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Äspö Hard Rock Laboratory

TBM assembly hall

Geological mapping of the assembly hall and deposition hole

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Abstract

As a part of the general geological characterization of the tunnels at Äspö HRL the geological mapping of the walls and roof of the TBM assembly hall was finished shortly after the excavation had ended in 1994. Later, in 1998, a pit was opened up in a part of the paved floor to expose the rock underneath. The pit floor was mapped and the result was used to decide where to drill two short core bore holes, KA3147G01 and KA3153G01.

The cores from the two holes were logged according to the Boremap system. By using the results from the logging and the previously performed mapping of the pit floor the location of the large deposition hole DA3147G01 was decided.

In 1999 the deposition hole DA3147G01 was accomplished by using a vertically drilling TBM. The hole was shortly after geologically mapped in detail from a cage hooked up to a lift.

All mapping has been digitized and the data fed into a computer and stored in a database according to SKB's TMS mapping system.

The results of the performed various geological mappings of the TBM assembly hall show that basically four rock types are present. Grey, medium-grained Äspö diorite (with or without feldspar megacrysts) is the completely dominating rock type. Reddish or sometimes grey, fine to medium-grained "fine-grained granite" occurs in minor amounts as veins, dykes or irregular bodies. A dark-blackish green, fine- to medium-grained greenstone is less common than the reddish fine-grained granite and occurs mainly as xenoliths within the Äspö diorite. Pinkish to reddish pegmatite is the least common rock type in the TBM assembly hall. Fine-grained granite sometimes forms hybrids with Äspö diorite.

The rock has been regarded as fresh (no alteration), besides some minor oxidation of the rock commonly in connection with fractures.

The contacts between the rock types are mostly tight and sharp. More diffuse contacts are commonly found where a distinct rock type grades into a hybrid one.

All recorded fracture orientations have been plotted in Schmidt net and joint rosette diagrams. Three major fracture sets have been distinguished having the following mean orientations: 120°/80°, 180°/15° and 20°/80° (strike/dip right hand rule). The 120°/80° fracture set is the most prominent of them. It may, however in some of the diagrams be divided into two sets with the mean orientations: 120°/80° and 140°/90°.

Only a few fractures have shown evidence of displacements along the fracture surfaces. The apparent dislocations vary between 0.05-0.2m. All these fractures except one are steeply dipping. Three of them strike WNW-NW or ESE-SE and two of them, found in the deposition hole, lack record of strike. Lineations on the fracture planes have not been recorded, neither on dislocated planes or non-dislocated ones.

Most fractures contain more than one type of filling. Chlorite is by far the most common fracture filling and is found in 60-80% of all fractures. Calcite, epidote and oxidation rims along fractures appear frequently too. Quartz, fine-grained granite and pegmatite appear in a few of the fractures. The latter two fillings are veins that are too thin to be recorded as rock types. Clay and grout was observed in a few fractures in the walls of the TBM assembly hall. Fe-precipitation/gel was found in a few fractures in the deposition hole.

The fracture surfaces are mostly planar and rough. Planar and smooth fracture surfaces are rather common too in the walls, roof and pit floor of the TBM assembly hall. A few fractures are undulating or arched. They may be smooth or rough. Since healed and tight fractures commonly were regarded to be rough this "roughness-class" is believed to be over-represented. It is often impossible to judge how rough fracture planes of tight, healed fractures are. Therefore, the roughness class "undefined" later has been introduced.

Most of the fractures (57%) in the deposition hole are "induced/natural open fractures" (formerly healed and tight fractures that have been mechanically re-opened due to e.g. drilling or blasting). Twenty-nine (29) % are healed and tight fractures and 14% are open.

When the mapping of the walls and roof of the TBM assembly hall took place all fractures were regarded as tight and healed. If all the water bearing fractures in the walls and roof are considered as open they will constitute 13% of the fractures recorded there, which is similar to the deposition hole.

With a few exceptions, the fracture widths were not recorded while the geological mappings of the TBM assembly hall took place. Most fractures are, however, rather narrow, <1-2mm.

Most of the fractures (about 85%) in the deposition hole are shorter than 2m and 45% of the fractures are less than 1m in length (cut-off 0.5m). The standard mapping of the assembly hall (walls and roof) and the pit-floor, using a cut-off of about 1m, shows that only 7% and about 45% respectively of the fractures are shorter than 2m. With the same cut-off, about 70% of the fractures measured in the deposition hole are less than 2m in length. The longest fracture in the deposition hole doesn't exceed 6m, in the pit-floor 7m whereas the longest ones in the walls and roof of the assembly hall are 20-25m.

Leakage of water has been recorded at a number of locations of which some were patches on the rock surface and some were fractures. The water-bearing fractures in the deposition hole are, besides a few sub-horizontal-gently dipping ones, mostly rather steeply dipping towards SW whereas those in the walls and roof of the assembly hall are steeply dipping towards the SW or NE. In the Äspö tunnel system as a whole the water-bearing fractures commonly are steeply dipping, striking NW or SE.

Where the quantity of the water leakage, originating from micro-cracks in the rock mass or from distinct fractures in the walls and roof of the assembly hall, was measured it was normally <0.3litres/minute. Three fractures gave, however, each as much as 2-4litres/minute. The leakage of water in the deposition hole mostly was of the nature minor seepage or occasional drops. It was, however, not measured. Leakage between concrete and rock at the top of the hole and a drill hole ending close to the bottom of the deposition hole gave each about 0.5litres of water/minute. Observations of water leakage are lacking from the pit-floor due to constant inflow from the side-walls of the pit.

The measured inflow of water in the two pilot holes KA3147G01 and KA3153G01 was about 1.15 and 0.1litres/minute respectively during the pressure build up test with water pressures about 9 and 13bars.

The TBM assembly hall can probably not be regarded to be wetter than the Äspö tunnel system in large but on the other hand the walls and roof are considered to give some water, however unevenly distributed.

The RMR-values (approximately 70-75) indicate that the rock mass of the TBM assembly hall and the deposition hole can be classified as being of good quality.

Sammanfattning

Geologisk kartering utfördes i Monteringshallen för TBM:en i samband med och strax efter det att hallen färdigställdes 1994. Karteringen utfördes som ett led i den allmänna kartering som utförts av samtliga tunnlar i Äspölaboratoriet. Senare, 1998, grävdes en rektangulär grop i tunnelns/hallens sula för att blottlägga berget under den i övrigt asfalterade ytan. Botten på gropen karterades och med hjälp av resultatet bestämdes sedan det slutliga läget för två korta borrhål KA3147G01 och KA3153G01.

Borrkärnorna från de två hålen karterades med hjälp av Boremapsystemet. Bl.a. denna kartering och den tidigare karteringen av gropens botten användes sedan för att bestämma läget för ett stort deponeringshål, DA3147G01.

1999 borrades deponeringshålet med hjälp av en vertikalt borrande TBM. Strax därefter karterades hålet från en hisskorg.

All geologisk kartering har blivit digitaliserad och all data har lagts in i en databas med hjälp av SKB:s tunnelkarteringssystem, TMS.

De olika karteringarna som utförts i TBM-monteringshallen visar att berget i huvudsak består av fyra bergarter: 1) Grå, medelkornig Äspödiorit (med eller utan fältspat-”megacryster”) är den helt dominerande bergarten. 2) Rödaktig, ibland ljust grå, fin-medelkornig s.k. finkornig granit förekommer i mindre skala som gångar eller oregelbundna kroppar. Den finkorniga graniten bildar ibland en hybridbergart med Äspödioriten. 3) En mörk-svartgrön, fin-medelkornig grönsten förekommer som xenoliter i framför allt Äspödioriten. Grönsten är mindre vanlig än den finkorniga graniten. 4) Rosa till rödaktig pegmatit är den mist förekommande bergarten i TBM-monteringshallen.

Bergarterna har betraktats som friska med undantag för den oxidation som åtföljer en del sprickor.

Kontakterna mellan bergarterna är mestadels täta och tydliga. Något diffusa kontakter uppträder dock i samband att en bergart övergår i en hybrid.

Alla sprickorienteringar har plottats i Schmidtnät eller sprickrosdiagram. Tre dominerande sprickgrupper har urskiljts: 120°/80°, 180°/15° och 20°/80° (strykning/stupning, högerhandsregeln). 120°/80° -gruppen är den klart dominerande av dem. Möjligen kan denna delas upp i två grupper med orienteringen: 120°/80° och 140°/90°.

Förskjutning längs sprickplanen har endast noterats för ett fåtal sprickor (6 st). Den synbara förskjutningen har då endast varit 0.05-0.2m. Nämnda sprickor stupar alla brant utom en. Tre av de branta sprickorna stryker VNV-NV eller OSO-SO, två av dem vilka återfinns i deponeringshålet saknar notering om strykning. Lineationer på sprickplanen har inte iakttagits vare sig på dem som förskjutits eller övriga.

Oftast finns mer än en sprickfyllnad när sådan förekommer i sprickorna. Klorit är den vanligaste fyllnaden och återfinns i 60-80 % av alla sprickor. Vanligt förekommande är även kalcit, epidot och oxidation av sprickkanterna. Kvarts, finkornig granit och pegmatit uppträder i ett fåtal sprickor. De två sistnämnda är egentligen tunna gångar som är för tunna att kartera som enskilda bergarter. Lera och cement (injekteringsmedel) har iakttagits i några sprickor i väggarna och taket till monteringshallen. Fe-utfällningar, mestadels som gel återfinns i några sprickor i deponeringshålet.

Sprickplanen är mestadels plana och råa. Plana och släta sprickplan har rapporterats från en hel del sprickor i monteringshallen väggar och tak. Vid ett fåtal tillfällen har undulerande eller bågformiga sprickor noterats, som antingen är råa eller släta. Då det är i det närmaste omöjligt att avgöra råhetsgraden i täta, läkta sprickor har numera en ny ”råhetsklass” införts, ”odefinierad” (”undefined”).

De flesta av sprickorna (57 %) i deponeringshålet är s.k. inducerade/naturliga öppna sprickor (”induced/natural open fractures”, d.v.s. tidigare läkta sprickor som återöppnats helt eller delvis efter mekanisk åverkan, såsom vid sprängning eller borrning). Tjugonio (29) % är läkta, slutna sprickor och 14 % är öppna.

Då väggar och tak i montagehallen karterades ansågs alla sprickor vara slutna läkta sprickor. Om alla vattenförande sprickor skulle anses vara öppna eller delvis så skulle de utgöra 13 % av alla sprickorna som registrerats i detta område. Detta är ett liknande förhållande som det som erhölls i deponeringshålet.

Med få undantag så registrerades inte sprickvidderna då de olika karteringarna av TBM-monteringshallen utfördes. De flesta sprickorna är dock tämligen smala <1-2mm.

De flesta sprickorna (85 %) i deponeringshålet är kortare än 2m och 45% av dem är <1m långa (0.5m ”cut-off”). Vid standardkarteringen av TBM-montagehallens tak och väggar och gropens sula, som använde 1m ”cut-off”, var 7 % respektive 45 % av sprickorna <2m långa. Om samma ”cut-off” (1m) användes för deponeringshålet visar det sig att c:a 70 % av sprickorna, som registrerades där, då var <2m långa. Den längsta sprickan i deponeringshålet överskrider inte 6m i längd, i gropens golv inte 7m medan de längsta sprickorna i själva hallen är 20-25m långa.

Vattenläckage har noterats på ett antal platser. I vissa fall rörde det sig om fläckar på bergytan och i vissa fall om vatten i sprickor. De vattenförande sprickorna i deponeringshålet är, förutom några flacka, brant stupande mot SV. Även i monteringshallens tak och väggar är de vattenförande sprickorna brant stupande men både mot SV och NO. I Äspös tunnelsystem som helhet är de vattenförande sprickorna brantstående och stryker NV eller SO.

Vid de platser som vatteninläckaget från mikrosprickor i bergarten och från enskilda sprickor mättes i TBM-montagehallens tak och väggar var det normalt <0.3liter/minut. Tre sprickor gav dock var och en så mycket som 2-4liter/minut. Vatteninläckaget från deponeringshålets vägg var för det mesta i form av ett svagt sipprande till enstaka droppar. Mängden uppmättes dock inte. Läckage mellan berg och ovanliggande betong i hålets övre del noterades liksom rinnande vatten från ett borrhål som mynnade nära deponeringshålets botten. Dessa gav var och en c:a 0.5liter/minut. Inga observationer rörande vatteninläckage gjordes i gropens botten då denna ständigt var utsatt för inläckage från gropens sidoväggar.

Under den utförda tryckuppbyggnadstesten var flödet av vatten från de två pilothålen KA3147G01 och KA3153G01 1.15 respektive 0.1liter/minut. Det uppmätta vattentrycket var 9 respektive 13bar.

TBM-montagehallen kan troligen inte anses vara blötare än de flesta andra delar av Äspös tunnelsystem. Väggar och tak i hallen anses dock kunna föra en del vatten även om detta är ojämnt fördelat.

Bergkvalitén i TBM-montagehallen och deponeringshålet DA3147G01 får anses vara god med RMR-värden mellan 70-75.

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1 Background and purpose

The intention with this report is to summarize the knowledge about the rock and to some extent the hydro-geological conditions in the TBM assembly hall which is situated approximately on the 420m-level of the tunnel system at the Äspö Hard Rock Laboratory (Äspö HRL, appendix 1). The tunnel system is composed of an approximately 3600m long underground access ramp. It is to the major part almost straight but within approximately section 1600-3100 it turns in a spiral. From the access ramp some minor (50-100m long) drifts branch off.

The assembly hall constitutes only a minor but enlarged part (higher and wider in about a 30m long section, 3/137.5-3/167.5) of the main tunnel TASA (the access ramp). Conventional drilling and blasting techniques was used to excavate this part of the tunnel in 1994. On the left hand side (looking downwards the TASA) between sections 3/145.5 and 3/158.5 the assembly hall was made even a little wider. Nowadays most parts of walls and roof in the assembly hall are covered with shot crete and the floor is paved.

The assembly hall was originally excavated for the assemblage of the tunnel boring machine that later in 1994 was used to accomplish the final part of the TASA (408.5m, section 3/191.2-3/599.7).

Later on, the TBM assembly hall was a part of the SKB-project "Demonstration of the Deposition Technology". The purpose of that project was to develop and test methodology and equipment for deposition of canisters for spent fuel in full-scale and in a realistic environment. The assembly hall was intended to serve as a reloading station for canisters. During the reloading process a temporary deposition hole for a canister was needed. The reloading station was, however, never constructed.

As a part of the characterisation work at that time a pit was excavated to expose the rock in the TBM assembly hall floor in an area suitable for the reloading station. Two pilot holes (KA3147G01 and KD3153G01, appendix 2) were in 1998 drilled (core drilling) in the pit with the purpose to find the best location for the temporary deposition hole.

The large deposition hole was drilled in 1999 (DA3147G01). The approximate depth of the hole is 8.5m and the diameter is 1.75m. To accomplish the deposition hole a specially made vertically drilling Robbins TBM was used. The location of the deposition hole is illustrated in appendix 2. For further information about hole locations see Table 1-1 below.

The next project to take place in the TBM assembly hall is the LASGIT (Large scale gas injection test) project. The objective of the project is to undertake a large-scale gas injection test by using the KBS-3 geometry, i.e. a full-size copper canister installed in a vertical deposition hole and bentonite rings between the canister and the hole walls. Gases will be injected through the canister into the buffer of bentonite rings. The gases will then be studied at the boundary between the buffer and the hole walls as well as in the surrounding host rock.

The intention with the LASGIT experiment is to provide detailed information on the mechanics of gas flow which can be used in the development and validation of process models for repository safety analysis.

The data used in this report, for the characterization of the rock and to some extent the hydro-geological conditions, is obtained from geological mapping of tunnel roof, walls, parts of the floor, and the deposition hole. The logging of the cores from the two pilot holes has contributed with some information too.

Table 1-1. Co-ordinates of the pilot and the deposition holes in the TBM assembly hall

BORE HOLE CATEGORY	ID - Codes	X co-ordinate	Y co-ordinate	Z co-ordinate	Dip°	Length (m)
DEPOSITION HOLE	DA3147G01	7 312.491	2 313.562	**-418.450	-90	***8.830
PILOT HOLE	KA3147G01	7 312.490	2 313.554	*-419.561	-90	8.0
PILOT HOLE	KA3153G01	7 311.511	2 308.194	*-419.053	-90	8.0

Notes: Dip° with a "–" as a prefix indicates downwards

* = centre of top of the hole, natural tunnel rock floor

** = centre of top of the hole, top of tunnel concrete floor at the time of the drilling

*** = centre of hole bottom

2 Preparations and mapping procedures

2.1 General mapping procedures

The geological mapping of the tunnel and deposition holes was basically performed in accordance with the standard procedure for tunnel mapping at Äspö HRL (Annertz & Stenberg 1994: Teknisk PM nr. 25-95-018). The standard mapping is mostly performed in the scale of 1:100.

Briefly, the documentation of the geological features is carried out in the following way. In the tunnel the geological mapping is made on paper. The orientations of structural features are obtained by compass readings. Magnetic north is used for reference and orientations of planar structures are given according to the "right hand rule". Certain forms are commonly used to record the characteristics of rock types, fractures etc. The field documentation is later fed into the computer. An SKB application called TMS (Tunnel Mapping System) based on Micro Station J is used for the drawings and Microsoft's Access database v.2002 is used for the data. The standard tunnel mapping is presented on a 2-D drawing where the tunnel walls have been unfolded to form a plane together with the tunnel roof. If the tunnel floor has been mapped it is presented on a separate drawing. The TBM-tunnel of the Äspö HRL and the deposition holes are presented on 2-D drawings where the entire surface of the tunnel tubes has been unfolded to form a plane. The deposition holes are here regarded as small tunnels or vertical shafts.

