International
Progress Report

IPR-02-49

Äspö Hard Rock Laboratory

Tunnel for the canister retrieval test

Geological mapping of tunnel and deposition holes

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July 2002

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Äspö Hard Rock Laboratory

Report no.	No.
IPR-02-49	F69K
Author	Date
Hardenby	02-07-04
Checked by	Date
Christer Svemar	02-09-11
Approved	Date
Christer Svemar	02-09-11

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Keywords: Äspö, canister retrieval test tunnel, deposition hole, geological mapping

Summary

The geological mapping of the Canister Retrieval Test Tunnel at Äspö HRL took place shortly after the excavation of this extended part of the tunnel TASD had ended in 1998. First the walls, front and roof was cleaned and mapped. After that, when the debris on the floor had been removed and the floor had been thoroughly cleaned, a grid was laid out and the floor was mapped.

Two pilot holes KD0086G01 and KD0092G01 were drilled prior to the excavation of two deposition holes. The cores were logged according to the Boremap system.

In 1999 the two deposition holes DD0086G01 and DD0092G01 were accomplished by using a vertically drilling TBM. Both holes were in the year of 2000 geologically mapped from a cage hooked up to a lift.

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

The result of the performed geological mapping of the Canister Retrieval Test Tunnel and the deposition holes show that basically four rock types are present. These are dark grey to black fine to medium-grained "greenstone", grey medium-grained "Äspö diorite" (with or without feldspar megacrysts), reddish or sometimes grey fine to medium-grained "fine-grained granite", and pinkish to reddish pegmatite. Although all the rock types vary to some extent it has not been found relevant to sub-divide them.

The dominating rock type in the Canister Retrieval Test Tunnel is greenstone. The second most common type is Äspö diorite. Fine-grained granite is the third most common rock type and pegmatite is the least occurring type. In the Äspö tunnel system as a whole greenstone appear only in minor amounts whereas the Äspö diorite probably is the most dominating type. Fine-grained granite sometimes forms hybrids with pegmatite or Äspö diorite and greenstone may form a hybrid rock with Äspö diorite.

The distribution of rock types is almost the same in the deposition holes as in the tunnel. The fine-grained granite appears however, to be overrepresented in both the deposition holes and in hole DD0092G01 the Äspö diorite is the dominating rock type.

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. From them it has been concluded that three or four fracture sets are present. One of the sets is composed of fractures that are gently – steeply dipping mostly towards the S - SW and striking W-NW. Another set is rather steeply dipping towards the ESE-NE with strikes varying between NNE-NW. The latter may be divided into two sets, E-ESE dipping and N-NNE striking and NE-ENE dipping and NNW-NW striking respectively. Particularly in the deposition holes it is evident that sub-horizontal fractures are represented as well.

Some iron bars and sensors that had been left in the walls of the deposition holes sometimes affected the compass readings while measuring the orientation of structural features such as fractures. It could, however, be concluded that these sensors and iron bars did not have such a great influence on the major part of the compass readings as was expected.

The recorded few lineations have W – NW trends with sub-horizontal to gentle plunges. Some of them are slickensides, some are crenulations and some of them lack notes concerning lineation type.

None of the observed lineations occur on fracture planes that show evidence of displacements along them. Only a few dislocations due to movements along fracture planes have been recorded. Most of these fractures have strikes that lie within the sector W to NW and the dip is mostly gentle to steep towards N-NE or S-SW. The strikes of the fractures more or less coincide with the maximum horizontal stresses in the rock mass. Dislocations are normally less than 0.1m in the deposition holes and less than 0.5m in the tunnel.

Most fractures contain more than one type of filling. Chlorite is by far the most common fracture filling and is found in 65-80% of all fractures. Calcite, epidote and oxidation rims along fractures appear frequently too. Quartz, amphibole, biotite, fine-grained granite, and pegmatite appear not in more than 10% of the fractures. The latter two fillings are veins that are too thin to be recorded as rock types. Grout was observed in some fractures in the upper parts of the deposition holes and clay in a few fractures in the tunnel.

The fracture surfaces are mostly planar and rough. In the tunnel planar and smooth fracture surfaces are rather common too. Only a minor amount of the fractures are undulating or arched. They may be slickensided, smooth or rough. When the tunnel was mapped the fracture roughness class “undefined” had not yet been introduced and was at that time included in roughness class rough. In the deposition holes, however, a lot fractures have been classified as having surface roughness undefined independent of their planarity.

Most of the fractures (about 90%) in the tunnel floor as well as in the deposition holes are shorter than 2m and more than 50% of the fractures are less than 1m in length (cut-off 0.5m). The standard mapping of the tunnel (walls, roof and front) using a cut-off of about 1m, show that only about 30% of the fractures are shorter than 2m. With the same cut-off, it will be found that 60-80% of the fractures measured in the floor and deposition holes are less than 2m in length. Although the exposure of rock surface is much larger in the tunnel than in the deposition holes only a few fractures can be traced over a longer distance in the former.

The fracture widths were not studied while the tunnel was mapped. The mapping of the deposition holes shows, however, that half of the fractures (about 50%) are very thin, less than 1mm in width. About 60-80% of the total fracture population is less than 2mm in width. Wider fractures, 5-10mm or more are commonly filled with fine-grained granite or pegmatite.

Most of the fractures (65-75%) in the deposition holes were healed and tight. Induced/natural open fractures (formerly healed and tight fractures that have been mechanically reopened) constitute most of the remaining fractures.

The latter group was not separated from the healed and tight fractures while the tunnel was mapped. If it had it would most probably have constituted a greater part of all the fractures together with induced open fractures (mechanically made fractures) since drilling and blasting was used to excavate the tunnel.

Water in minor quantities was found only at a few locations of which some were patches on the rock surface and some were fractures. The water-bearing fractures in the deposition holes are mostly E-W to WNW striking and gently to steeply dipping whereas those in the tunnel are almost N-S striking and steeply dipping. In the Äspö tunnel system as a whole the water-bearing fractures commonly are steeply dipping, striking NW-SE.

Taking into account that the pilot holes KD0086G01 and KD0092G01 were almost dry and it took a very long time to build up any water pressure at all in them, the Canister Retrieval Test Tunnel must be regarded as a very dry part of the Äspö tunnel system.

The RMR-values (approximately 65-80) indicate that the rock mass of the Canister Retrieval Test Tunnel and the deposition holes is of good quality.

Sammanfattning

Den geologiska karteringen av Återtagstunneln (the Canister Retrieval Test Tunnel), som är en förlängning och del av Äspölaboratoriets tunnel TASD, utfördes strax efter det att sprängningsarbetena var avslutade 1998. Först utfördes en s.k. normalkartering av tak, sidoväggar och front. När sulan var rensad och väl rengjord från diverse rester efter sprängningarna lades ett 2x2m rutnät med mellanliggande 1m-markeringar ut. Därefter karterades sulan mera i detalj än tak och väggar.

Två pilothål KD0086G01 och KD0092G01 borrades i sulan på tunneln innan borrningen av de två stora deponeringshålen påbörjades. Kärnorna från pilothålen karterades enligt det s.k. Boremap-systemet.

De två deponeringshålen DD0086G01 och DD0092G01 färdigställdes 1999 med hjälp av en vertikalt borrande TBM. Båda hålen karterades år 2000 från en hisskorg, som hängde i en wire från en bockkran.

All kartering, tunnelkartering såväl som karteringen av deponeringshålen, har digitaliserats och data har lagrats i en databas med hjälp av SKB:s karteringssystem TMS (Tunnel Mapping System).

De utförda karteringarna av Återtagstunneln och de två deponeringshålen visar att det i stort sett bara uppträder fyra bergartstyper. Dessa är mörkt grå-svart, fin –medelkornig ”grönsten”, grå medelkornig ”Äspödiorit” (med eller utan fältspat-megacryster), rödaktiga ibland grå, fin-medelkorniga ”finkorniga graniter” och slutligen rosa-rödaktiga pegmatiter. Samtliga bergarter varierar en del i utseende och troligen även sammansättning men det har här inte ansetts vara befogat att göra en mera detaljerad indelning av dem.

Den dominerande bergarten i Återtagstunneln är grönsten och den näst vanligaste är Äspödiorit. På tredje plats kommer finkornig granit och minst vanlig är pegmatit. Tar man Äspös tunnelsystem i sin helhet så förekommer grönsten endast i mindre mängd medan Äspödiorit troligen är den vanligast förekommande bergarten. Ibland bildar den finkorniga graniten hybrider med pegmatit och ibland övergår den från granit till pegmatit. Även hybrider mellan Äspödiorit och finkornig granit förekommer liksom mellan Äspödiorit och grönsten.

Bergartsfördelningen är likartad i de båda deponeringshålen. Den finkorniga graniten är dock överrepresenterad i båda hålen. I hål DD0092F01 är Äspödiorit den dominerande bergartstypen.

Bergarterna har ansetts vara friska förutom en mindre oxidation i samband med flera av de förekommande sprickorna.

Bergartskontakterna är mestadels täta och skarpa. Mera diffusa kontakter förekommer i samband med att en bergartstyp övergår i en hybrid av något slag.

Alla sprickorienteringar har plottats i Schmidt nät och i sprickrosdiagram. Av dessa diagram framgår det att tre eller fyra sprickgrupper förekommer. En av grupperna stupar måttligt-brant mestadels mot S-SV och stryker i V-NV riktning. En andra grupp är

tämligen brant stupande mot OSO-NO och stryker mellan NNO-NV. Den senare gruppen skulle eventuellt kunna delas upp i två grupper: O-OSO stupande och N-NNO strykande respektive NO-ONO stupande och NNV-NV strykande. Särskilt i deponeringshålen framgår det att även mer eller mindre horisontella sprickor förekommer.

I deponeringshålens väggar hade ett antal järnstänger och givare lämnats kvar efter tidigare utförda undersökningar. Dessa föremål störde emellanåt kompassen vid mätning av t.ex. sprickorienteringar. Det visade sig emellertid att för den stora massan av utförda kompassmätningar hade de kvarlämnade stängerna och givarna en mindre påverkan än vad som hade förväntats.

Endast ett fåtal lineationer har noterats. Riktningen på dessa är V-NV och lutningen är svag till i det närmaste horisontell. Några av lineationerna är strieringar på harneskytor (slickensides), några är krenulationer (crenulations) och för vissa saknas information om lineationstyp.

Inga av de noterade lineationerna förekommer på sprickplan där någon tydlig förskjutning har kunnat observerats. De sprickor där en tydlig förskjutning har kunnat påvisats är sällsynta. Dessa har en strykning, som ligger inom en sektor V-NV med en måttlig till brant stupning mot N-NE eller S-SV. Strykningen för dessa sprickor sammanfaller mer eller mindre med de största horisontella bergspänningarna. De synbara förskjutningarna är i allmänhet inte mer än 0.1m i deponeringshålen och mindre än 0.5m i tunneln.

De flesta sprickorna innehåller mer än en typ av sprickfyllning. Den vanligast förekommande fyllningen är klorit, som återfinns i 65-80% av alla sprickor. Vanligt förekommande är även mineralen kalcit och epidot samt en oxidationskant längs sprickplanen. Kvarts, amfibol, biotit, finkornig granit och pegmatit förekommer bara i 10% eller färre av sprickorna. De senare två sprickfyllnaderna är egentligen sliror eller gångar, som är för tunna för att karteras som bergarter. Lera har bara observerats i några få sprickor i tunneln. I de övre delarna av deponeringshålen har några sprickor med injekteringsbruk noterats.

Mestadels är sprickytorna plana och råa. I tunneln är även plana och släta sprickytor tämligen vanliga. Bara en mindre mängd har klassats som undulerande eller böjda. Dessa ytor kan vara antingen harneskytor (slickensides), släta eller råa. När tunnelkarteringen genomfördes fanns inte sprickplanens råhetsklass ”odefinierad” (undefined), som markerar sprickplan vars yta ej kunde studeras. Dessa sprickplan ingick tidigare i råhetsklassen ”rå”. Vid karteringen av deponeringshålen däremot hade denna råhetsklass introducerats varför ett flertal sprickor har klassats som odefinierade oberoende av deras planhet (planarity).

De flesta av sprickorna (ca 90%) i sulan och depositionshålen är kortare än 2m och mer än 50% av sprickorna är mindre än 1m i längd vid en ”cut-off” på 0.5m.

Standardkarteringen av tunneln (väggar, front och tak) med en ”cut-off” på 1m visar att bara 30% av sprickorna är kortare än 2m. Med samma ”cut-off” för karteringen av sulan respektive deponeringshålen finner man att 60-80% av sprickorna då är kortare än 2m i längd. Trots att den exponerade bergytan är mycket större i tunneln än i deponeringshålen är antalet långa sprickor i tunneln inte särskilt stort.

Sprickvidderna noterades ej när tunneln karterades. Vid karteringen av deponeringshålen å andra sidan kunde det konstateras att hälften (ca 50%) av sprickorna är mycket tunna (mindre än 1mm:s vidd). Mellan 60-80% av sprickorna har en vidd som är mindre än 2mm. De sprickor som är bredare, 5-10mm eller mer, är vanligen fyllda med finkornig granit eller pegmatit.

De flesta sprickorna (64-75%) i deponeringshålen är läkta och slutna. Resterande sprickor tillhör kategorin ”inducerade/naturliga öppna sprickor” (induced/natural open fractures). Dessa utgörs av före detta läkta sprickor, som har bedömts ha blivit mekaniskt återöppnade (t.ex. genom borrning eller sprängning). Vid karteringen av tunneln ingick denna kategori i kategorin ”läkta, slutna sprickor”. Om kategorierna vid detta tillfälle skulle ha varit åtskilda skulle med all säkerhet de ”inducerade/naturliga öppna sprickorna” tillsammans med sant ”inducerade öppna sprickor” (induced open fractures) utgjort den dominerande gruppen sprickor då själva tunneln är en sprängd tunnel. Till kategorin ”inducerade öppna sprickor” hör sådana sprickor som är mekaniskt skapade vid t.ex. tunnelsprängning och inte har något ursprung i en tidigare läkt spricka.

Mindre kvantiteter vatten har återfunnits på ett fåtal platser. Några utgjordes bara av fuktiga-blöta fläckar på bergytan medan andra var sprickor. De vattenförande sprickorna i deponeringshålen stryker mestadels O-V till VNV och stupar måttligt till brant medan de i tunneln stryker i stort sett N-S och stupar brant. Generellt i Äspös tunnelsystem stryker de vattenförande sprickorna NV-SO och stupar brant.

Med tanke på att pilothålen KD0086G01 och KD0092G01 var i stort sett torra och att det tog väldigt lång tid att bygga upp något vattentryck i dem samt att de i övrigt noterade vatteninläckagen var små så måste Återtagstunneln (Canister Retrieval Test Tunnel) anses vara en mycket torr del av Äspös tunnelsystem.

RMR-värdena för tunneln och deponeringshålen ligger på 65-80 vilket indikerar att bergmassan i Återtagstunneln är av en god kvalitet.

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1 Background and purpose

SKB has decided to carry out a project with the designation ”Canister Retrieval Test” (CRT). The aim of this project is to test and demonstrate the feasibility of canister retrieval after deposition in full-scale and in a realistic environment. The project is one of many performed by SKB in preparation for construction and operation of the coming deep repository for spent fuel.

The tunnel for the canister retrieval test is a part of the TASD-tunnel. It is situated approximately on the 420m-level of the tunnel system at the Äspö Hard Rock Laboratory (Äspö HRL, appendix 1). The total length of TASD is 100m of which the Canister Retrieval Test Tunnel (CRT-tunnel) constitutes the inner 20m (approximately section 84.0-100.5). Conventional drilling and blasting techniques was used to excavate the tunnel in 1998.

To accommodate the canisters two large deposition holes were drilled in 1999 (DD0086G01 and DD0092G01). The approximate depth of these holes is 8.5m and the diameter is 1.75m. To accomplish the deposition holes a specially made vertically drilling Robbins TBM was used. The location of the deposition holes is illustrated in appendix 2. In 1998, before the final location of the large holes was decided a pilot hole was drilled (core drilling) in the expected centre of each deposition hole (KD0086G01 and KD0092G01). For further information about hole locations see Table 1-1 below.

This paper concerns the characterisation of the host rock and the hydro-geological condition. To obtain necessary information, geological mapping of the tunnel as well as of the deposition holes was performed and the core from the pilot holes were logged.

Table 1-1. Co-ordinates of the pilot and the deposition holes in the CRT-tunnel

BORE HOLE CATEGORY	ID - Codes	X co-ordinate	Y co-ordinate	Z co-ordinate	Dip°	Length (m)
DEPOSITION HOLE	DD0086G01	7 227.716	2 304.405	**-416.710	-90	***8.750
DEPOSITION HOLE	DD0092G01	7 221.796	2 305.452	**-416.590	-90	***8.750
PILOT HOLE	KD0086G01	7 227.757	2 304.366	*-417.374	-90	8.0
PILOT HOLE	KD0092G01	7 221.789	2 305.491	*-417.384	-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. A SKB application called TMS (Tunnel Mapping System) based on Micro Station is used for the drawings and Microsoft's Access database 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 and deposition holes have been photographed. These photos are stored both in binders and on CD.

2.2 Preparations and mapping procedures for the tunnel

Before the mapping of the CRT-tunnel could take place the tunnel walls, roof and floor had to be cleaned. Water had to be pumped away every now and then during the mapping of the floor. Tunnel sections were marked on the walls every 2:nd meter. On the floor grid-lines (2x2m) were marked out.

The tunnel walls, roof and front were mapped 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).

The tunnel floor was, however, mapped in more detail than the standard procedure prescribes. Mapping was here done in 1:20 scale. The cut off for fractures was set to 0.5m instead of 1-1.5m and veins with widths <0.1m were drawn as separate rock types down to a width that was practically mappable. In the standard mapping procedure the latter were shown as fractures.

2.3 Preparations and mapping procedures for the deposition holes

The deposition holes, too, were cleaned prior to the mapping and water was pumped away. For orientation in the holes 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.

As the mapping of the tunnel floor, the mapping of the deposition holes was performed in greater detail (1:25 scale) than the ordinary tunnel mapping. Again the cut off for 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 mappable.

Besides being done in greater detail than the ordinary tunnel mapping, the mapping of the deposition holes had to deal with a few items that at this time had been added to the general mapping procedure. Records had now to be kept over fracture width and whether the fracture was open or closed.

The fracture width includes the three components: “aperture” (open space between fracture walls or coating on the fracture walls), “width” (aperture plus fracture filling/coating) and finally “oxidation rim” (width plus zone of oxidation along a fracture). It should be noted that the fracture widths are only estimations.

