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Äspö Hard Rock Laboratory

Äspö Pillar Stability Experiment

Geological mapping of tunnel TASQ

Björn Magnor

Svensk Kärnbränslehantering AB

February 2004

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

Äspö Hard Rock Laboratory

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Abstract

The results from mapping of the Q-tunnel (TASQ) at Z 450 in Äspö HRL show that the tunnel is situated in an area dominated by different varieties of Äspö diorite. The major rock volume consists of unaltered Äspö diorite, but relatively large volumes also contain oxidized, sheared or mylonitic Äspö diorite. Also more mafic varieties of Äspö diorite are present. Other rock types present are mafic rocks, pegmatite and fine-grained granite.

Regional metamorphism appears absent or of very low grade. In a few localities a diffuse foliation can be seen in the Äspö diorite. It seems to be associated with the regional foliation pattern, but was not accompanied by any visually detectable mineral alteration.

Hydrothermal, low grade alteration is rare and is only mapped in association to a shear zone (see below).

Rock contacts generally are diffuse, as they are successive transitions from one type of Äspö diorite to another. Contacts between dikes and host rock are sharp.

In the Rock Mass Rating (RMR) the rocks in all mapping sections in TASQ are characterized as "good".

Geological structures are dominated by brittle fractures in three main orientations. One set is striking NW-SE and dipping sub vertically. It consists of relatively wide continuous fractures and faults. This set is common in the whole Äspö HRL and is often associated with water leakage. Another set has an orientation parallel with the mapped shear zone (see below). It is suggested that these fractures are reactivated planes of weakness associated with the shearing. The third main structural set is sub horizontal.

A brittle-ductile shear zone has been mapped along the major part of the tunnel, striking approximately in the same direction as the tunnel, 034º, and dipping to the southeast. The shear zone is the dominating structural feature in the tunnel, but is mainly sealed and not as critical for rock stability as could be expected.

Displacements are rare. In general, offset is less than 3 dm. There are, however, three faults showing offset in meter-scale. The faults belong to the NW-SE striking set of structures. Since these faults were discovered after uncovering the floor and after completed mapping, they are not included in the stereographic projections.

Water leakage is mainly associated with fractures. Generally the leakage is small. The dominating fracture set concerning leakage strikes NW-SE.

Sammanfattning

Q-tunneln (TASQ) på Z 450 karterades under sommar och höst 2003, huvudsakligen i samband med att tunneln drevs. Tunneln är 70 m lång. Från nollpunkten i TASA är den 81 m och vid sektionsangivelser är det avståndet från denna punkt som används.

Syftet med tunneln är att utgöra testområde för ett bergmekaniskt försök (APSE, Äspö Pillar Stability Experiment). Försöket går ut på att i fullskala visa på förutsättningarna för att prognostisera spröda brott i pelare mellan deponeringshål.

Karteringen visar att TASQ domineras av olika typer av Äspödiorit. Till största delen består den av oomvandlad Äspödiorit, men förhållandevis stora volymer upptas också av oxiderade eller deformerade varianter, liksom av Äspödiorit med inblandat basiskt material. Övriga bergarter förutom Äspödiorit är basiter, pegmatiter och finkorniga graniter.

Bergartskontakter i TASQ är generellt diffusa. Framför allt gäller detta successiva övergångar mellan olika typer av Äspödiorit. Skarpa kontakter återfinns mellan Äspödiorit och gångbergarter som basiter, pegmatiter och finkorniga graniter.

Bergstabilitetsutvärderingar (Rock Mass Rating, RMR) som gjorts i varje karteringssektion visar att hela tunneln faller inom stabilitetsklassen II, d v s bra berg.

Regionalmetamorf omvandling tas inte upp mer detaljerat i denna rapport, eftersom bergarterna generellt är ometamorfa eller mycket lågmetamorfa. På ett fåtal lokaler kan en svag foliation ses i Äspödioriten. Denna foliation motsvarar det regionala mönstret, men verkar inte vara associerad med någon för blotta ögat synlig mineralomvandling.

Hydrotermal, låggradig omvandling är sällsynt och har endast karterats i samband med en skjuvzon (se nedan). Observera att med *omvandling* här avses engelskans *alteration*, d v s mineralnedbrytning eller leromvandling.

Strukturgeologin i TASQ domineras av spröda strukturer i tre huvudorienteringar. Ett set stryker i NV-SO och stupar subvertikalt. Det består av väl markerade, ofta breda och uthålliga sprickor och förkastningar. Detta set är vanligt i hela Äspö HRL och är, både i TASQ och i resten av HRL, associerat med vattenläckage. Nästa framträdande set är parallellt med en utkarterad skjuvzon i TASQ (se nedan). Troligen är många av de karterade sprickorna i detta set spröda reaktiveringar av ursprungligen semiduktilt genererade plan. Den tredje dominerande orienteringen i Q-tunneln är subhorisontell. Sprickor i detta set är relativt diskreta och inte så framträdande under jord som stereoplottar från karteringen tyder på.

En semiduktil skjuvzon har karterats längs större delen av TASQ. Den stryker i liknande riktning som tunneln, 034°, och stupar medelbrant mot SO. Skjuvzonen är den dominerande strukturgeologiska företeelsen i Q-tunneln, men är i huvudsak läkt och inte så allvarlig för bergstabiliteten som kunde förväntas.

Förkastningar är sällsynta i Q-tunneln. I de förkastningar som förekommer är förkastningsbeloppet generellt 1-3 dm. Det finns emellertid tre förkastningar som visar belopp i meterskala. De tillhör alla samma set av strukturer i NV-SO/subvertikalt. De finns dock inte presenterade i stereoplottar eller på karteringen, eftersom de upptäcktes först efter avslutad kartering, efter att sulan frilagts vid APSE testområde. I Appendix 2 visas översiktligt en tolkning av förkastningsgeometrin vid APSE testområde.

Vattenläckage förekommer i huvudsak i sprickor. En mindre del av de noterade läckagen tolkas komma från bergytan (mikrosprickor) och ett fåtal från borrhål och sprickzoner. Det dominerande vattenförande setet stryker i NV-SO och stupar subvertikalt. Generellt är läckaget litet. Dominerande antal vattenförande sprickor återfinns i den lägsta läckageklassen.

Contents

1 Introduction

The TASQ tunnel was mapped during May-September 2003, during and shortly after excavation. The main purpose of the Q-tunnel is to serve as experiment area for the rock mechanical experiment Äspö Pillar Stability Experiment (APSE).

APSE is a full-scale rock mechanical experiment with purpose to show the possibilities to predict spalling in a fractured rock mass. In addition, the effect of backfill on the rock mass response will be studied and a comparison between 2d and 3d mechanical and thermal predictions capabilities will be performed.

TASQ is situated at a depth of 450 m in the Äspö Hard Rock Laboratory (HRL) (Figure 1). The total length of the tunnel is 81 m from starting point in the centre of TASA, excavated length is 70 m. Locations in the tunnel are given from starting point, thus excavation starts at 11 m. Tunnel height is 5.5 m in the outermost 25 m. From 25 to 40 m the height is successively increasing from 5.5 m to 7.5 m, which is the height in the innermost 40 m towards the tunnel front. During mapping the tunnel was, however, 5.5 m high all over. The final excavation of the floor was undertaken after completed mapping.

Prior to excavation of the tunnel a core hole was drilled sub parallel to the planned tunnel orientation. The results from the logging of this drill core are briefly presented in Fransson /1993/ and Staub and others /2003/. As information is sparse in the core logging, a complementary logging was performed. This logging was entirely focused on deformational features in the drill core (Appendix 3).