The code chart called "Codes and information for the TMS mapping forms and the tables of the TMS database" gives further information about the mapping and the codes used to describe the geological features.

As a supplement to the mapping, the tunnels including the TBM assembly hall and deposition holes have been photographed. These photos are stored in binders and lately also on CD. This is the case for the deposition hole DA3147G01

2.2 Preparations and mapping procedures for the assembly hall – walls, roof and floor

The geologist crew at the time performed the mapping of the TBM assembly hall shortly after the excavation was completed in 1994.

Before mapping of the excavated pit in the tunnel floor took place in 1998 sections had been marked on the pit walls every meter. Water had to be pumped away every now and then during the mapping.

The tunnel walls, roof and floor had to be cleaned before they were mapped and mapping was performed in the scale 1:100 according to the standard procedure for tunnel mapping at Äspö HRL (Annertz & Stenberg 1994: Teknisk PM nr. 25-95-018). Thus, the minimum length for recorded fractures was set to 1-1.5m and veins with widths <0.1m were regarded as fractures.

2.3 Preparations and mapping procedures for the deposition hole

The deposition hole, too, were cleaned prior to the mapping and water was pumped away. For orientation in the hole a grid was accomplished by dividing the hole circumference into six (6) equal parts that were marked out by studs both at the top of the hole and at the bottom. Plastic ribbons of different colours were then tied between the top and bottom studs, thus forming vertical lines. Every meter was market out on the ribbons from the top of the hole and downwards. The mapping was then performed from cage hooked up on a lift.

The mapping of the deposition hole was performed in greater detail (1:25 scale) than the ordinary tunnel mapping. The cut off for the minimum length of recorded fractures was set to approximately 0.5m instead of 1-1.5m (standard mapping) and veins with widths <0.1m were drawn as separate rock types down to a width that was practically mapable.

Besides being done in greater detail than the ordinary tunnel mapping, the mapping of the deposition hole had to deal with a few items that at this time had been added to or changed in the general mapping procedure.

Records had now to be kept over whether the fracture was open or closed. Open/closed fractures are divided into four categories: “open” (defines a natural open fracture), “induced open” (defines an induced, mechanically made open fracture), “induced/natural open” (defines a natural, formerly healed fracture that has been mechanically more or less re-opened), and “tight” (defines a natural healed fracture).

Another general change that has taken place since the mapping of the assembly hall (walls, roof and pit floor) is how fracture lengths are defined and measured. The length is now defined as the “trace length”, i.e. the total length of the visible part of a fracture along the surface or surfaces (e.g. tunnel walls) where it is seen.

Unfortunately a great deal of the mapping was performed from an iron lift-cage. This affected the compass and made the compass readings of structural features unreliable. It was only at the bottom and the lower parts of the hole, when the lift cage was not needed, the compass could be used. Where it was possible, graphical interpretations of the strike of planar structures were made as a complement to the lack of compass readings.

2.4 Core logging and investigations in the pilot holes

As mentioned earlier, the two core boreholes KA3147G01 and KA3153G01 were both drilled in the presumed centre of the respective tentative location of a large canister hole. The core holes are almost vertical with a length of 8m and diameter of 76mm.

Logging of the cores from the pilot holes used the Äspö HRL version of the Boremap-system. Prior to the core logging the drill holes have been investigated by the use of a borehole TV (BIPS). Hydraulic tests and investigations by high frequent borehole radar were carried out too. The results of the borehole radar investigation are presented in a separate report (Carlsten, S. 1998).

3 Geological mapping

3.1 Mapping of the TBM assembly hall - walls and roof

Some photos showing parts of the tunnel interior including some of the rock types will be found in appendix 3. The results of the mapping of the walls and roof are presented in appendices 4 (rock types and fractures presented in drawing) and 5-7 (fracture orientations presented in Schmidt net and joint rosette diagrams). The geological mapping of the walls and roof of the TBM assembly hall was performed by the geologist team at the time: K. Annertz, R. Gass, A. Stråhle, and B. Gentzschein.

3.1.1 Bedrock

Rock types

At the time, when the mapping of the walls and roof of the TBM assembly hall took place, three rock types were recorded. They are: Äspö diorite, fine-grained granite and greenstone. A fourth rock type is pegmatite which has only been recorded as fracture filling and therefore is not included in the statistics below. In the Äspö tunnel as a whole there occur varieties of these major rock types and some of them may grade into each other to form hybrids. The estimated distribution of the various rock types has been summarized in Table 3.1-1. A more thorough description of the rock types can be found in e.g. Wikman, H & Kornfält, K-A 1995 and Rhén, I et al. 1997. As was mentioned earlier, today most parts of the walls and roof of the assembly hall are covered with shotcrete.

- **Äspö diorite.** The Äspö diorite is a grey to dark grey, medium-grained and massive rock. It is commonly not a diorite proper but grades from a granitic - granodioritic - quartz monzodioritic composition. Often it has a porphyritic texture with megacrysts (sometimes called eyes) of feldspar that are 10-30mm across and white to pink in colour. Inclusions of greenstone may be present. Normally in the lower parts of the Äspö tunnel system the Äspö diorite is the dominating rock type. In the roof and walls of the assembly hall, 93% of the mapped surfaces consist of Äspö diorite.

  In some places of the Äspö tunnel system it may occasionally be difficult to see the difference between a darker, non-megacryst bearing variety of Äspö diorite and dark grey, medium grained varieties of “greenstone”.

- **Fine grained granite.** It is reddish-reddish brown in colour, massive, even grained and commonly rather brittle. The colour may in other parts of the tunnel system occasionally be more grey than red. The typical and characteristic fine-grained granite is, as the name indicates, fine-grained but the grain size may very well vary between very fine-grained, almost aphanitic, to medium-grained in parts of the tunnel system.

  Totally 5% of the mapped roof and wall surfaces are composed of the fine-grained granite. It appears commonly as irregular dykes or bodies.

- **Greenstone.** This name has been used as a collective name for all dark and basic rock types in the Äspö tunnel system. It is, however, doubtful that they should be referred to as greenstones. One variety is a dark grey to black, medium-grained and massive rock type that may be of gabbroic origin. It commonly appears as large bodies and quite often as xenoliths in the Äspö diorite.

  Another variety found in the Äspö tunnel system is dark grey to black in colour and massive too but fine-grained. It occurs as veins, minor dykes or as small irregular bodies.

  A fine grained greenstone occupies 2% of the mapped roof and walls of the TBM assembly hall where it forms a small body within fine-grained granite.

- **Pegmatite.** This is the least common rock type found in the walls and roof of the assembly hall. As mentioned above, it has only been recorded as fracture filling and therefore is not a part of the statistics below (table 3.1-1). Commonly in the Äspö tunnels the pegmatite is pinkish to reddish in colour, medium- to coarse-grained and massive. It appears mainly as irregular dykes. Occasionally it may form a boundary zone to some of the fine-grained granites or it may even grade into the latter.

Table 3.1-1 Rock type distribution – the TBM assembly hall, walls and roof

Rock type	**Area m^2**	**% of mapped area (side walls, and roof, $809m^2$)**
Äspö diorite	752,37	93
Fine-grained granite	40,45	5
Greenstone	16,18	2
Total	809	100

Contacts

The rock boundaries between Äspö diorite and fine-grained granite as well as those between greenstone and fine-grained granite are mostly distinct (sharp and tight). Normally the contacts are irregular and therefore the orientation of them has not been recorded.

Alteration

The rock is regarded to be fresh, i.e. unaltered. Minor oxidation may occur along some of the fractures (cf. the paragraph about fracture filling).

3.1.2 Fractures

The distribution of the fractures can be seen in appendix 4 (mapping of walls and roof). Fracture orientations presented in Schmidt net and joint rosette diagrams are found in appendices 5-7. No adjustments for the orientation of the mapped surfaces have been made in the diagrams. Nor has the compass readings been corrected for magnetic declination.

All the fractures have been recorded as healed natural fractures commonly with some filling material between the fracture walls. Since drilling and blasting was used to excavate the tunnel/assembly hall, many of the fractures have, however, been partly re-opened. Water bearing fractures may be regarded to be fully or partly naturally open.

At the time for the mapping of the tunnel/assembly hall no record was kept for the width of the fractures. The fracture widths are, however, mostly small, less than 1mm. Wider fractures commonly consist of fine-grained granite or pegmatite. The standard mapping classifies veins and dykes of these rock types that are thinner than 0.1m as fractures.

Orientation

Only one major fracture set can be distinguished when studying the diagrams in appendices 5 (fractures in walls and roof) and 6 (fractures, total). The mean orientation (strike/dip, right hand rule) of the set is approximately 120°/80°. Some minor sets, dipping about 80° and striking NNE – NNW as well as a few sub-horizontal fractures can be found too.

Lineation

No fractures containing lineations have been recorded. This doesn't mean that lineations do not exist since many of the fractures have been classified as "lineations could exist".

Filling

Seven (7) types of filling material have been observed. Mostly more than one filling is observed in the fractures. Some (2%) of the fractures lack filling material or it was not possible to control the fracture. The most common filling material is chlorite that appears in 79% of all the fractures and the second most common filling is calcite that is found in 36% of them. The other fillings such as epidote, clay, grout, fine-grained granite, and pegmatite are each found in 7% or less of the fractures. A reddish rim of oxidation, which may be regarded as an eighth type of filling, has been observed along 29% of the fractures (see table 3.1-2).

Table 3.1-2 Distribution of fracture fillings – TBM assembly hall, walls and roof

Filling	**No of observations**	**% of all observations (totally 132 fractures)**
Chlorite	104	79
Calcite	47	36
Oxidation rim	38	29
Epidote	4	3
Clay	8	6
Grout	9	7
Fine-grained granite	1	1
Pegmatite	1	1
No filling or not observed	2	2

Fracture surfaces

The fracture surfaces are mostly planar and rough (45% of the fractures), planar and smooth (37% of the fractures) or undulating and rough (16% of the fractures). The rest of them (2%) are categorized as undulating and smooth. It should be noted that truly healed fractures always have been regarded as rough. Table 3.1-3 shows the distribution of the various fracture surface categories.

Table 3.1-3 Distribution of fracture surface categories – TBM assembly hall, walls and roof

Surface category	No of fractures	% of all fractures (totally 132)
Planar and rough	60	45
Planar and smooth	49	37
Undulating and rough	21	16
Undulating and smooth	2	2
Total	132	100

Persistence

At the time for the mapping of the TBM assembly hall, the length of the fractures was defined as the shortest distance between the end points of the fractures. The cut-off for the fractures to be recorded was 1-1.5m. The fracture lengths are illustrated in table 3.1-4. Seven (7)% of all fractures are less than 2m in length, 35% are less than 4m and 55% are less than 6m. The maximum observed fracture length is about 23m and is represented by only 2 fractures (1.5% of all fractures).

Table 3.1-4 Distribution of fracture lengths – TBM assembly hall, walls and roof

Length interval in meters	Standard mapping of roof and walls, cut off about 1m	
	No of fractures	% of all the 132 fractures
1<2	9	7
2<3	21	16
3<4	14	11
4<5	15	11
5<6	12	9
6<7	9	7
7<8	9	7
8<9	10	8
9<10	4	3
10<15	23	17
15<20	4	3
20<25	2	1
Total	132	100

Displacements

On the walls and roof only 2 displacements along the fracture planes have been recorded. The displacements are small, about 0.15m. They occur along fractures oriented 64°/18° and 111°/76° respectively. Lineations on the fracture planes have not been reported.

3.1.3 Water

Seventeen (17) fractures (or 13% of the fractures) are shown to be water bearing. They are all steeply dipping (80-90°) and strike 290-305° alternatively 105-130°, except the one which is the most water bearing (4litres/minute) that strike 205°. The orientations of fractures that carry water are shown in stereo net and joint rosette diagrams (appendix 7). Four records of patches of water that probably originate from minor cracks in the rock mass have been observed too.

Mostly only small quantities of water have been recorded (<0.3litre/minute). Three of the fractures, however, deliver as much as 2-4 litre of water/minute (see table 3.1-5).

Table 3.1-5 Occurrences of water - TBM assembly hall, walls and roof

Object from which the water originates	Number of observations	Character of water leakage	Quantity per observation (litre/minute)
Rock	1	(1) Damp, minor seepage or occasional drops	"0"
Rock	3	(2) Wet, seepage, minor flow or drops	0.01-0.05
Fracture	12	(2) Wet, seepage, minor flow or drops	0.01-0.08
Fracture	2	(2)Wet, seepage, minor flow or drops	0.1-0.3
Fracture	3	(3)Flow	2-4

3.1.4 Rock quality

The Rock Mass Rating (RMR) classification system was used to estimate the rock quality of the TBM assembly hall. The rock mass of the hall as a whole has been classified as good rock (RMR = 70).

3.2 Mapping of the TBM assembly hall - the pit floor

The location of the pit is shown in appendix 2. Appendix 8 presents some photos of the pit. The result of the standard mapping of the pit floor is shown in appendix 9. Fracture orientations are presented in appendices 7 and 10. The geological mapping of the pit-floor was performed by one of the authors, C. Hardenby.

3.2.1 Bedrock

Rock types

Three rock types have been distinguished in the pit floor. They are Äspö diorite, fine-grained granite and pegmatite. The description of them is mainly the same as the one given for the mapping of the walls and roof in the TBM assembly hall. Only specific features will be dealt with below. Table 3.2-1 summarises the occurrence of the rock types where it is shown as the estimated area of rock type exposure and in % of total mapped area.

- **Äspö diorite.** In the pit floor the Äspö diorite is mainly of the feldspar megacryst bearing type. The main part of the diorite is a fresh rock (90% of the pit floor) whereas in 5% of the floor it is slightly oxidized and reddish in colour. Thus, it constitutes totally about 95% of the floor.

- **Fine-grained granite.** This is the second most common rock type but constitutes only 5% of the pit floor. It appears as 0.1-0.2m wide dykes or veins in part rather irregular and is reported to be fine-grained and red.

- **Pegmatite.** It has been recorded only as 0.01-0.03m wide fracture fillings and is therefore not a part of the statistics in table 3.2-1 below.

Table 3.2-1 Rock type distribution - TBM assembly hall, the pit floor

Rock type	Area m^2	% of mapped area
Äspö diorite	90	95
Fine grained granite	5	5
Total	95	100

Contacts

Most contacts are tight and sharp. The one between the fresh and slightly oxidized varieties of Äspö diorite is, however, diffuse. Although the contacts are commonly rather irregular, the orientations of the boundaries between fine-grained granite and Äspö diorite were measured at two occasions. The following values were obtained: 310°/70° and 210°/80° (strike/dip, right hand rule).

Alteration

Besides a few thin streaks of oxidation accompanying some of the fractures and the small field of slightly oxidized Äspö diorite in the eastern part of the pit, all the rock types have been regarded as fresh.

3.2.2 Fractures

The fracture distribution is shown in appendix 9 (mapping of pit floor). The fracture orientations, presented in Schmidt net and joint rosette diagrams, are found in appendix 10. No adjustments for the orientation of the mapped surfaces have been made in the diagrams. Nor has the compass readings been corrected for magnetic declination.

Orientation

In appendix 10 three major fracture sets have been distinguished. The mean orientations of them are about 140°/90°, 120°/80° and 10°/80°. The first two sets may be regarded as one set. In the stereo net diagram in appendix 10, however, they appear as two rather clear clusters of fractures. Besides the three mentioned fracture sets there appear to be some of sub-horizontal fractures (cf. the collective diagrams in appendix 6).

Lineation

No lineations have been recorded. A few fractures may have lineations but this has been impossible to check.

Filling

Five types of fracture filling material have been observed (table 3.2-2 below). The most common material is chlorite that is found in 62% of the 76 recorded fractures. Epidote is the second most common filling material appearing in 16% of all the fractures. Calcite occurs in 12% of the fractures while quartz and pegmatite are found each in about 5 % or less of the fractures. Oxidation, which may be regarded as filling type number 6, is found along some of the fractures. Almost 30% of the fractures show some oxidation.

Table 3.2-2 Distributions of fracture fillings – TBM assembly hall, the pit floor

Filling	**No of observations**	**% of all observations (totally 76 fractures)**
Chlorite	47	62
Oxidation rim	17	22
Epidote	12	16
Calcite	9	12
Quartz	4	5
Pegmatite	2	3
No filling or not observed	22	29

Fracture surfaces

The fracture surfaces are mostly planar and rough (70% of all fractures) and planar and smooth (23% of all fractures). A few fractures are undulating, either rough or planar (6% of all fractures), see below table 3.2-3.

Table 3.2-3 Distribution of fracture surface categories – TBM assembly hall, the pit floor

Surface category	**No of fractures**	**% of all fractures (totally 76 fractures)**
Planar and rough	53	70
Planar and smooth	17	23
Undulating and rough	4	5
Undulating and smooth	1	1
Not observed	1	1
Total	76	100

Persistence

The same definition of fracture length and cut-off for the fractures to be recorded, i.e. about 1m, was used while mapping the walls, roof and the pit floor. In table 3.2-4 the fractures have been classified into length intervals of 1m. As can be seen from the table the most common fracture lengths are in the intervals 1-2m (46%) and 2-3m (28%). In spite of the fact that the cut-off was about 1m a few fractures <1m in length were recorded. They constitute only 5% of the total amount (76) of recorded fractures. Twenty (20)% of the fractures are longer than 3m. None of the observed fractures exceeded 7m in length. Due to the size of the pit some fractures may, however, very well be longer than 7m.

