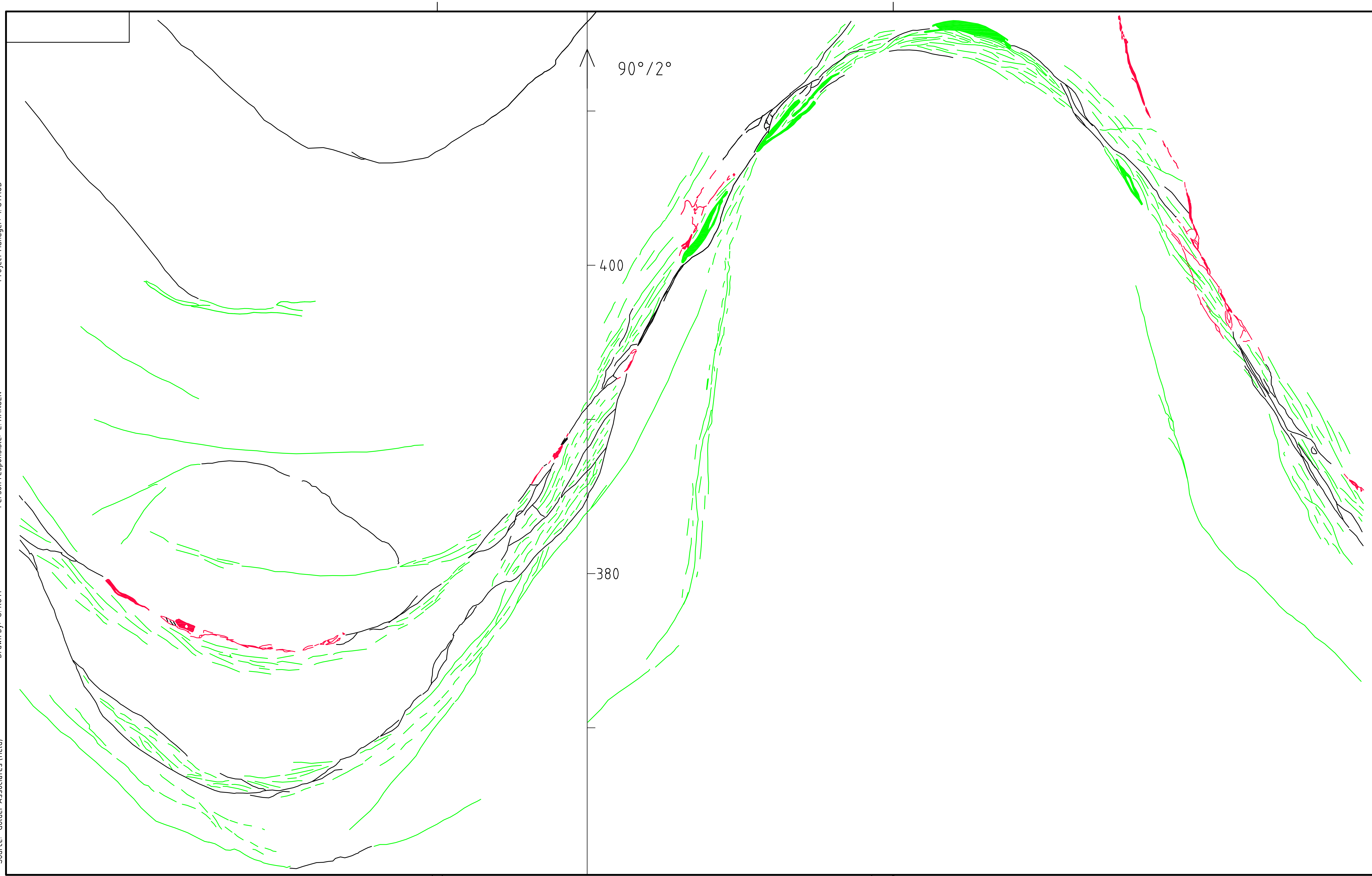


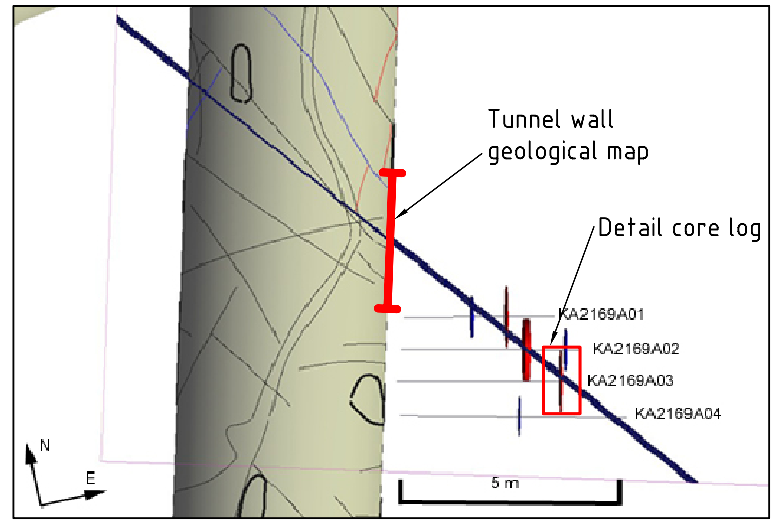


The cores were mapped in detail by covering the envelope surface of the core with a transparent drawing film. Structures were copied with ink on the film. The sketch shows the drawing film after unfolding from the core, giving a picture of the envelope surface of the core.