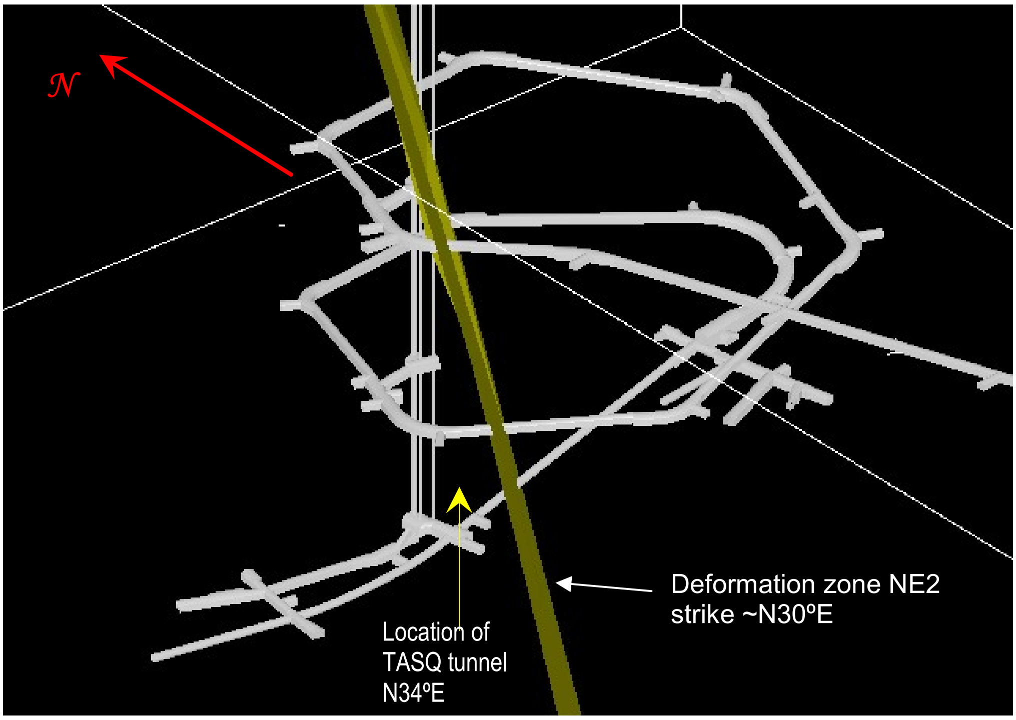


Figure 1: *View towards the NNE, along the Q-tunnel (TASQ) and the strike of deformation zone NE2. TASQ is not shown in picture, but the location is indicated by arrow.*

2 Mapping procedures

The mapping in the section 10-20 m was performed by Carljohan Hardenby and in the section 20-30 m by Carljohan Hardenby and Björn Magnor. From 30 m and onwards to the tunnel front B Magnor performed the mapping. In the sections close to the tunnel front, summer worker Xavier Dewinter assisted with writing. "Time conflicts" between geological mapping and excavating processes occurred, resulting in shortened or cancelled mapping sessions.

The main method of mapping has been "roof and walls unfolded", following the SKB/Äspö standard mapping procedure /Annertz & Stenberg, 1994: Äspölaboratoriets manual för tunnelkartering av front, nischer och sidotunnlar. SKB Tekniskt PM nr. 25-95-018/. This method also is a conventional method in underground mapping. For practical reasons, a minimum width of 1 dm concerning rock types has been used as a condition to present it as a separate rock unit. More narrow rock units were mapped as fractures with fillings of the present rock type.

A general cut off in fracture length at 1 m has been used. The majority of the fractures probably are longer than measured, but to be sure to only map what is observed, no interpretations concerning fracture extensions were made during mapping.

All orientations are given in magnetic north. For structural orientations the "right hand rule" is used.

Concerning fracture fillings, main filling mineral and subordinate filling minerals have consequently been separated during mapping. The fracture filling minerals are presented in the way that "main mineral", "filling mineral 2", "filling mineral 3" and "filling mineral 4" indicate a decreasing amount of the minerals noted.

In the APSE test section, between 64-69 m, a more detailed mapping of roof and walls was undertaken, using fracture cut-off at 0.5 m. Further, Christer Andersson performed a detailed mapping of the floor in the APSE test section (Appendix 4). In the rest of the tunnel, the floor has not been mapped.

All geological features, including rock strength, rock types, rock contacts, fractures, fractures zones and water leakage were mapped in conventional way, on a gridded paper layout map. All parameters associated with each feature were noted in field notes from the SKB underground mapping system TMS (Tunnel Mapping System). The mapping was subsequently digitized in the TMS and all notes were fed into the TMS database. As a last stage in data treatment, all data fed into the database was checked against field notes, to ensure reliability.

All TMS files, both digitized geology and data fed into the database, were sent to Isabelle Staub at Golder, Stockholm for constructing a 3d-model of the tunnel, in purpose to achieve a detailed overview of the APSE experiment rock volume. A more detailed description will be presented in a separate report /Staub, in preparation/.

3 Geology of TASQ

3.1 Rock quality- RMR

Rock mass rating is rather uniform throughout the tunnel (Figure 2). Every mapping section is characterized as “good rock”, which is between 61-80 in the RMR system, even though individual faults and fractures may be of lower stability.

Dominating structure in the tunnel is the heavily oxidized brittle-ductile shear zone running in the left tunnel wall, approximately parallel to the tunnel. In places, this set of structures generates critical surfaces of brittle reactivation with fracture filling of mainly epidote-chlorite. Generally the shear zone is, however mainly sealed along the whole tunnel and not as critical for the rock stability as could be expected.

The structure set generating most critical zones of weakness instead is a set of brittle fractures and faults almost perpendicular to the tunnel, *i.e.* striking NW-SE and dipping sub vertically. This set becomes more pronounced in the inner half part of the tunnel, even though present, but more spaced also in the outer half part. The APSE test area is bordered by two members of this set, in this particular place represented by two faults with offset in meter-scale.

Not very much evidence of alteration of the rocks has been found in the tunnel. Even the shear zone is generally only slightly more altered than the surrounding wall rock. An exception to this is the oxidation, widespread in the shear zone and surrounding rock units.

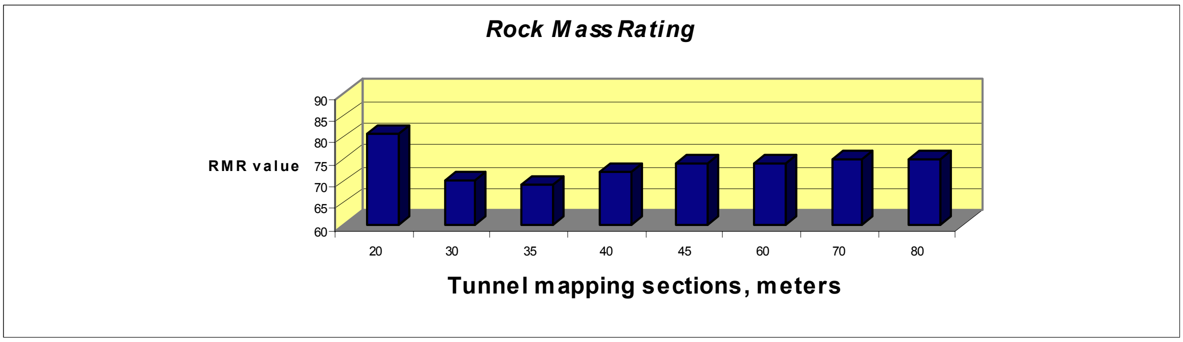


Figure 2: *Rock mass rating (RMR) in TASQ. Note that despite being presented in equally long segments, the rating was logged in each mapping section, indicated by the numbers in the lower row.*

3.2 Rock types and rock contacts

3.2.1 Rock types

The Q-tunnel is dominated by different varieties of Äspö diorite. The right wall along the tunnel is dominated by unaltered Äspö diorite, while the left wall is dominated by an oxidized variety of Äspö diorite related to the main shear zone running along the tunnel. Also more mafic and felsic varieties of Äspö diorite occur, as well as diorite with crystalloblastic texture. Intrusions of greenstone, pegmatite and fine-grained granite occur. In table 1, relative volumes of different rock types in TASQ are presented.

Geology becomes less complex approaching the tunnel front, mainly because the shear zone is absent in the tunnel walls from 68 m and onwards.

Table 1: Rock types in TASQ

Rock type	% of mapped rock area
Äspö diorite, unaltered	62
Äspö diorite, oxidized	19
Hybrid rock, mixture of Äspö diorite and greenstone	1
Hybrid rock, crystalloblastic. Composition between Äspö diorite and granite	4
Mylonite	5
Greenstone	4
Fine-grained granite	3
Pegmatite	2
Total	**100**

Äspö diorite is the by far dominating rock type in the TASQ. It occurs in several different varieties.