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).

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. 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.

Another general change that has taken place since the mapping of the D-tunnel 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.

A problem concerning compass readings was discovered at the end of the mapping of the deposition holes. Some iron bars and sensors used for tests while drilling the deposition holes had been left in the hole-walls. This affected the compass and made some of the compass readings of structural features unreliable. Where possible, graphical interpretations of the strike of planar structures were made as a complement to the compass readings.

2.4 Core logging and investigations in the pilot holes

As mentioned earlier, the two core boreholes KD0086G01 and KD0092G01 were both drilled in the presumed centre of the respective planned 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: “Demonstration of deposition technology. Borehole radar measurements in D-tunnel, K-tunnel, and TBM-hall”. Not yet in print.).

3 Geological mapping

3.1 Mapping of the CRT-tunnel

Some photos showing the tunnel interior including some of the rock types will be found in appendix 3. The results of the tunnel mapping are presented in appendices 4 (mapping of walls and roof), 5 (detailed mapping of tunnel floor) and 6-9 (fracture orientations presented in Schmidt net and joint rosette diagrams).

3.1.1 Bedrock

Rock types

Four major types of rock have been recorded in the tunnel for the retrieval test. They are: Äspö diorite, greenstone, fine-grained granite and pegmatite. There are, however, varieties of these major rock types and some of them may grade into each other to form hybrids. The distribution of the various rock types has been summarized in Table 3.1-1. A more thorough description of the various rock types can be found in e.g. Wikman, H & Kornfält, K-A 1995 and Rhén, I et al. 1997.

- **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. The dominating variety is a dark grey to black, medium-grained and massive rock type that may be of gabbroic origin. It appears as large bodies and quite often as xenoliths in the Äspö diorite (below).

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

  The "greenstones" occupy 56% of the mapped surfaces in the tunnel and is here the most common rock type.

- **Äspö diorite.** The Äspö diorite is a grey to dark grey, medium-grained and massive rock. It is not a diorite proper but grades from a granitic - granodioritic - quartz monzodioritic composition. Commonly it has a porphyritic texture with megacrysts 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 canister retrieval test tunnel, however, only 31% of the mapped surfaces consists of Äspö diorite. Most of it is of an even grained variety. The porphyritic variety, having feldspar megacrysts, appear mainly in the inner part of the tunnel.

  Occasionally it is difficult to see the difference between the darker, non-megacryst bearing variety of Äspö diorite and the dark grey, medium grained variety of greenstone.

  A minor portion of a reddish medium-grained hybrid rock of Äspö diorite and what appears to be fine-grained granite (below) is also found in the tunnel.

- **Fine grained granite.** The typical and characteristic fine-grained granite is, as the name indicates, fine-grained. It is reddish in colour, massive, even grained and commonly rather brittle. The colour may occasionally be more grey than red. The grain size varies between very fine-grained, almost aphanitic, to medium-grained. Sometimes the fine-grained granite grades into a pegmatite or as can be seen e.g. in the inner part of the canister retrieval test tunnel where pegmatite borders the granite.

  Totally 11% of the mapped tunnel surfaces is composed of the fine-grained granite. It appears commonly as irregular dykes or bodies.

- **Pegmatite.** This is the least common rock type of the canister retrieval test tunnel. Only 2% of the mapped surfaces consist of pegmatite. It has only been observed in the tunnel floor. The pegmatite is pinkish to reddish in colour, medium- to coarse-grained and massive. It appears mainly as irregular dykes or as a border to some of the fine-grained granites.

Table 3.1-1 Rock type distribution – the CRT-tunnel

Rock type	% of mapped area		
	Standard mapping of side walls, front and roof (295m^2)	Detailed mapping of tunnel floor (107m^2)	Total – detailed and standard mapping (402m^2)
Greenstone	60	44	56
Äspö diorite	30	37	31
Fine grained granite	10	12	11
Pegmatite	0	7	2
Total	100	100	100

Contacts

The rock boundaries are mostly distinct (sharp and tight). A few diffuse boundaries have, however, been observed. They are some of the Äspö diorite/greenstone contacts, the fine-grained granite/pegmatite contacts and the contacts between oxidized or hybrid rock and the host rock.

Normally the contacts are irregular and therefore the orientation of them very seldom has been recorded. This has been done only for a contact approximately at section 90m where a dyke of fine-grained granite cuts through mainly some greenstone. The strike is 270° and the dip 60° (E-W with 60°dip towards the north).

Alteration

Most of the rock is regarded to be fresh, i.e. unaltered. Minor oxidation may occur along some of the fractures. A narrow (approx. 0.1m wide) short zone of oxidized reddish Äspö diorite has been recorded at the inner end of the tunnel.

3.1.2 Fractures

The distribution of the fractures can be seen in appendices 4 (mapping of walls and roof) and 5 (detailed mapping of tunnel floor). Fracture orientations presented in Schmidt net and joint rosette diagrams are found in appendices 6-9. 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, 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 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 two major fracture sets can be distinguished when studying the diagrams in appendices 6, 8 and 9. The orientations (strike/dip, right hand rule) of the two sets are approximately 90-110°/60-90° and 0-20°/60-80°. A third less conspicuous set has the orientation 290-320°/70-80°. A few sub-horizontal fractures have been recorded too. Appendix 7, showing fracture orientations from the front, shows a little different picture that of course has to do with the orientation of the front wall. Here only one fracture set dominates with the orientation 120-170° or 300-350°/50-90°.

Lineation

Only three fractures containing lineations have been recorded. No notes on what type were made. The lineation orientations were the following: 305°/35°, 330°/50° and 320°/55° (trend/plunge).

Filling

Ten (10) types of filling material have been observed. Mostly more than one filling is observed in the fractures. Some (11%) 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 75% of all the fractures and the second most common filling that is calcite is found in 18% of them. The other fillings such as epidote, clay, amphibole, fine-grained granite, quartz, pegmatite are found in about 10% or less of the fractures. A reddish rim of oxidation has been observed along about 10% of the fractures
(see table 3.1-2).

Table 3.1-2 Distribution of fracture fillings – the CRT-tunnel

Filling	No of observations	% of all observations (totally 381 fractures)
Chlorite	287	75
Calcite	66	18
Epidote	43	11
Oxidation rim	35	9
Fine-grained granite	20	5
Clay	21	5
Quartz	12	3
Amphibole	14	3
Pegmatite	9	2
Pyrite	2	<1
No filling or not observed	43	11

Fracture surfaces

The fracture surfaces are mostly planar and rough (67% of the fractures) or planar and smooth (20% of the fractures). Undulating and rough, undulating and smooth, arched and rough, and arched and smooth fracture surfaces are less common. 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 - the CRT-tunnel

Surface category	No of fractures	% of all fractures (totally 381)
Planar and rough	256	67
Planar and smooth	77	20
Undulating and rough	17	4
Undulating and smooth	21	6
Arched and rough	7	2
Arched and smooth	3	1
Total	381	100

Persistence

At the time for the mapping of the tunnel in question, the length of the fractures was defined as the shortest distance between the end points of the fractures. The fracture lengths are illustrated in table 3.1-4. About 30% of all fractures recorded during the standard mapping are less than 2m in length and about 85% are less than 4m. The detailed mapping of the tunnel floor shows about 50% of all fractures are less than 1m in length, almost 90% are less than 2m and 98% are less than 4m. It has to be remembered however, that during the standard mapping cut-off for the fractures was 1-1.5m and during the detailed mapping around 0.5m.

Table 3.1-4 Distribution of fracture lengths - the CRT-tunnel

Length interval in meters	Standard mapping of roof and walls, cut off about 1m		Detailed mapping of tunnel floor, cut off 0.5m	
	No of fractures	% of all the 133 fractures	No of fractures	% of all the 248 fractures
<1	-	-	125	50
1<2	44	33	95	38
2<3	46	35	22	9
3<4	21	16	3	1
4<5	8	6	2	1
5<6	6	5	1	1
6<7	3	2	0	0
7<8	3	2	0	0
8<9	2	1	0	0
Totally	133	100	248	100

Displacements

Not many fractures show that any displacement has occurred along the fracture planes. In the tunnel only 3 displacements have been recorded. It is evident that there are more. E.g. the two displacements seen in the pictures (appendix 3B and 3D) have not been recorded for some reason. Here they have, however, been taken into account. The displacements are between 0.05 – 0.5m. They all occur along fractures striking 100-130° and dipping 40-75° except the one seen in the picture in appendix 3D which occur along a fracture with the orientation 160°/80°. Lineations on the fracture planes have not been reported.

3.1.3 Water

Only two fractures were recorded to be water bearing. Some patches of water that probably originate from minor cracks in the rock mass have been observed too. No water leakage could be observed from the tunnel floor. Some parts of it were damp to wet all the time probably due to minor seepage from the walls and roof and may be from the floor itself. Water appears, however, to be present only in minor quantities, <0.002litre/minute and observation. The over all impression of the Canister Retrieval Test Tunnel is that it is a rather dry tunnel.

3.1.4 Rock quality

The Rock Mass Rating (RMR) classification system was used to estimate the rock quality of the floor and the front of the Canister Retrieval Test Tunnel. To judge by the results the rock mass for the tunnel as a whole is classified as good rock (RMR = 60-80) Most part of the floor lies within the interval RMR=76-79 whereas the inner part of the floor and the front has the RMR values 66 and 67 respectively. These lower values are caused by unfavourable fracture orientations.

3.2 Mapping of deposition hole DD0086G01

The location of the canister hole is shown in appendix 2. Appendix 10 presents in some photos the arrangements around the deposition hole, the lift cage used for the mapping and parts of the interior of the hole. The result of the mapping of the deposition hole is shown in appendix 11. Fracture orientations are presented in appendices 12 and 13.

3.2.1 Bedrock

Rock types

Four major rock types have been distinguished in the deposition hole. They are Äspö diorit, greenstone, fine-grained granite, and pegmatite. The description of them is mainly the same as the one given for the mapping of the tunnel. Only specific features will be dealt with below. Table 3.2-1 summarises the occurrence of the rock types.

- **Äspö diorite.** In the deposition hole the Äspö diorite is mainly of the feldspar megacryst bearing type. The rock is partly slightly schistose. It constitutes about 55% of the hole-surfaces (wall and bottom).

- **Greenstone.** As was the case in the tunnel the greenstone appears in a medium- and to a much lesser extent fine-grained variety. They both occur as irregular masses and as xenoliths in the Äspö diorite. Totally they constitute 23% of the hole-surfaces.

- **Fine-grained granite.** This is the third most common rock type that constitutes 19% of the hole-surfaces. It appears in two varieties. The clearly dominating one is light red and fine-grained whereas the other one is greyish red and medium-grained. They both appear as veins or narrow dykes. The truly fine-grained variety, however, occurs also as a rather wide dyke (approximately 1 metre across) and as a small body at the bottom of the hole. Pegmatite may border the granite.

- **Pegmatite.** It constitutes only 3% of the mapped surfaces. It appears as narrow dykes or as veins on its own or sometimes forms a narrow border-zone to the fine-grained granite.

Table 3.2-1 Rock type distribution - DD0086G01

Rock type	% of mapped area
Äspö diorite	55
Greenstone	23
Fine grained granite	19
Pegmatite	3
Total	100

Contacts

Most contacts are tight and sharp. Those between the fine-grained granite varieties and those between the fine-grained granites and pegmatite are normally more diffuse in their appearance.

Since the contacts commonly are very irregular no special effort was made measure their orientations. A graphical interpretation of the contact between the broad fine-grained granite dyke and the surrounding rock types in the upper half of the hole gave, however, the following orientation: 285°/70° (strike/dip, right hand rule).

Alteration

Besides a few thin streaks of oxidation commonly accompanying some of the fractures, all the rock types have been regarded as fresh.

3.2.2 Fractures

The fracture distribution is shown in appendix 11 (mapping of hole wall and bottom). The fracture orientations, presented in Schmidt net and joint rosette diagrams, are found in appendices 12 (based on compass readings) and 13 (based on graphical interpretation). 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 12, that shows fracture orientations obtained by compass readings, there is one clearly dominant fracture set with the orientation varying between 95-140°/50-80° (mean value 120°/60°). Besides some scattered orientations there appear to be a set of sub-horizontal fractures and one steeply dipping towards the east, striking NNW to N-S (325-010°/60-80°, mean value 345°/70°).

Appendix 13 that shows the fracture orientation based on graphical interpretation of the mapping indicates almost the same distribution of fracture orientations. The NNW striking, steeply east dipping fracture set is missing in the diagram and the sub-horizontal set is a little more accentuated. Thus, the sensors and iron bars left in the hole wall may after all not have had such a great influence on the compass readings.

The few graphically obtained strikes were compared with those obtained by compass readings for corresponding fractures. It was found that maximum deviation between the two methods was 25°. Mostly, however, there was only a difference between 0-10°.

Lineation

Only two observations of lineations were made. The trend/plunge of them were 285/75 and 340/35 respectively. Both lineations are slickensides.

Open/closed

The majority of the fractures (64%) were found to be tight (healed) which was expected since the hole had been drilled. The second most common type was the induced/natural fracture (32%) and only a few were regarded as mechanically made (induced open, 4%).

Fracture widths

No apertures have been recorded. They have been included in the width (aperture plus filling). The width of most of the fractures, almost 45%, is less than 1mm. Some of them have no visible width (width zero, 0). They can all be referred to streaks of reddish oxidation recorded as fractures (se below in Filling). With increasing width from 1-5mm the number of fractures decreases from constituting 19% - 1% of all fractures. Fracture widths between 10 and 20mm that constitutes 10% of all fractures commonly are filled with pegmatite or fine-grained granite (se below in Filling).

Most fractures, about 90%, are not associated with an oxidation rim. For those that are, the oxidation rim/zone is less than 30mm across. The distribution of fracture widths and oxidation rims/zones is found in Table 3.2-2.

Table 3.2-2 Distribution of width of fractures and oxidation rims or streaks – DD0086G01

Interval mm	Width (aperture plus filling)		Oxidation rims or streaks (width plus oxidized zone)	
	Number of observations	% of all observations	Number of observations	% of all observations
0	5	6	72	89
>0<1	30	37	1	1
1<2	15	19		
2<3	10	12	1	1
3<4	5	6		
4<5	1	1		
5<10	6	8	4	5
10<20	8	10	1	1
20<30			2	3
30<40	1	1		
Totally	81	100	81	100

Filling

Eight types of fracture filling material have been observed (table 3.2-3 below). The most common material is chlorite that is found in 65% of the 81 recorded fractures. Calcite is the second most common filling material appearing in 30% of all the fractures. Grout, epidote, fine-grained granite, pegmatite, and quartz are found in about 10 % or less of the fractures. Grout appears mainly in the upper part of the deposition hole. Oxidation is found as separate thin reddish streaks, recorded as fractures, or along some of the fractures proper. Slightly more than 10% of the fractures show some oxidation.

Table 3.2-3 Distributions of fracture fillings – DD0086G01

Filling	No of observations	% of all observations (totally 81 fractures)
Chlorite	53	65
Calcite	24	30
Grout	9	11
Oxidation rim/streak	9	11
Pegmatite	7	9
Fine-grained granite	4	5
Epidote	3	4
Quartz	1	1

Fracture surfaces

The fracture surfaces are mostly planar with surface roughness undefined (49% of all fractures) and planar and rough (36% of all fractures). A few fractures are undulating or arched. Two observations with slickensides, planar and undulating respectively, have been made (see below table 3.2-4).

Table 3.2-4 Distribution of fracture surface categories – DD0086G01

Surface category	No of fractures	% of all fractures (totally 81)
Planar and undefined	40	49
Planar and rough	28	36
Planar and slickensided	1	1
Undulating and undefined	3	4
Undulating and rough	1	1
Undulating and smooth	1	1
Undulating and slickensided	1	1
Arched and undefined	5	6
Arched and rough	1	1
Totally	81	100

Persistence

The size of the canister borehole will delimit the fracture trace lengths. In table 3.2-5 the fractures have been classified into length intervals of 0.5m. As can be seen from the table the majority of fractures (51%) are found in the length interval 0.5<1.0m. Close to 80% of the fractures are shorter than 1.5m. None of the observed fractures exceeded 5.5m in length.

Table 3.2-5 Distribution of fracture lengths – DD0086G01

Length interval in meters	No of fractures	% of all the 81 fractures
<0.5	14	17
0.5<1.0	41	51
1.0<1.5	9	11
1.5<2.0	7	9
2.0<2.5	1	1
2.5<3.0	5	6
3.0<3.5	2	3
3.5<4.0	1	1
4.0<4.5	0	0
4.5<5.0	0	0
5.0<5.5	1	1
Totally	81	100

Displacements

In deposition hole DD0086G01 only two displacements have been recorded. Both of them show a relative movement of 0.1m along the fracture planes. The orientations of the fractures are 100°/75° and 100°/55° respectively. No lineations have been observed on the fracture planes.

3.2.3 Water

The observed water leakage is found in the upper 2m of the hole. Minor seepage, a few drops or just some moisture has been noted in three of the fractures. A fourth observation was made in the rock itself (greenstone) shown as an approximately 0.3x2m wet patch. Some Ca-precipitation was observed too. Thus, the hole can be regarded to be rather dry.

3.2.4 Rock quality

The rock mass of the walls of the deposition hole DD0086G01 is classified as good rock (RMR value 79).

3.3 Mapping of deposition hole DD0092G01

The location of the canister hole is shown in appendix 2. Appendix 14 presents some photos of the interior of the hole. The result of the mapping of the deposition hole is shown in appendix 15. Fracture orientations are presented in appendices 16 and 17.

3.3.1 Bedrock

Rock types

The same four major rock types, Äspö diorite, greenstone, fine-grained granite, and pegmatite, which were recorded in the previous deposition hole (DD0086G01), have been distinguished in the present one. Besides the specific features that will be dealt with below, the rock types resemble those that were described in the paragraph about the mapping of the tunnel. Table 3.3-1 summarises the occurrence of the rock types.

- **Äspö diorite.** In this deposition hole too, the Äspö diorite is mainly of the feldspar megacryst bearing type and it is partly slightly schistose. It constitutes about 30% of the hole-surfaces (wall and bottom) and appears mainly in the lower half of the hole.

- **Greenstone.** The two types of “greenstone” that were found in the deposition hole are both medium-grained and grade into each other. The most common variety, covering 30% of the hole-surface area (wall and bottom), is slightly schistose or even gneissic and appears to have suffered from some sort of granitization. The other type is more homogeneous. Both occur as irregular masses and as xenoliths in the Äspö diorite. Totally they constitute 38% of the hole-surfaces which make them the most common rock type. Their major occurrence is at upper half of the hole.