Table 3.2-4 Distribution of fracture lengths – TBM assembly hall, the pit floor

Length interval in meters	**Standard mapping of walls and floor, cut off about 1m**	
	No of fractures	**% of all the 76 fractures**
<1	4	5
1<2	35	46
2<3	21	28
3<4	4	5
4<5	6	8
5<6	5	7
6<7	1	1
Totally	76	100

Displacements

Two displacements have been recorded in the pit floor. Both of them show minor relative movements along the fracture planes, 0.1m and 0.05m respectively. The orientations of the respective fractures are 145°/90° and 140°/90°. No lineations have been observed on the fracture planes.

3.2.3 Water

Since the pit was always wet and water had to be pumped out every now and then it was impossible to distinguish any water leakage from separate fractures and the rock mass. Some of the water was without doubt coming from the gravel walls of the pit.

3.2.4 Rock quality

The rock mass of the pit floor is classified as good rock (RMR value 77).

3.3 Mapping of deposition hole DA3147G01

The location of the canister hole is shown in appendix 2. Appendix 11 presents some photos of the interior of the hole. The result of the detailed mapping of the deposition hole is shown in appendix 12. Fracture orientations are presented in appendices 7 and 13. The geological mapping of the deposition hole was performed by one of the authors, C. Hardenby.

3.3.1 Bedrock

Rock types

Four major rock types, Äspö diorite, greenstone, fine-grained granite, and pegmatite have been distinguished in the deposition hole. Besides the specific features, that will be dealt with below, the rock types resemble those that have been described in the paragraph about the mapping of the walls and roof of the assembly hall. Table 3.3-1 summarises the occurrence of the rock types. It is shown as the estimated area of rock type exposure and in % of total mapped area.

- **Äspö diorite.** In the deposition hole the Äspö diorite is mainly of the feldspar megacryst bearing type. The colour is grey-dark grey sometimes slightly reddish grey. It constitutes about 85% of the hole-surfaces (wall and bottom) and is spread through out the hole.

- **Greenstone.** The "greenstone" that was found in the deposition hole is fine-grained and black. It occurs as xenoliths scattered in the Äspö diorite. The patches of "greenstone" (7% of the hole-surfaces) seen in appendix 12 may sometimes include minor amounts of the Äspö diorite itself and pegmatite.

- **Fine-grained granite.** Two greyish red to pinkish red rock varieties assembled under the generic name fine-grained granite constitute 5% of the hole-surfaces. They appear in approximately equal amounts mainly in the lower part of the hole. One type is medium grained and may be regarded as a hybrid between fine-grained granite and Äspö diorite and occurs often as small "lenses" in the Äspö diorite proper. The other, fine- to medium-grained type and a more typical representative of the fine-grained grained granite forms 0.05-0.1m wide veins. It occurs also as fracture filling.

- **Pegmatite.** It constitutes only 3% of the mapped surfaces. It appears as a light red approximately 0.1m wide vein in the lower part of the hole.

Table 3.3-1 Rock type distribution – DA3147G01

Rock type	**Area m²**	**% of mapped area (hole wall and bottom, 48 m²)**
Äspö diorite	40.8	85
Greenstone	3.36	7
Fine grained granite	2.4	5
Pegmatite	1.44	3
Totally	48	100

Contacts

About 50% of the contacts are tight and sharp. They are the ones between Äspö diorite and pegmatite, Äspö diorite and the fine-grained granite (in its "pure" state) and Äspö diorite and greenstone xenoliths (without any admixture of Äspö diorite or pegmatite). The boundaries between Äspö diorite and the impure greenstone xenolites, the Äspö diorite and the hybrid variety of fine-grained granite as well as the boundaries between the latter and the "pure" variety are on the other hand diffuse.

The orientations of the contacts have not been measured.

Alteration

Besides a few streaks of oxidation accompanying fractures, the rock of the deposition hole must be regarded as fresh.

3.3.2 Fractures

The distribution of fractures on the hole wall and bottom is shown in appendix 12 (mapping of hole wall and bottom). The fracture orientations are presented in Schmidt net and joint rosette diagrams. They are found in appendices 7 and 13 (based on compass readings as well as on graphical interpretations). Unfortunately orientations are only registered for about 1/3 of the recorded fractures (see paragraph 2.3). No adjustments for the orientation of the mapped surfaces have been made in the diagrams. Nor has the compass readings been corrected for magnetic declination.

Orientation

Appendix 13 shows two major fracture sets. One of them is rather steeply dipping and has a mean orientation of approximately 120°/75° (strike/dip right). The other one is gently dipping with a mean orientation of 195°/20° (strike/dip right).

Lineation

None of the recorded fractures have been reported to contain any lineations. In many cases, however, the possibility cannot be ruled out since the surface of the fracture was not exposed.

Open/closed

As much as 57% of the fractures were found to be natural, most probably formerly healed and tight fractures, that now are more or less re-opened due to the drilling of the hole. Almost one third (29%) of the fractures were found to be tight (healed). The rest of them, 14% were truly open natural fractures. This result is a little unexpected. One would have expected more of the fractures to still be of the category healed and tight since the hole had been drilled.

Fracture widths

With a few exceptions, fracture apertures, widths (aperture plus filling material) and oxidation rims have not been recorded (cf. Hardenby 2002). Most of the fractures are, however, quite narrow (commonly <1mm). The width has only been recorded for 6 fractures. They were all a little wider than normal. Four of them contained fine-grained granite (5-7mm wide) and two of them (both 3mm wide) contained epidote and chlorite (one had some quartz in addition).

Filling

Six types of fracture filling material (oxidation included) have been observed (table 3.3-2 below). The most common material is chlorite that is found in 72% of the 92 recorded fractures. Epidote and calcite are noted in 13% respectively 12% of the observations. Fine-grained granite and quartz is found in 5% respectively 2% of the fractures. Reddish oxidation of the rock is found along some of the fractures proper or occasionally as separate thin reddish streaks, recorded as fractures. Twenty-eight (28)% of the fractures show some oxidation. Some Fe-precipitate often as a gel has been found along a few (8%) of the fractures of which about half of them are water bearing.

Table 3.3-2 Distributions of fracture fillings – DA3147G01

Filling	No of observations	% of all observations (totally 92 fractures)
Chlorite	66	72
Oxidation rim/streak	26	28
Epidote	12	13
Calcite	11	12
Fine-grained granite	5	5
Quartz	2	2
Fe-precipitate/gel	7	8
No filling or not observed	6	7

Fracture surfaces

According to the database all the fractures have a rough surface, mostly planar (80% of all fractures) but also undulating (19%) and arched (1%), see table 3.3-3.

Table 3.3-3 Distribution of fracture surface categories – DA3147G01, alternative 1

Surface category	No of fractures	% of all fractures (totally 92)
Planar and rough	74	80
Undulating and rough	17	19
Arched and rough	1	1
Totally	92	100

Since many fractures are tight and healed it is often difficult to determine the surface roughness. For these cases, the surface structure term "undefined" has been introduced. This occurred, however, after the occasion when the deposition hole DA3147G01 was mapped. The form of the fractures i.e. if they are planar, undulating etc. could, as before, be determined from shape of the intersection between the fracture and the surface (wall, floor etc.) they intersect (cf. Hardenby 2002).

If the remark just mentioned is taken into account the distribution of fracture surface categories will be a little different than shown above in table 3.3-3. When all fractures that are tight and healed are considered having surface roughness "undefined" and those that are open one way or another are "rough" as originally indicated in the database, then the distribution will be as in table 3.3-4 below.

Table 3.3-4 Distribution of fracture surface categories – DA3147G01, alternative 2

Surface category	No of fractures	% of all fractures (totally 92)
Planar and rough	49	54
Planar and undefined	25	27
Undulating and rough	14	15
Undulating and undefined	3	3
Arched and rough	1	1
Totally	92	100

Persistence

The size of the canister deposition hole will delimit the fracture trace lengths. In table 3.3-5 the fracture lengths have been grouped into intervals of 1m. The table shows that 45% of the fractures are shorter than 1m while 38% is found within the interval 1<2m. Only 2% of the fractures exceed 4.0m in length. The table also shows what the distribution of fracture lengths will look like if cut off is set to 1m instead of 0.5m. When making a comparison with the fracture length distribution obtained from the mapping of the walls, roof and floor of the assembly hall it has to be remembered that fracture length cut off was about 1m when that mapping took place.

Table 3.3-5 Distribution of fracture lengths – DA3147G01

Length interval in meters	Detailed mapping of canister deposition hole cut off 0,5m (cut off 1m)			
	No of fractures		% of all the 92 fractures	(% of all the 51 fractures)
<1	41	(-)	45	(-)
1<2	35	(35)	38	(68)
2<3	9	(9)	10	(18)
3<4	5	(5)	5	(10)
4<5	1	(1)	1	(2)
5<6	1	(1)	1	(2)
Totally	92	(51)	100	(100)

Displacements

The mapping of deposition hole DA3147G01 has revealed two fractures along which displacements between have occurred, 0.2 and 0.05m respectively. Both fractures are steeply dipping (85°). The strike of the fractures has not been recorded. Nor has any lineations on the fracture planes.

3.3.3 Water

Most of the 17 recorded locations of water leakage appear in the lower half of the hole (appendix 12 and table 3.3-6). Two locations are found almost at the top of the hole giving each 0.1-0.5litre of water/minute. Most of the hole wall is damp to wet and the hole bottom is very wet due to the leakage above. Three of the observations originate from the rock mass itself probably due to minor cracks. Most of the leakage was not measured but was of the character seepage or occasional drops.

Thirteen (13) fractures appear to be water bearing as well. Most of them have only a minor seepage although a few fractures that are wet or have flowing water have been observed. The majority of the water bearing fractures is steeply dipping. For some of these fractures the strike could not be determined. The rest are orientated 120-130º/60-65º. A few sub-horizontal to gently dipping fractures are water bearing as well (190-215º/10-20º). The orientations for most of them are included in appendix 7.

A bore hole coming from above (floor of the assembly hall) and ending in the lower part of wall of the large deposition hole has flowing water measured to about 0.5litre/minute.

Table 3.3-6 Occurrences of water - DA3147G01

Object from which the water originates	Number of observations	Character of water leakage (1-3, character code)	Quantity per observation (litre/minute)	Remarks
Rock	1	(1) Damp, minor seepage or occasional drops	"0"	The whole hole wall is damp to wet.
Rock	2	(3) Wet - flow	0.1-0.5	Quantity estimated from leakage between concrete and rock The whole bottom is very wet due to leakage above
Fracture	11	(1) Damp, minor seepage or occasional drops	"0"	Quantity has not been estimated or measured
Fracture	1	(2) Wet, seepage, minor flow or drops	"0"	Quantity has not been estimated or measured
Fracture	1	(3) Wet - Flow	"0"	Quantity has not been estimated or measured. Most leakage from lower part of fracture
Drill hole	1	(3) Wet - Flow	0.5	

3.3.4 Rock quality

The rock mass of the walls of the deposition hole DA3147G01 is classified as good rock (RMR value 71).

3.4 Logging of pilot hole KA3147G01

The approximate location of the 8m long borehole, almost in the centre of the later drilled deposition hole, DA3147G01 is shown in appendix 2. The core log, appendix 14, shows major rock types, possible alteration, fracture frequency and RQD. The result of the water pressure build up test is shown in appendix 15. The core logging was originally performed by G. Nilsson and later modified by C. Hardenby.

3.4.1 Rock types

As shown in appendix 14 most of the core is composed of **Äspö diorite** (totally 7.88m or 99% of the core) with a weak foliation about 30-40º to the core axis. Reddish **fine-grained granite** that occupies a little more than 0.1m or 1% of the core appears mainly in the lower part of it. At about section 5.3m a thin (0.02m wide) vein appears surrounded by an approximately 0.1m wide oxidized zone of country rock. Small **greenstone xenoliths** appear mainly in section 1-2m.

The core is composed mainly of fresh rock. Besides the mentioned oxidized zone, the rock shows a weak tendency of being oxidized to about 0.3m above the zone.

3.4.2 Fractures

The fracture frequency is rather low. It varies between 0-4 fractures/meter (calculated on fractures that have caused a core break, mechanical fractures excluded) throughout the core. If healed fractures are included in the fracture count the frequency will be a little higher, 0-16 fractures/meter, mostly 0-6 fractures/meter. The peak value 16 fractures/metre occurs within the last metre of the core where most of the fractures are found within section 7.15-7.45m. This section appears to be slightly tectonized, partly re-crystallized and rather rich in chlorite and epidote.

The fracture fillings include chlorite, epidote and calcite. A reddish rim of oxidation appears along a few fractures.

The RQD-values for the rock are high, 93-100%. The lowest value (RQD=93%) is found in section 5-6m. Thus, this indicates a good-excellent rock quality.

3.4.3 Water

During the pressure build up test the inflow of water was measured to 1.15litres/minute and the obtained water pressure is 8-9bars (see appendix 15).

3.5 Logging of pilot hole KA3153G01

The approximate location of the 8m long borehole, in the centre of a tentative location for a deposition hole, is shown in appendix 2. The core log, appendix 16, shows major rock types, possible alteration, fracture frequency and RQD. The result of a water pressure build up test is illustrated in appendix 15. As for KA3147G01, the core logging of KA3153G01 was originally preformed by G. Nilsson and later modified by C. Hardenby.

3.5.1 Rock types

Three rock types are present according to the core log (appendix 16). The dominating one is **Äspö diorite** (totally 82% or 6.6m of the core). Veins or, as logged, two **xenoliths** of greenstone and three veins or dykes of **fine-grained granite** occupy approximately the same shares of the core (10 and 8% or 0.8 and 0.6m respectively of the core. The former is found in the upper parts of the core whereas the latter is mainly found in the lower parts of it.

The rock types have been regarded to be unaltered. They show, however, a weak oxidation within section 5-6m.

3.5.2 Fractures

This core, too, shows a low fracture frequency, 0-4 fractures/metre (calculated on fractures that have caused a core break, mechanical fractures excluded). The highest one, 4 fractures/meter, is found in section 7-8m. Healed fractures commonly have a fracture frequency of 0-2 fractures/metre. When both fracture categories are taken into account the frequency will vary between 0-4 fractures/metre except in section 7-8m where it is 19 fractures/metre. The reason for this is the reddish fine-grained granite which is rich in small healed fractures. Small shear zones, 0.02 and 0.1m respectively, with epidote/chlorite laminated fine-grained granite appear at about 7 and 7.9m.

Here too, the fracture fillings commonly are composed of chlorite, epidote and calcite. A few fractures are accompanied by a reddish rim of oxidation.

The RQD-value is 100% except in the last metre (section 7-8m) where it is 91% which indicates rock of good-excellent quality.

3.5.3 Water

The inflow of water during the pressure build up test was a little less in this hole (0.098litres/minute) compared to KA3147G01. The recorded pressure on the other hand was a little higher, 13-13.5bars (see appendix 15).

4 Concluding remarks

The walls, roof and floor of the multi use TBM assembly hall are composed almost entirely of Äspö diorite (>90%). This is in agreement with the overall picture of the lower parts of the Äspö tunnel system where the Äspö diorite clearly is the dominating rock type (Markström & Erlstöm 1996 and Rhen et al. 1997).

To a much lesser extent appear fine-grained granite, greenstone and pegmatite. The fine-grained granite commonly constitutes about 5% of the rock types. Greenstone and pegmatite may or may not show up on the mapped surfaces. Pegmatite has, as a matter of fact, not been recorded as a separate rock type. It should, however, be remembered that greenstone often appears as minor xenoliths in the Äspö diorite and is as such not distinguished. Pegmatite as well as fine-grained granite is often recorded as fracture fillings and may therefore be more common than shown on the maps (appendices 4 and 9).

In the deposition hole DA3147G01 all four rock types have been recorded. The Äspö diorite is as usual the dominating one (85% of the mapped surface of the hole wall and bottom) followed by greenstone, fine-grained granite and pegmatite (7, 5 and 3% respectively). In this case, however, all rock occurrences were recorded down to a much smaller size than was the case for the assembly hall itself.

The Äspö diorite dominates the two pilot holes KA3147G01 and KA3153G01, too, and only minor amounts of fine-grained granite and greenstone are present. Pegmatite is missing totally.

The Småland (Ävrö) granite which is common in some parts of the tunnel system is not present at all at the 420m level.

All the rock types have been regarded as fresh (no alteration), besides some minor oxidation of the rock commonly in connection with fractures.

The fracture orientation diagrams show a similar pattern of fracture concentrations that can be regarded as fracture sets. The mean orientation of the clearly dominating fracture set is 120º/80º. This may in some of the diagrams be divided into two sets 120º/80º and 140º/90º. All diagrams show a sub-horizontal set, dipping 10-20º towards WNW-WSW. Another steeply dipping set is found in the diagrams from the mapping of the walls, roof and floor. The mean orientation is about 20º/80º.

No lineations on the fracture planes were recorded. This does not exclude the possibility of their existence since many of the fracture surfaces were not exposed.