The unaltered Äspö diorite (Figure 3) is a medium-grained, dark grey to dark reddish grey rock. Generally it is porphyritic, with megacrysts of red feldspar. It is, together with true granite, the dominating rock type in the Äspö HRL, especially on deeper levels. The Äspö diorite is not a true diorite, but ranges in composition from granite to granodiorite to quartz monzonite /Rhén et al, 1997, Wikman & Kornfält, 1995/. It may contain inclusions of greenstone. Just over 60% of the area mapped in the TASQ consists of unaltered Äspö diorite.

The oxidized variety of Äspö diorite is red to greyish red in colour (Figure 4). It is mainly restricted to areas bordering the shear zone. Is usually constitutes a transition zone from the shear zone rock type to the unaltered Äspö diorite. Almost 20% of the tunnel consists of this rock type.

The hybrid rock which is a mixture of Äspö diorite and greenstone probably has no relation to the greenstones mapped in the tunnel, but merely represents a less common end member in the transitional suite of different varieties of Äspö diorite in TASQ. In this tunnel it is interpreted to be crystalloblastic by heating. Only 1% of the tunnel area is occupied by this rock type.

The hybrid rock which is a mixture of Äspö diorite and granite constitutes 4% of the tunnel area and is a variety of Äspö diorite, which appears to have a more felsic composition than the ordinary type.

The ***mylonite*** (Figure 5) is restricted to the major shear zone running along the left tunnel wall. According to the mapping the zone is continuous up to 60 m, but after excavation of the floor (also after completed mapping) it is obvious that the shear zone continues to 68 m. From 68 m and to the tunnel front the shear zone is absent due to faulting (see 3.4).

This rock type is inhomogeneous. True mylonitic bands alternate with less deformed zones, in which the rock origin as Äspö diorite is obvious. In the mylonitic bands, the rock is reddish and fine-grained with elongated porphyroclasts. Infill of epidote, chlorite and to some extent calcite and quartz in the shear zone foliation occurs in cm-wide bands. The unit has a width of 0.5-1.5 m. This rock type makes up 5% of the tunnel area. For further interpretations of the tectonic implications, see 3.3.2.

Greenstone is a collective term used in the Äspö HRL for all mafic rocks. In the TASQ it generally is a greenish black to black, fine- to medium-grained rock. It may have been generated as diabase dikes. It is homogenous, except in one unit which shows a weak foliation oblique to the tunnel, but parallel to the regional foliation in the Äspö area (strike to the east-northeast/dip steep to the south). The greenstones occur mainly in the outer 40 m of the tunnel and makes up 4% of the tunnel area.

Fine-grained granite occurs as 2-3 dm wide dikes and veins in the tunnel. It occupies 3% of the tunnel area. The colour is generally greyish red or red. In places a margin-parallel banding can be found. It is also common to find cm-wide pegmatite along the margins of the fine-grained granites. These dikes and veins are among the youngest rocks in the tunnel, as they cut all varieties of diorite. They are only seen to be cut by the mylonite. Age relation between fine-grained granite and pegmatite is not clear. It is, however indicated at one locality in the right wall at 49 m (see Figure 6), where a pegmatite is interpreted to crosscut a vein of fine-grained granite.

Pegmatite occurs in the same manner as the fine-grained granites, as dikes and veins. They make up 2% of the tunnel area. They are red and contain mainly feldspars and quartz. Generally they lack darker minerals. Pegmatite also occurs in the margins to many of the fine-grained granites.

Figure 3: *Unaltered Äspö diorite in TASQ.*

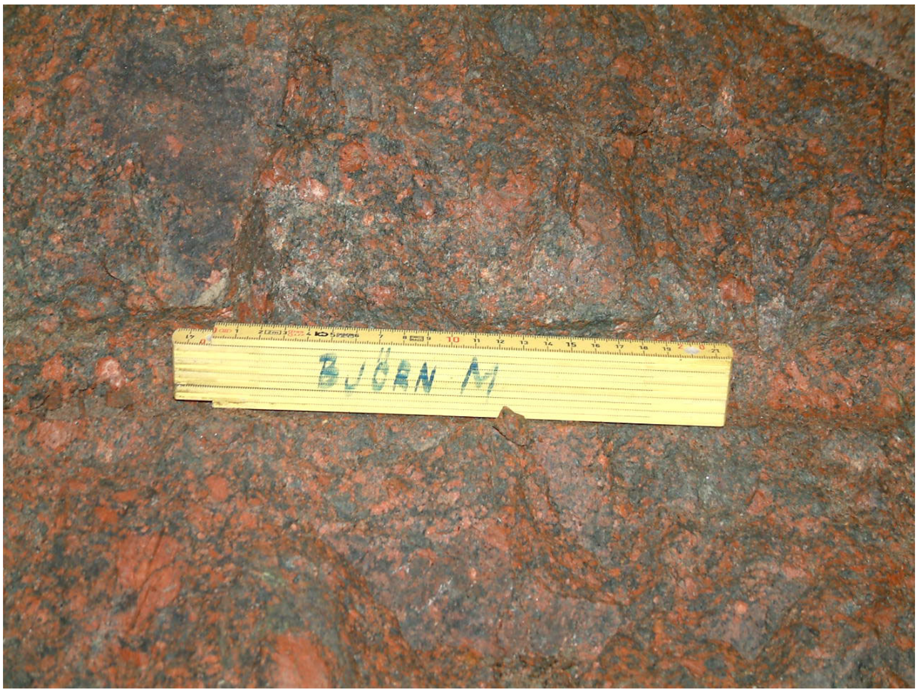


Figure 4: *Oxidized Äspö diorite in TASQ. Oxidation is located to the rock volume surrounding the mylonitic shear zone.*

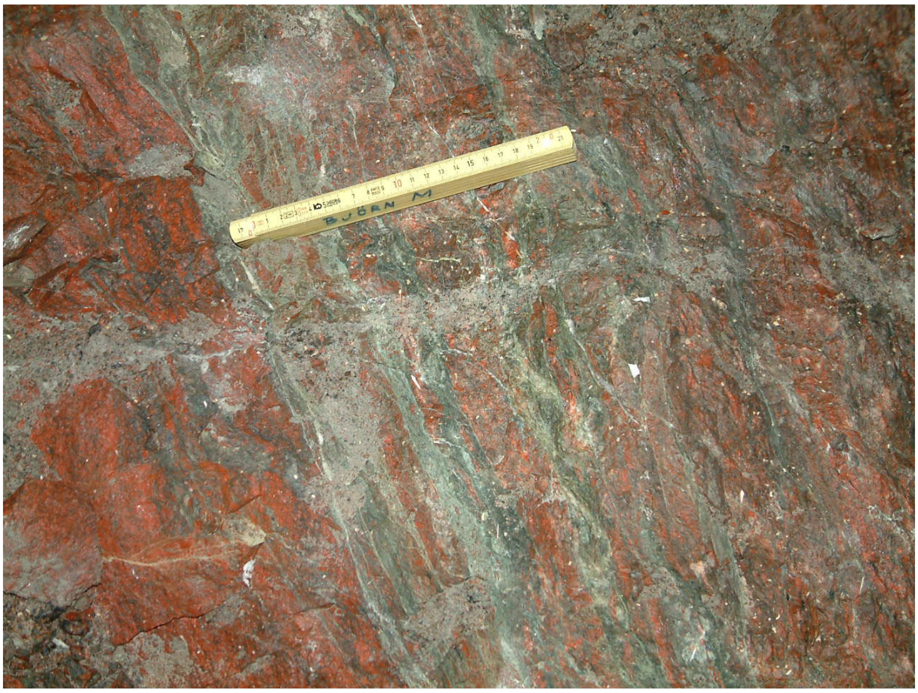


Figure 5: *Mylonite in TASQ. This rock has originally been a Äspö diorite, as seen in the transition from mylonite to fresh rock.*

Figure 6: *Pegmatite dike crosscutting a fine-grained granite. Host rock is unaltered Äspö diorite.*

3.2.2 Contacts

Contacts between the different varieties of Äspö diorite are diffuse. No orientations have been measured in these contacts. Sharp contacts are found between the main rock units (varieties of Äspö diorite) and later intrusions, such as fine-grained granites, pegmatite veins and some of the greenstones. Also, the mylonite zone shows sharp contacts to the surrounding rocks. Figure 7 shows orientations of measured rock contacts. Different rock types are shown with different symbols, see legend. In the figure it is indicated, although few contacts have been found, that fine-grained granites are oriented perpendicular to the tunnel and sub vertically. The mafic dikes are found in the same orientation as the shear zone.