  The orientation of the schistosity is 210/50°. Due to the earlier mentioned iron bars and sensors in the hole-wall the strike may not be completely reliable.

  At about the 4m section of the hole, on the boundary between the two greenstone varieties a small lens of fine-grained, whitish yellow pyrite was observed.

- **Fine-grained granite.** The three rock varieties assembled under the generic name fine-grained granite constitute 25% of the hole-surfaces. The dominating variety, covering 15% of the surfaces, is fine-grained and pinkish red. It forms two approximately 0.5m wide bands (dykes/sills) on the hole wall. The upper parts of the granite bands are commonly bordered by pegmatite.

  The other two varieties appear as irregular veins and are medium-grained and greyish red and fine-grained and grey respectively. They constitute about 5% each of the hole-surfaces. The medium-grained type may be regarded as a hybrid between fine-grained granite and pegmatite.

- **Pegmatite.** It constitutes only about 5% of the mapped surfaces. It appears as light red narrow dykes or veins on its own but mostly forms a narrow (0.05m wide) border-zone to the fine-grained granite.

Table 3.3-1 Rock type distribution – DD0092G01

Rock type	% of mapped area
Äspö diorite	32
Greenstone	38
Fine grained granite	25
Pegmatite	5
Totally	100

Contacts

The majority of the contacts are tight and sharp. The one between the two greenstone varieties is mostly diffuse and the greeenstones may often grade into each other. Between the fine-grained granite varieties and between the fine-grained granites and pegmatite the boundaries are normally diffuse in their appearance.

As in the deposition hole DD0086G01 the contacts commonly are very irregular. Hence no special effort was made measure their orientations. The orientations between the two broad fine-grained granite sills/dykes and the surrounding rocks were, however, measured. The compass readings gave the approximate orientation 230/50° (strike/dip, right hand rule) whereas the graphical interpretation showed a strike varying between 235-245°.

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 15 (mapping of hole wall and bottom). The fracture orientations are presented in Schmidt net and joint rosette diagrams. They are found in appendices 16 (based on compass readings) and 17 (based on graphical interpretation). 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 16, with fracture orientation obtained by compass readings, show two major fracture sets. One of them has the orientation between 75-150°/30-85° (average 110°/50°, strike/dip) and the other one 310-20°/60-80° (average 335°/70°, strike/dip).

The major fracture concentration of the latter is around 315°/75°. This part of the set may be regarded as a separate set. A third set of fractures appears within the interval 10-45°/25-40° and has the mean orientation 30°/35°

The graphically obtained fracture orientations illustrated in appendix 17 show a similar pattern of fracture concentrations as appendix 16. The major differences are that the 30°/35° set is missing in appendix 17 and some of the peak concentrations of the set orientation intervals have moved a little in the diagram. When comparing the orientations of corresponding fractures obtained by compass readings and by graphical interpretation of the mapping it was found that the maximum difference in strike was 30°. The difference in strike between the majority of the compared fractures was 0-10°. Also for deposition hole DD0092G01, it appears as if the sensors and iron bars that were left in the hole wall did not have such a great influence on the bulk of compass readings after all.

Lineation

Six observations of lineations have been made. Four of them are crenulations on the fracture plane. The type of lineation is unknown for two of them. The orientations (trend/plunge) are 290/20° (two observations), 265/0°, 265/3°, 265/10°, and 310/30°. Thus, they all have a WNW trend and a gentle plunge.

Open/closed

As much as 74% of the fractures were found to be tight (healed). The rest of them, 26% were of the type induced/natural. This result is not unexpected since the hole had been drilled.

Fracture widths

Apertures have not been recorded separately. They have been included in the width (aperture plus filling). Fifty-five (55%) of the fractures are less than 1mm in width. Some of these fractures (9% of all fractures) are only streaks of reddish oxidation (see below in Filling) that have no visible width. Fractures less than 2mm in width constitute 80% of the total population. The rest (20%) have widths between 2 - <20mm. The fractures that exceed 5mm in width are often filled with pegmatite or fine-grained granite (se below in Filling).

Oxidation rims/zones associated with fractures including the oxidation streaks are commonly between 5 - <20mm across (about 20% of the population). Most the remaining fractures are, however, not associated with an oxidation rim. The distribution of fracture widths and oxidation rims/zones is found in Table 3.3-2.

Table 3.3-2 Distribution of width of fractures and oxidation rims or streaks – DD0092G01

Interval mm	Width (aperture plus filling)		Oxidation rims or streaks (width plus oxidized zone)	
	Number of observations	% of all observations	Number of observations	% of all observations
0	16	9	138	77
>0<1	83	46		
1<2	45	25		
2<3	14	8		
3<4	7	4		
4<5	1	1		
5<10	8	4	20	11
10<20	5	3	18	10
20<30				
30<40			2	1
40<50				
50<100				
100<150			1	1
Totally	179	100	179	100

Filling

Eleven types of fracture filling material have been observed (table 3.3-3 below). The most common material is chlorite that is found in 82% of the 179 recorded fractures. Epidote is the second most common filling material appearing in 25% of all the fractures. Reddish oxidation of the rock is found as separate thin reddish streaks, recorded as fractures, or along some of the fractures proper. Slightly more than 20% of the fractures show some oxidation. A little less than 20% of the fractures contain calcite and about 5% contain quartz. Fine-grained granite, pegmatite, amphibole, biotite, and grout are each found in about 2 % or less of the fractures. Grout appears only in the upper part of the deposition hole. Besides the small pyrite lens described above in the greenstones, pyrite was only found in one of the fractures.

Table 3.3-3 Distributions of fracture fillings – DD0092G01

Filling	No of observations	% of all observations (totally 179 fractures)
Chlorite	147	82
Epidote	44	25
Oxidation rim/streak	42	23
Calcite	33	18
Quartz	11	6
Fine-grained granite	4	2
Pegmatite	4	2
Amphibole	3	2
Biotite	2	1
Grout	2	1
Pyrite	1	<1

Fracture surfaces

The fracture surfaces are mostly planar with surface roughness undefined (59% of all fractures) and planar with surface roughness rough (23% of all fractures). Sixteen % (16 %) of the fracture population is undulating with mostly undefined surface roughness (table 3.3-4).

Table 3.3-4 Distribution of fracture surface categories – DD0092G01

Surface category	No of fractures	% of all fractures (totally 81)
Planar and undefined	106	59
Planar and rough	42	23
Undulating and undefined	20	11
Undulating and rough	8	5
Arched and undefined	2	1
Arched and rough	1	1
Totally	179	100

Persistence

As already mentioned for canister hole DD0086G01, the size of the hole will delimit the fracture trace lengths. In table 3.3-5 the fracture lengths have been grouped into intervals of 0.5m. The table shows that 85% of the fractures are shorter than 1.5m. The largest group (44% of the population) is found within the interval 0.5<1.0m. None of the observed fractures exceeded 7.0m in length.

Table 3.3-5 Distribution of fracture lengths – DD0092G01

Length interval in meters	No of fractures	% of all the 179 fractures
<0.5	52	29
0.5<1.0	79	44
1.0<1.5	22	12
1.5<2.0	11	6
2.0<2.5	5	2
2.5<3.0	2	1
3.0<3.5	2	1
3.5<4.0	1	1
4.0<4.5	1	1
4.5<5.0	2	1
5.0<5.5	1	1
5.5<6.0		
6.0<6.5		
6.5<7.0	1	1
Totally	179	100

Displacements

The mapping of deposition hole DD0092G01 has revealed six fractures along which displacements between 0.005-0.3m have occurred. The majority of the displacements are, however, less than 0.05m. Most of the fractures (four of them) strike NW and dip 40-80° toward NE or SW. One fracture is oriented 20°/75° and another one 260°/30°. No lineation has been recorded on the fracture planes.

3.3.3 Water

Six of the observed seven locations of water leakage appear in the upper 3m of the hole. Seepage as drops and wet surface below, all the way down to the bottom of the hole, has been found to originate from 0.2x0.2m patches in the rock mass itself. Some calcite precipitates, probably originating from grout, accompany the water seepage. Five fractures appear to be water bearing as well. Parts of the fractures are damp to wet. The wall of the hole may be wet below. Although, some water leakage has been recorded there is not a great deal of water in the hole.

3.3.4 Rock quality

The rock mass of the walls of the deposition hole DD0092G01 is classified as good rock (RMR value 74). The RMR value is slightly less than the value (RMR = 79) obtained for the hole DD0086G01. This is due to the somewhat higher fracture frequency and water content in the deposition hole DD0092G01.

3.4 Logging of pilot hole KD0086G01

The approximate location of the borehole in the centre of deposition hole DD0086G01 is shown in appendix 2. The core log, appendix 18, shows major rock types, alteration, prominent structures, and RQD.

3.4.1 Rock types

The core is composed of only two rock types. Reddish **fine-grained granite** (totally 45% of the core) dominates the upper part of the core whereas **Äspö diorite** (totally 55% of the core) dominates the lower part. Both rock types may in minor amounts be found in the other one. All the rock types are fresh.

3.4.2 Fractures

According to the core log, the fracture frequency is very low. In the sections 1-3m and 7-8m the frequency is 1-2 fractures/meter. RQD is 90-95 in the upper half of the core and 100 in the lower half.

3.4.3 Water

The core hole is almost dry. The inflow of water is only 1.8105E-9 m3/s and no water pressure could be obtained (0 bars).

3.5 Logging of pilot hole KD0092G01

The approximate location of the borehole in the centre of deposition hole DD0092G01 is shown in appendix 2. The core log, appendix 19, shows major rock types, alteration, prominent structures, and RQD.

3.5.1 Rock types

Three rock types are present. The dominating one is Äspö diorite (totally 72% of the core) followed by veins or dykes of fine-grained granite (totally 21% of the core) and greenstone (totally 7% of the core). The latter is found at the top of the core. The rock types have been regarded to be unaltered.

3.5.2 Fractures

This core, too, shows a low fracture frequency. The highest one, 2-3 fractures/meter, is found around section 2-3m. Below the 3m section RQD is 100 and above RQD is 85-95.

3.5.3 Water

The inflow of water is a little higher in this hole in comparison to KD0086G01. The recorded inflow was 5.32475E-9 m3/s and the pressure 5 bars. Thus, this hole too must be regarded as rather dry.

4 Concluding remarks

The extended part of the TASD tunnel, the Canister Retrieval Test Tunnel, is composed basically of four rock types. These are greenstone, Äspö diorite, fine-grained granite, and pegmatite. All the rock types vary to some extent but it has not been found relevant to sub-divide them.

The dominating type in the Canister Retrieval Test Tunnel is the greenstone. This is, however, not the typical situation for the Äspö tunnels as a whole where the greenstone appears only in smaller amounts. The second most common rock type in the test tunnel is the Äspö diorite that probably is the most common type when the whole Äspö tunnel system is taken into account. The fine-grained granite that in the Canister Retrieval Test Tunnel is the third most common of the rock types has the same ranking in the Äspö tunnel as a whole where it comes after Äspö diorite and Ävrö granite. Only a few percent of the mapped surfaces are composed of pegmatite, which is consistent with the rest of the Äspö tunnels.

Besides the clearly defined rock types there appear some hybrid varieties. E.g. the fine-grained granite may form a hybrid rock with pegmatite or Äspö diorite. Sometimes it appears as if greenstone grades into a megacryst free variety of Äspö diorite. The contact between a more distinct rock type and a hybrid one is commonly rather diffuse since they grade into each other. Normally, however, the contacts between the rock types are tight and distinct.

The distribution of rock types is almost the same in the deposition holes as in the tunnel. The fine-grained granite appears however, to be over-represented in the deposition holes and in hole DD0092G01 the Äspö diorite is the dominating type.

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

Most of the fracture orientation diagrams show a similar pattern of fracture concentrations that can be regarded as fracture sets. One of the sets is composed of fractures that are gently – steeply dipping towards the S – SW. Another set is rather steeply dipping towards the ESE-NE. The latter may be divided into two sets, ESE and NE dipping respectively. Particularly in the deposition holes it is evident that sub-horizontal fractures are represented as well.

It can be concluded that the sensors and iron bars that were left in the hole walls of the deposition holes after all did not have such a great influence on the major part of the compass readings as was expected.

Only a few lineations were recorded. Most of them have W – NW trends with sub-horizontal to gentle plunges. Some of the lineations are slickensides, some are crenulations and some of them lack notes concerning lineation type.

Often the fractures contain more than one type of filling. The by far most common fracture filling is chlorite that is found in 65 – 80% of all fractures. Calcite, epidote and oxidation rims along fractures are quite common too. Quarts, amphibole, biotite, fine-grained granite, and pegmatite appear not in more than 10% of the fractures. The latter two fillings are veins that are too thin to be recorded as rock types. Grout was observed in some fractures in the upper parts of the deposition holes and clay was observed in a few fractures in the tunnel.

The fractures have mostly planar and rough surfaces. In the tunnel planar and smooth fracture surfaces are rather common too. Only a few percent of the fractures are planar or undulating with slickensides, undulating and rough or smooth, and finally arched and rough or smooth. When fractures are healed and tight it is difficult, not to say impossible, to see the actual fracture surface. Due to this a roughness class has been introduced that has been called “undefined”. In the deposition holes a lot fractures have been classified as having surface roughness “undefined” independent of their planarity. When the tunnel was mapped the fracture roughness class “undefined” had not yet been introduced but was at that time included in roughness class “rough”.

When studying only the fracture lengths recorded during the detailed mapping of the tunnel floor and the deposition holes (cut-off 0.5m) it is evident that most (about 90%) of the fractures are shorter than 2m. More than 50% of the fractures are less than 1m in length.

To compare fracture lengths from the standard mapping of the tunnel (walls, front and roof) with those from the detailed mappings of the tunnel floor and the deposition holes, fractures shorter than 1m have to be left out from the latter. It will then be found that fractures shorter than 2m constitute about 60-80% of the fractures recorded during the detailed mapping and only a little more than 30% of those recorded during the standard tunnel mapping.

The larger the exposure is the longer fractures can be traced. It was found, however, that although the exposed rock surface of the tunnel is much larger than that exposed in the deposition holes only a few fractures exceeding 4m in length were found and none was exceeding 10m. If “fracture trace length” had been used to define fracture length instead of “shortest distance between fracture end points” during the standard mapping of the tunnel, many of the fracture lengths most probably would have been reported to be longer.

The fracture widths were not studied while the tunnel was mapped. The mapping of the deposition holes shows, however, that most fractures (about 50%) are very thin, less than 1mm in width. About 60-80% of the total fracture population is less than 2mm in width. Wider fractures, 5-10mm or more are commonly filled with fine-grained granite or pegmatite.

When the tunnel was mapped, fractures were either both tight and healed or open. Due to the difficulty in discriminating fractures that had been naturally open from those that had been mechanically opened during the drill and blast process involved in the excavation of the tunnel all fractures were regarded as tight and healed. Before the deposition holes were mapped, however, the terms “induced/natural open fractures” (formerly healed and tight fractures that have been mechanically reopened) and “induced open fractures” (mechanically made fractures) were introduced.

Most of the fractures (65-75%) of the population in the deposition holes were healed and tight fractures. Induced/natural open fractures constitute most of the remaining fractures. If the latter group had been separated from the healed and tight fractures while the tunnel was mapped it would most probably have constituted a greater part of all the fractures together with induced open fractures than is the case now.

Only a few fractures show any evidence of displacements along the fracture planes. The strike of most of these fractures lies within the sector W to NW and the dip is mostly gentle to steep towards N-NE or S-SW. Dislocations are normally less than 0.1m in the deposition holes and less than 0.5m in the tunnel. Lineations on the fracture planes are absent. The strikes of the fractures coincide more or less with the maximum horizontal stresses in the rock mass (Rhén et al.1977).

Water was found only at a few locations of which some were patches on the rock surface and some were fractures. Where water was observed it appeared in only minor amounts. The water-bearing fractures in the deposition holes are mostly E-W to WNW striking and gently to steeply dipping whereas those in the tunnel are almost N-S striking and steeply dipping. In the Äspö tunnel system as a whole the water-bearing fractures commonly are steeply dipping, striking NW-SE.

The pilot holes KD0086G01 and KD0092G01 were almost dry and it took a very long time to build up any water pressure at all. The Canister Retrieval Test Tunnel must be regarded as a very dry part of the Äspö tunnel system.

The quality of the rock mass based on RMR values is considered to be good. In the tunnel and the deposition holes the RMR-values are between approximately 65-80 (RMR = 60-80, good rock).