Mostly the fractures contain more than one type of filling. The by far most common fracture filling is chlorite that is found in about 60 – 80% of all fractures. Calcite, epidote and oxidation rims along fractures are quite common too. Their relative order of appearance varies in the mapped parts of the assembly hall. Calcite is found in about 10-40%, epidote in 5-15% and an oxidation rim in 20-30% of the fractures.

Quarts, fine-grained granite, and pegmatite appear only in a minor amount of the fractures. The latter two fillings are veins that are too thin to be recorded as rock types. Clay and grout was found in a couple of fractures recorded during the mapping of the walls and roof of the TBM assembly hall. A rather large percentage (29%) of the fractures recorded during the mapping of the pit floor has no filling or filling could not be observed.

Due to the difficulty in discriminating fractures that were naturally open from those that had been mechanically re-opened during the drill and blast process involved in the excavation of the assembly hall all fractures were regarded as tight and healed. Before the deposition hole was mapped, however, the terms "induced/natural open fractures" (formerly healed, tight fractures that have been mechanically re-opened) and "induced open fractures" (mechanically made fractures) were introduced.

Tight, healed fractures constitute 29% of the fracture population in the deposition hole and 57% belong to the category "induced/natural open fractures". The rest of the fractures (14%) were regarded as "open". No "induced open" fractures were recorded.

All fractures (100% of all fractures) were regarded as healed, tight fractures when the mapping of the walls and roof of the assembly hall itself took place. If, at that time, the induced/natural open fractures had been separated from the healed and tight ones the former would most probably have constituted a great part of all the fractures. If water bearing fractures had been regarded as open or at least partially so, open fractures would have constituted about 13% of all the fractures in the walls and roof. This is in accordance with what was found in the deposition hole.

It may be argued that all fractures with an oxidation rim should be regarded as open or at least partially so. This has not been the case, however.

Forty five - eighty (45-80) % of the fractures have planar and rough surfaces. In the assembly hall (walls, roof and pit floor) planar and smooth fracture surfaces are rather common too. This category has not been reported from the canister hole DA3147G01. Undulating and rough or smooth and finally arched and rough or smooth fractures are present too in varying amounts.

Fractures with rough surfaces are overrepresented since, when not stated otherwise, all tight fractures were given the roughness "rough". When fractures are healed and tight it is difficult, not to say impossible, to see the actual fracture surface. Due to this the roughness class "undefined" has been introduced. This was, however, done after the mapping of the walls, roof, floor and the deposition hole of assembly hall. When the mapping of the deposition hole took place it was discriminated between truly healed fractures (tight fractures) and due to drilling, blasting etc re-opened fractures (induced/natural open fractures). If all fractures in the deposition hole that are considered to be tight are given roughness "undefined" the percentage of e.g. surface category "plane and rough" will change from 80% to about 50% (tables 3.3-3 and 3.3-4). This little exercise can not be done for the fractures of the walls, roof and floor since any separation of truly tight and re-opened fractures wasn't performed when mapping took place, they were all considered to be healed and tight.

The larger the exposure is the longer fractures can be traced. Therefore it is not surprising to find that about 45% of all fractures are longer than 6m in the walls and roof of the assembly hall. The longest fractures are 20-25m whereas in the pit floor the longest fracture is <7m.

When studying only the fracture lengths recorded during the detailed mapping of the deposition hole (cut-off 0.5m) it is evident that most (about 85%) of the fractures are 2m or shorter. Forty five (45)% of the fractures are less than 1m in length and none is as long as 6m.

To compare fracture lengths from the standard mapping of the assembly hall (walls, roof and pit floor) with those from the detailed mappings of the deposition hole, only fractures longer than 1m are taken into account. It will then be found that fractures shorter than 2m constitute almost 70% of the fractures recorded during the detailed mapping of the deposition hole, about 45% of those recorded during the standard mapping of the pit floor and only 7% of those in the walls and roof. Most likely more effort has been put into recording shorter fractures during the detailed mapping than during the standard mapping.

The fracture widths were not studied while the mapping of the assembly hall and its deposition hole took place. Most fractures are, however, rather thin (commonly <1-2mm). A few fracture widths were recorded from the deposition hole and these fractures contained fine-grained granite or epidote and chlorite. They were all a little wider than normal (3-7mm).

Only 6 fractures have been reported to show evidence of displacements along the fracture planes. Except one (64º/18º, strike/dip) all of them are steeply dipping. Three of them dip towards NNE-NE or SSW-SW. Two of them (almost vertical) are found in the deposition hole but unfortunately there is no strike registered. The dislocations are between 0.05-0.2m. Lineations on the fracture planes are absent.

The rather high fracture frequencies occurring in the last metre of the cores of both the pilot holes have no correspondence in the deposition hole. This indicates that these fractures have very little persistence.

Water was found at a number of locations of which some were patches on the rock surface and some were fractures. Where water was observed it appeared commonly in only minor amounts (<0.5 litres/minute). Three fractures in the walls and roof have, however, been reported to each carry 2-4 litres of water /minute. The water-bearing fractures mostly dip steeply towards the NE or SW. In the deposition hole a few sub-horizontal (10-20ºNNW dipping) are found as well. In the Äspö tunnel system as a whole the water-bearing fractures commonly are steeply dipping, striking NW or SE (cf. appendix 7).

The inflow of water in the two pilot holes KA3147G01 and KA3153G01 was 1.15 and 0.1 litre/minute respectively with water pressures of 8-9 and 13-13.5 bars. Water observations were not made in the pit since there was a constant inflow of water mainly from the gravel in the pit walls.

As a whole the TBM assembly hall is probably not wetter than the major part of the Äspö tunnel system. There are, however, areas with increased leakage of water, such as the above mentioned fractures that give 2-4litres/minute.

The strikes of the majority of water bearing fractures and those containing grout coincide more or less with the maximum horizontal stresses in the rock mass (Rhén et al.1977).

The quality of the rock mass based on RMR values is considered to be good. The RMR-values in the assembly hall and the deposition hole are between 70-77 (RMR = 60-80, good rock). The cores from the two pilot holes show the same good rock quality given in RQD-values between 90-100% (good-excellent rock quality).

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Appendices

1. Location map of the 420-450m level at Äspö HRL
2. TBM assembly hall, outline of the pit (dashed line) and location of the deposition hole DA3147G01 and the pilot holes KA3147G01 and KA3153G01
3. Photos showing the interior of the TBM assembly hall (photos: Geologist team at the time, SKB).
   3A. Small niche, left side wall. Mainly Äspö diorite (grey)
   3B. Left side wall, section 3/152-3/156. Mainly Äspö diorite (grey) and fracture with some oxidation (reddish brown)
   3C. Roof, right side, section 3/160.5-3/167.5. Mainly Äspö diorite (grey) with some fine-grained granite (brownish red)
   3D. Right side wall, section 3/136-3/140. Mainly Äspö diorite (grey) with fine-grained granite (brownish red). A greenstone xenolith (black) is seen in the left upper corner of the picture
4. Geological mapping of the TBM assembly hall, roof and side walls
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6. Fracture orientations presented in Schmidt net and joint rosette diagrams. The TBM assembly hall, collective diagrams – roof, walls, pit floor and deposition hole
7. Fracture orientations of water-bearing fractures presented in Schmidt net and joint rosette diagrams. The TBM assembly hall, collective diagrams – roof, walls and deposition hole
8. Photos showing the pit-floor in the TBM assembly hall (photos: Lars Andersson, SKB).
   8A. Overview of the pit looking up the ramp
   8B. Section 3/138-3/142, Äspö diorite (grey) with some fine-grained granite (pinkish red)
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11. Photos from deposition hole DA3147G01 (photos: Lars Andersson, SKB).
    11A. Top of the hole with safety fence and part of the lift
    11B. Top of the hole with safety fence and lift cage. The blue and red ribbons were used during the mapping procedure not only for orientation but were also a part of a grid system
    11C. Upper part of the hole. Boundary between concrete (top) and bedrock below. Rock types: Äspö diorite (greyish) and impure greenstone xenolith (dark grey - black). The blue and red ribbons were used during the mapping procedure not only

for orientation but were also a part of a grid system
11D. Section 5-6m. Rock types Äspö diorite (greyish) and greenstone xenolith (dark grey – black). Water bearing fracture with rust staining below. The grooves are a result from the drilling. The yellow and green ribbons were used during the mapping procedure not only for orientation but were also a part of a grid system
11E. Bottom part of the hole. Rock types: Äspö diorite (greyish) with minor greenstone xenoliths (dark grey – black) and fine-grained granite (pinkish red). Water bearing fracture with rust staining below. The grooves are a result from the drilling. The white, pink and blue ribbons were used during the mapping procedure not only for orientation but were also a part of a grid system

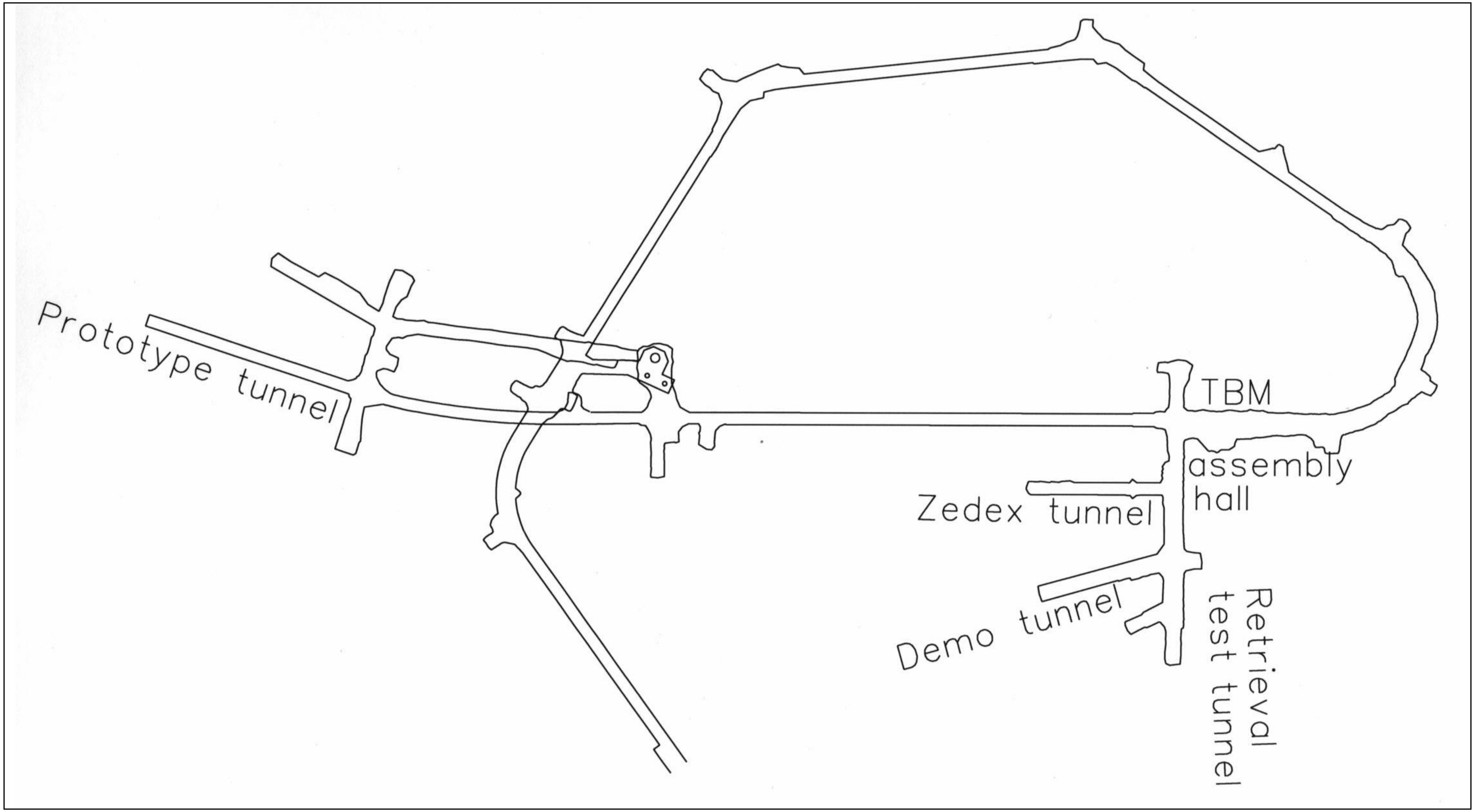
12. Geological mapping of the deposition hole DA3147G01

13. Fracture orientations (partly compass readings and partly graphical interpretation) from DA3147G01 presented in Schmidt net and joint rosette diagrams

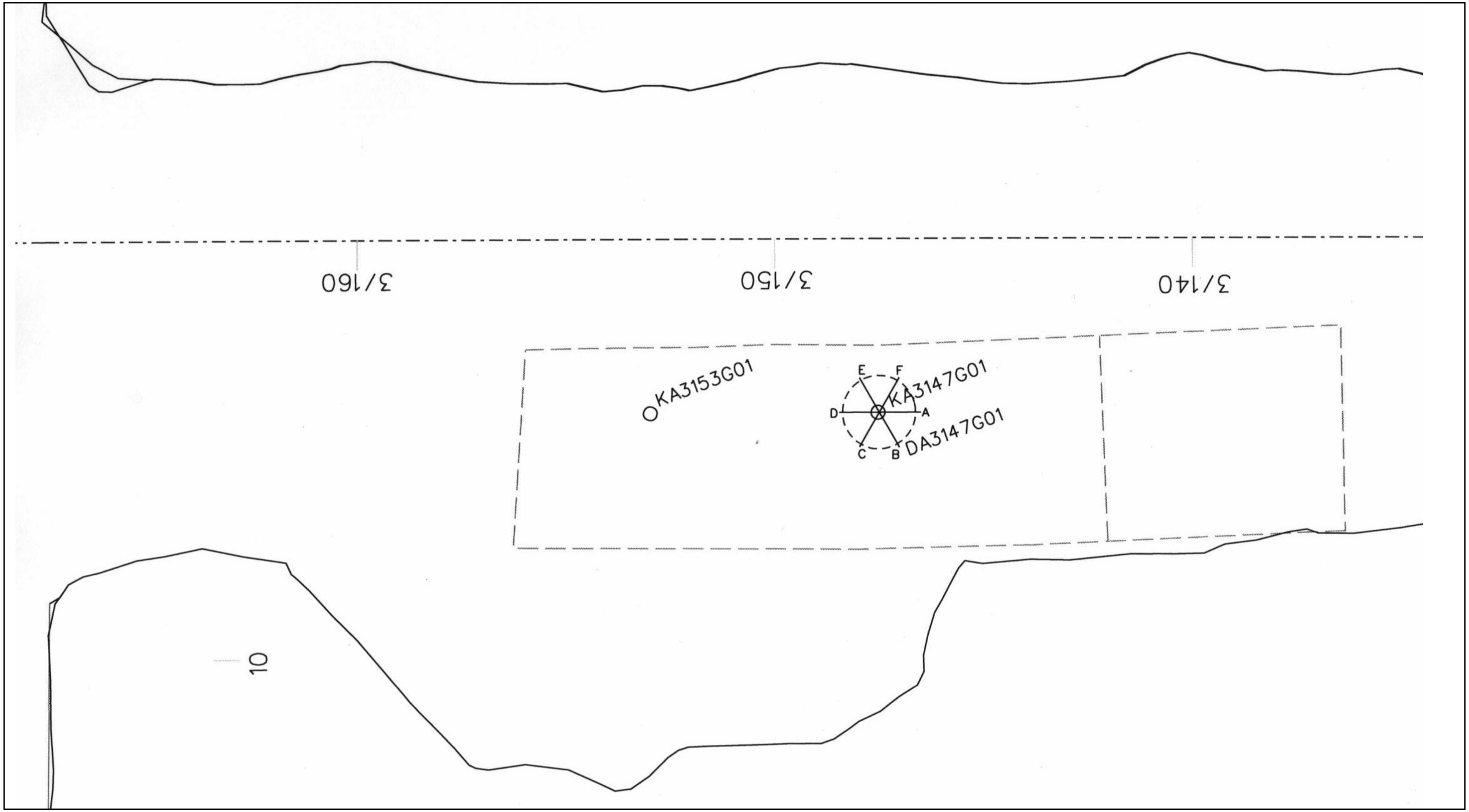
14. Core log from pilot hole KA3147G01 (plot: Pär Kinnbom). Major rock type: Äspö diorite (red with dots). Accessory rock types: xenoliths of greenstone (green) and veins or minor bodies of fine-grained granite (red). Rock alteration: slightly oxidized section.

15. Water pressure build up test in KA3147G01 and KA3153G01 (Diagram, slightly modified: Lars Andersson, SKB)

16. Core log from pilot hole KA3153G01 (plot: Pär Kinnbom). Major rock type: Äspö diorite (red with dots). Accessory rock types: xenoliths of greenstone (green) and veins or minor bodies of fine-grained granite (red). Rock alteration: slightly oxidized section.