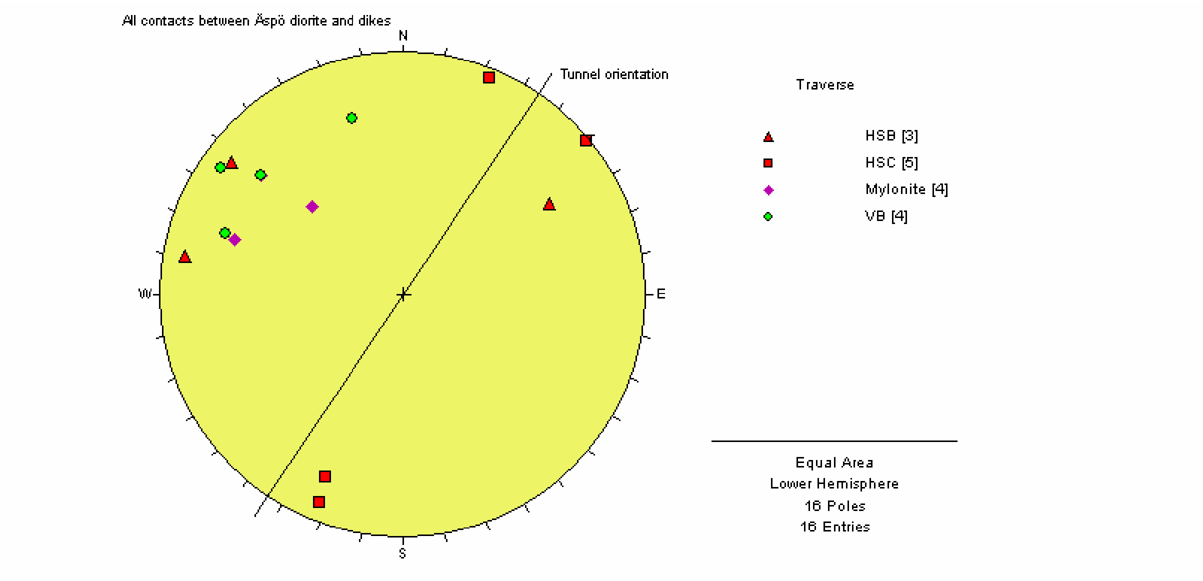
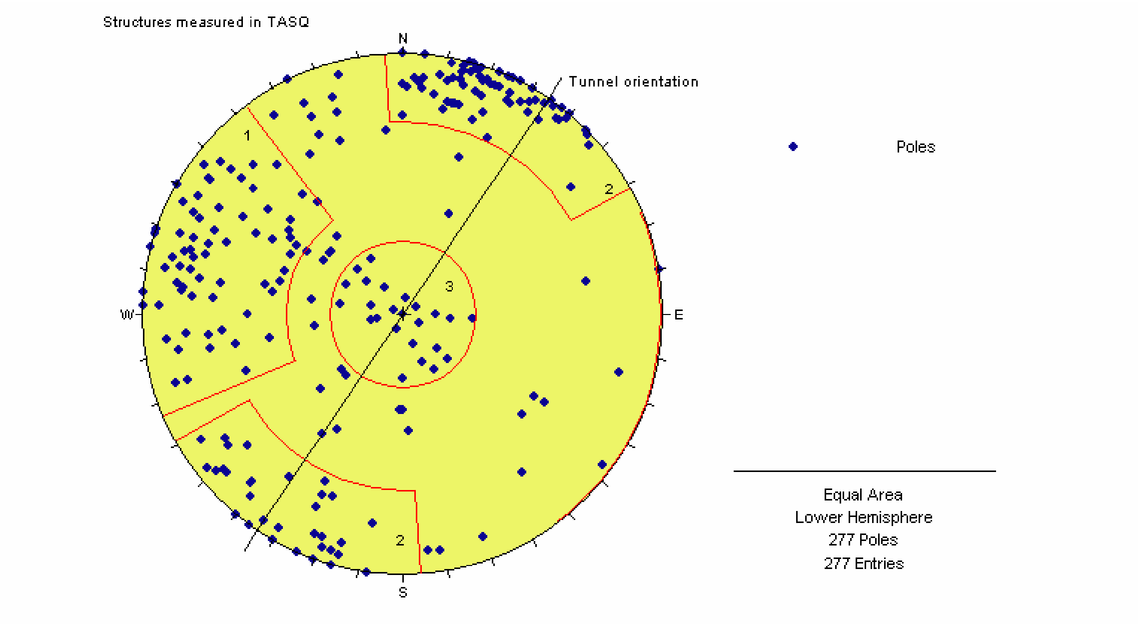


Figure 7: *All measured contacts between the main rock type Äspö diorite and dike rocks. Except the contacts to magmatic dikes, also the contacts to mylonite has been plotted here. HSB=pegmatite, HSC=fine-grained granite, VB=mafic rock.*

3.3 Geological structures

All planar geological structures measured in the TASQ are plotted in equal area Schmidt stereographic projections (see Figures 8-9). The plots display three dominating sets of planar structures. One set is parallel with the shear zone in the left tunnel wall. The second set strikes perpendicular to the tunnel and dips sub vertically. The third set consists of discrete sub horizontal brittle fractures (Figure 8).

A subdivision into brittle and ductile structures has been made (see below). All ductile (brittle-ductile) structures recorded belong to the shear zone.



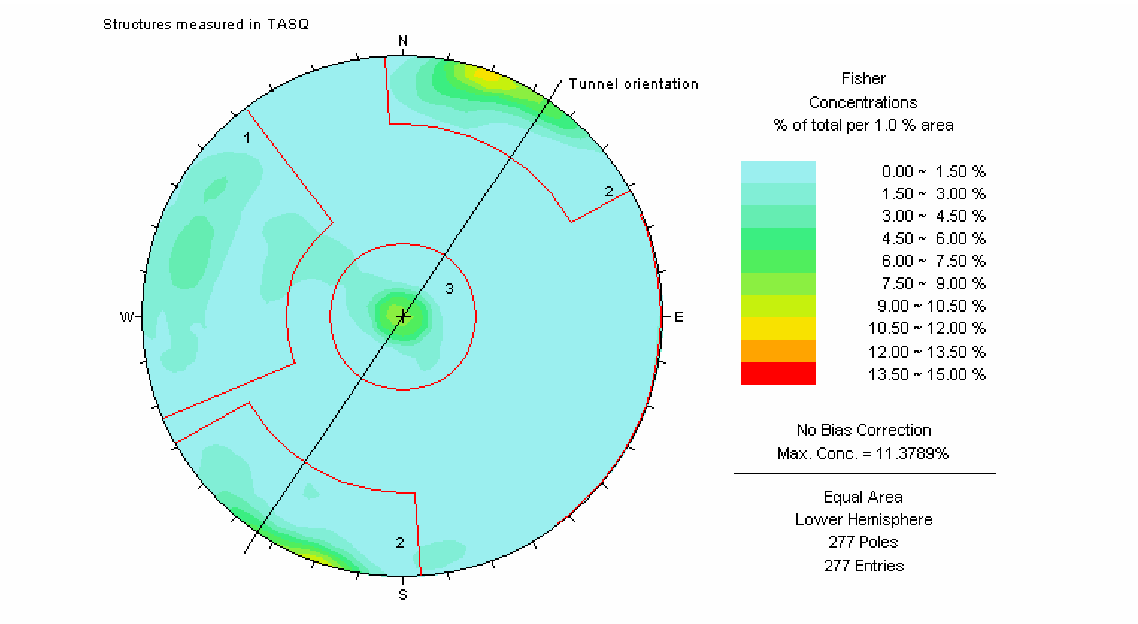


Figure 8: *All structures measured in tunnel TASQ. Group 1 includes the shear zone parallel structures. It also contains a set of brittle, steeply dipping structures striking N-NNE. Group 2 consists of a brittle, sub vertical set striking perpendicular to the tunnel. This group includes the majority of the faults in TASQ and also the majority of the water bearing structures. Group 3 represents a set of discrete, sub horizontal brittle fractures.*