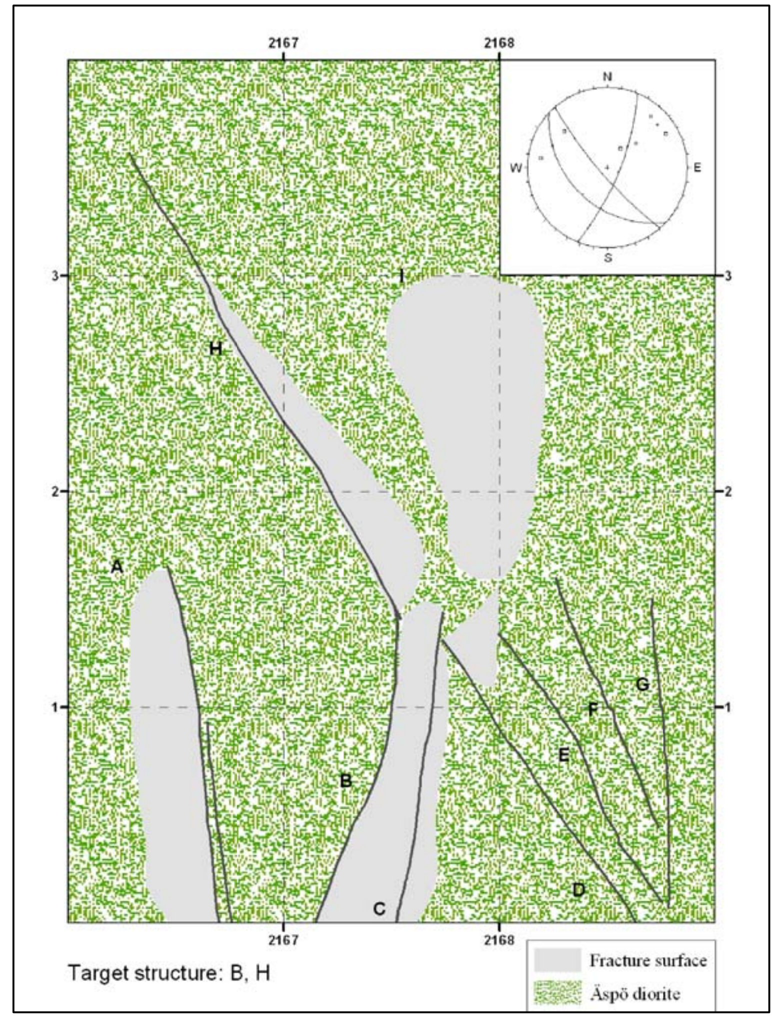
Golder Associates	TRUE-1 CONTINUATION PROJECT Characterisation of fault rock zones Overcoring 300 mm of investigation/grouting holes in the Äspö tunnel at chainages 2/430, 2/545, 2/163 and 1/600	Project No. 0370536 Scale 1:200 Date March 2004	APPENDIX 1:2 Object ID: KA2169 A03

Project Manager: I. STAUB
Person responsible: L. HANSEN
Drawn by: S. KOYI
Source: Golder Associates (field)





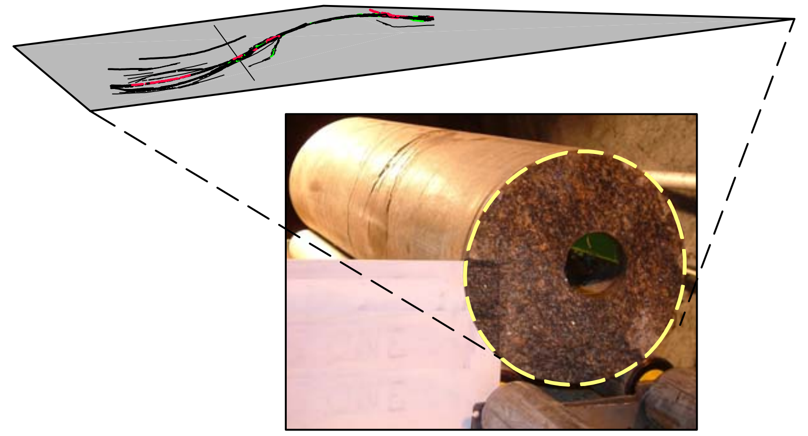
Model C, Chainage 2163



Tunnel wall geological map

LEGEND

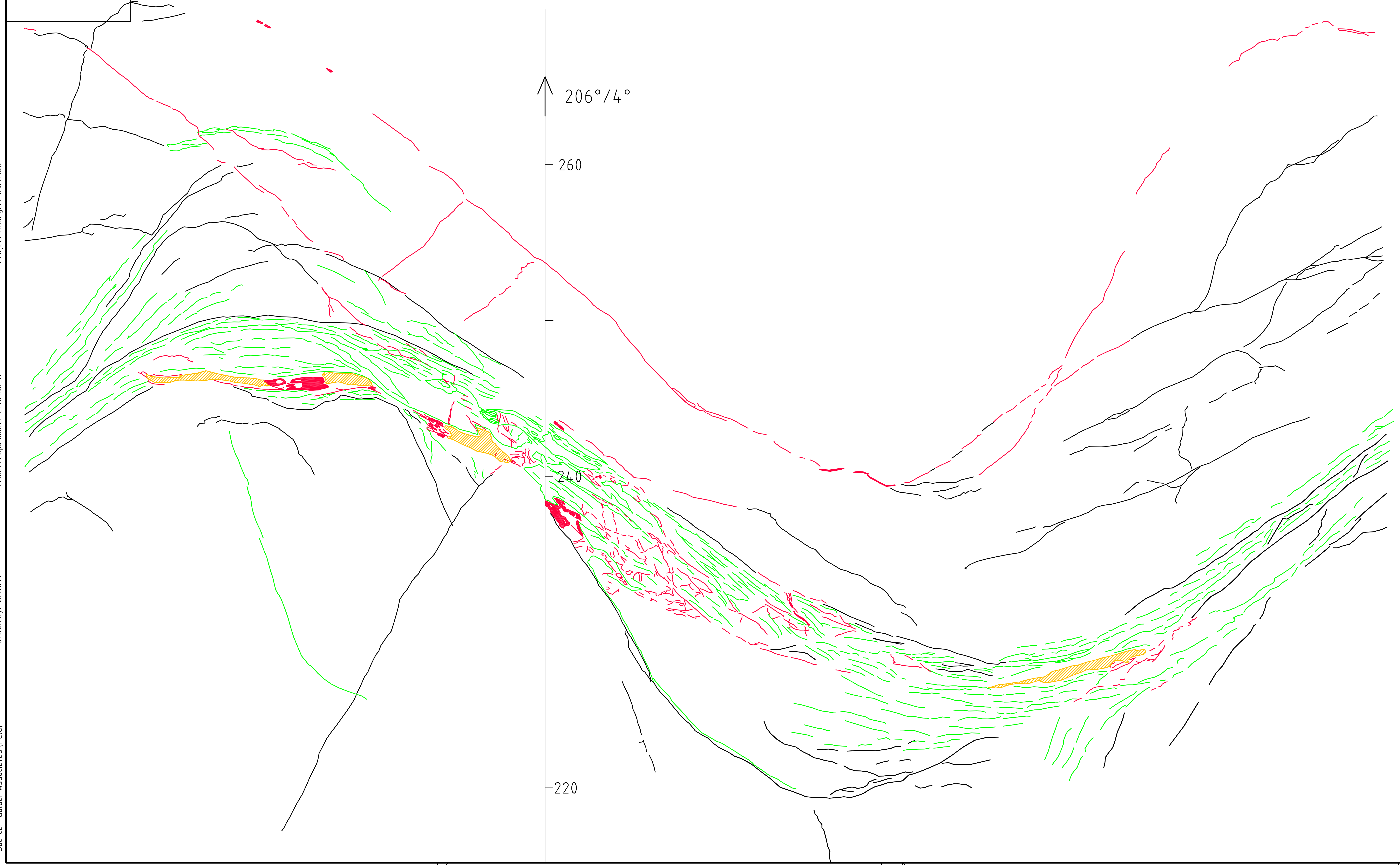
- FRACTURE, TIGHT
- MYLONITIC FOLIATION
- EPOXY FILLED FRACTURE
- EPOXY FILLED CAVITY