Appendix 1. *Location map of the 420-450m level at Äspö HRL*

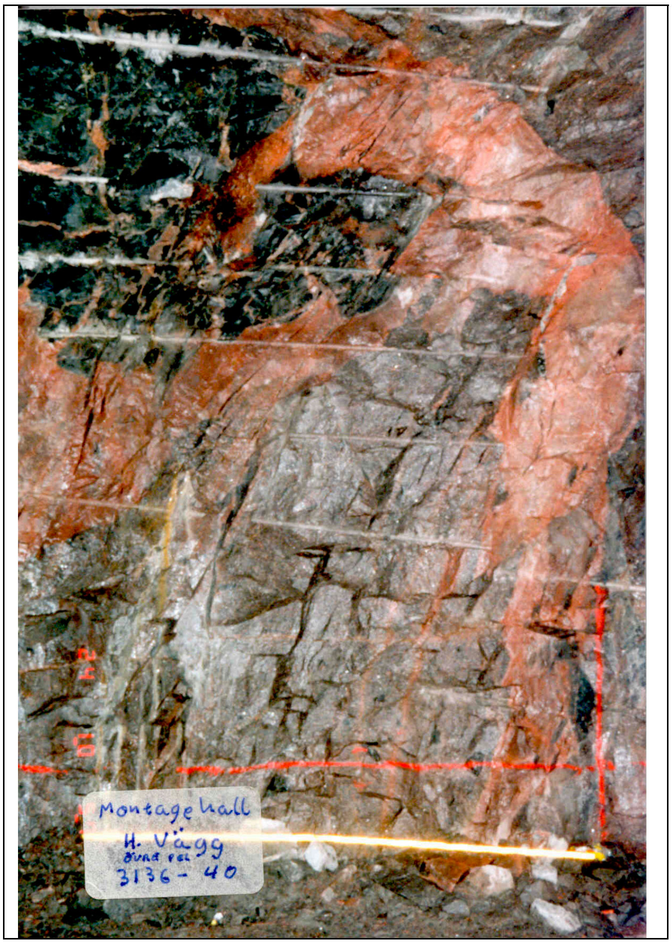


Appendix 2. *TBM assembly hall, outline of the pit (dashed line) and location of the deposition hole DA3147G01 and the pilot holes KA3147G01 and KA3153G01*

Appendix 3A. *Photos showing the interior of the TBM assembly hall (photos: Geologist team at the time, SKB). Small niche, left side wall. Mainly Äspö diorite (grey).*

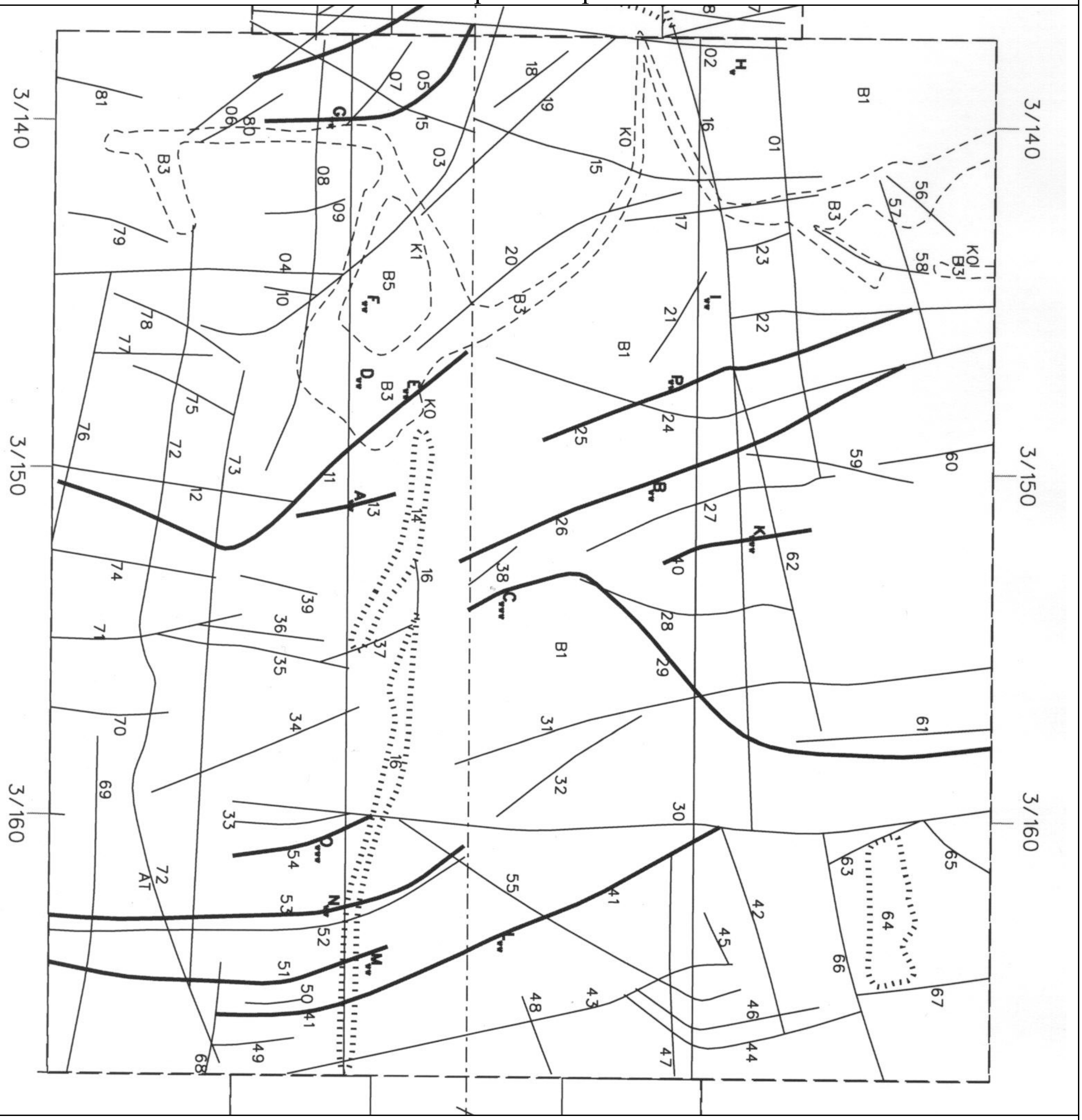
Appendix 3B. *Photos showing the interior of the TBM assembly hall (photos: Geologist team at the time, SKB). Left side wall, section 3/152-3/156. Mainly Äspö diorite (grey) and fracture with some oxidation (reddish brown)*

Appendix 3C. *Photos showing the interior of the TBM assembly hall (photos: Geologist team at the time, SKB). Roof, right side, section 3/160.5-3/167.5. Mainly Äspö diorite (grey) with some fine-grained granite (brownish red).*



Appendix 3D. *Photos showing the interior of the TBM assembly hall (photos: Geologist team at the time, SKB). Right side wall, section 3/136-3/140. Mainly Äspö diorite (grey) with fine-grained granite (brownish red). A greenstone xenolith (black) is seen in the left upper corner of the picture*

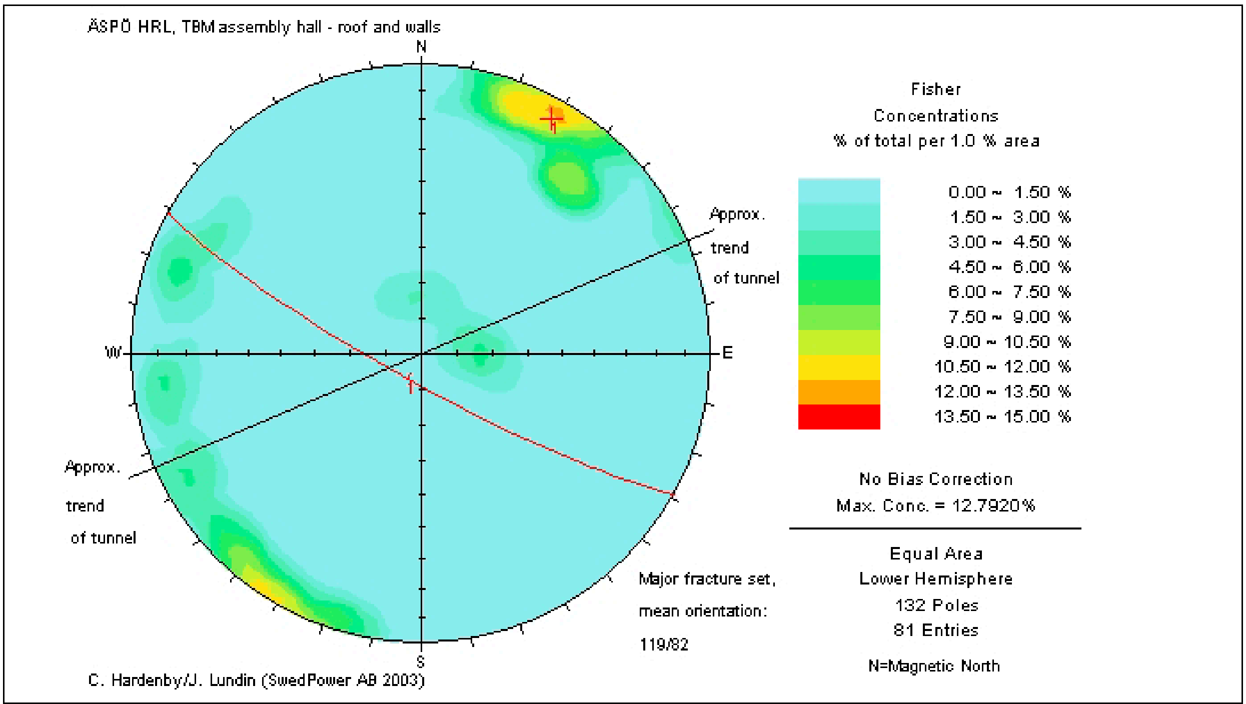
Up the ramp

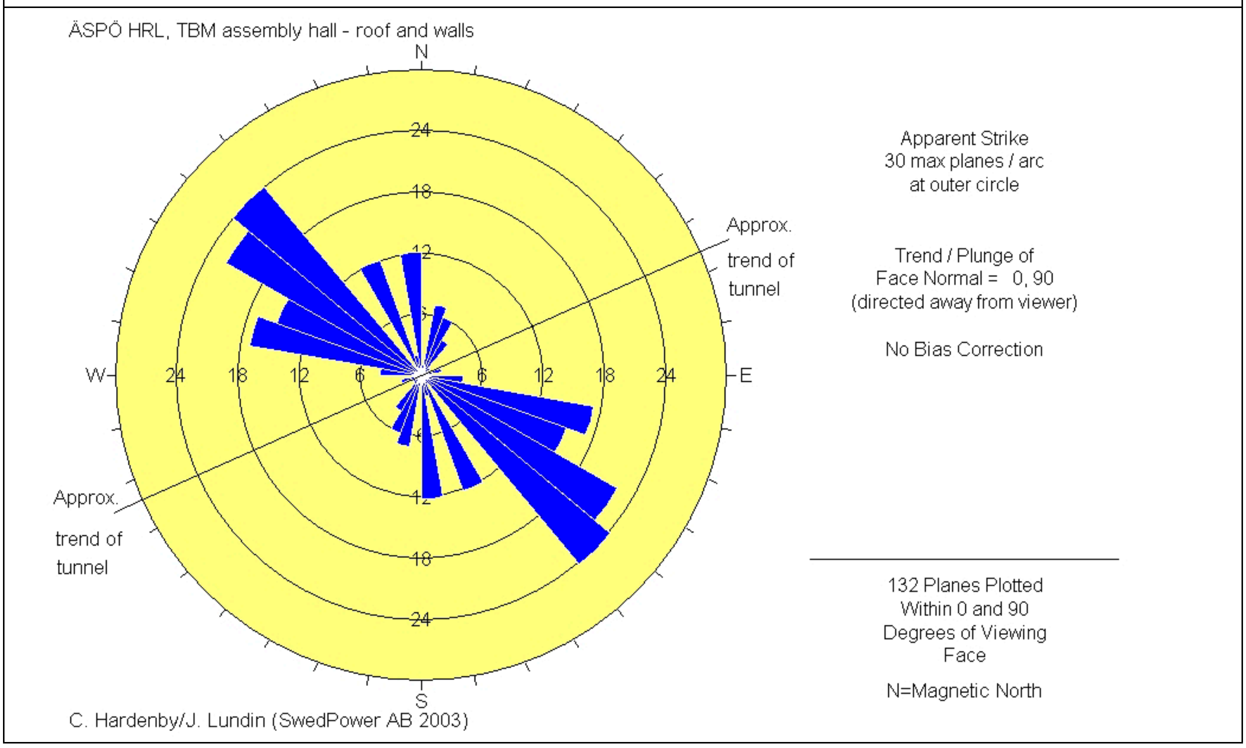


Legend:

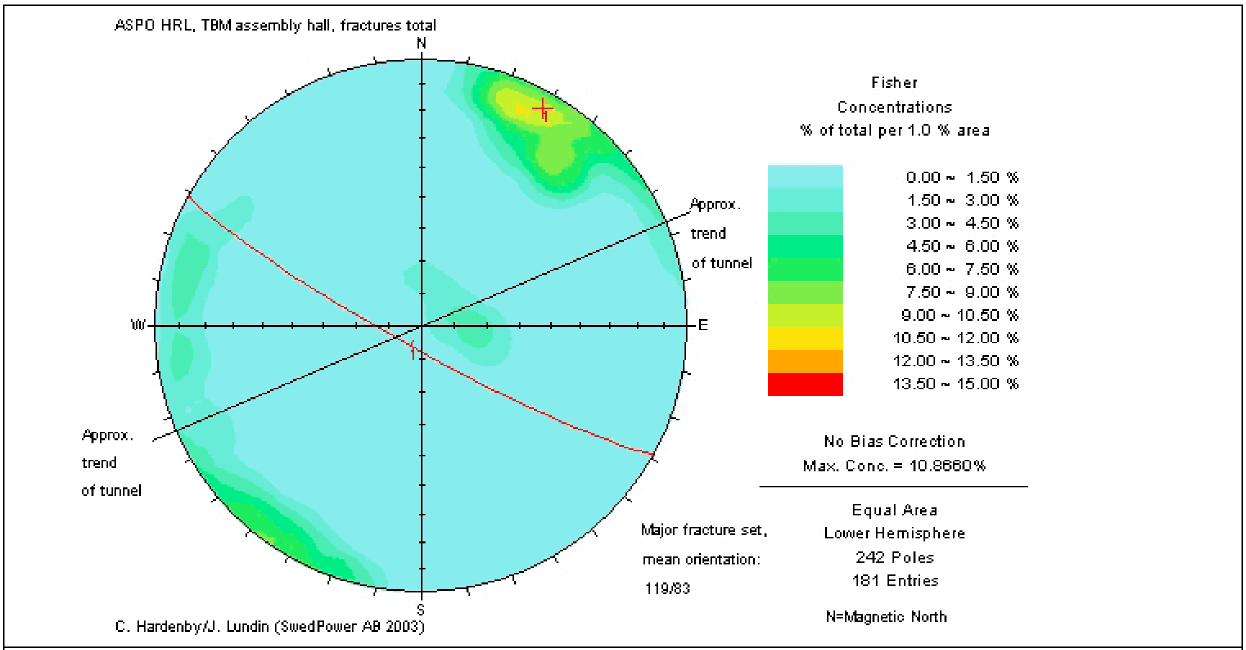
Rock types:	B1, B3 and B5 B1=Äspö diorite, greyish and medium-grained with feldspar megacrysts B3=Fine-grained granite, reddish brown B5=Greenstone, dark and fine-grained
Contacts:	K0-K1 and dashed line K0=Contact between B1 and B3 K1=Contact between B3 and B5
Fractures:	01-81 and continuous line (thick lines represent water bearing fractures)
Water:	A-I and K-P and v=damp-minor seepage, occasional drops vv=wet-seepage, drops or minor flow or vvv=flow

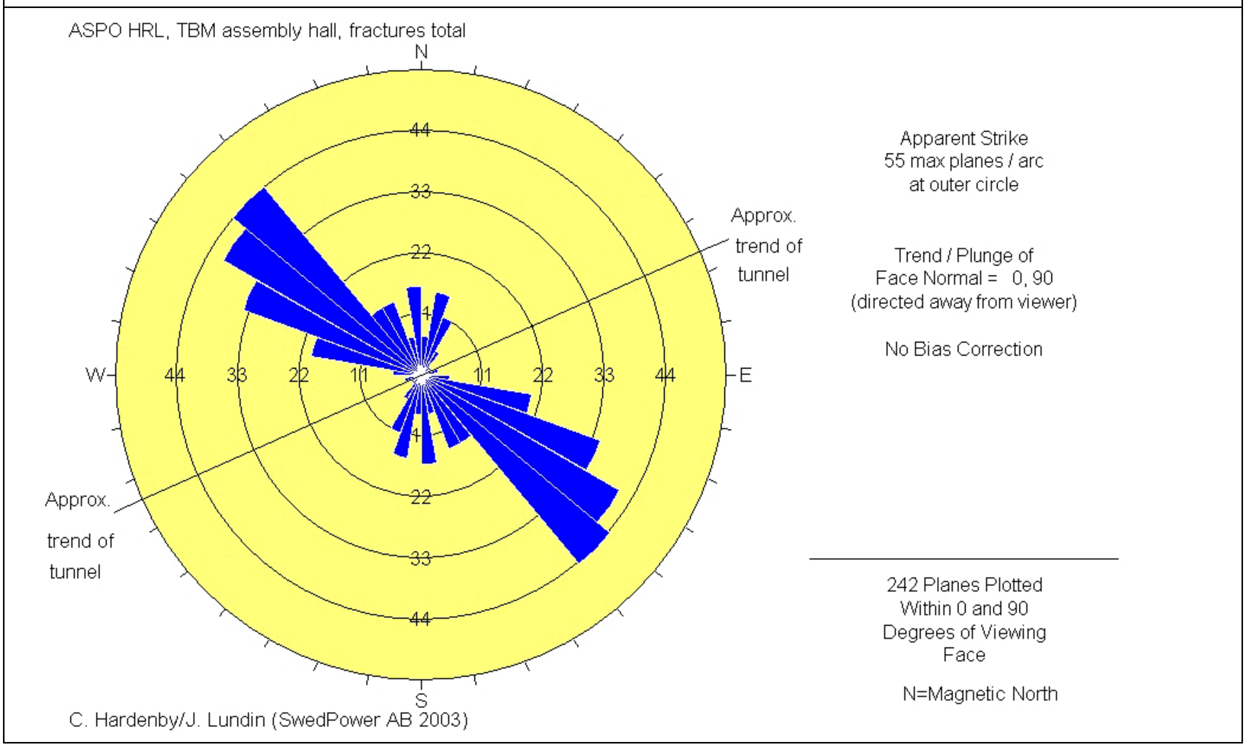
Appendix 4. *Geological mapping of the TBM assembly hall, roof and side walls*