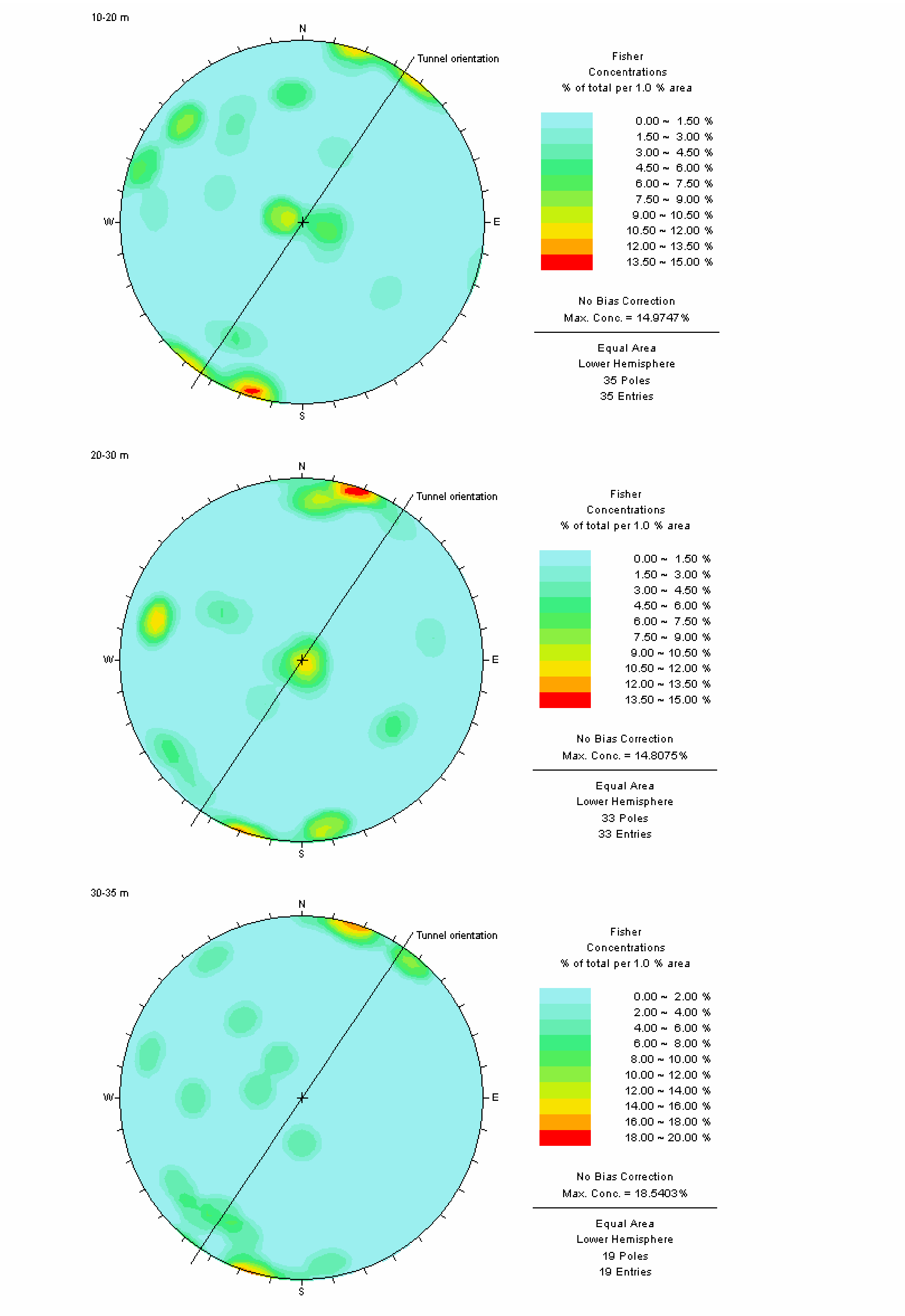


***Figure 9:** 10-35 m (figure continues)*

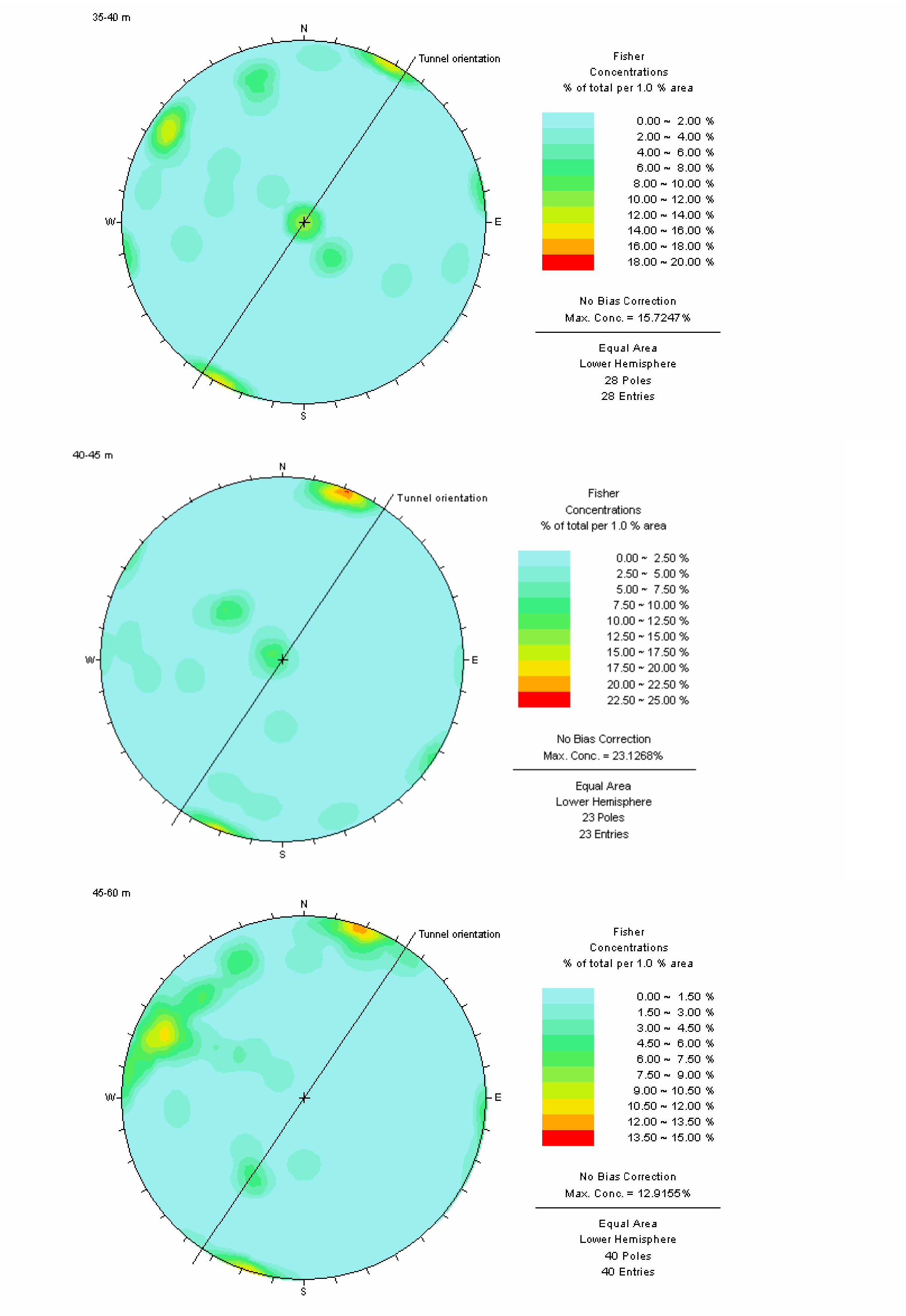


***Figure 9,** continued: 35-60 m.*

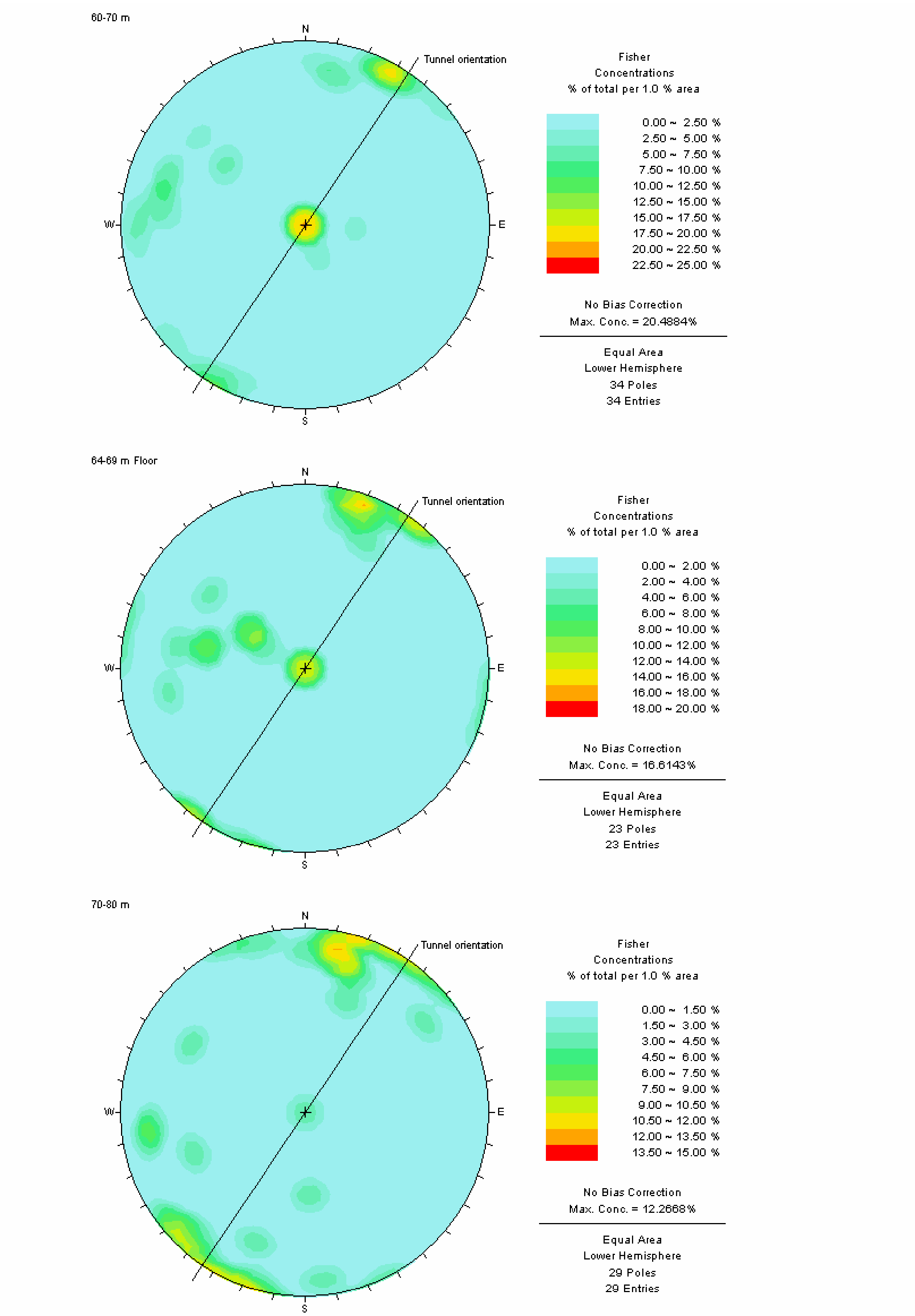


***Figure 9**, continued: 60-80 m.*

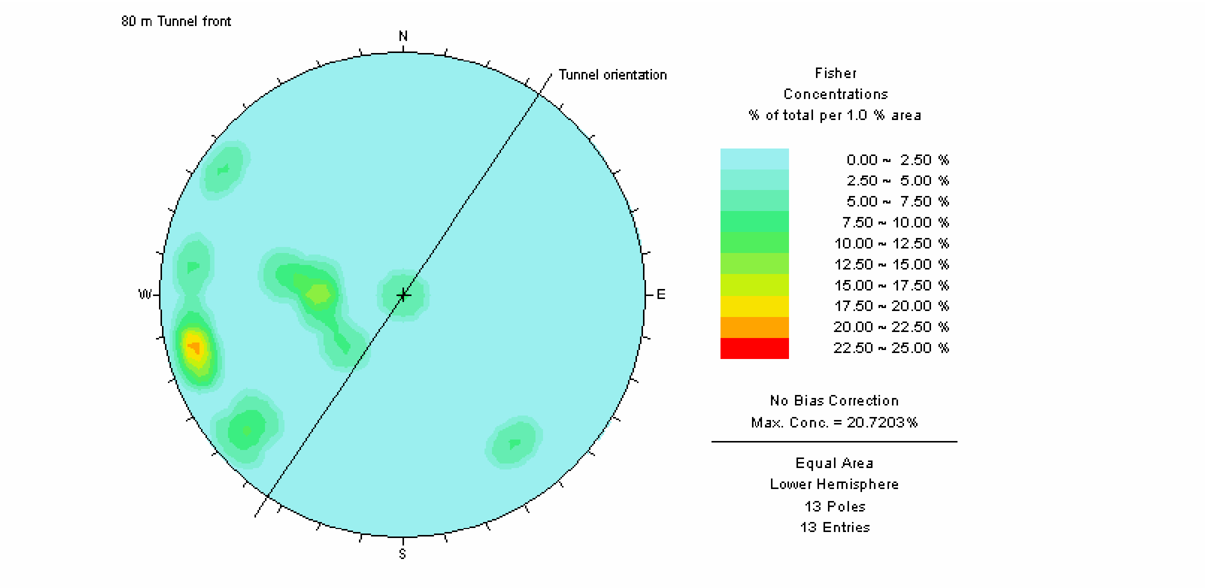


Figure 9: *Contoured stereonet projections for each mapping section in TASQ. Note that all sections are not equally long, but vary between 5-15 m (see numbers in upper left part of each figure). Compare with appendix 1 for the geological mapping of TASQ.*

3.3.1 Brittle structures - fractures and fracture zones

Fractures

Orientations

The brittle structures in the tunnel are dominated by three sets of continuous fractures, as seen in figure 8. One set is approximately perpendicular to the tunnel and dips sub vertically, NW-SE/~90. This set is associated with water leakage, both in the Q-tunnel and in the rest of the Äspö HRL. In the Q-tunnel it also includes the larger faults, with offset in m-scale.

A second brittle set plots around a brittle-ductile shear zone with orientation NE-NNE/45-60 running in the left tunnel wall. Orientation of the set is 020-045/45-70. This implies that brittle reactivation of the ductile shear zone has occurred. The interpretation from the underground mapping sessions is that reactivation of pre-existing structures is more common than development of new structures.

There also is a third, sub horizontal set. This set is not, however as pronounced in the tunnel as is indicated in the stereographic projections. Fractures in this third set are mainly sealed and rarely more than 0.5 mm in width.

Persistence

Fracture length is defined as the trace length of the fracture. Fracture lengths mapped in the Q-tunnel are presented in table 2 and figure 10. The numbers in the table includes both the regular mapping of roof and walls unfolded and the mapping of the floor between 64-69 m. The table shows that 75% of all fractures are between 1-5 m in length and that the largest group is the 2-3 m long fractures. From mapping it is concluded that the longer fractures belong to either of three sets; NW-SE/sub vertical (perpendicular to the tunnel), NE-NNE/45-60 SE (associated with the shear zone parallel to the tunnel) and N to NNE/sub vertical-70 E.