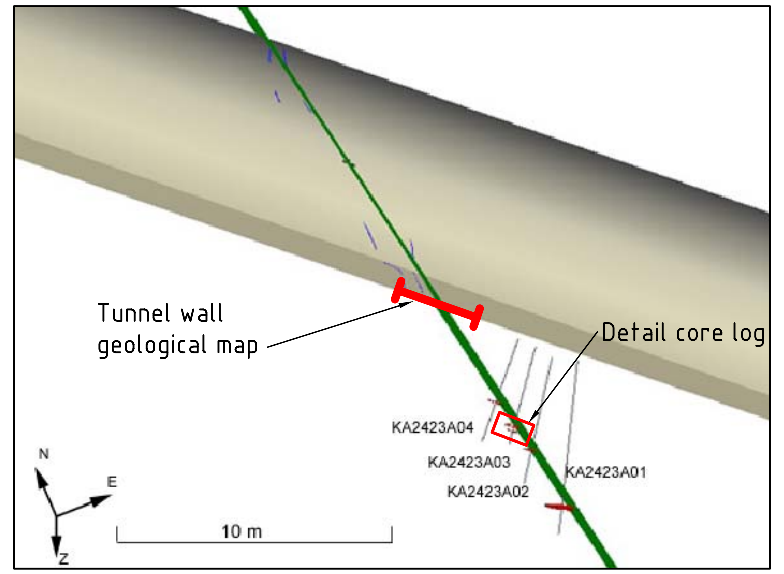


The cores were mapped in detail by covering the envelope surface of the core with a transparent drawing film. Structures were copyed with ink on the film. The sketch shows the drawing film after unfolding from the core, giving a picture of the envelope surface of the core.

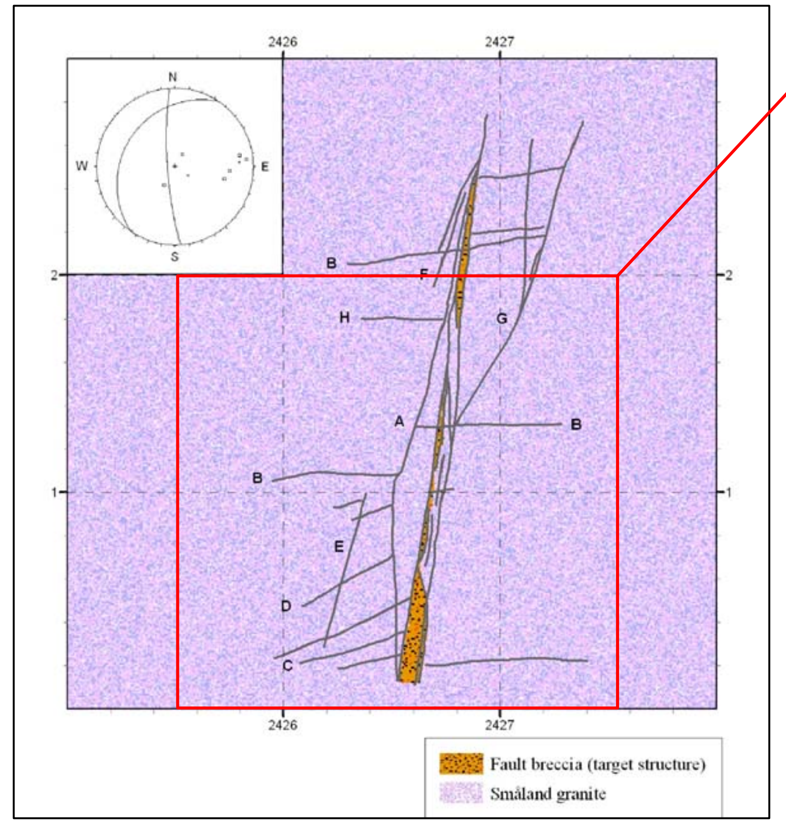
	TRUE-1 CONTINUATION PROJECT Characterisation of fault rock zones Overcoring 300 mm of investigation/grouting holes in the Äspö tunnel at chainages 2/430, 2/545, 2/163 and 1/600	Project No. 0370536	APPENDIX 1:3
Golder Associates		Scale 1:200 Date March 2004	Object ID: KA2423 A03

Project Manager: I. STAUB
Person responsible: L. HANSEN
Drawn by: S. KOYI
Source: Golder Associates (field)