References

Wikman, H. and Kornfält, K-A., 1995: Updating of a lithological model of the bedrock of the Äspö area.
SKB Äspölaboratoriet, Progress Report 25-95-04

Rhén, I., Gustafson, G., Stanfors, R., and Wikberg, P., 1997: Äspö HRL – Geoscientific evaluation 1997/5. Models based on site characterization 1986-1995.
SKB Technical Report 97-06

Appendices

1. Location map of the 420-450m level at Äspö HRL
2. Tunnel for the canister retrieval test, location of deposition holes
3. Photos showing the tunnel interior (photos: Lars Andersson, SKB).
   3A Overview of the entire Canister Retrieval Test Tunnel
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14. Photos from deposition hole DD0092G01 (photos: Lars Andersson, SKB).
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    14B Part of the hole wall, section 4-5m, with an intersection between pegmatite (pinkish white) and fine-grained granite/pegmatite hybrid rock. Surrounding rock types are greenstones (grey-dark grey)
    14C Bottom of the deposition hole composed of Äspö diorite

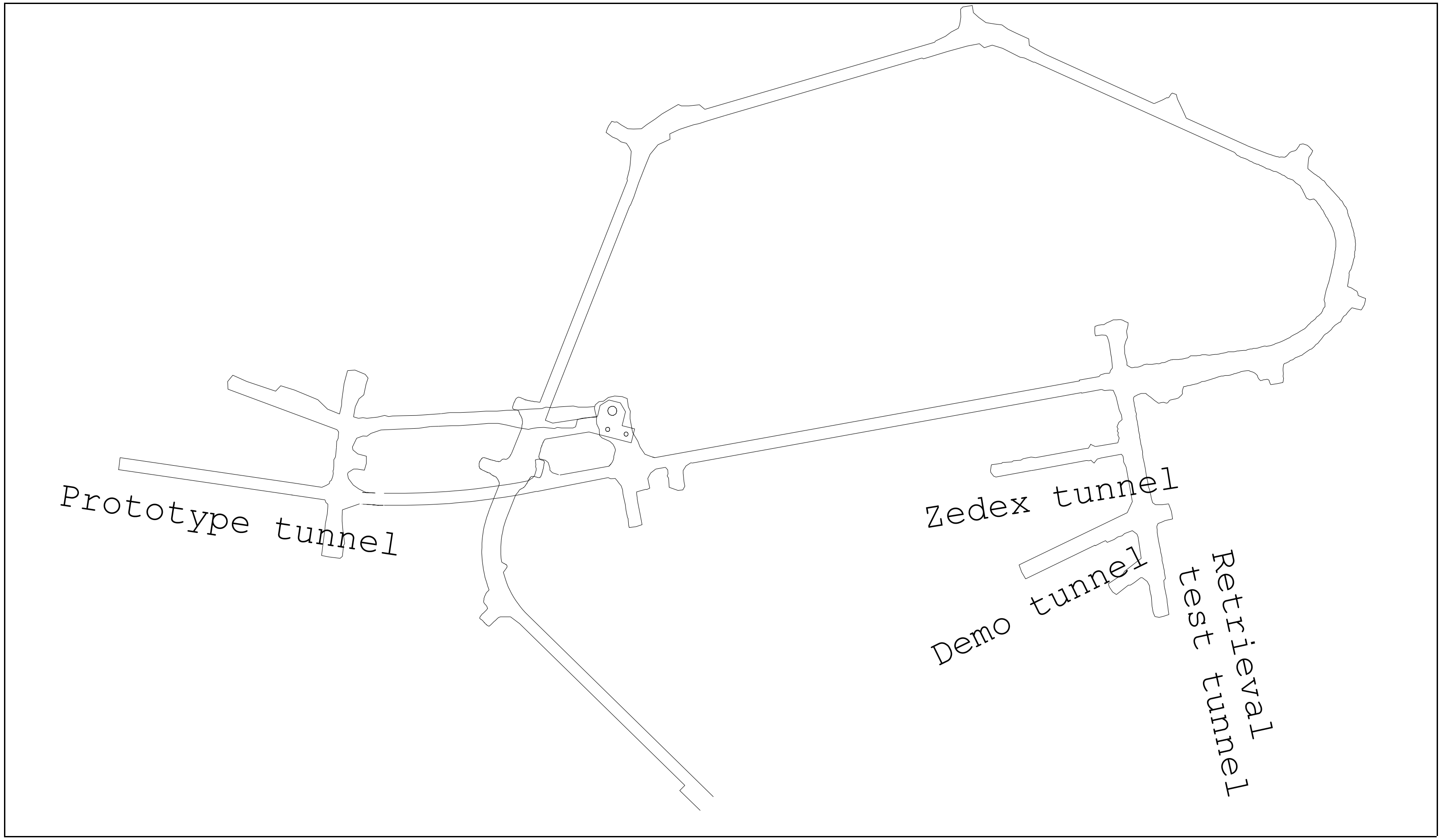
15. Geological mapping of the deposition hole DD0092G01

16. Fracture orientations (compass readings) from DD0092G01 presented in Schmidt net and joint rosette diagrams

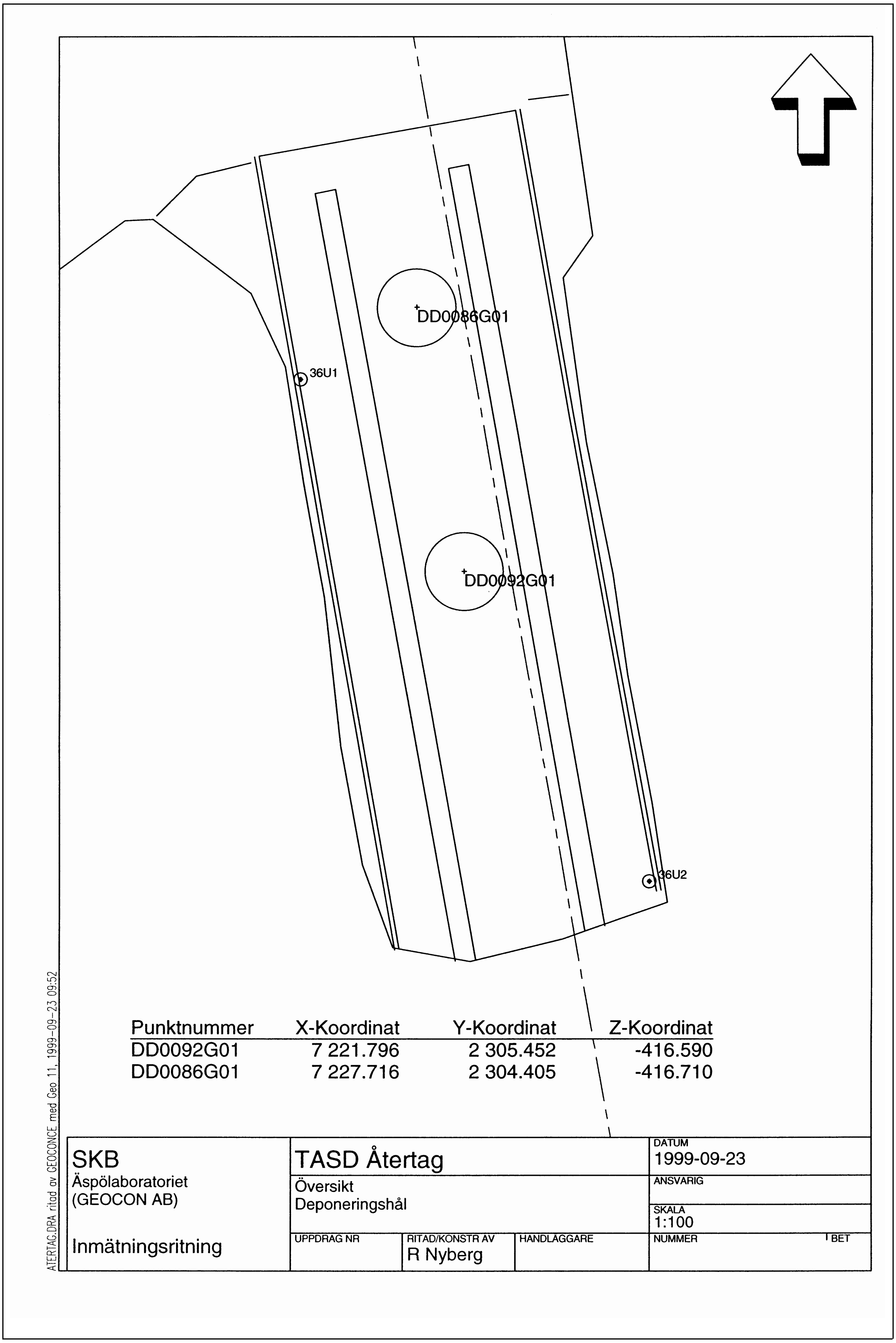
17. Fracture orientations (graphical interpretation) from DD0092G01 presented in Schmidt net and joint rosette diagrams

18. Core log from pilot hole KD0086G01

19. Core log from pilot hole KD0092G01



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



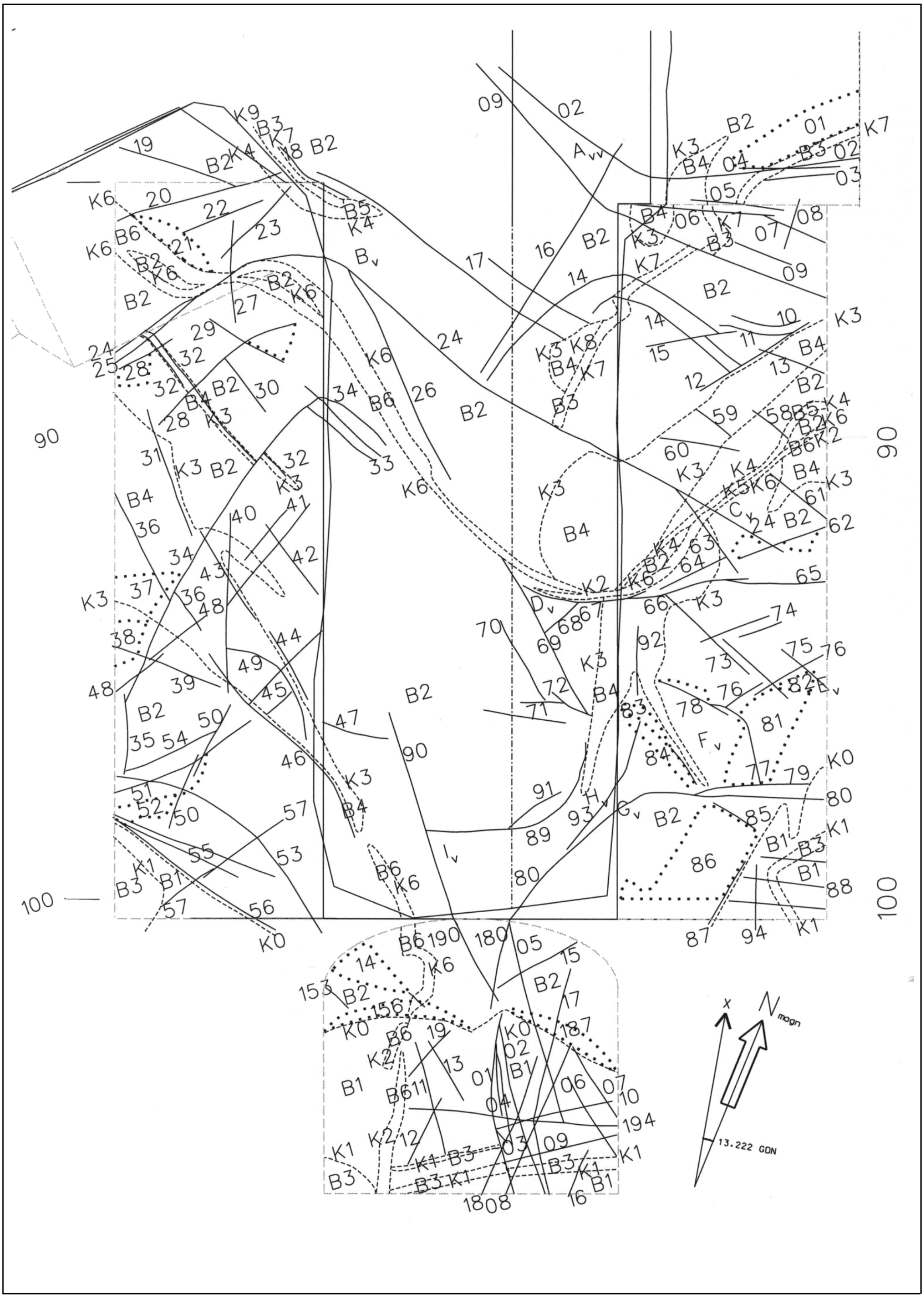
Appendix 2. *Tunnel for the canister retrieval test, location of deposition holes.*

Appendix 3A. *Photos showing the tunnel interior. Overview of the entire Canister Retrieval Test Tunnel. Photo: Lars Andersson, SKB.*

Appendix 3B. *Photos showing the tunnel interior. Part of the tunnel wall, right hand side, section 84-88. Dislocated fine-grained granite (reddish) in Äspö diorite and greenstone (both grey). Photo: Lars Andersson, SKB.*

Appendix 3C. *Photos showing the tunnel interior. Overview of the entire Canister Retrieval Test Tunnel. Tunnel floor cleaned 2x2m grid-lines marked out*
Photo: Lars Andersson, SKB.

Appendix 3D. *Photos showing the tunnel interior. Part of the tunnel floor and front with intersecting fine-grained granite dykes (reddish) in Äspö diorite (grey). One of the fine-grained granites in the front has been dislocated.*
Photo: Lars Andersson, SKB.

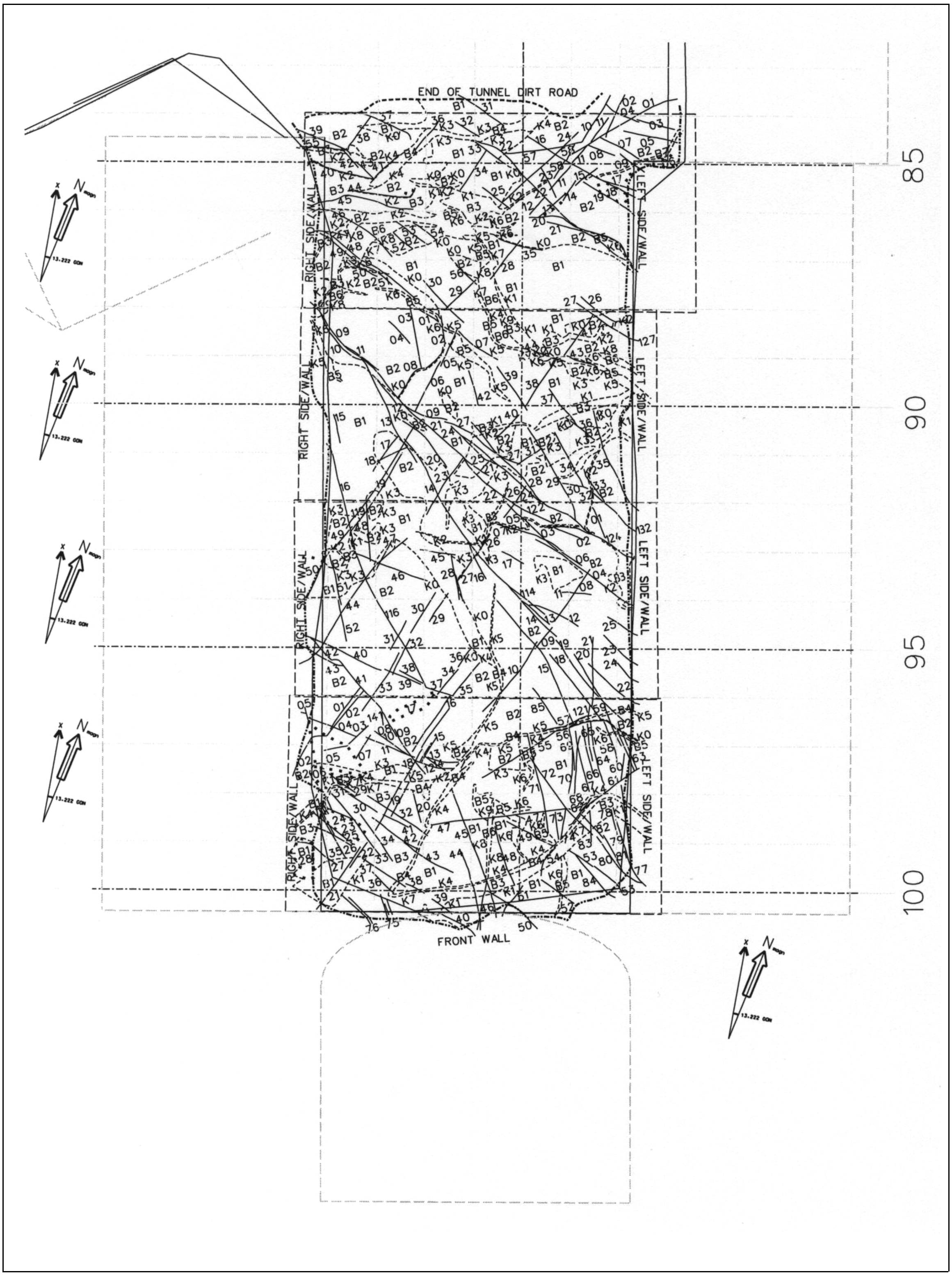


Appendix 4. *Geological mapping of the tunnel roof, side walls and front.*
Legend: see next page!

Appendix 4 continued

Legend:

Rock types:	B1=Äspö diorite, porphyritic variety B2=Greenstone, medium-grained variety B3=Fine-grained granite, fine-grained variety B4=Äspö diorite, non-porphyritic variety B5= Greenstone, fine-grained variety B6= Fine-grained granite, medium-grained variety
Contacts:	K0-K9 and dashed line
Fractures:	01-94 and continuos line
Water:	A-I and v. (v = damp or a few drops)



Appendix 5A. *Geological mapping of the tunnel floor. The whole tunnel floor.*
Legend: see next page!