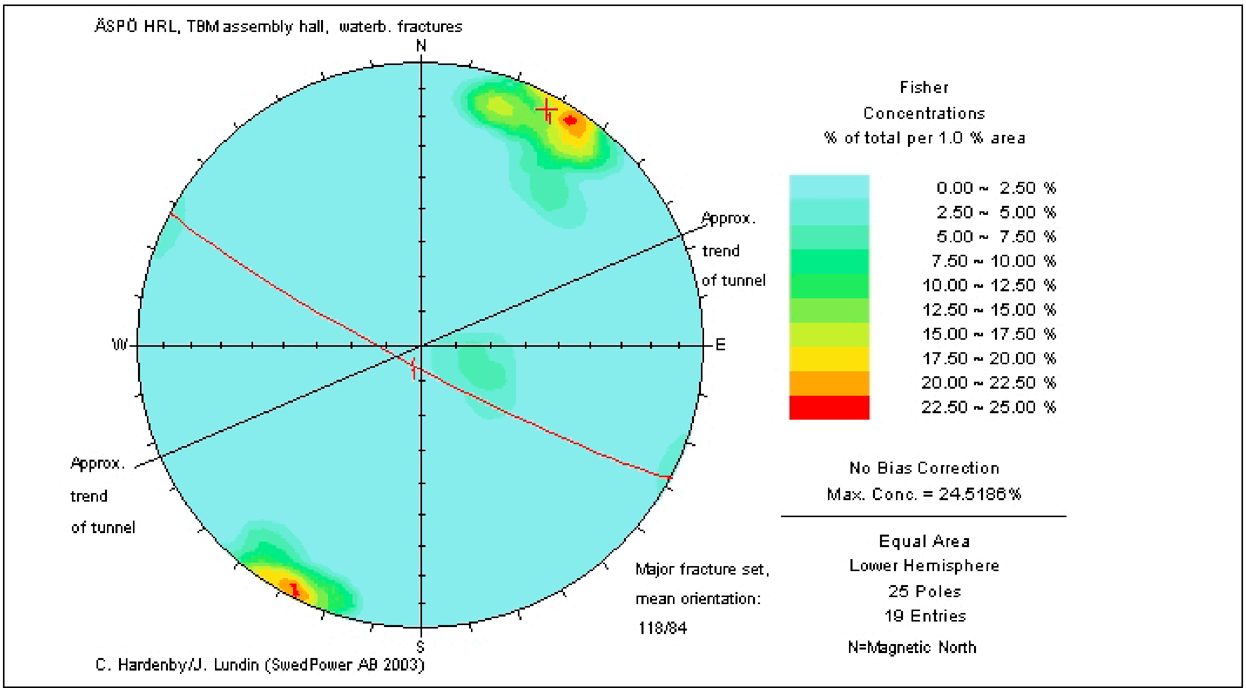


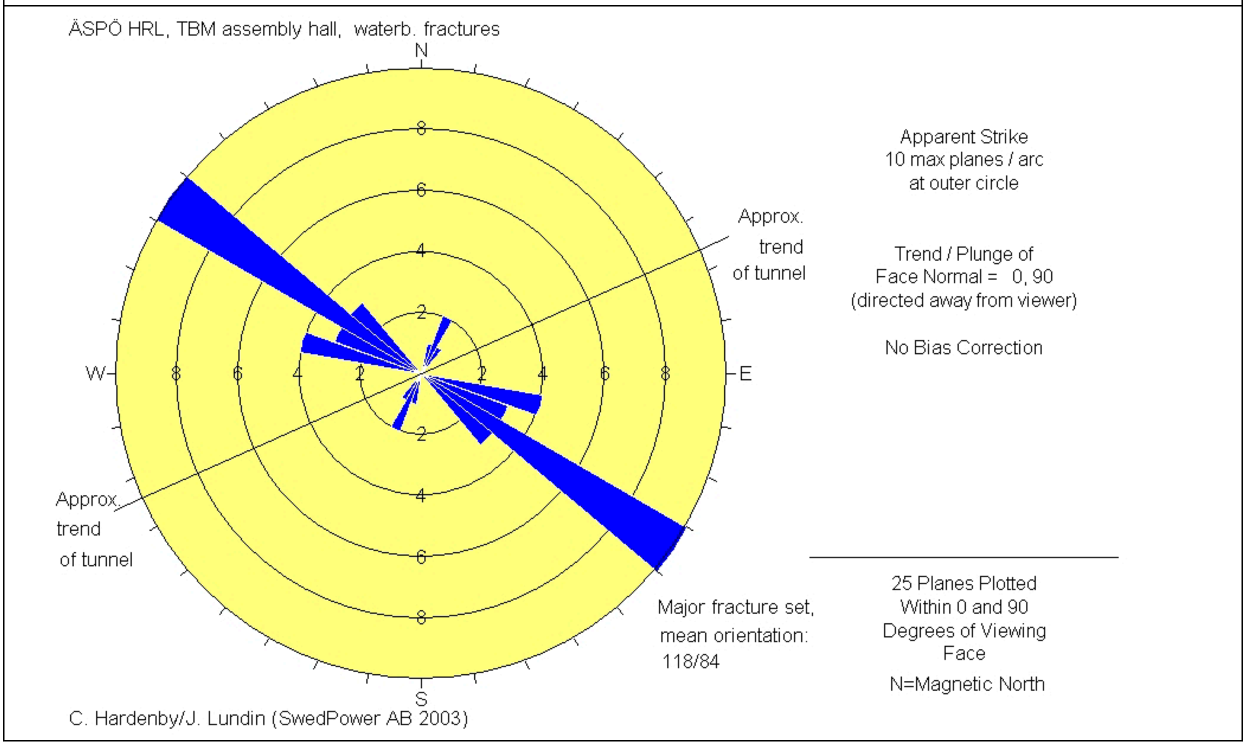
Appendix 5. *Fracture orientations from the roof and side walls of the TBM assembly hall presented in Schmidt net and joint rosette diagrams*





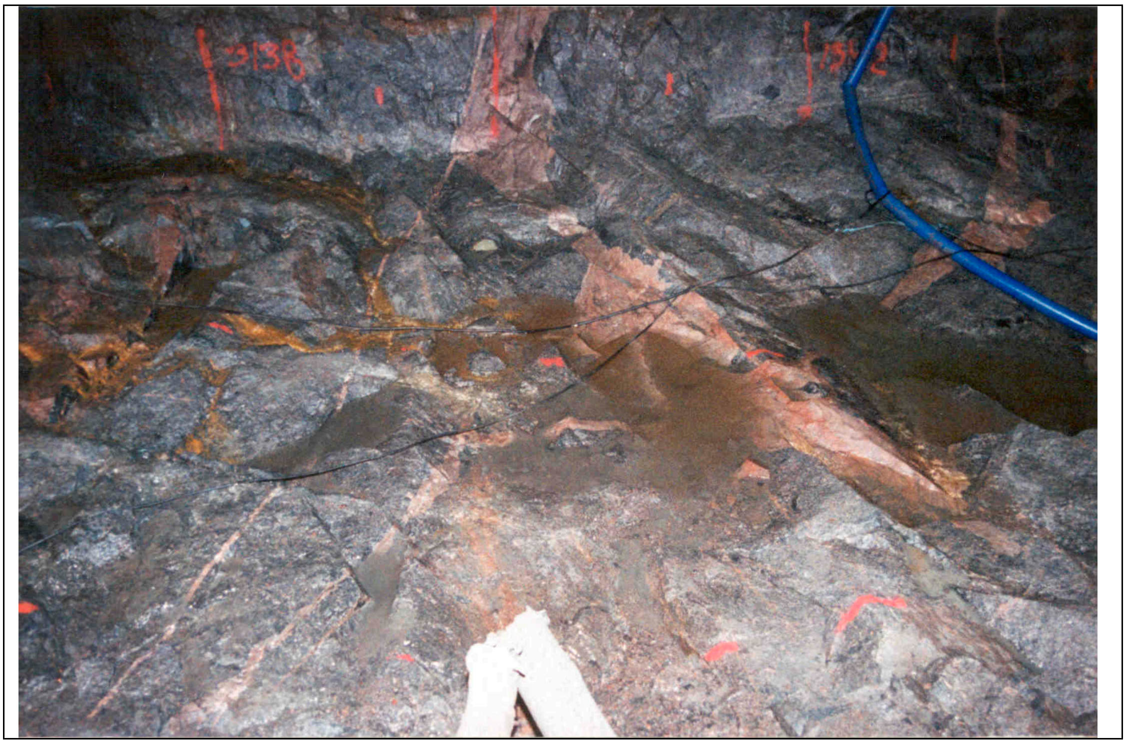
Appendix 6. *Fracture orientations presented in Schmidt net and joint rosette diagrams. The TBM assembly hall, collective diagrams – roof, walls, pit floor and deposition hole*





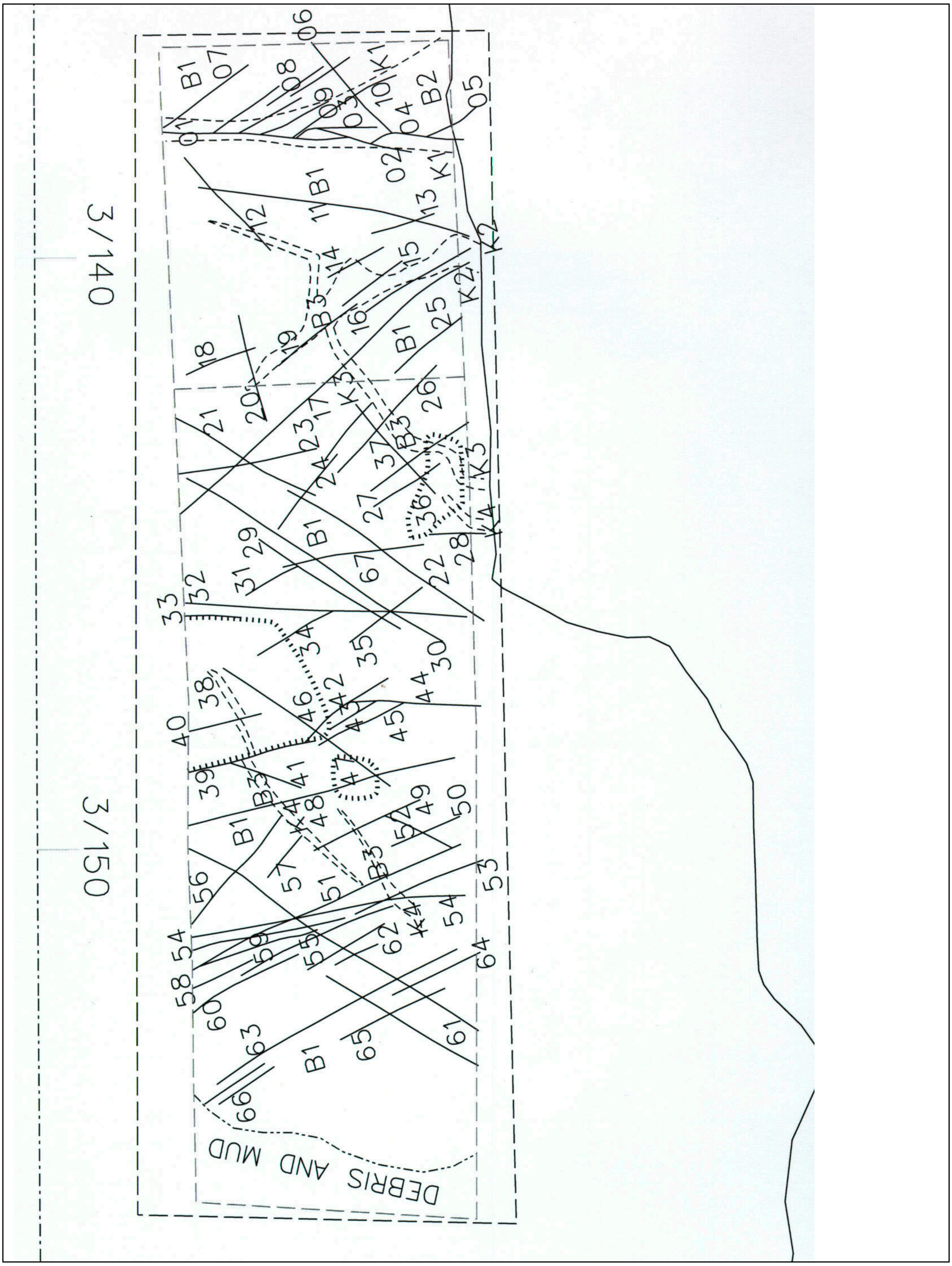
Appendix 7. *Fracture orientations of water-bearing fractures presented in Schmidt net and joint rosette diagrams. The TBM assembly hall, collective diagrams – roof, walls and deposition hole*

Appendix 8A. *Photos showing the pit-floor in the TBM assembly hall (photos: Lars Andersson, SKB). Overview of the pit looking up the ramp*



Appendix 8B. *Photos showing the pit-floor in the TBM assembly hall (photos: Lars Andersson, SKB). Section 3/138-3/142, Äspö diorite (grey) with some fine-grained granite (pinkish red)*

Appendix 8C. *Photos showing the pit-floor in the TBM assembly hall (photos: Lars Andersson, SKB). Section 3/148-3/153, Äspö diorite (grey) with fine-grained granite veins (pinkish red)*