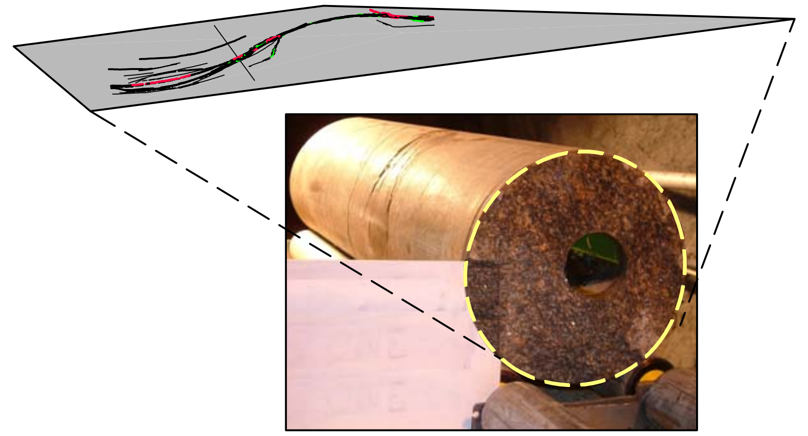
Model B, Chainage 2430



Tunnel wall geological map

LEGEND

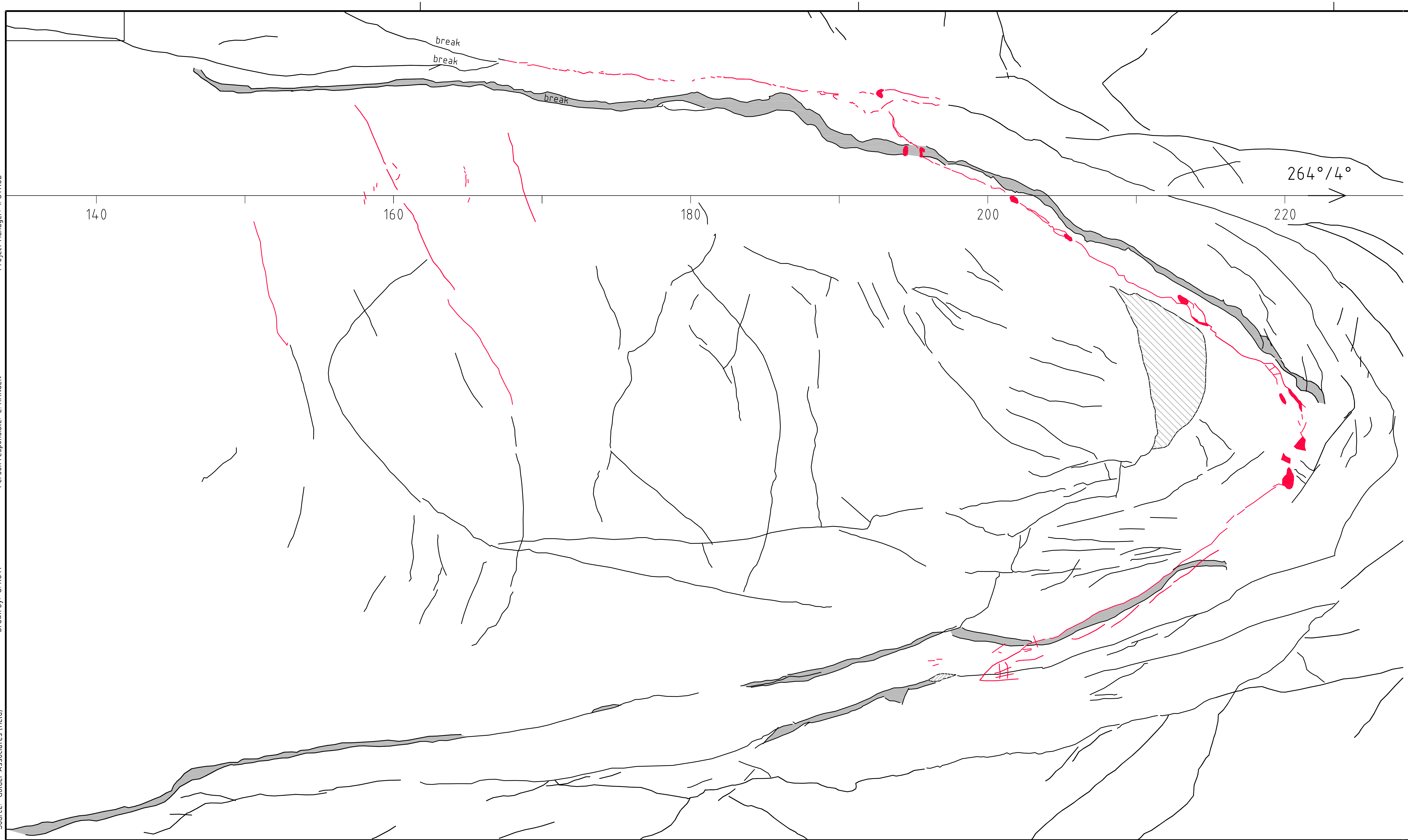
- FRACTURE, TIGHT
- MYLONITIC FOLIATION
- EPOXY FILLED FRACTURE
- EPOXY FILLED CAVITY
- QUARTZ VEIN



The cores were mapped in detail by covering the envelope surface of the core with a transparent drawing film. Structures were copyed with ink on the film. The sketch shows the drawing film after unfolding from the core, giving a picture of the envelope surface of the core.

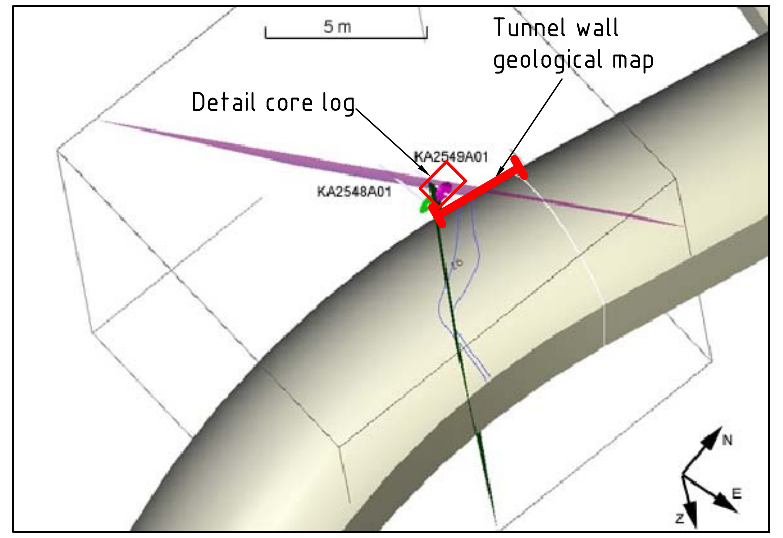
	TRUE-1 CONTINUATION PROJECT Characterisation of fault rock zones Overcoring 300 mm of investigation/grouting holes in the Äspö tunnel at chainages 2/430, 2/545, 2/163 and 1/600	Project No. 0370536	APPENDIX 1:4
Golder Associates		Scale 1:200 Date March 2004	Object ID: KA2549 A01