Appendix 5A continued

Legend (section 84-88m):

Rock types: B1=Äspö diorite, non-porphyritic variety
B2=Greenstone, medium-grained variety
B3=Fine-grained granite, medium-grained, reddish variety
B4=Fine-grained granite, fine-grained, reddish variety
B5= Pegmatite
B6= Greenstone, fine-grained variety
B7= Fine-grained granite, fine-grained, grey variety

Contacts: K0-K9 and dashed line

Fractures: 01-58 and continuos line

Legend (section 88-92m):

Rock types: B1=Äspö diorite, non-porphyritic variety
B2=Greenstone, medium-grained variety
B3=Fine-grained granite, medium-grained, reddish variety
B4=Fine-grained granite, fine-grained, reddish variety
B5= Pegmatite
B6= Greenstone, fine-grained variety

Contacts: K0-K9 and dashed line

Fractures: 01-44 and continuos line

Legend (section 92-96m):

Rock types: B1=Äspö diorite, non-porphyritic variety
B2=Greenstone, medium-grained variety
B3=Fine-grained granite, fine-grained, reddish variety
B4=Pegmatite

Contacts: K0-K5 and dashed line

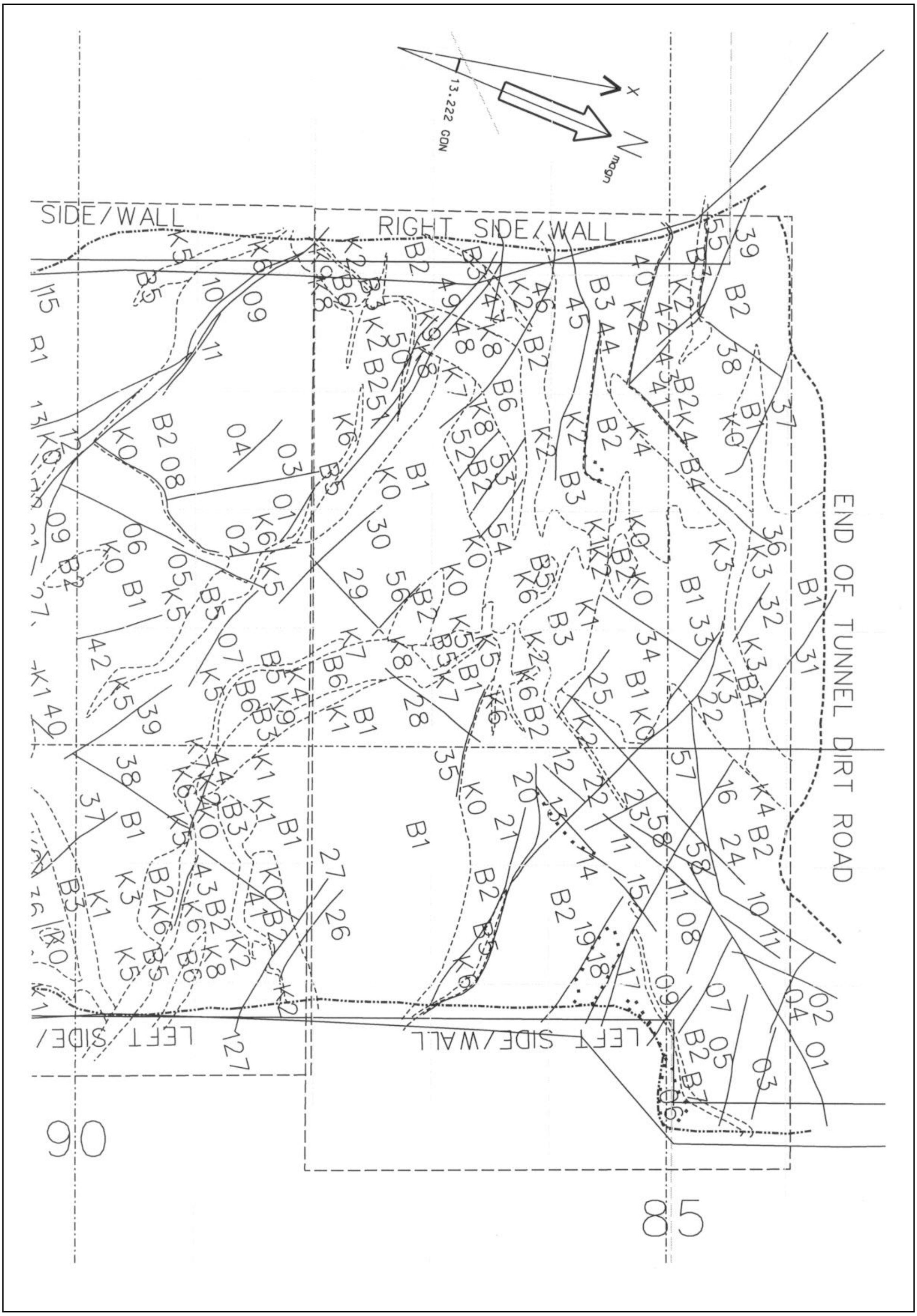
Fractures: 01-52 and continuos line

Legend (section 96-100.6m):

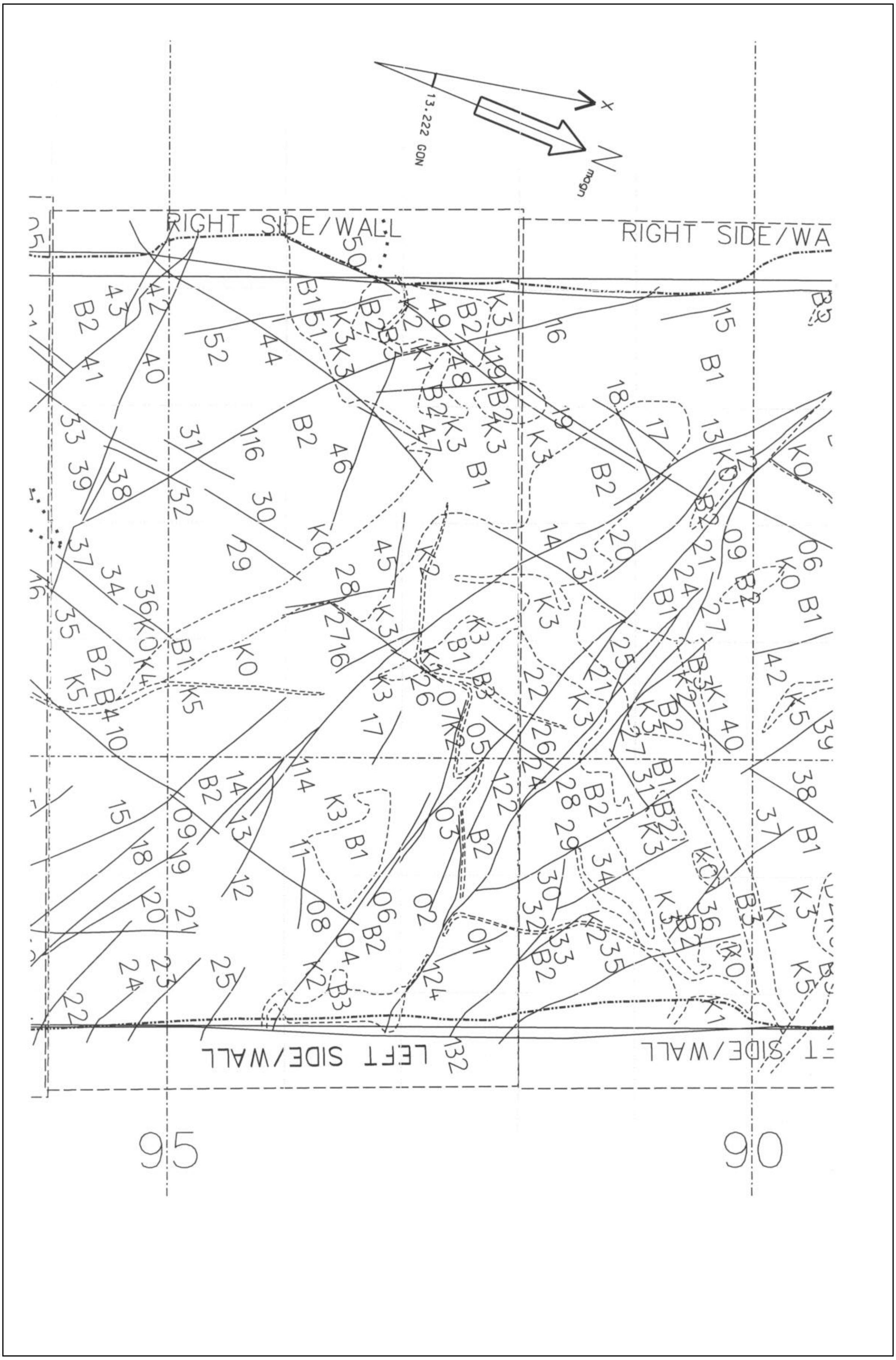
Rock types: B1=Äspö diorite, porphyritic variety
B2=Greenstone, medium-grained variety
B3=Fine-grained granite, fine-grained, reddish variety
B4=Pegmatite
B5=Äspö diorite/fine-grained granite hybrid
B6=Äspö diorite, non-porphyritic variety, slightly oxidized

Contacts: K0-K9 and dashed line

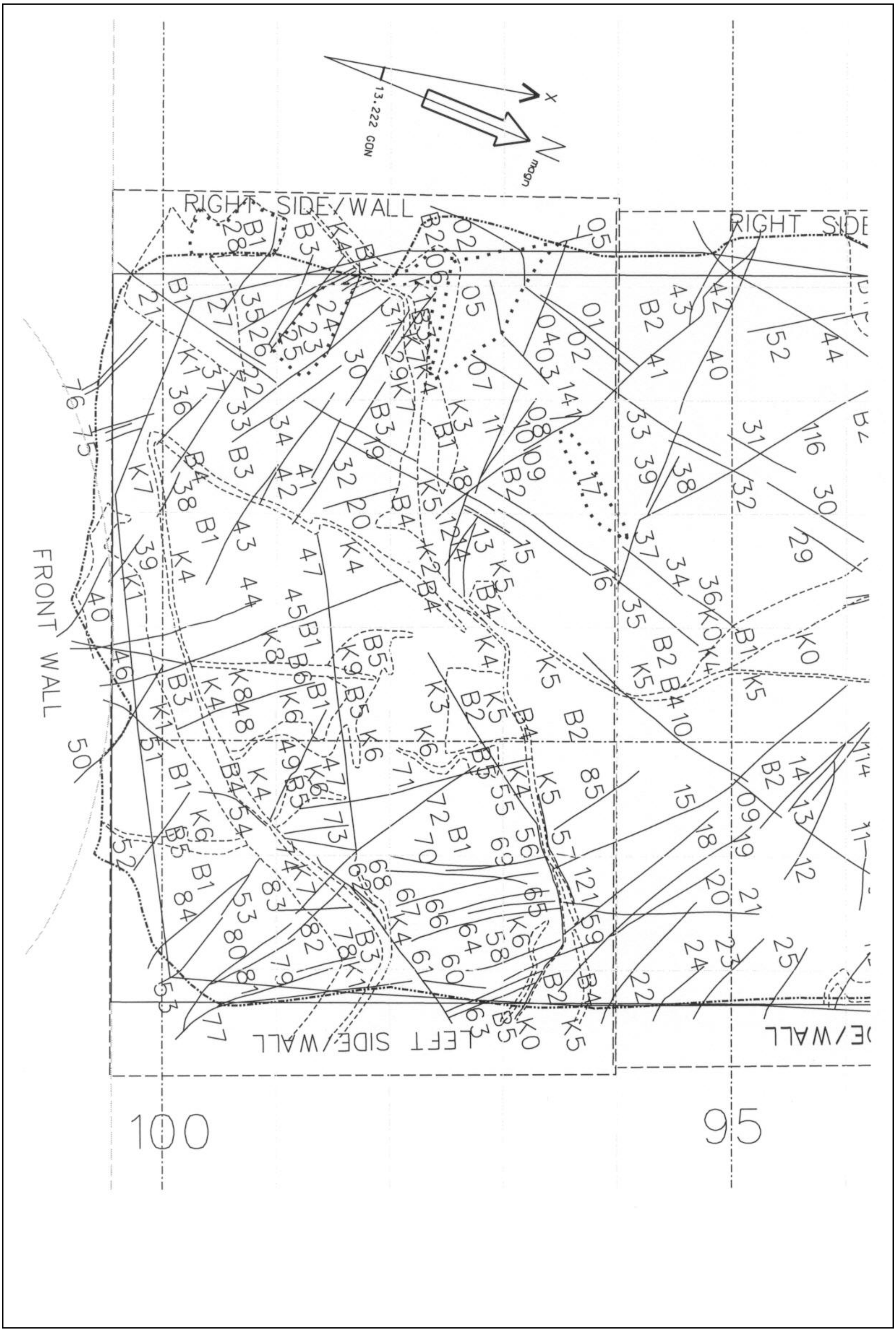
Fractures: 01-85 and continuos line



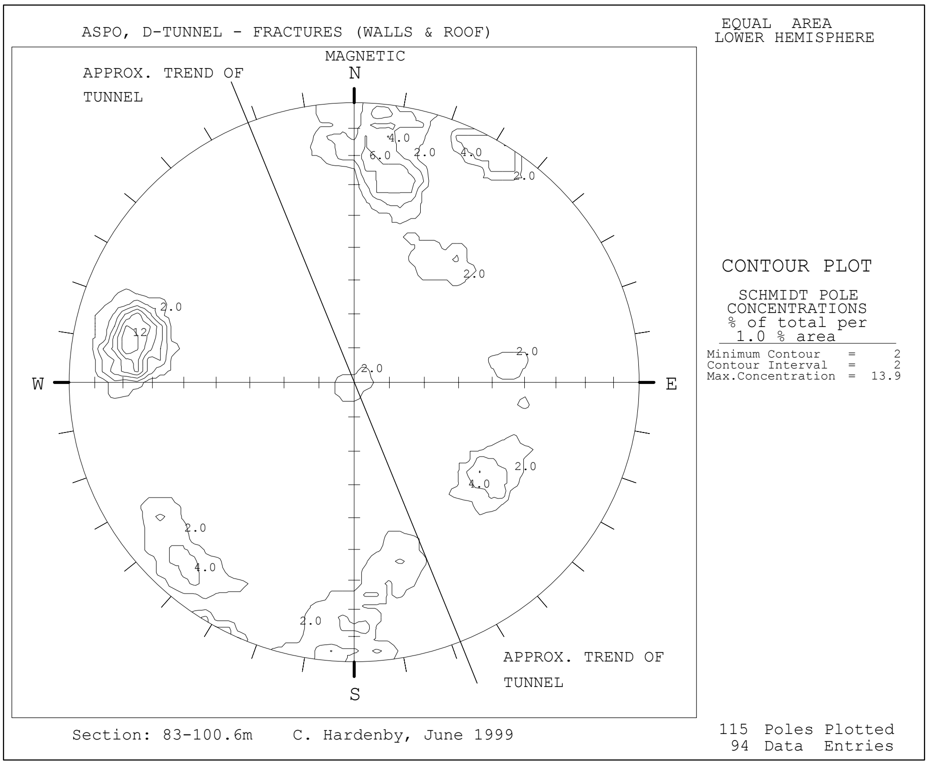
Appendix 5B. *Geological mapping of the tunnel floor. Section 84-90.*
Legend: see 5A!

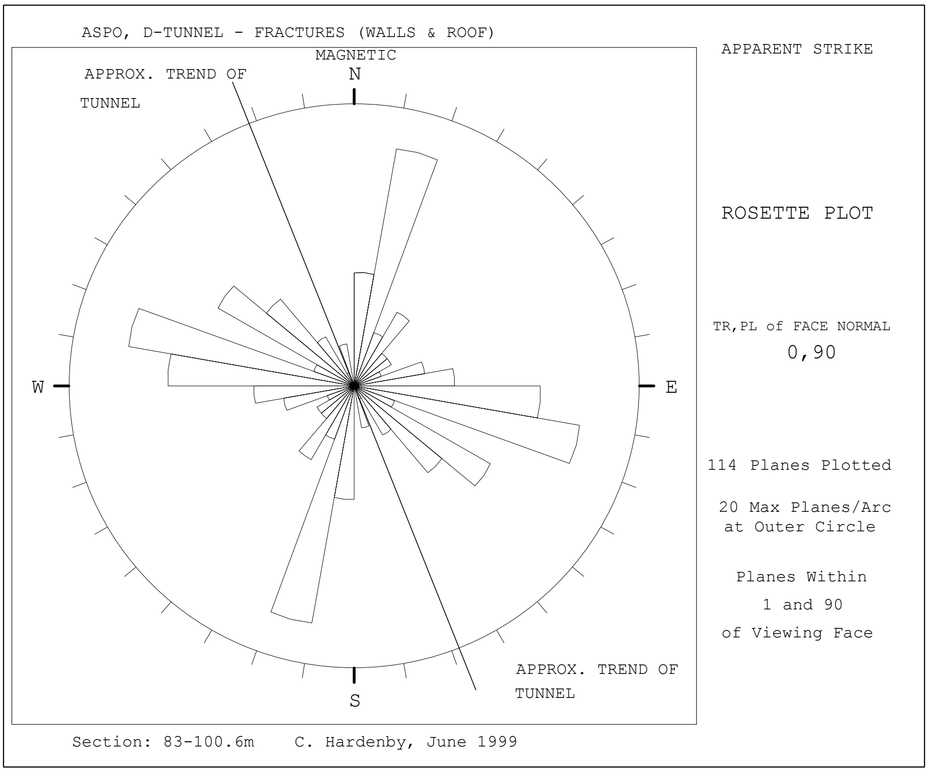


Appendix 5C. *Geological mapping of the tunnel floor. Section 90-95. Legend: see 5A!*

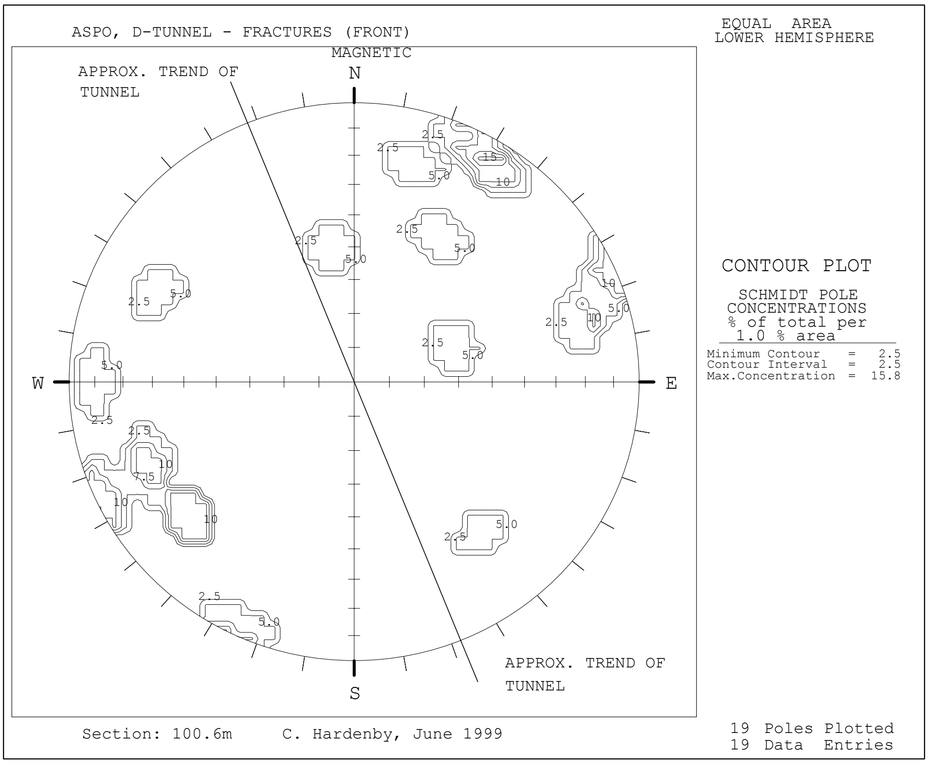


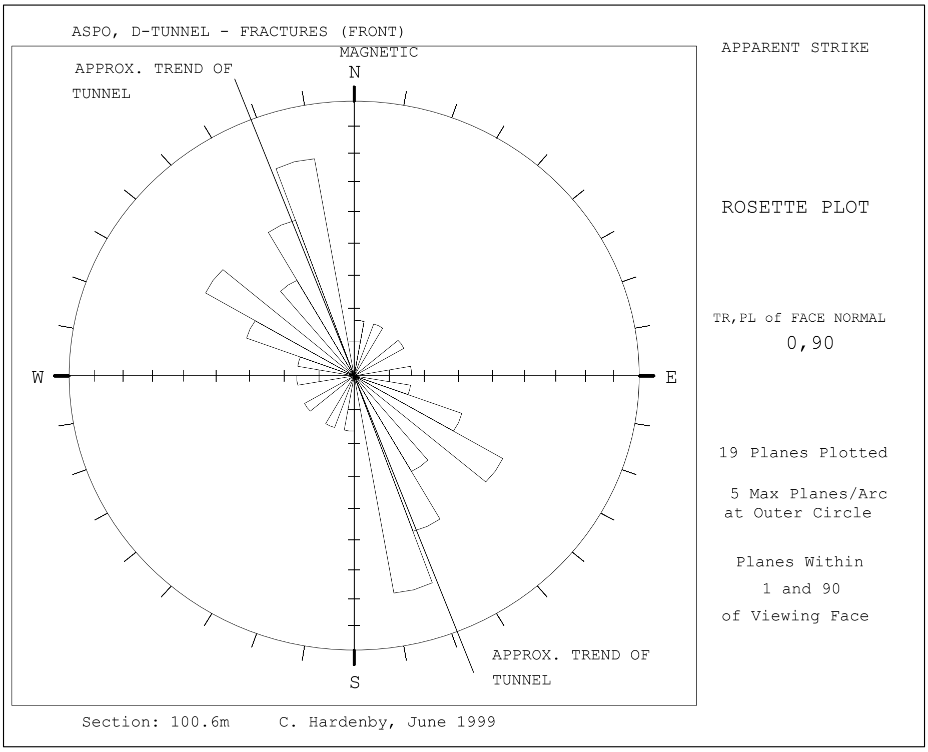
Appendix 5D. *Geological mapping of the tunnel floor. Section 95-100.6.* Legend: see 5A!