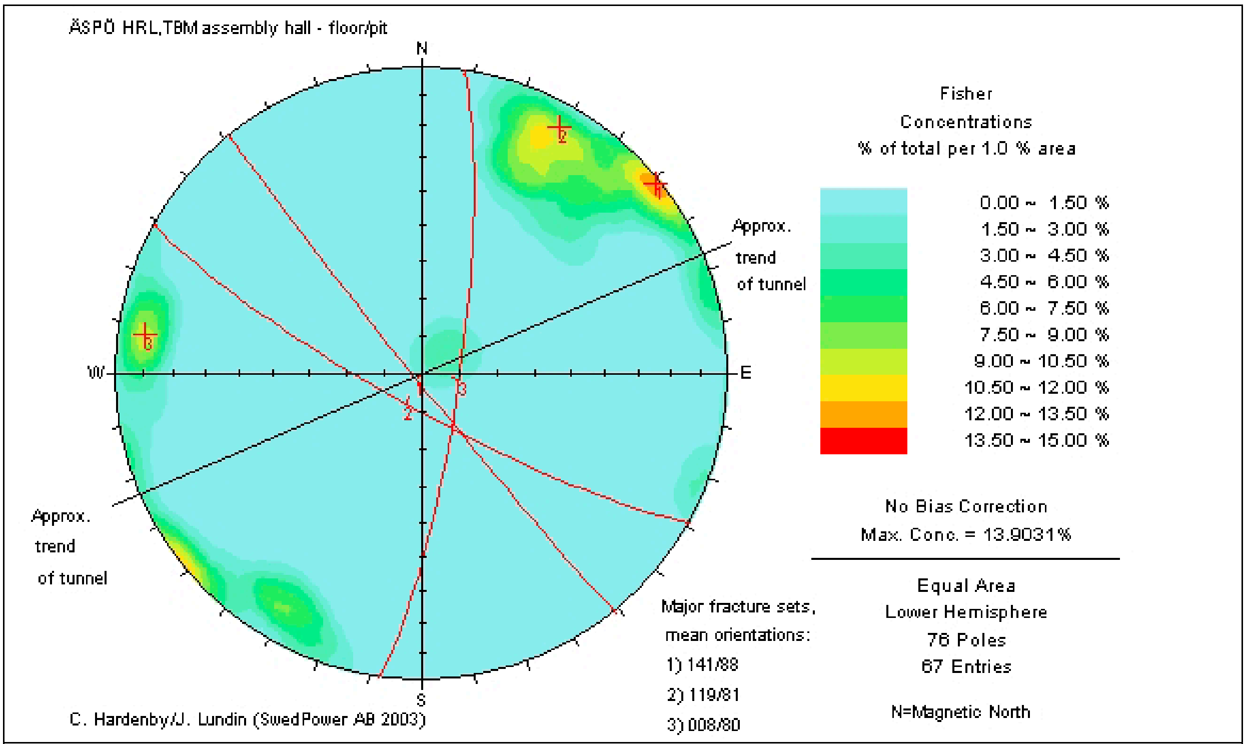


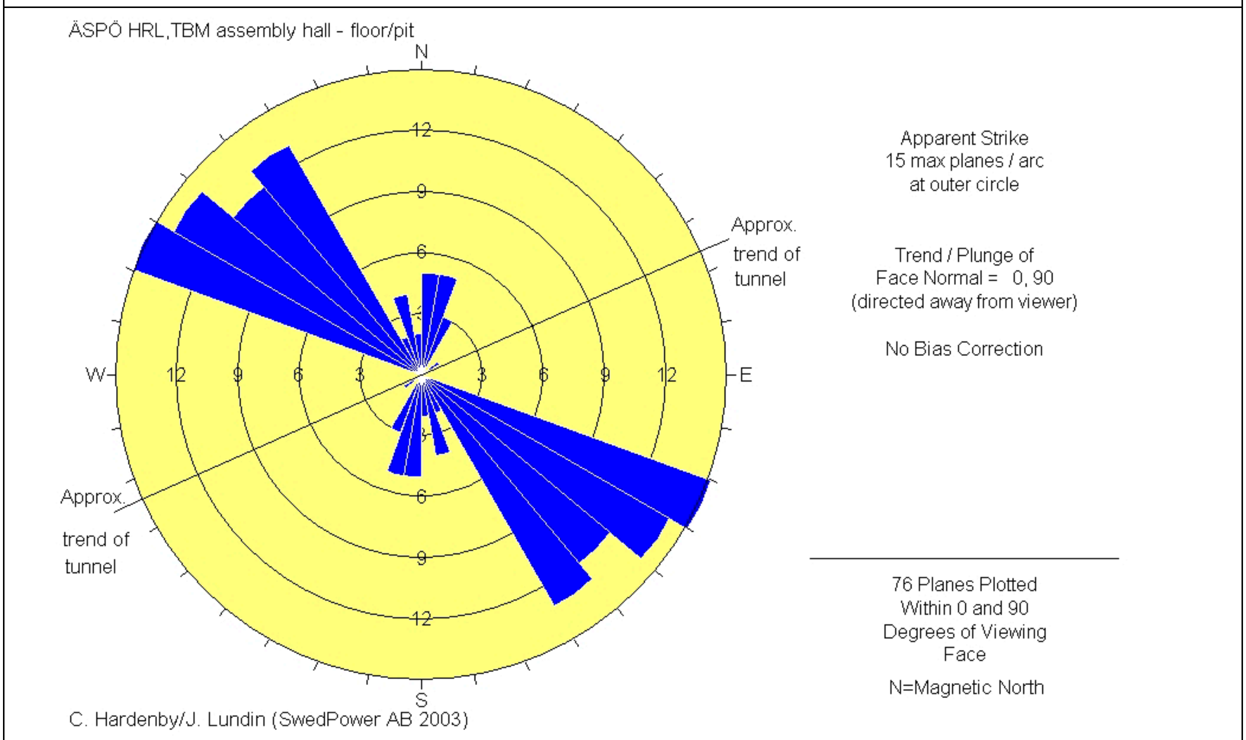
Legend: see next page!

Appendix 9: *Geological mapping of the pit floor in the TBM assembly hall*

Appendix 9 continued

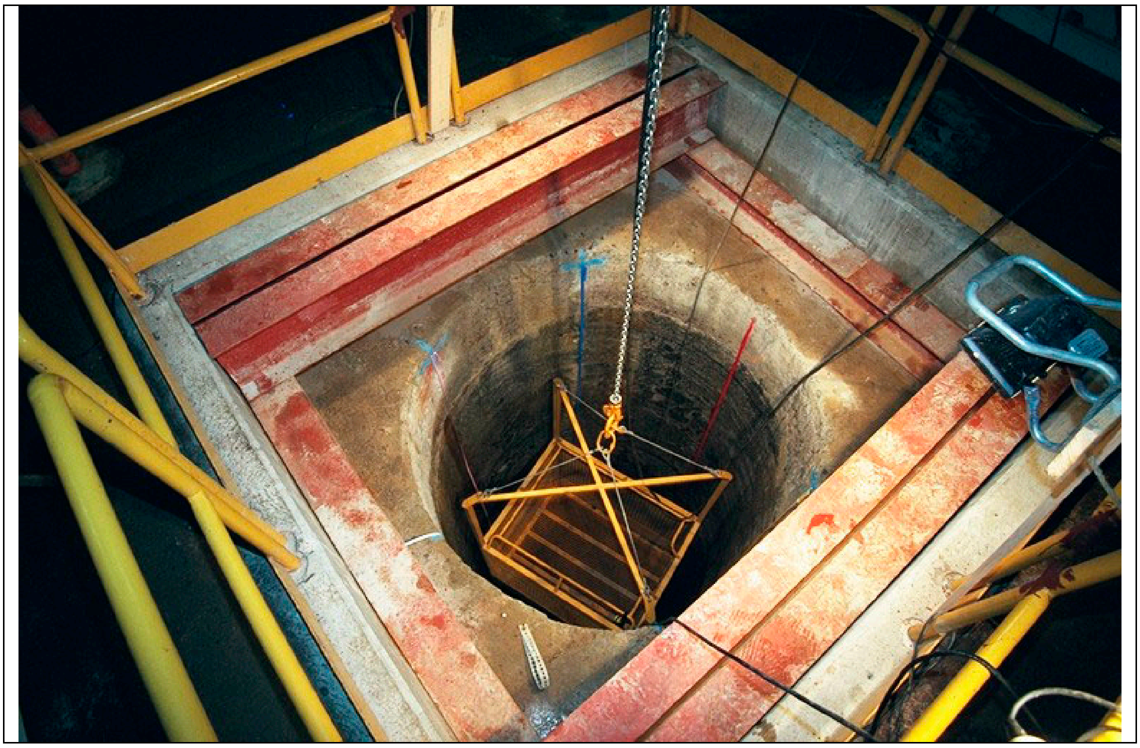
Legend:	
Rock types:	B1-B3 B1=Äspö diorite, greyish and medium-grained with feldspar megacrysts B2=Äspö diorite, greyish red, medium-grained with feldspar megacrysts, slightly altered - oxidized B3=Fine-grained granite, red
Contacts:	K1-K4 and dashed line K1=contact between B1 and B2 K2=contact between B1 and B3, orientation 310º/70º K3=contact between B1 and B3, orientation 210º/80º K4=contact between B1 and B3
Fractures:	01-67 and continuous line
Water:	Not registered due to inflow from the pit walls





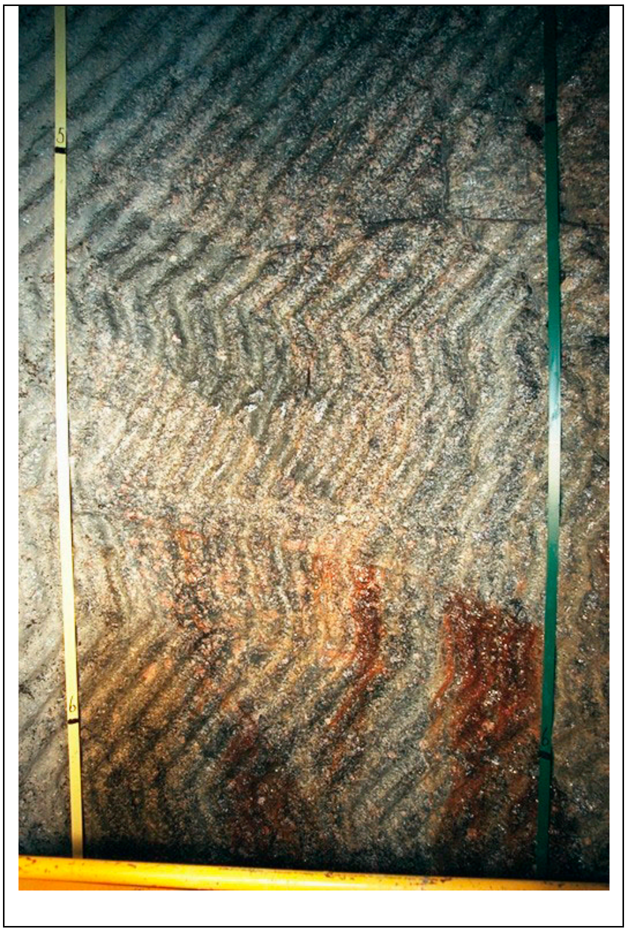
Appendix 10. *Fracture orientations from the pit floor in the TBM assembly hall presented in Schmidt net and joint rosette diagrams*

Appendix 11A. *Photos from deposition hole DA3147G01 (photos: Lars Andersson, SKB). Top of the hole with safety fence and part of the lift.*

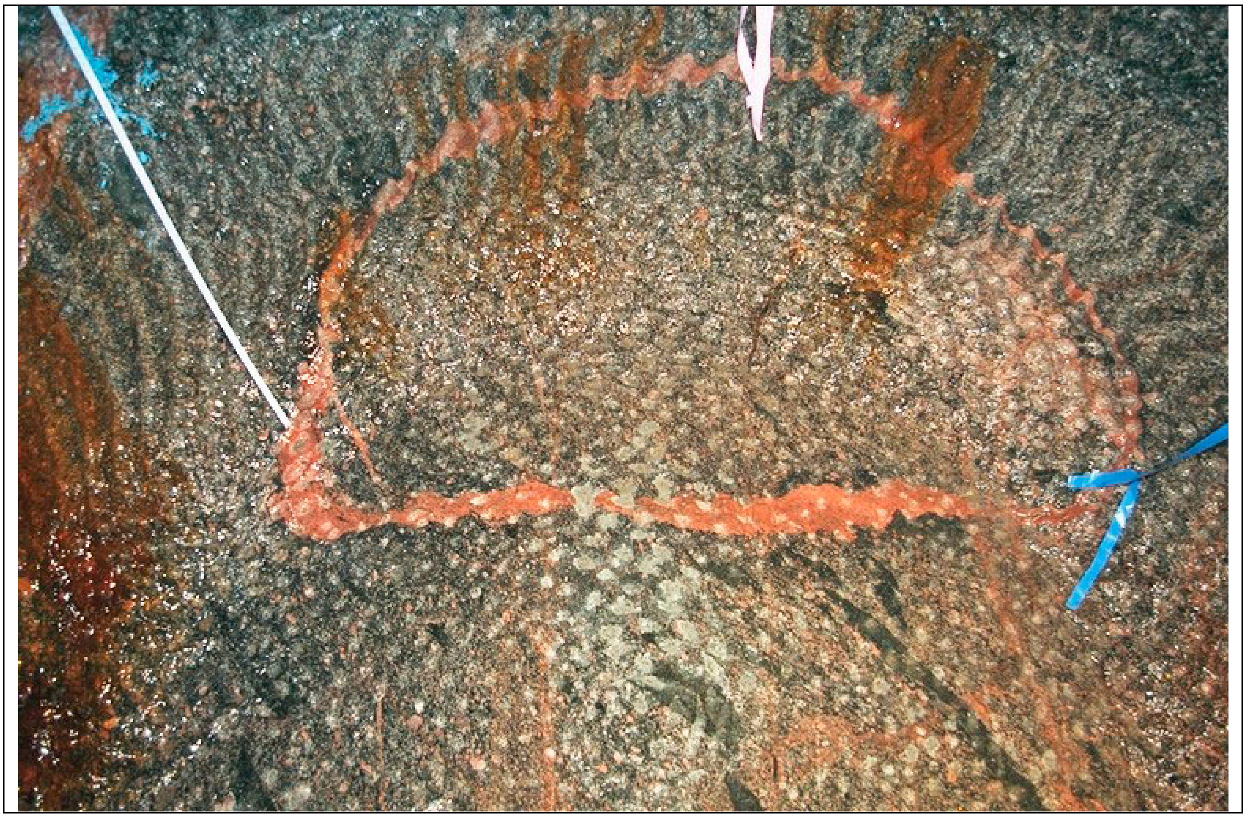


Appendix 11B. *Photos from deposition hole DA3147G01 (photos: Lars Andersson, SKB). Top of the hole with safety fence and lift cage. The blue and red ribbons were used during the mapping procedure not only for orientation but were also a part of a grid system*

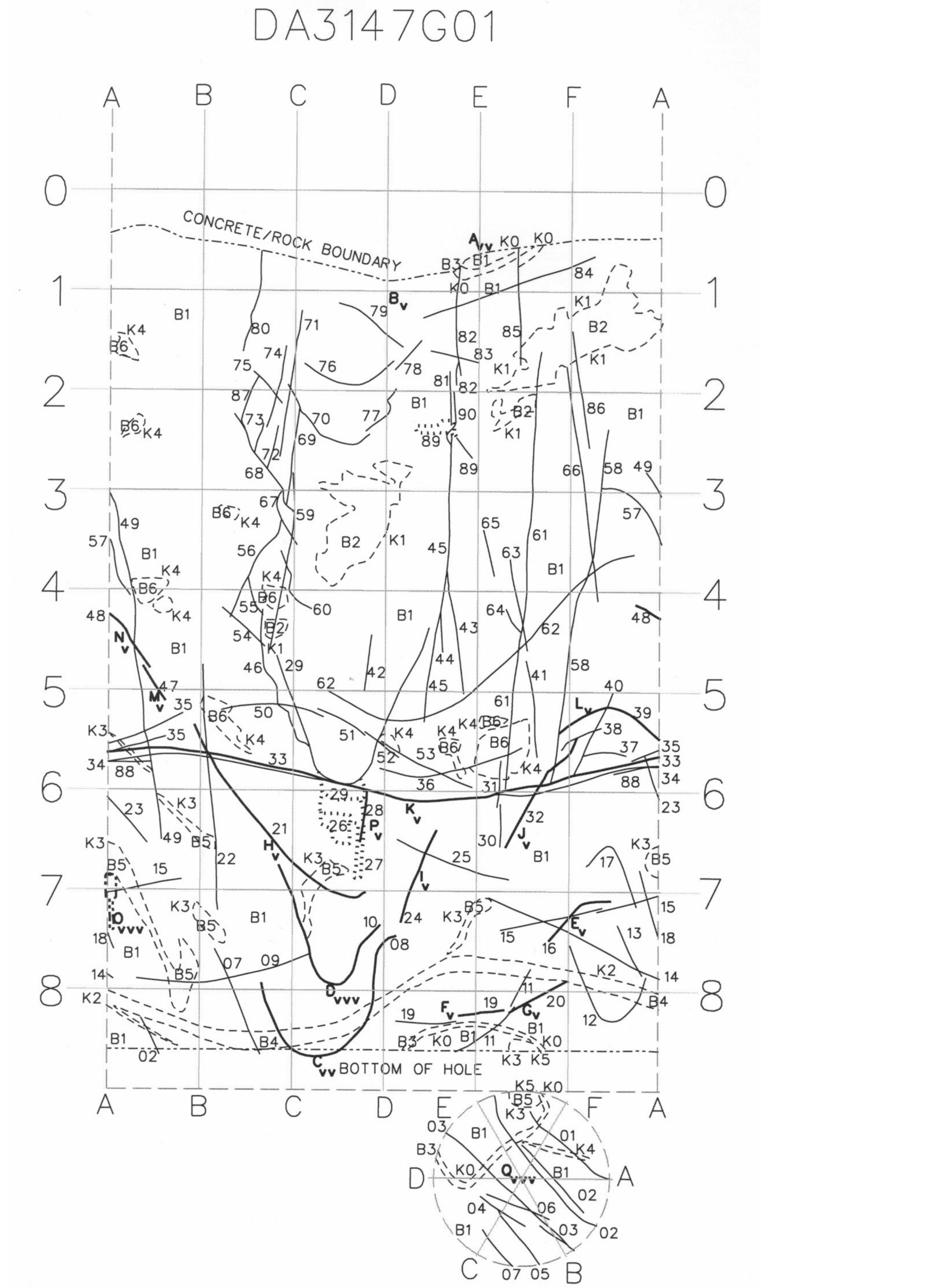
Appendix 11C. *Photos from deposition hole DA3147G01 (photos: Lars Andersson, SKB). Upper part of the hole. Boundary between concrete (top) and bedrock below. Rock types: Äspö diorite (greyish) and impure greenstone xenolith (dark grey – black). The blue and red ribbons were used during the mapping procedure not only for orientation but were also a part of a grid system*



Appendix 11D. *Photos from deposition hole DA3147G01 (photos: Lars Andersson, SKB). Section 5-6m. Rock types: Äspö diorite (greyish) and greenstone xenolith (dark grey – black). Water bearing fracture with rust staining below. The grooves are a result from the drilling. The yellow and green ribbons were used during the mapping procedure not only for orientation but were also a part of a grid system.*



Appendix 11E. *Photos from deposition hole DA3147G01 (photos: Lars Andersson, SKB). Bottom part of the hole. Rock types: Äspö diorite (greyish) with minor greenstone xenoliths (dark grey – black) and fine-grained granite (pinkish red). Water bearing fracture with rust staining below. The grooves are a result from the drilling. The white, pink and blue ribbons were used during the mapping procedure not only for orientation but were also a part of a grid system*