Source: Golder Associates (field)
Drawn by: S. KOYI
Person responsible: L. HANSEN
Project Manager: I. STAUB

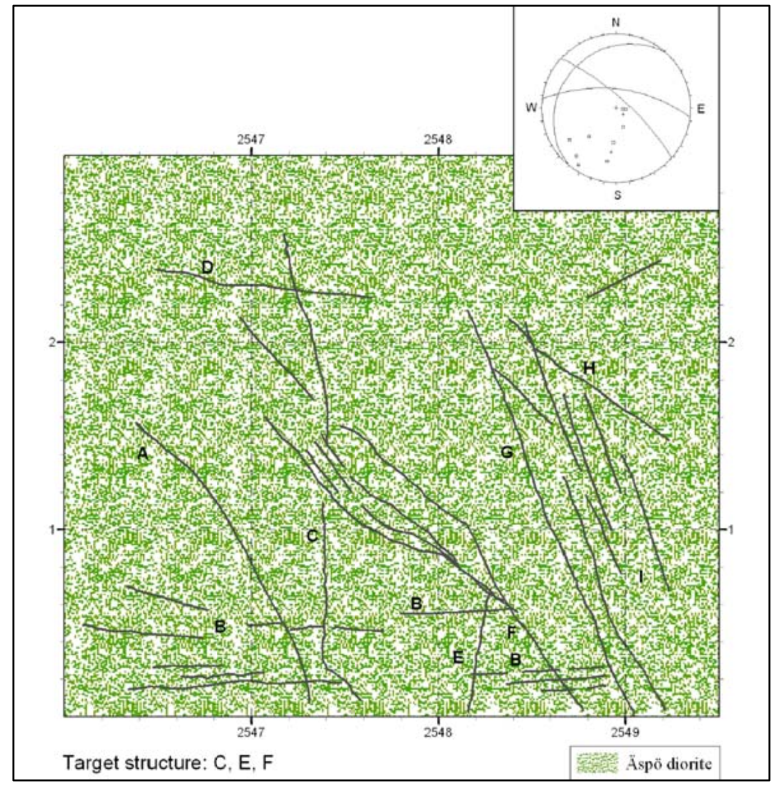


LEGEND

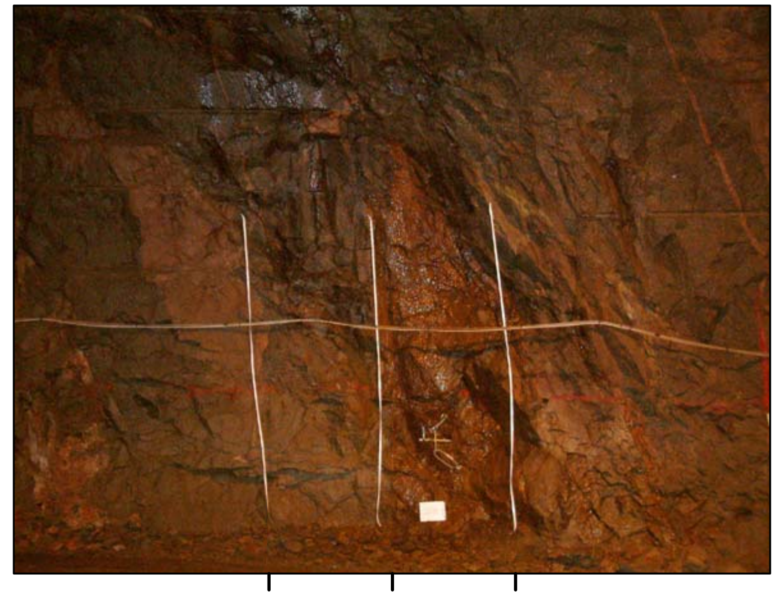
- FRACTURE, TIGHT
- EPOXY FILLED FRACTURE
- EPOXY FILLED CAVITY
- CEMENT GROUT
- FRACTURE SURFACE