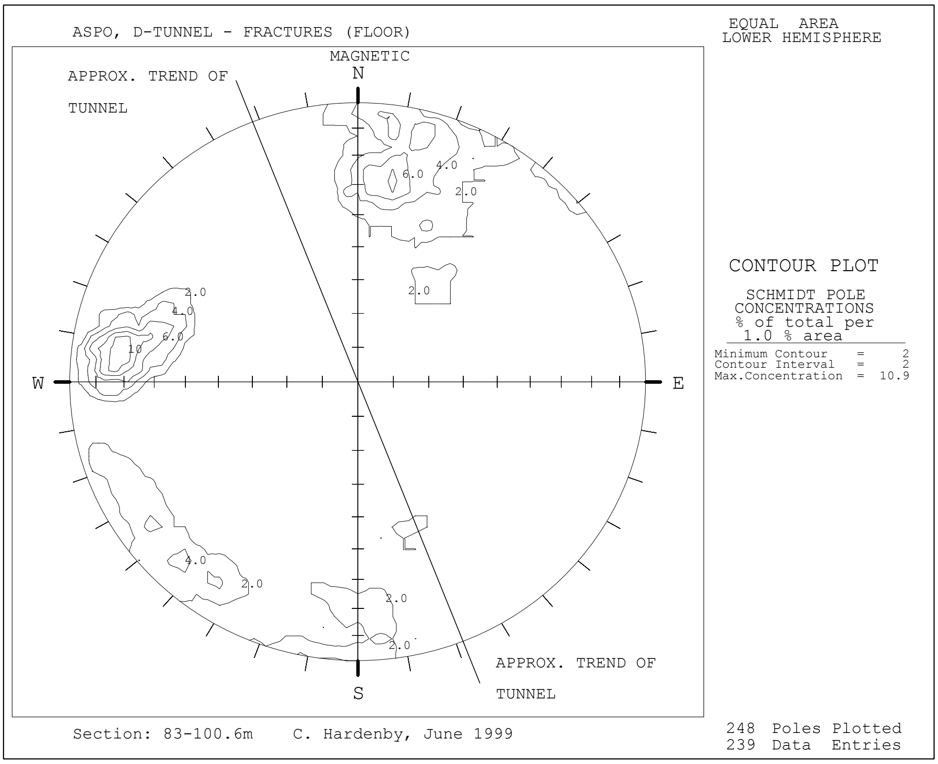


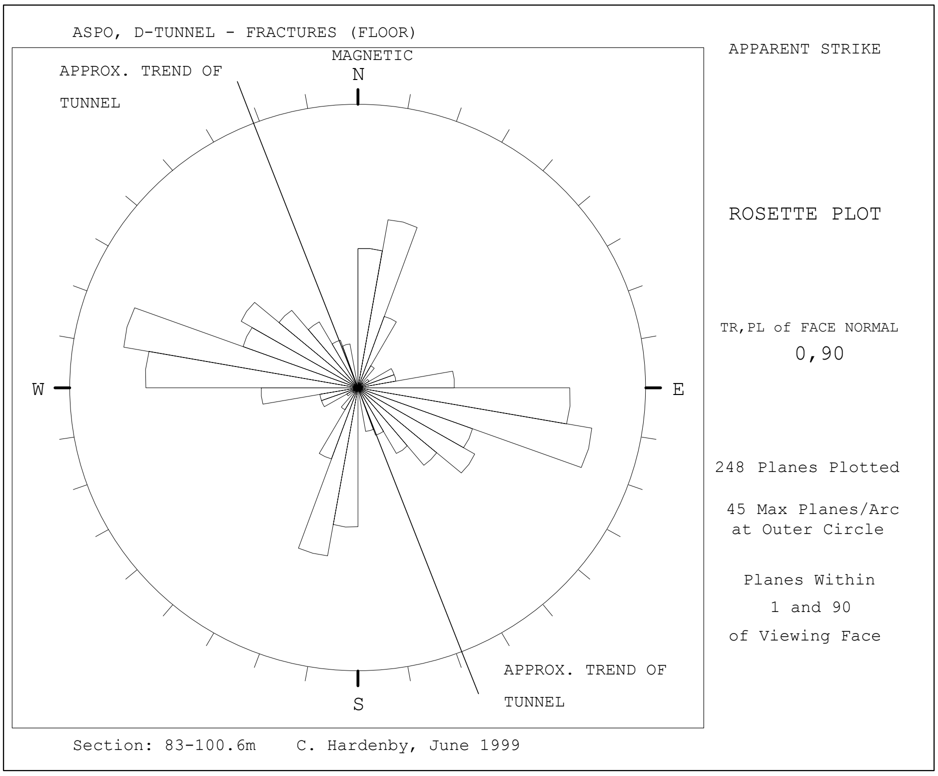
Appendix 6. *Fracture orientations from the roof and sidewalls presented in Schmidt net and joint rosette diagrams.*



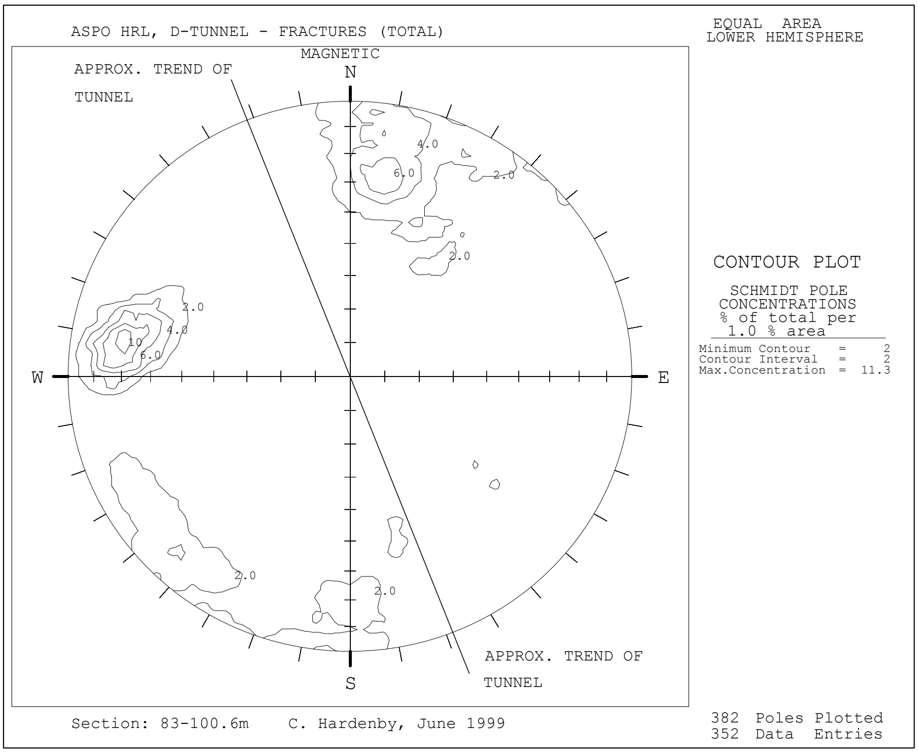


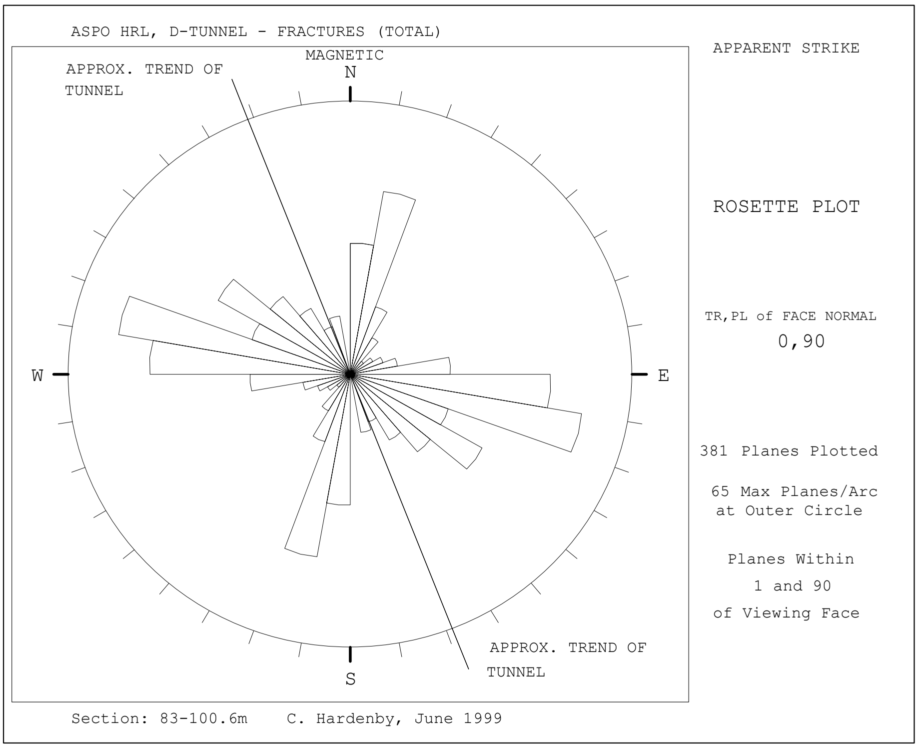
Appendix 7. *Fracture orientations from the front presented in Schmidt net and joint rosette diagrams.*



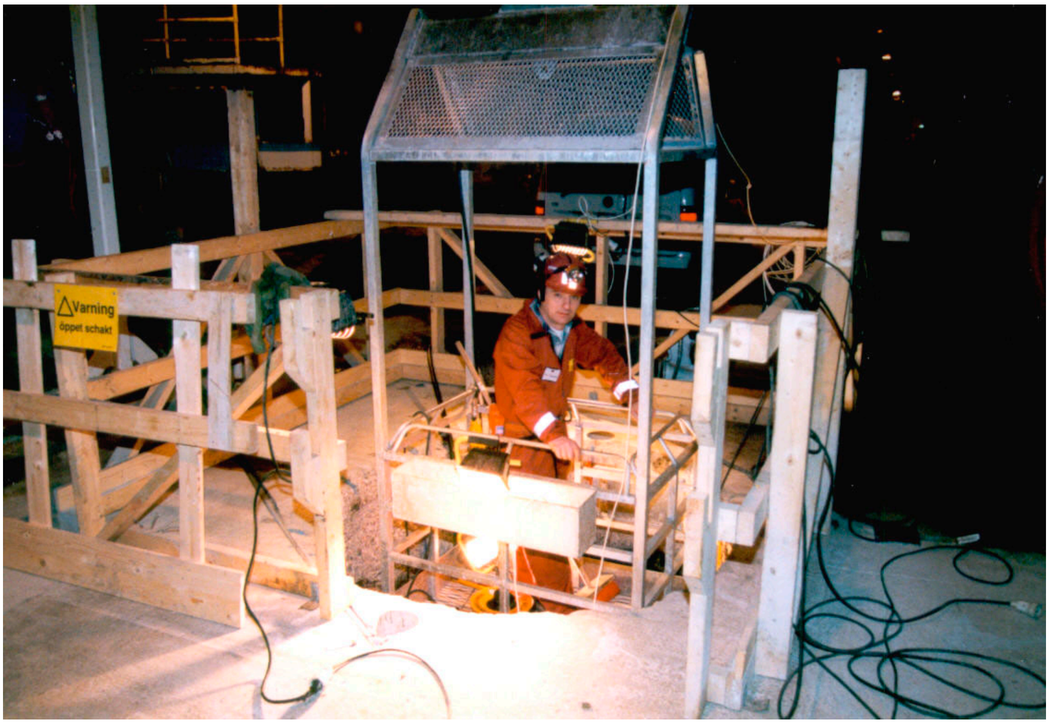


Appendix 8. *Fracture orientations from the floor presented in Schmidt net and joint rosette diagrams.*



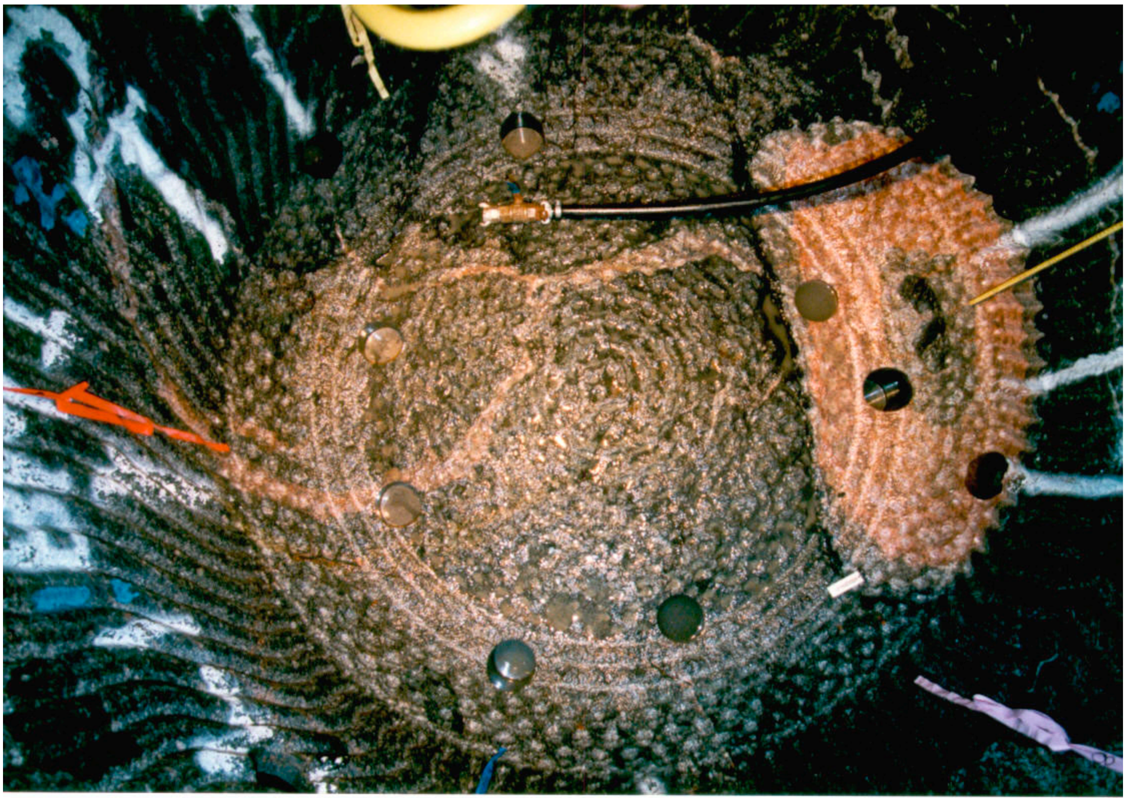


Appendix 9. *Fracture orientations from the Canister Retrieval Test Tunnel as a whole presented in Schmidt net and joint rosette diagrams (collective diagrams).*

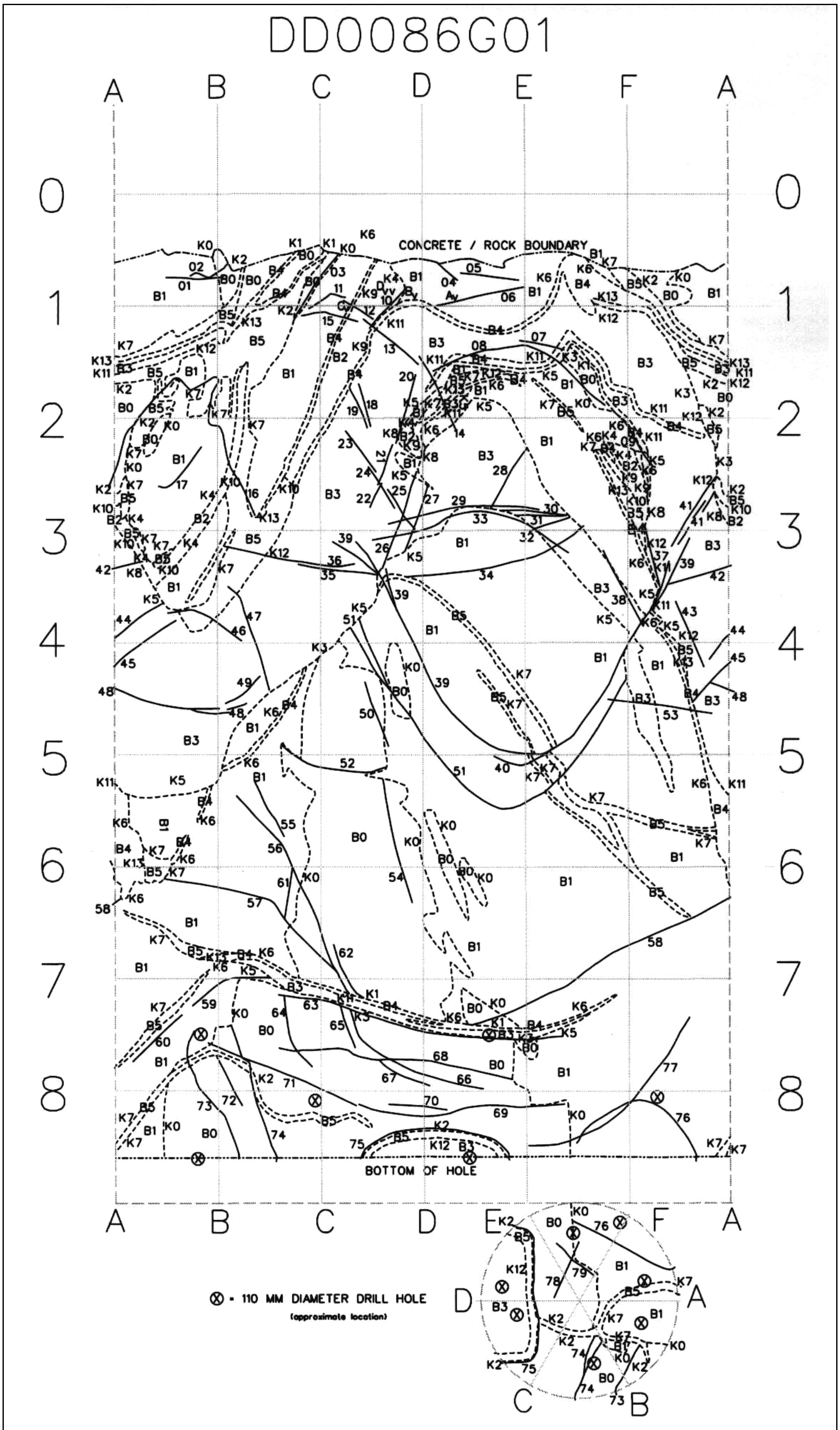


Appendix 10A. *Photos from deposition hole DD0086G01. Arrangements around the hole and the lift cage used for mapping of the hole.*
Photo: Lars Andersson, SKB.