Table 2: Fracture persistence

Fracture length, m	No of fractures	~% of total 277 fractures
0<1	2	1
1<2	41	15
2<3	66	24
3<4	52	19
4<5	44	16
5<6	22	8
6<7	6	2
7<8	12	4
8<9	7	2
9<10	5	2
10<15	14	5
15<20	3	1
>20	3	1

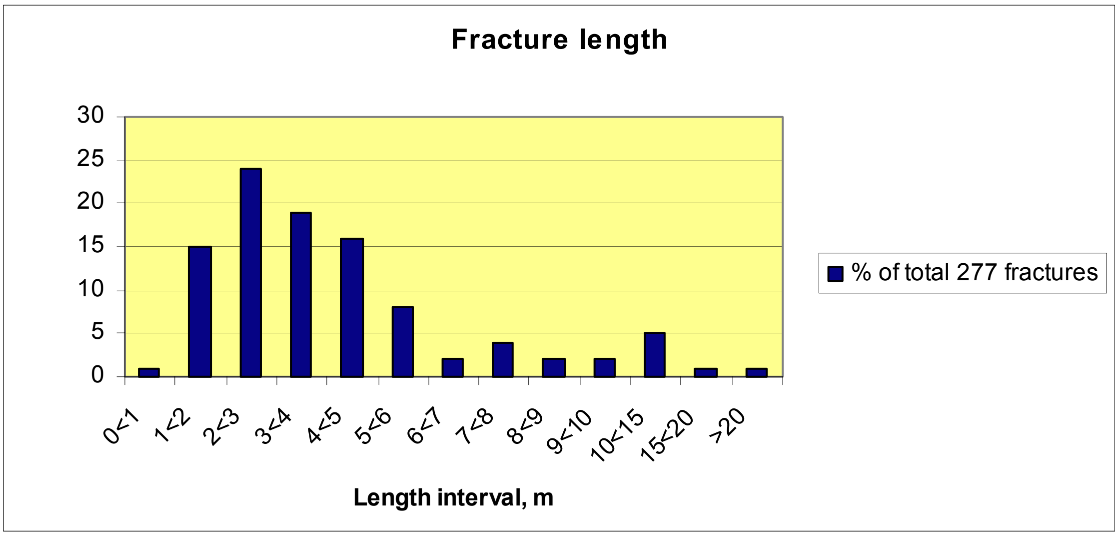


Figure 10: *Frequency of fractures in TASQ appearing in different length intervals. Almost 25% of the fractures are between 2-3 m long, 75% of the fractures are between 1-5 m long. Note that fractures over 10 m in length are rare and thus are presented in 5 m intervals.*

Fracture form

The majority of the fractures mapped in TASQ were considered to be plane, 248 of 277 (see Figure 11). Nineteen (19) fractures were considered to be undulating, which means an amplitude of >0.1 m. The last 10 fractures were arched, with height of arch >0.1 x length of fracture.

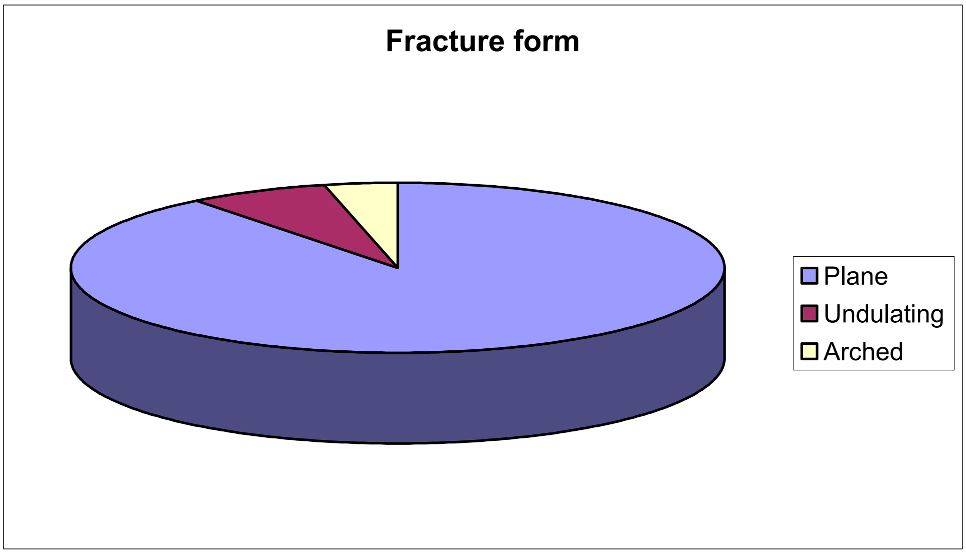


Figure 11: *Fracture forms in TASQ. Of the totally 277 fractures mapped, 248 have been considered to be plane, 19 undulating and 10 arched.*

Fracture type

All fractures in the Q-tunnel were interpreted to be natural, i.e. no fractures were created entirely by blasting. The major part, 212 fractures or 76%, of the total 277 fractures is found to be sealed (Figure 12). All but one of the remaining fractures belong to the group of formerly sealed natural fractures which have been re-opened by e.g. blasting. The remaining fracture was interpreted as a truly open fracture.

Fracture surfaces

Fracture surfaces are mainly rough. From the 159 fractures where fracture surfaces could be examined, only two are defined as smooth and one contains slickenside striation. Thus 156 fractures were defined as having rough surfaces. On 119 fractures, surfaces could not be examined, as they were situated in the roof or surfaces were not exposed.

Fracture fillings

Dominating fracture filling minerals are chlorite, epidote and calcite. These minerals dominate both considering the main filling mineral in each fracture and with respect to all observations made on fracture filling minerals (Figure 13, Table 3). At the most four mineral phases have been found in the same fracture.

Chlorite and epidote are widespread in most of the fracture orientations, with some dominance for the shear zone parallel fractures striking NE-NNE. They are not that dominating in the fractures striking perpendicular to the tunnel, in NW-SE (Figures 14 a and 14 b, respectively). In the latter orientation calcite is the dominating fracture filling mineral (Figure 14 c).

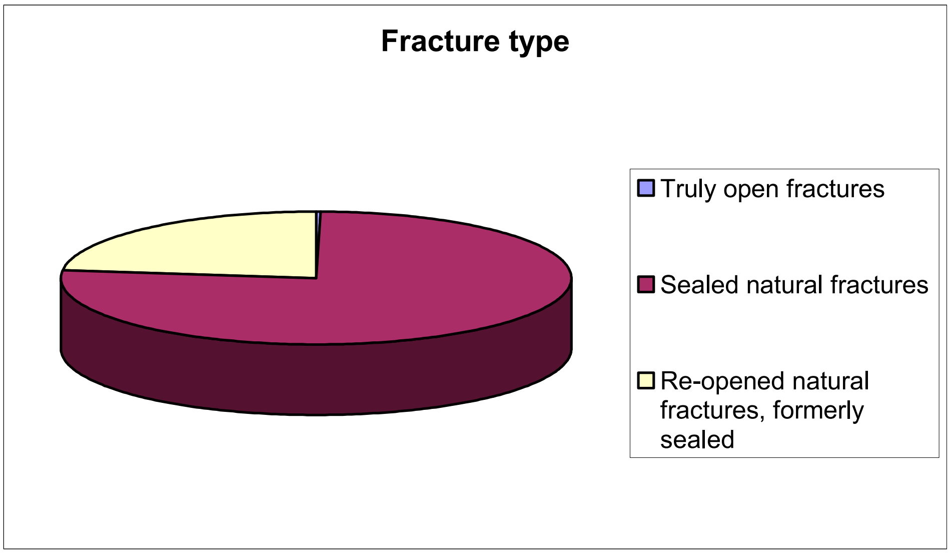


Figure 12: *Fracture types in TASQ. Note that all fractures mapped were considered to be naturally created, no fractures generated by excavation have been mapped. Of a total of 277 fractures, 212 of them were considered to be sealed natural fractures, 64 re-opened, formerly sealed fractures (re-opening probably by blasting) and 1 truly open fracture.*