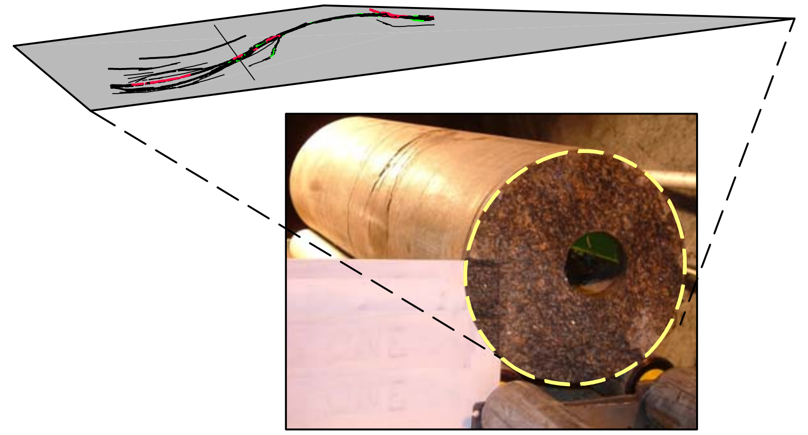
Model A, Chainage 2545



Tunnel wall geological map



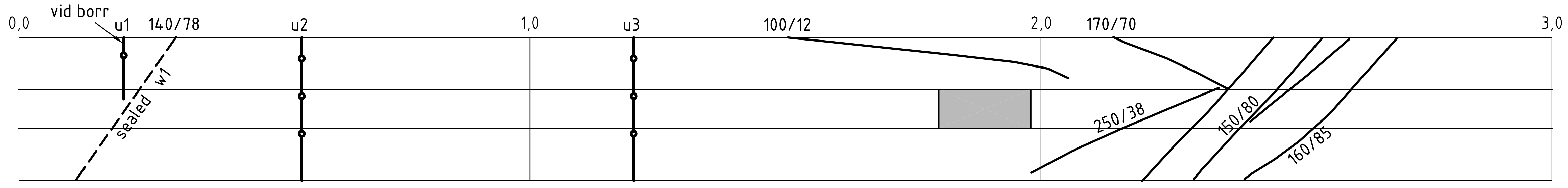
2547 m 2549 m



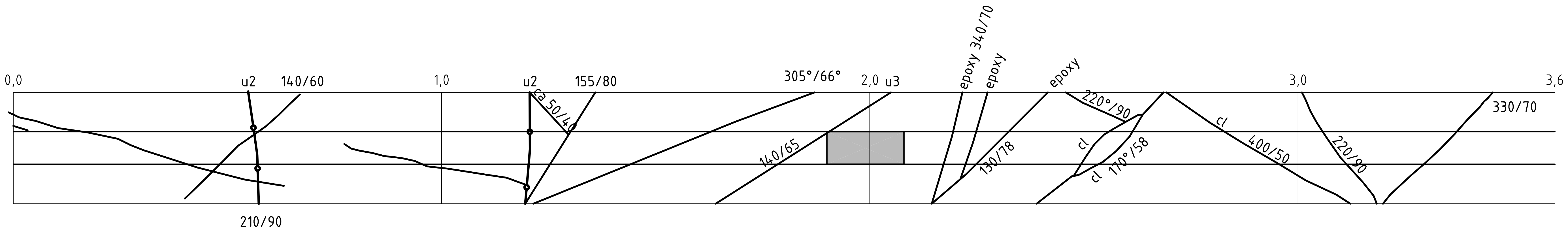
The cores were mapped in detail by covering the envelope surface of the core with a transparent drawing film. Structures were copyed with ink on the film. The sketch shows the drawing film after unfolding from the core, giving a picture of the envelope surface of the core.

TRUE-1 CONTINUATION PROJECT Characterisation of fault rock zones Overcoring 300 mm of investigation/grouting holes in the Äspö tunnel at chainages 2/430, 2/545, 2/163 and 1/600	Project No. 0370536	APPENDIX 2:1
	Scale 1:10	
	Date March 2004	

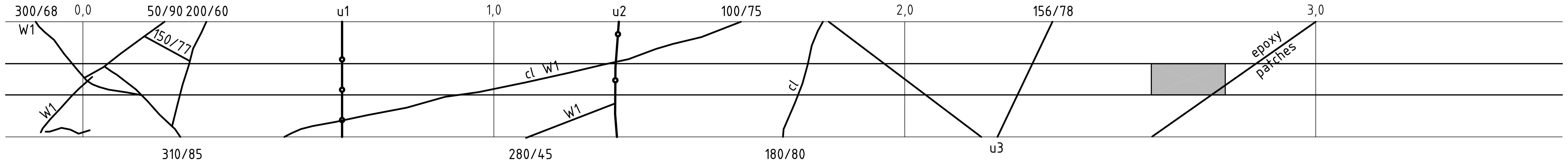
Golder Associates



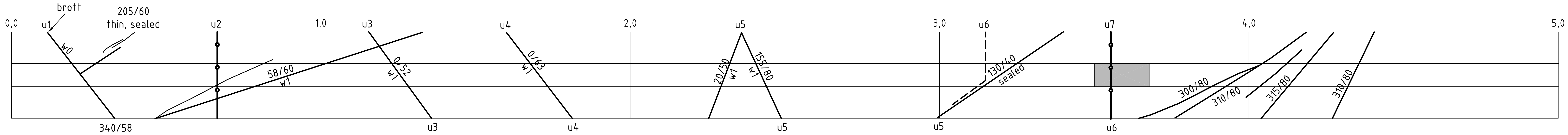
KA 2423 A03



KA 2169A01

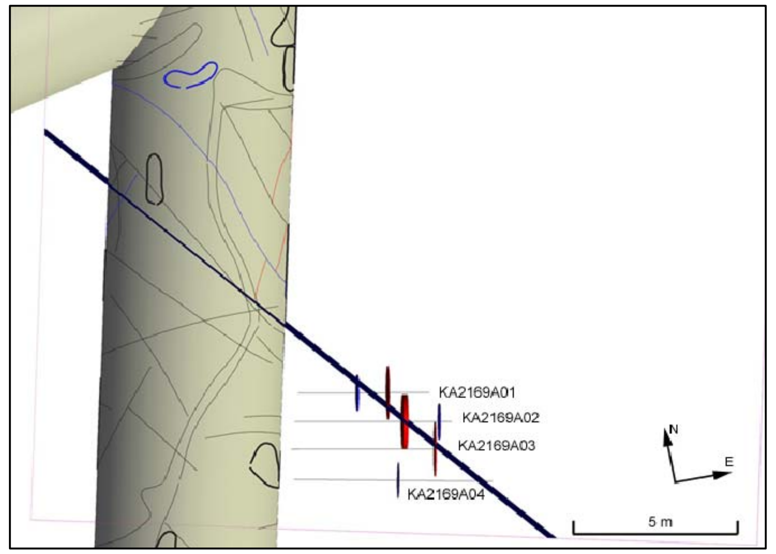


KA 2169A02

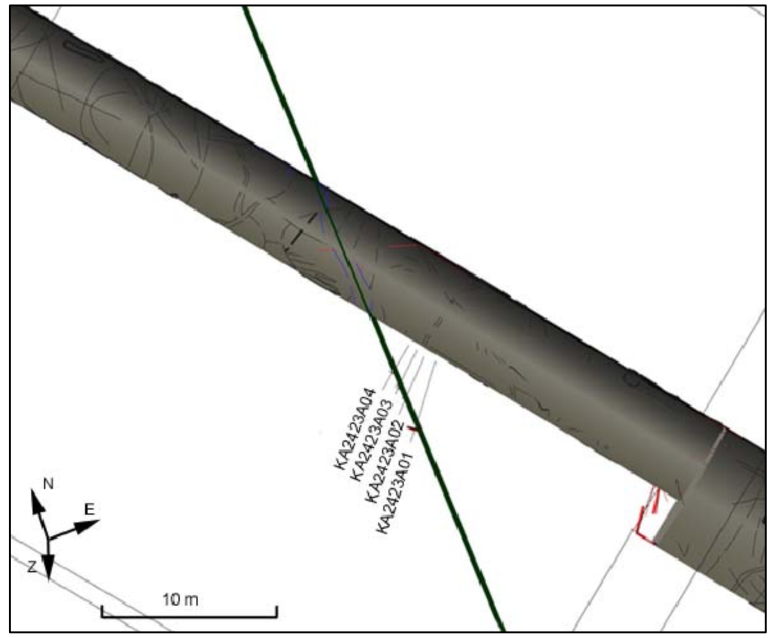


KA 2169 A03

Core logs are shown in two dimensions: a fracture intersection with the core forms an ellipse, and the long axes of all fractures are shown in the same plane, regardless of fracture orientation