Appendix 10B. *Photos from deposition hole DD0086G01. Part of the hole, section 4-5m, showing some rock types: Äspö diorite (grey), greenstone (black-dark grey) and fine-grained granite (reddish) and the grooves resulting from the drilling of the hole.*
Photo: Lars Andersson, SKB.



Appendix 10C. *Photos from deposition hole DD0086G01. The bottom of the hole with the rock types Äspö diorite (grey), fine-grained granite (reddish) and greenstone (dark grey).*
Photo: Lars Andersson, SKB.

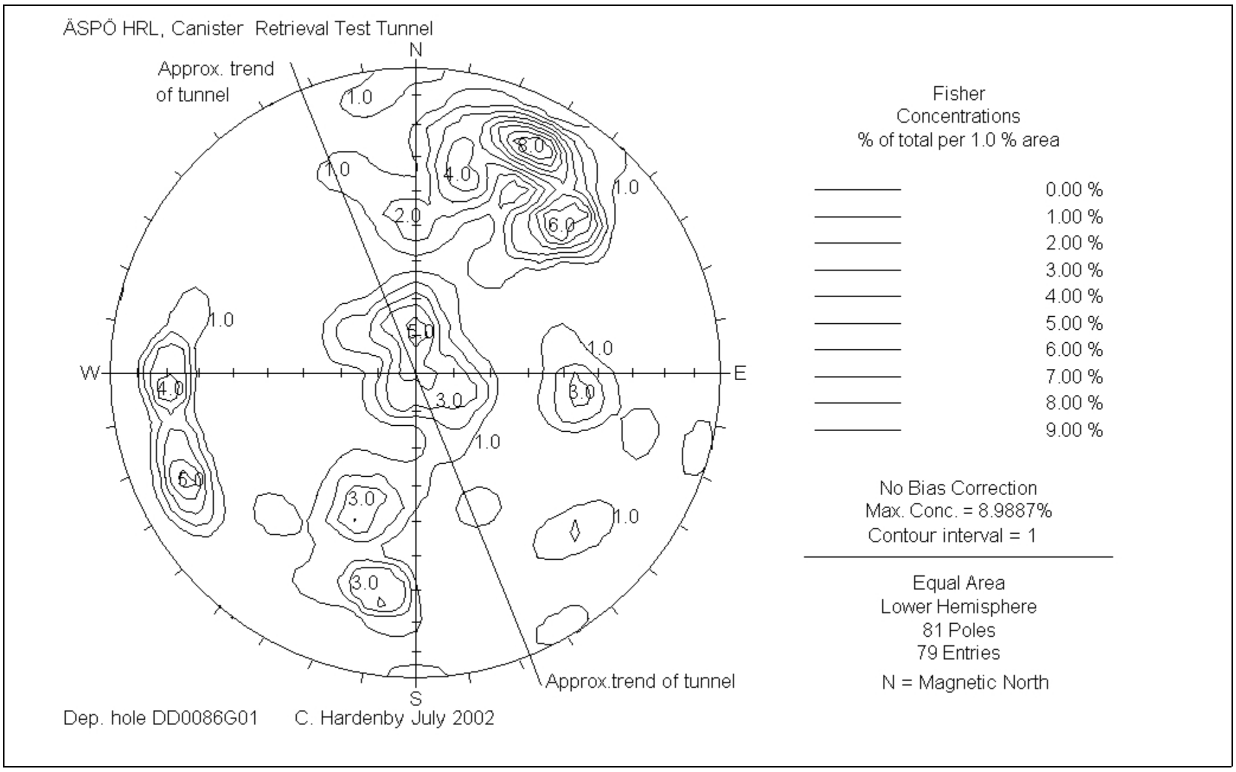


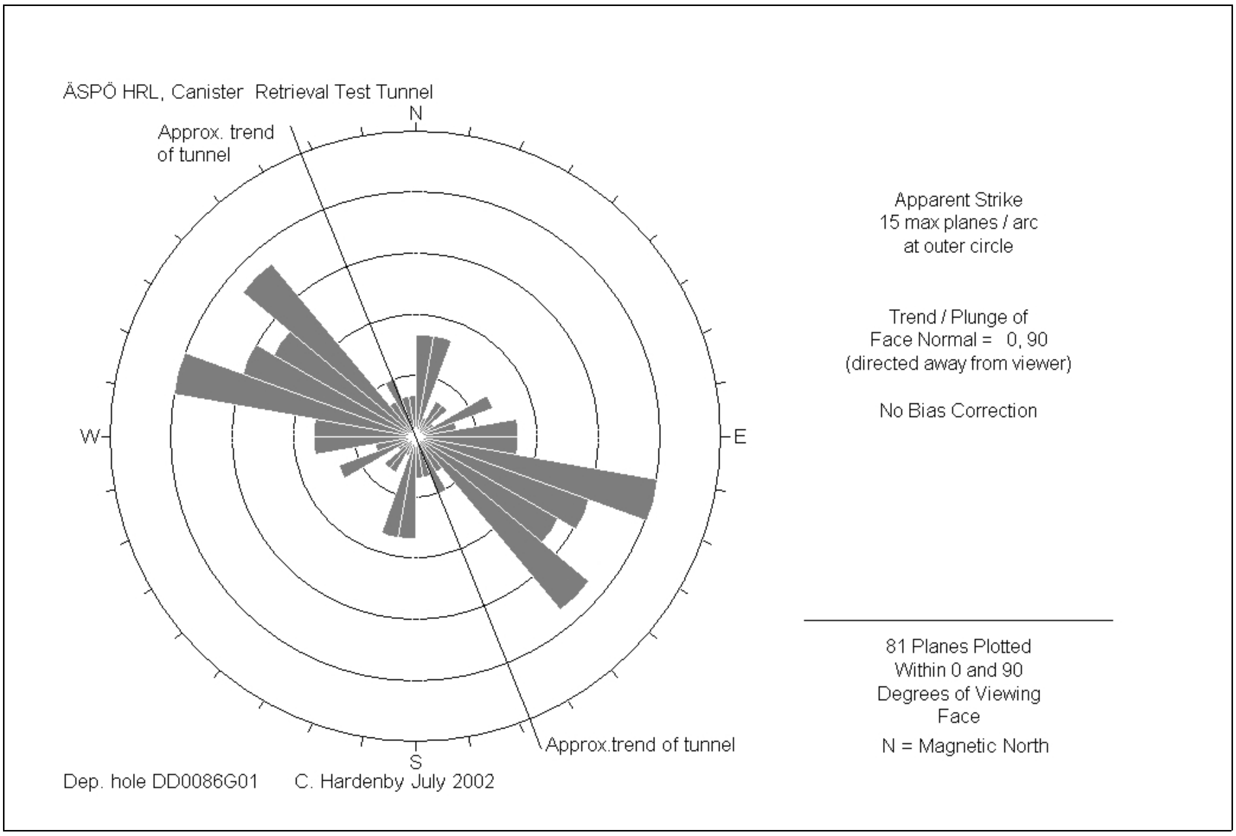
Appendix 11. *Geological mapping of the deposition hole DD0086G01. Legend: see next page!*

Appendix 11 continued

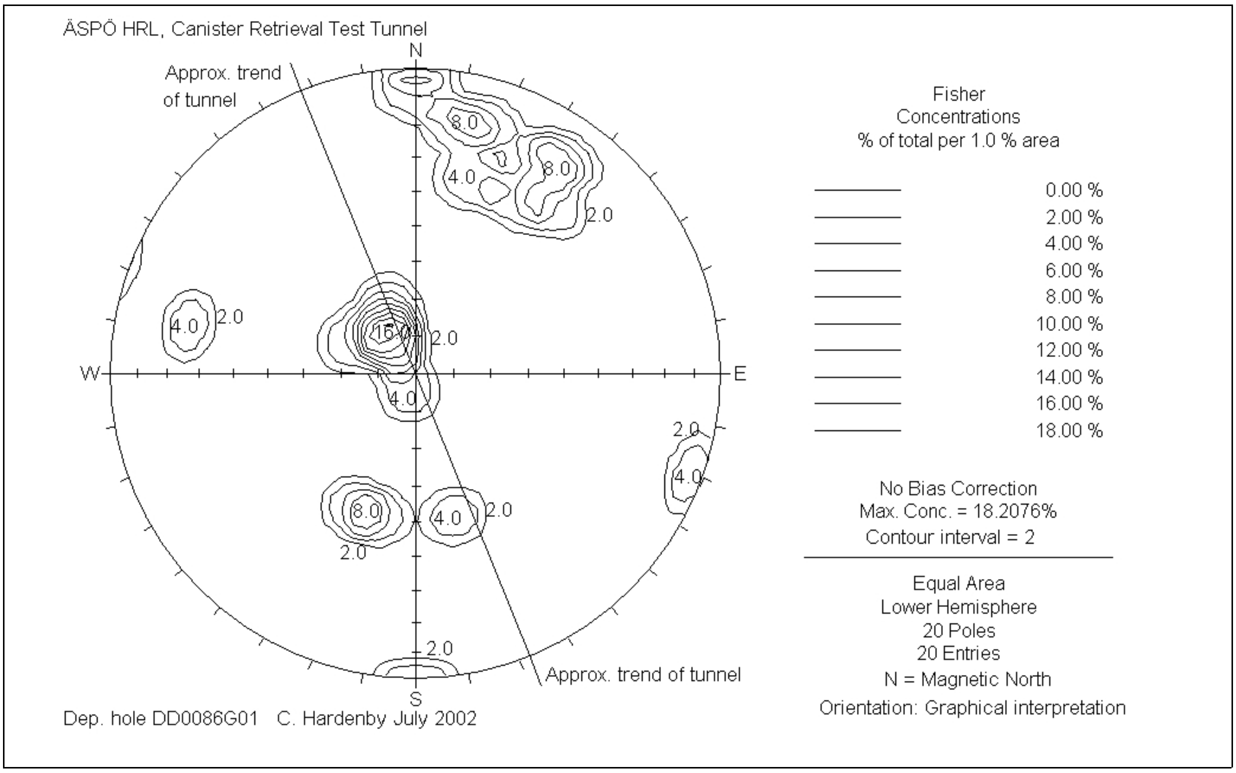
Legend:

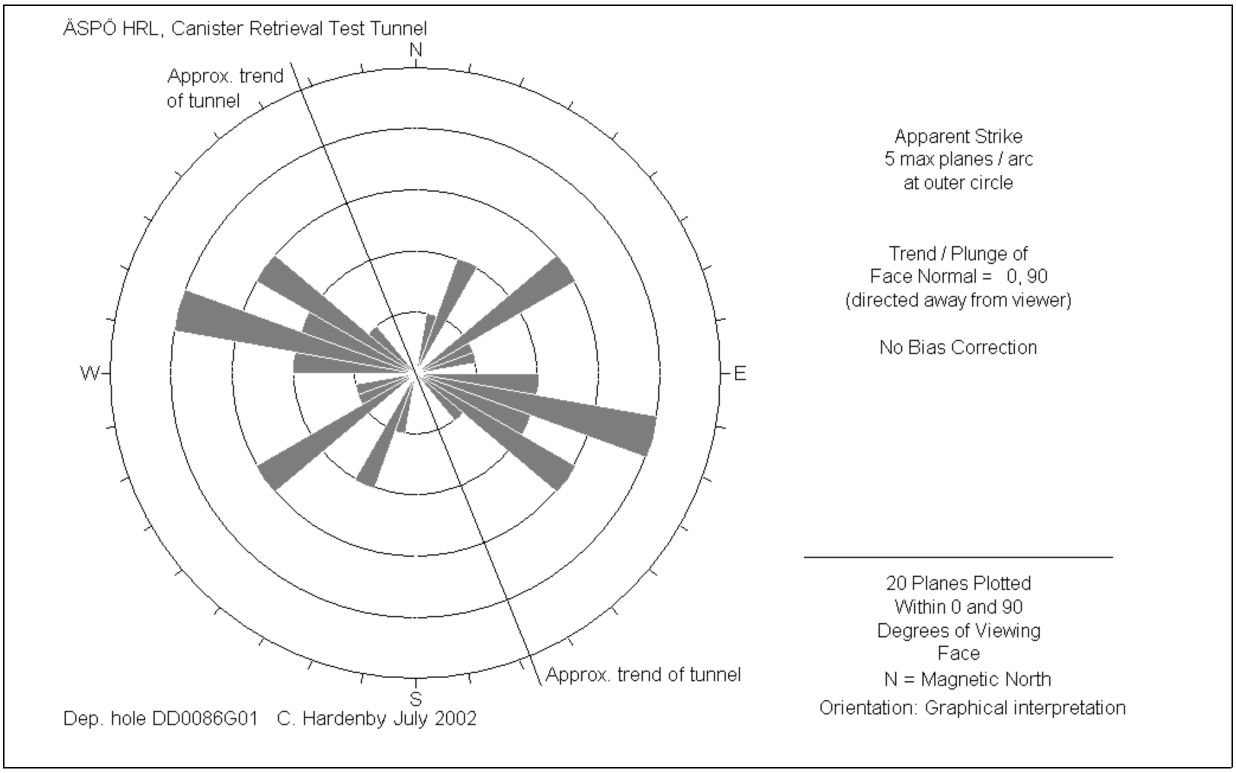
Rock types:	B0=Greenstone, medium-grained variety B1=Äspö diorite B2=Greenstone, fine-grained variety B3=Fine-grained granite, fine-grained variety B4=Pegmatite B5= Fine-grained granite, medium-grained variety
Contacts:	K0-K13 and dashed line
Fractures:	01-79 and continuos line
Water:	A-D and v-vv. (v-vv = damp – wet)





Appendix 12. *Fracture orientations (compass readings) from DD0086G01 presented in Schmidt net and joint rosette diagrams.*



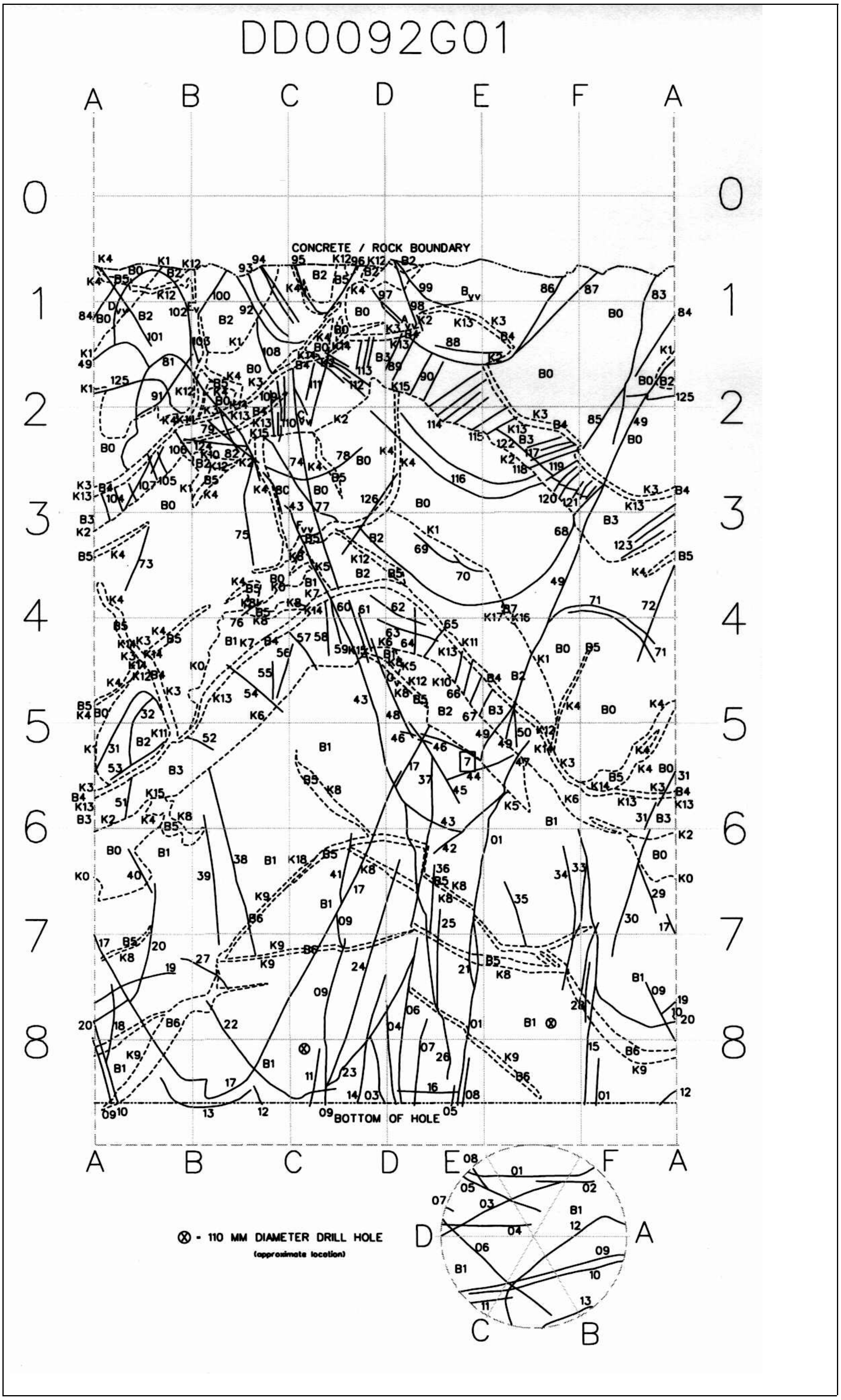


Appendix 13. *Fracture orientations (graphical interpretation) from DD0086G01 presented in Schmidt net and joint rosette diagrams.*