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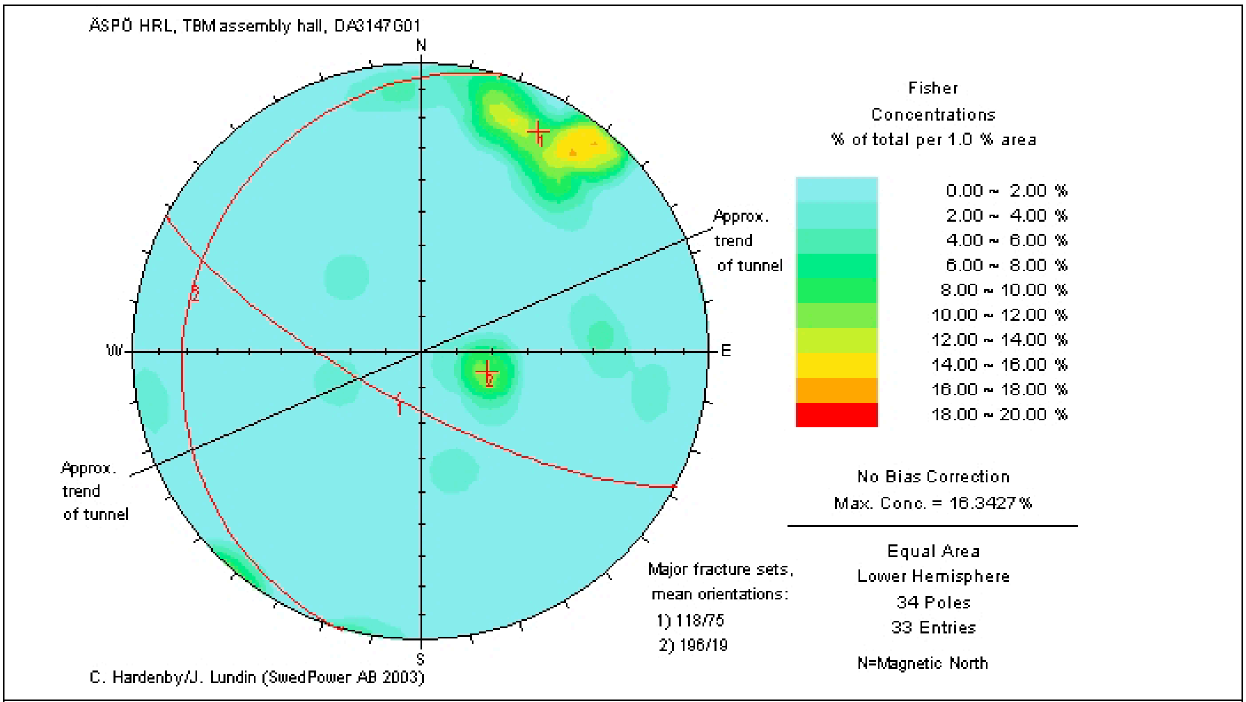
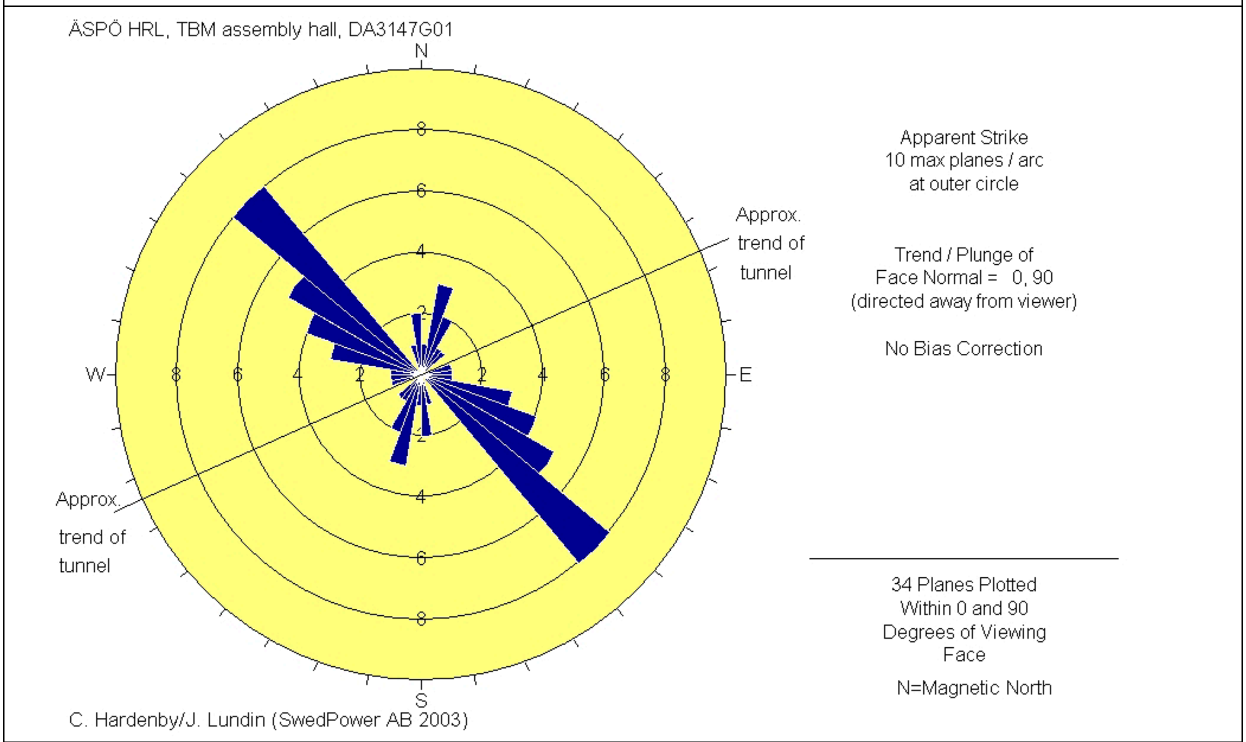
Appendix 12: *Geological mapping of the deposition hole DA3147G01*

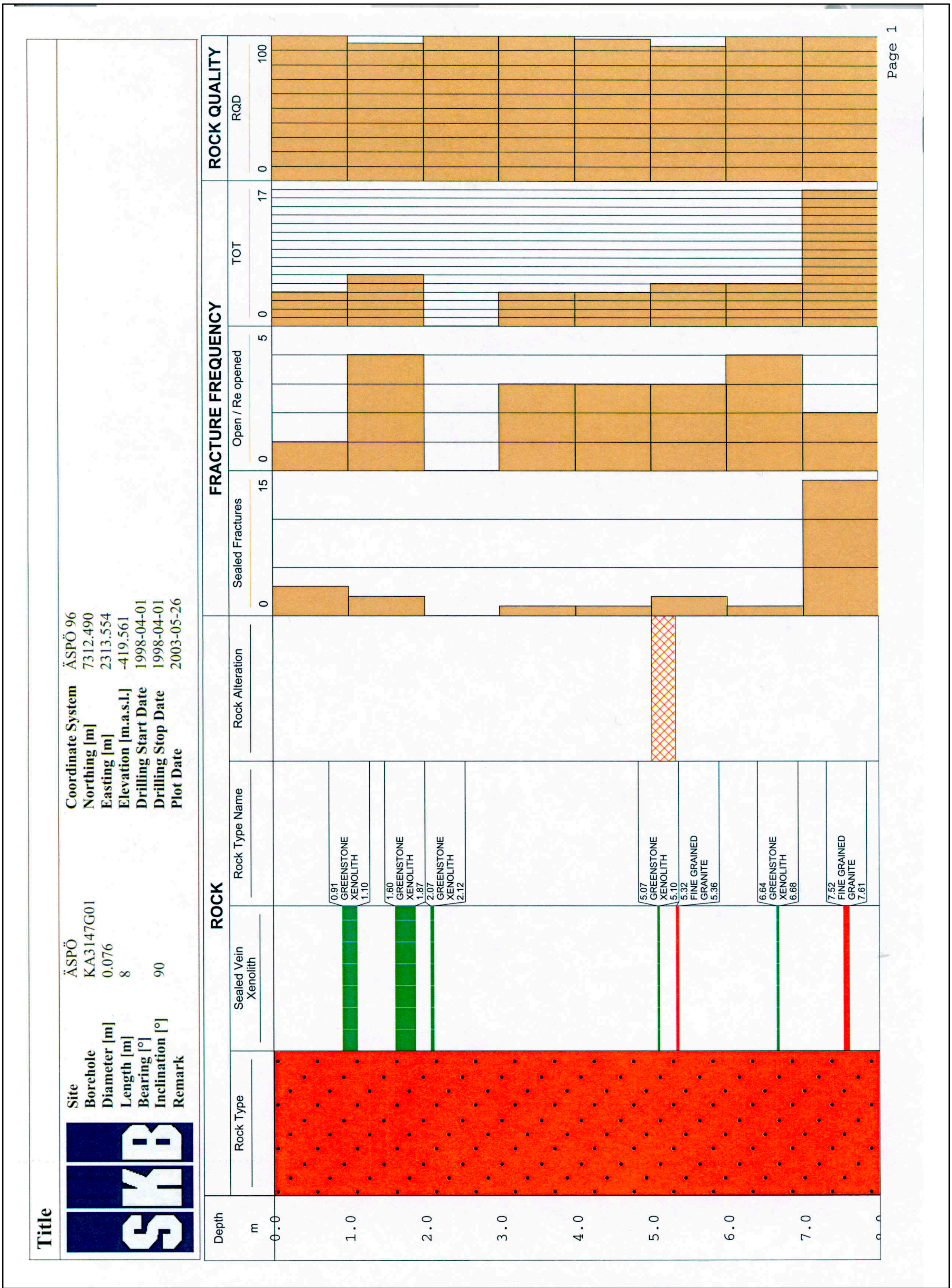
Appendix 12 continued

Legend:	
Rock types:	B1-B6 B1=Äspö diorite, greyish and medium-grained with feldspar megacrysts B2=Greenstone xenolith, black and fine-grained, includes some B1 and B4 B3=”Fine-grained” granite, greyish red and medium-grained B4=Pegmatite, red and coarse-grained B5=”Fine-grained” granite – hybrid of B1 and B3, greyish red and medium-grained B6= Greenstone xenolith, black and fine-grained
Contacts:	K0-K5 and dashed line K0=contact between B1 and B3 K1=contact between B1 and B2 K2=contact between B1 and B4 K3=contact between B1 and B5 K4=contact between B1 and B6 K5=contact between B5 and B3
Fractures:	01-90 and continuous line (thick lines represent water bearing fractures)
Water:	A-Q and v=damp-minor seepage, occasional drops vv=wet-seepage, drops or minor flow or vvv=flow

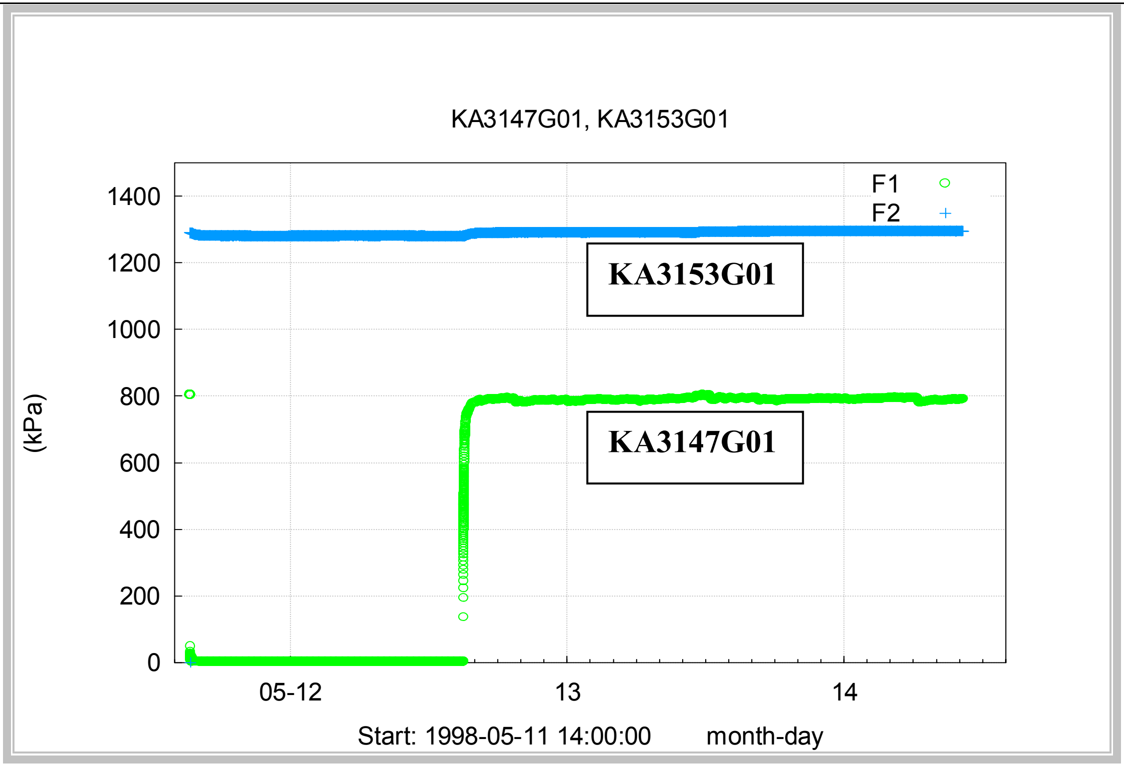




Appendix 13. *Fracture orientations (partly compass readings and partly graphical interpretation) from DA3147G01 presented in Schmidt net and joint rosette diagrams*

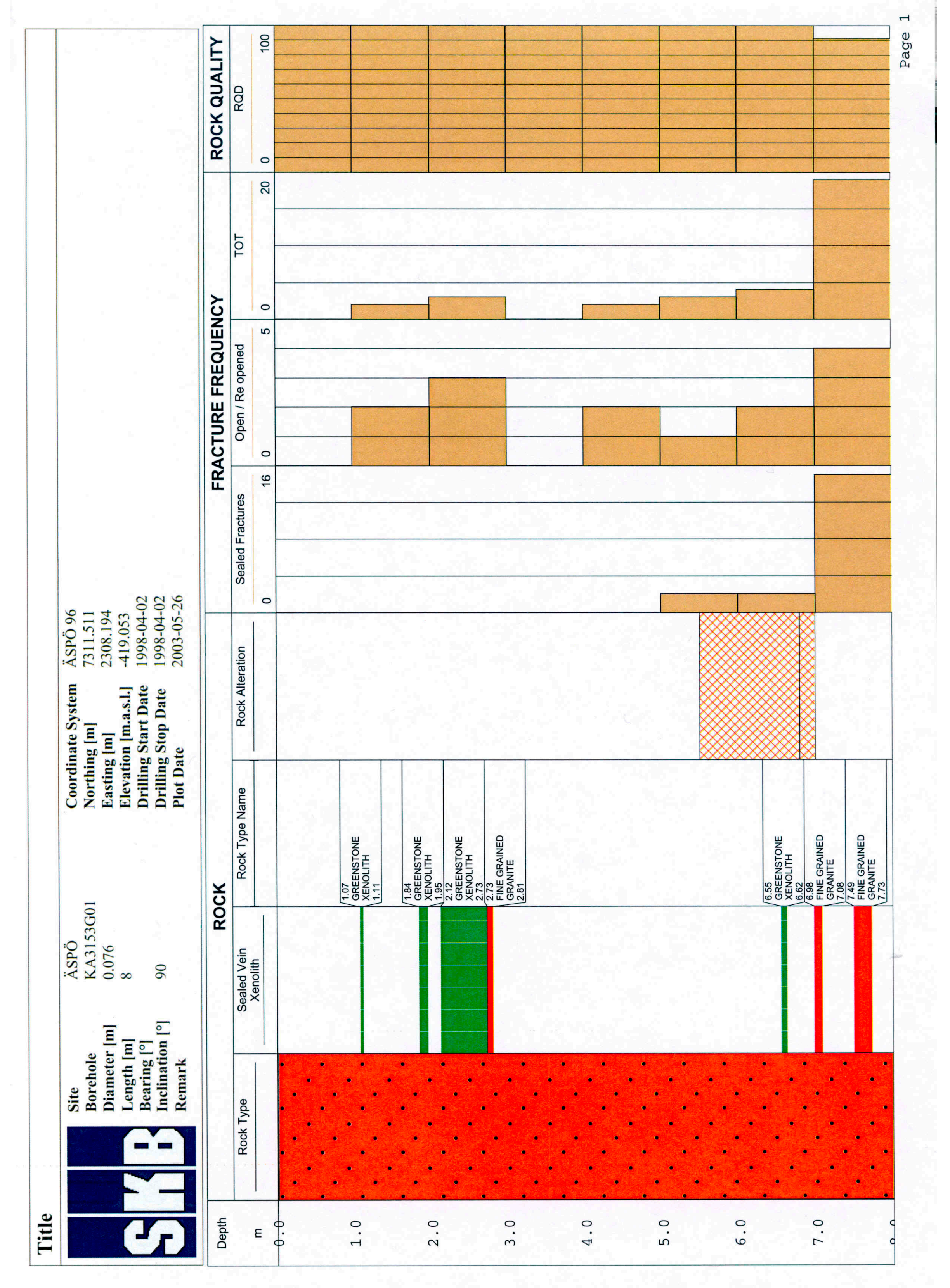


Appendix 14. *Core log from pilot hole KA3147G01 (Plot: Pär Kinnbom). Major rock type: Äspö diorite (red with dots). Accessory rock types: xenoliths of greenstone (green) and veins or minor bodies of fine-grained granite (red). Rock alteration: slightly oxidized section.*



- **KA3147G01-F1**
- **KA3153G01-F2**

Appendix 15. *Water pressure build up test in KA3147G01 and KA3153GO1 (Diagram, slightly modified: Lars Andersson, SKB)*



Appendix 16. *Core log from pilot hole KA3153G01 (Plot: Pär Kinnbom). Major rock type: Äspö diorite (red with dots). Accessory rock types: xenoliths of greenstone (green) and veins or minor bodies of fine-grained granite (red). Rock alteration: slightly oxidized section.*