Model C of the structure 2163 with location of drill holes



Model B of the structure 2430 with location of drill holes

LEGEND

u1, u2,etc	END OF CORE RECOVERY
	INDUCED BREAKAGE
	PACKER
w1	SURFACE STAINING
w2	ALTERED SURFACE
cl	CHLORITE
ca	CALCITE
ze	ZEOLITE
Feox	IRON OXIDE

Project Manager: I. STAUB
Person responsible: L. HANSEN
Drawn by: S. KOYI
Source: Golder Associates (field)

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Golder Associates	TRUE-1 CONTINUATION PROJECT Characterisation of fault rock zones Overcoring 300 mm of investigation/grouting holes in the Äspö tunnel at chainages 2/430, 2/545, 2/163 and 1/600	Project No. 0370536 Scale 1:10 Date March 2004	APPENDIX 2:2

Project Manager: I. STAUB

Person responsible: L. HANSEN

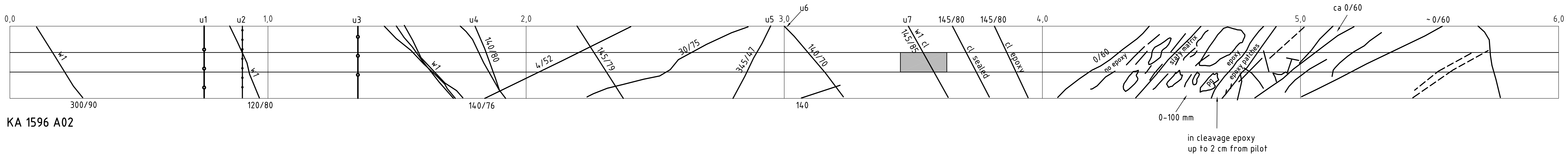
Drawn by: S. KOYI

Source: Golder Associates (field)

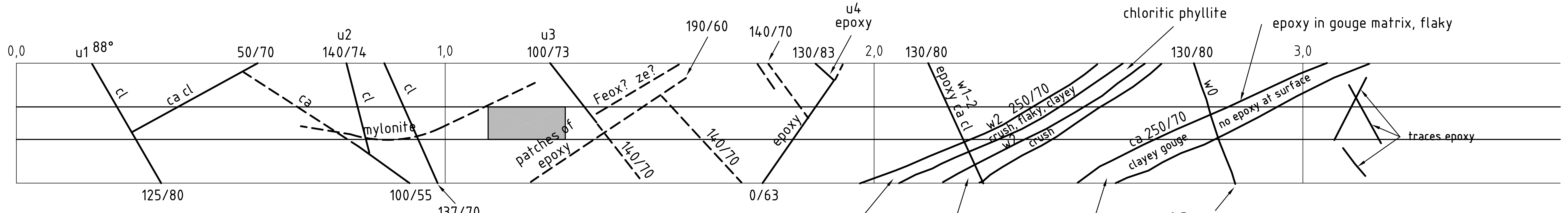
Core logs are shown in two dimensions: a fracture intersection with the core forms an ellipse, and the long axes of all fractures are shown in the same plane, regardless of fracture orientation

LEGEND

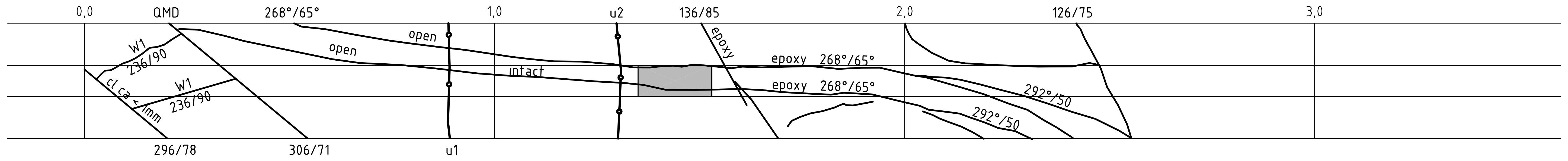
u1, u2, etc	END OF CORE RECOVERY
—o—o—	INDUCED BREAKAGE
(grey box)	PACKER
w1	SURFACE STAINING
w2	ALTERED SURFACE
cl	CHLORITE
ca	CALCITE
ze	ZEOLITE
Feox	IRON OXIDE