Appendix 14A. *Photos from deposition hole DD0092G01. Part of the wall, section 3-4m, showing fine-grained granite with pegmatite border (reddish), Äspö diorite (grey), greenstone (dark grey), and veins of fine-grained granite/pegmatite hybrid rock (light grey). Photo: Lars Andersson, SKB.*

Appendix 14B. *Photos from deposition hole DD0092G01. Part of the wall, section 4-5m, with an intersection between pegmatite (pinkish white) and fine-grained granite/pegmatite hybrid rock. Surrounding rock types are greenstones (grey-dark grey). Photo: Lars Andersson, SKB.*

Appendix 14C. *Photos from deposition hole DD0092G01. Bottom of the deposition hole composed of Äspö diorite. Photo: Lars Andersson, SKB.*

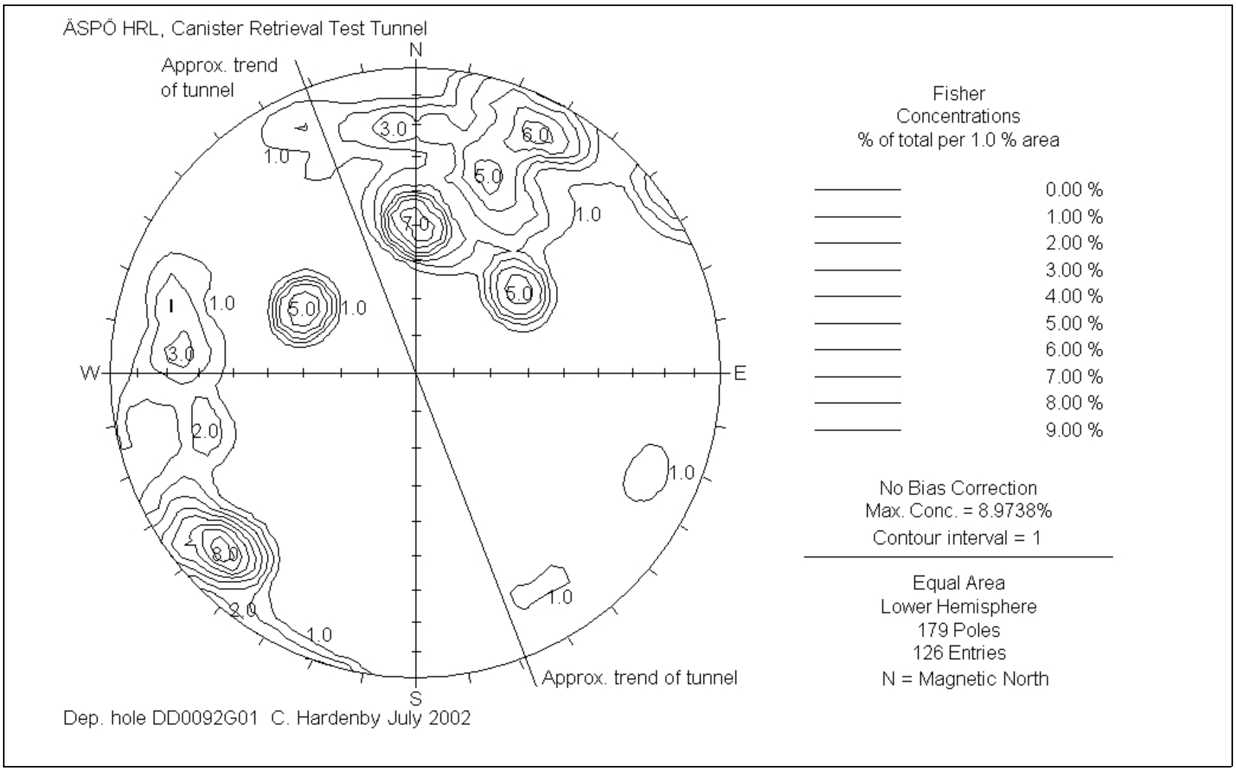


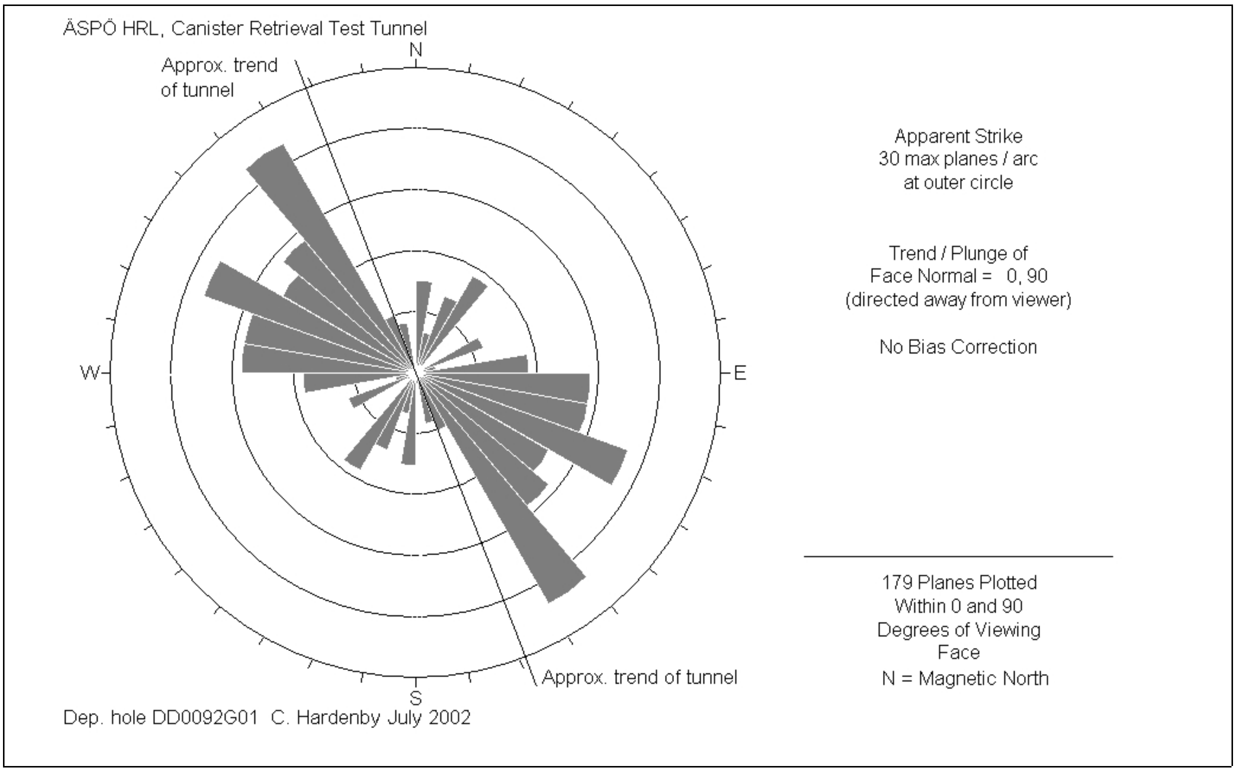
Appendix 15. *Geological mapping of the deposition hole DD0092G01.*
Legend: see next page!

Appendix 15 continued

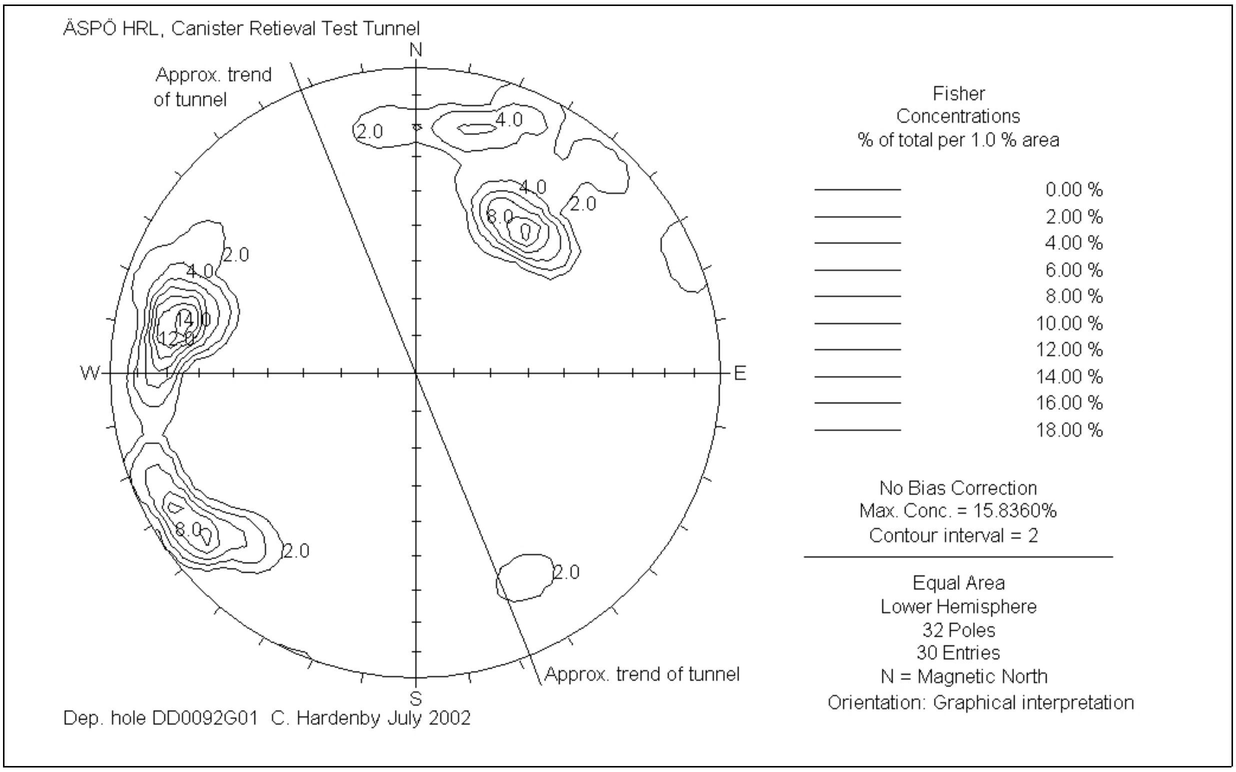
Legend:

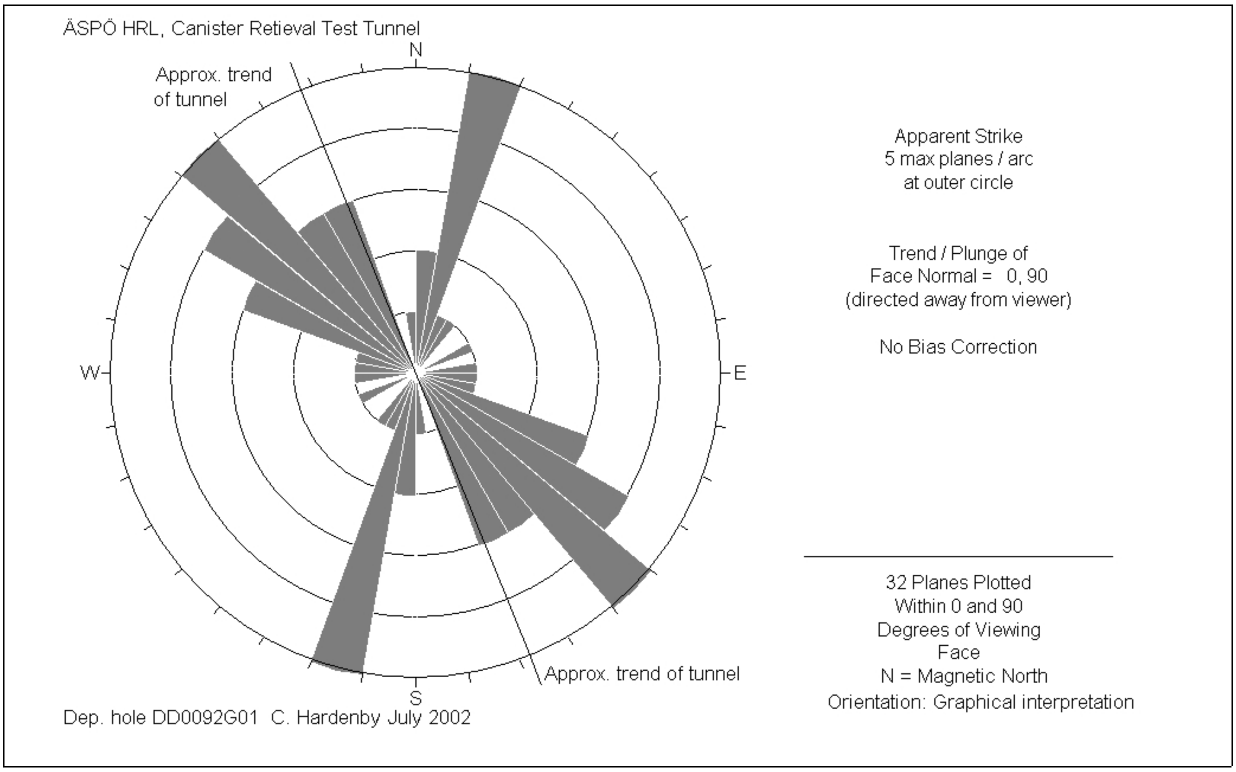
Rock types:	B0=Greenstone, medium-grained, gneissified/granitized variety B1=Äspö diorite B2=Greenstone, medium-grained, mainly homogenous variety B3=Fine-grained granite, fine-grained and reddish variety B4=Pegmatite B5=Fine-grained granite/pegmatite hybrid B6=Fine-grained granite, fine-grained and grey variety B7=Pyrite lens
Contacts:	K0-K18 and dashed line
Fractures:	01-126 and continuos line
Water:	A-G and v-vv. (v-vv = damp – wet)





Appendix 16. *Fracture orientations (compass readings) from DD0092G01 presented in Schmidt net and joint rosette diagrams.*

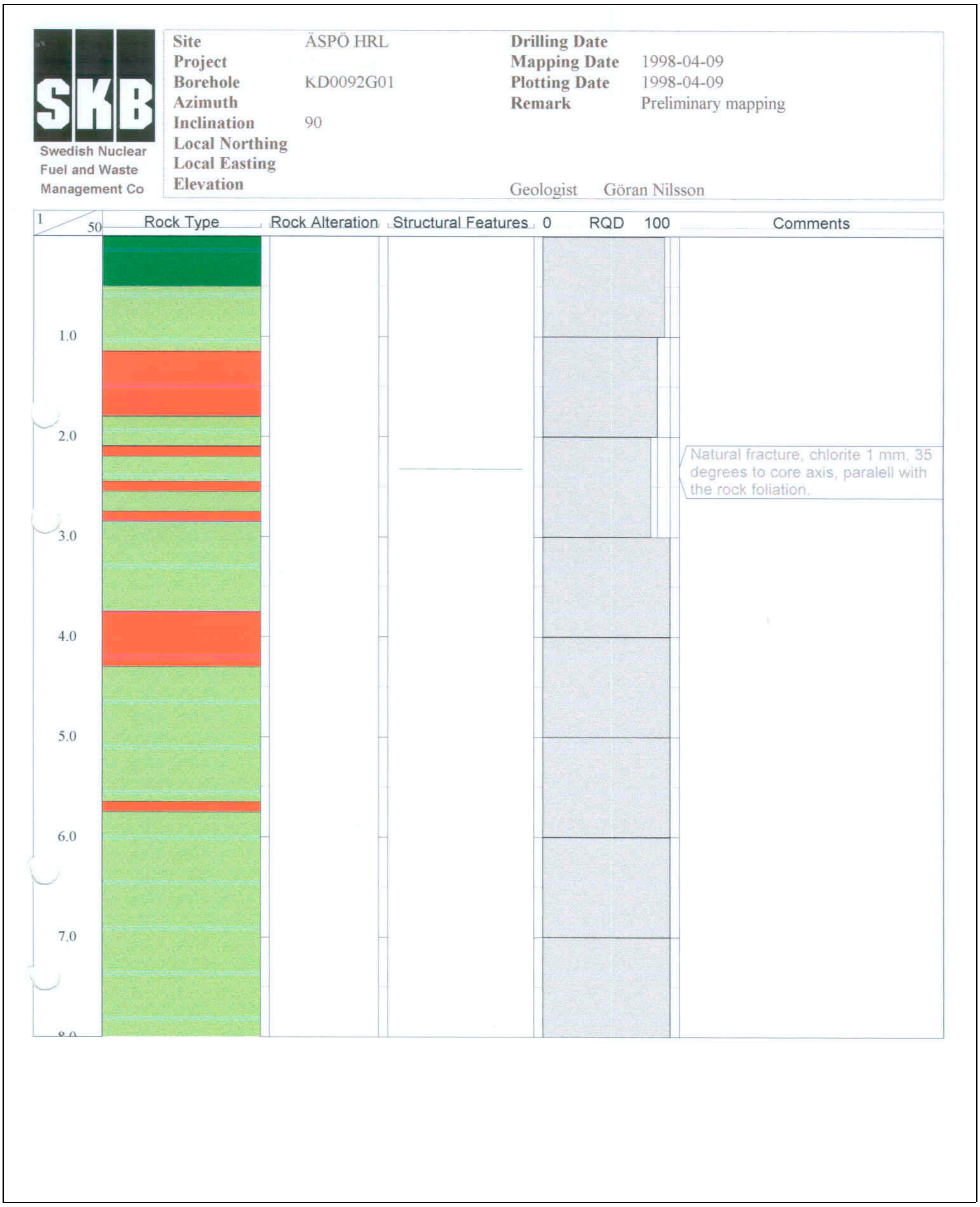




Appendix 17. *Fracture orientations (graphical interpretation) from DD0092G01 presented in Schmidt net and joint rosette diagrams.*

Appendix 18. *Core log from pilot hole KD0086G01.*

Legend: Green = Äspö diorite
Red = Fine grained granite



Appendix 19. *Core log from pilot hole KD0092G01.*

Legend: Dark green = Mafic volcanite
Light green = Äspö diorite
Red = Fine grained granite