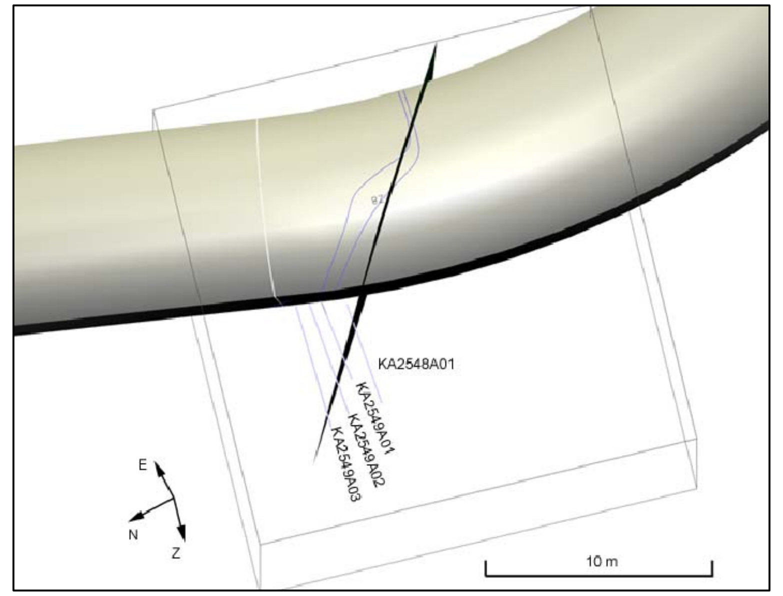
KA 1596 A02



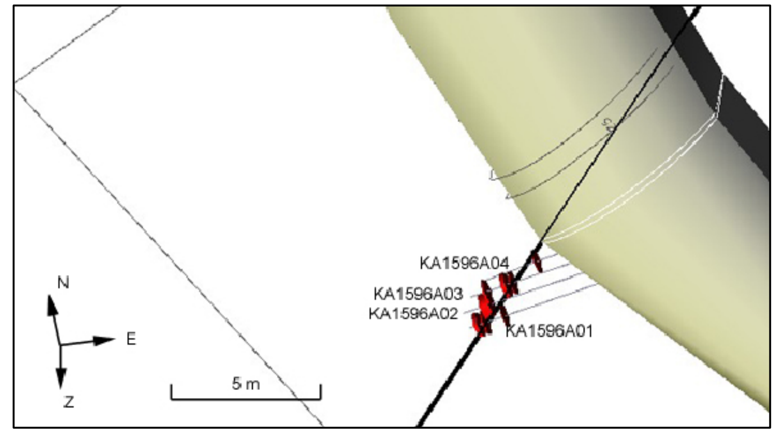
KA 1596 A04



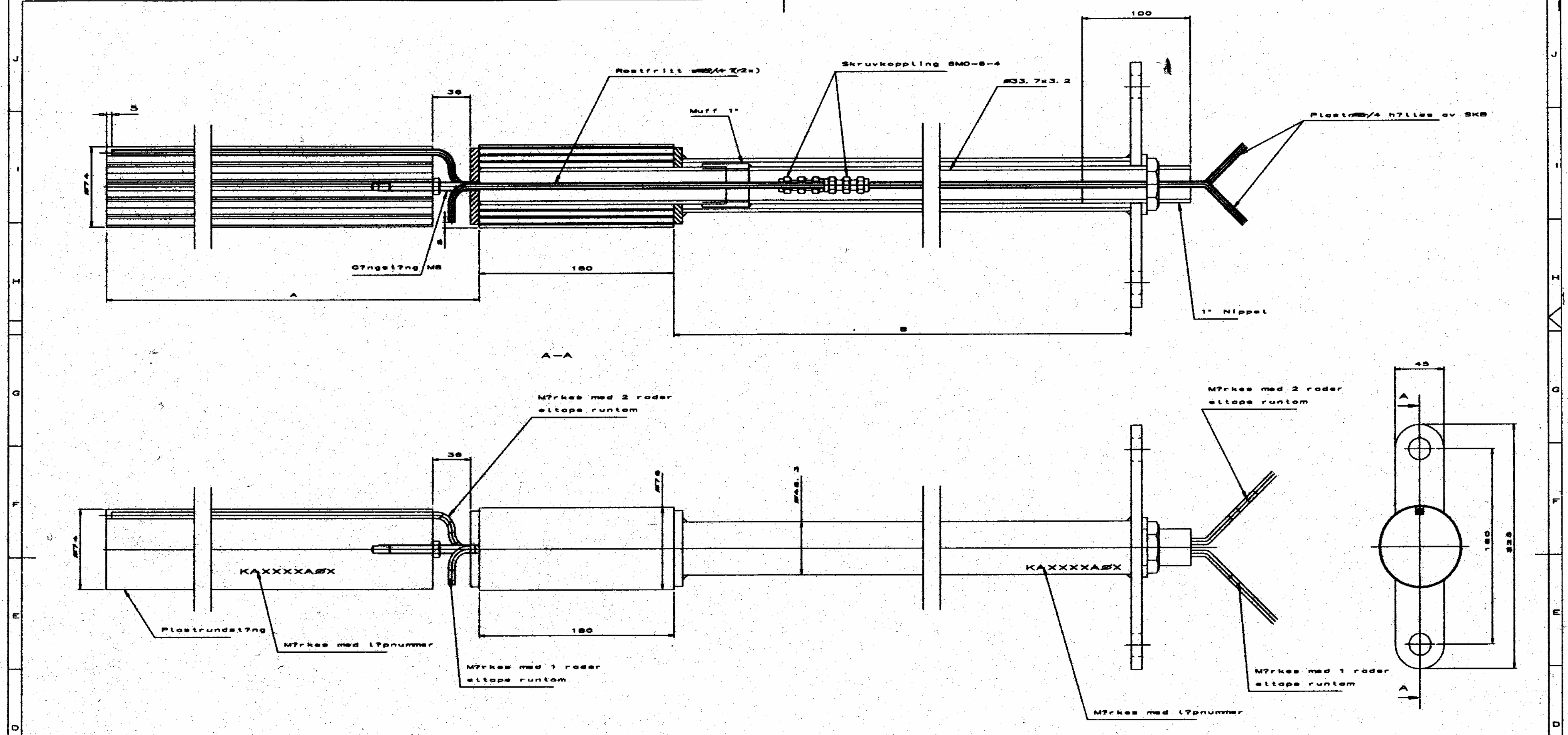
KA 2549A01



Model A of the structure 2545 with location of drill holes



Model D of the structure 1600 with location of drill holes



L?pnummer	A	B
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KA1598AØ	299	3950
KA1596AØ	397	3150
KA1596AØ	282	1600
KA2169AØ	154	2400
KA2169AØ	254	3100
KA2169AØ	800	4000
KA2423AØ	136	4000
KA2423AØ	234	2700
KA2423AØ	950	2300
KA2423AØ	463	1800
KA2548AØ	329	1670
KA2549AØ	216	1850

Det. nr	Ant.	Ben?mning	Material	Mod. nr ?mne Dimension	Anm.

Konstr. | Ritad ChS | Kop. | Kontr. | Stand. | Godk. | Skala 1:2.5 | Rev. status | Ersätt

elajo — Elajo Engineering AB

SKB AB

Manschett. Offertri EEDng03-004

Filnamn | Dat. 2003-05-23

Ritn. nr