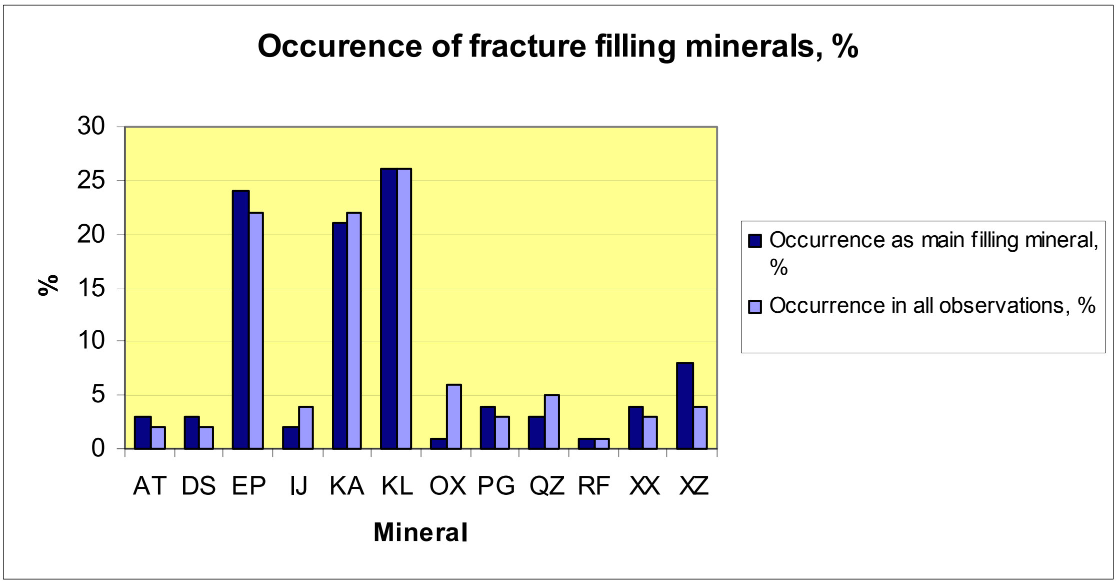


Figure 13: *Fracture filling minerals in TASQ. Dark columns show the occurrence of each mineral as main filling mineral, pale columns show all occurrences, also as subordinate filling mineral. AT=fine-grained granite, DS=dull surface, EP=epidote, IJ=grout, KA=calcite, KL=chlorite, OX=oxidation, PG=pegmatite, QZ=quartz, RF=red feldspar, XX=unidentified filling, XZ=filling could exist. The "unspecified" categories XX and XZ have been used when fracture surfaces were not clearly visible, mainly in the tunnel roof.*

Table 3: Occurrence of filling minerals in mapped fractures. Filling minerals 1, 2 and 3 constitute phases of subordinate occurrence.

Mineral	*Main filling mineral*	*Filling mineral 2*	*Filling mineral 3*	*Filling mineral 4*	*Total observations*
Chlorite	73	35	11	2	**121**
Epidote	67	33	6		**106**
Calcite	59	33	10	3	**105**
Oxidation	2	12	10	3	**27**
Quartz	8	4	7	4	**23**
Pegmatite	11		2		**13**
Fine grained granite	8	1			**9**
Red feldspar	4	2			**6**
Grout	5	8	3	1	**17**
”Dull surface”	8				**8**
Unidentified filling	10	2	2		**14**
Filling could exist	21				**21**

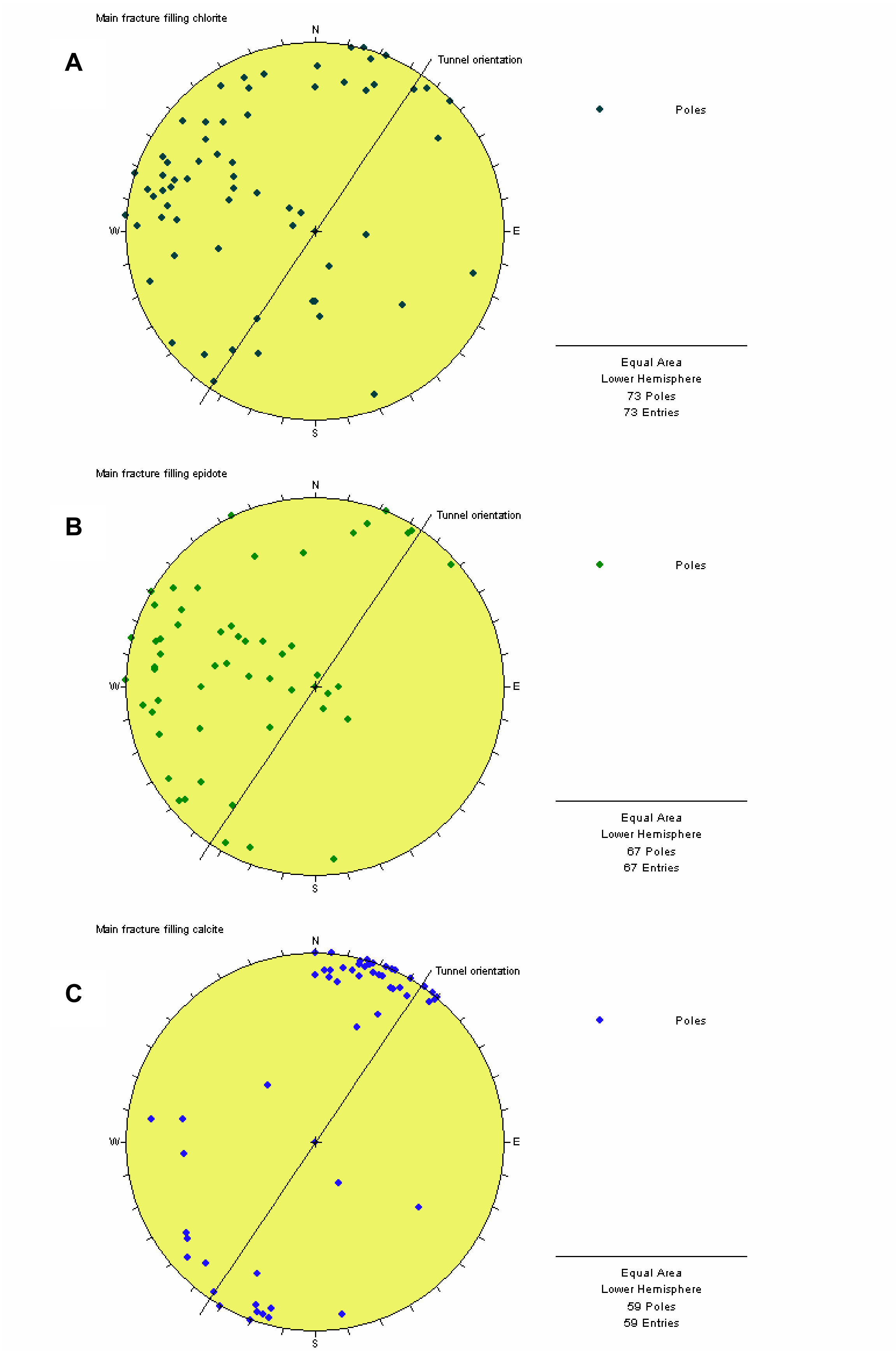


Figure 14: *Stereographic projections showing the distribution of main fracture filling minerals. A/ chlorite, B/ epidote and C/ calcite.*

Fracture zones

For practical reasons, the brittle-ductile shear zone in TASQ has been included in the fracture zones during mapping, although this group strictly should contain only brittle structures. The shear zone is more thoroughly described in 3.3.2.

A strictly brittle fracture zone is found in the left tunnel wall at 28-31 m. It has been defined as a zone of increased fracturing, which is more of a mapping technical definition than geological. The zone structure is lamellar. It has an orientation of 348/81. It consists of a set of epidote-chlorite covered fracture planes with 2 dm spacing. This fracture orientation is present in the tunnel between 10-50 m, however more commonly as individual fractures. The fractures in this set are prominent and are among the most continuous fractures in the Q-tunnel.

3.3.2 Ductile structures

One set of more ductile structures has been found during field work in the Q-tunnel. It belongs to the shear zone running in the left tunnel wall. The degree of ductility is in the brittle-ductile transition zone. Ductility also varies in the zone, as seen for example at 21-23 m, where pure mylonitic bands alternate with cm-wide zones of crush breccia. The varying ductility may be due to deformation during different stages in the development of the shear zone. It may also be caused by different deformation velocities or by different heat- or fluid flows.

Measurements of the zone (Figure 15) have been made in every mapping section up to 60 m. The width of the shear zone varies between 0.5 and 1.5 m. During excavation of the tunnel, the shear zone was found also in the tunnel face up to 60 m. Here, at the 60-70 m section, the zone has been faulted and is not visible in the present tunnel front or in the walls between 68-80 m. In total, ten measurements have been made in the shear zone. The mean orientation has been calculated to 029/54, with strike varying between 012-048° and dip between 40-65°. This is also the orientation for internal fracturing in the zone, implying reactivation of existing shear foliation. Spacing between internal fracture planes is generally c. 5 cm. “True” spacing is however less than 5 cm, as sealed foliation planes that did not develop fracturing but potentially could do so, have a more narrow spacing. Individual fractures in the shear zone are filled mainly with epidote in up to 1 cm thick zones.

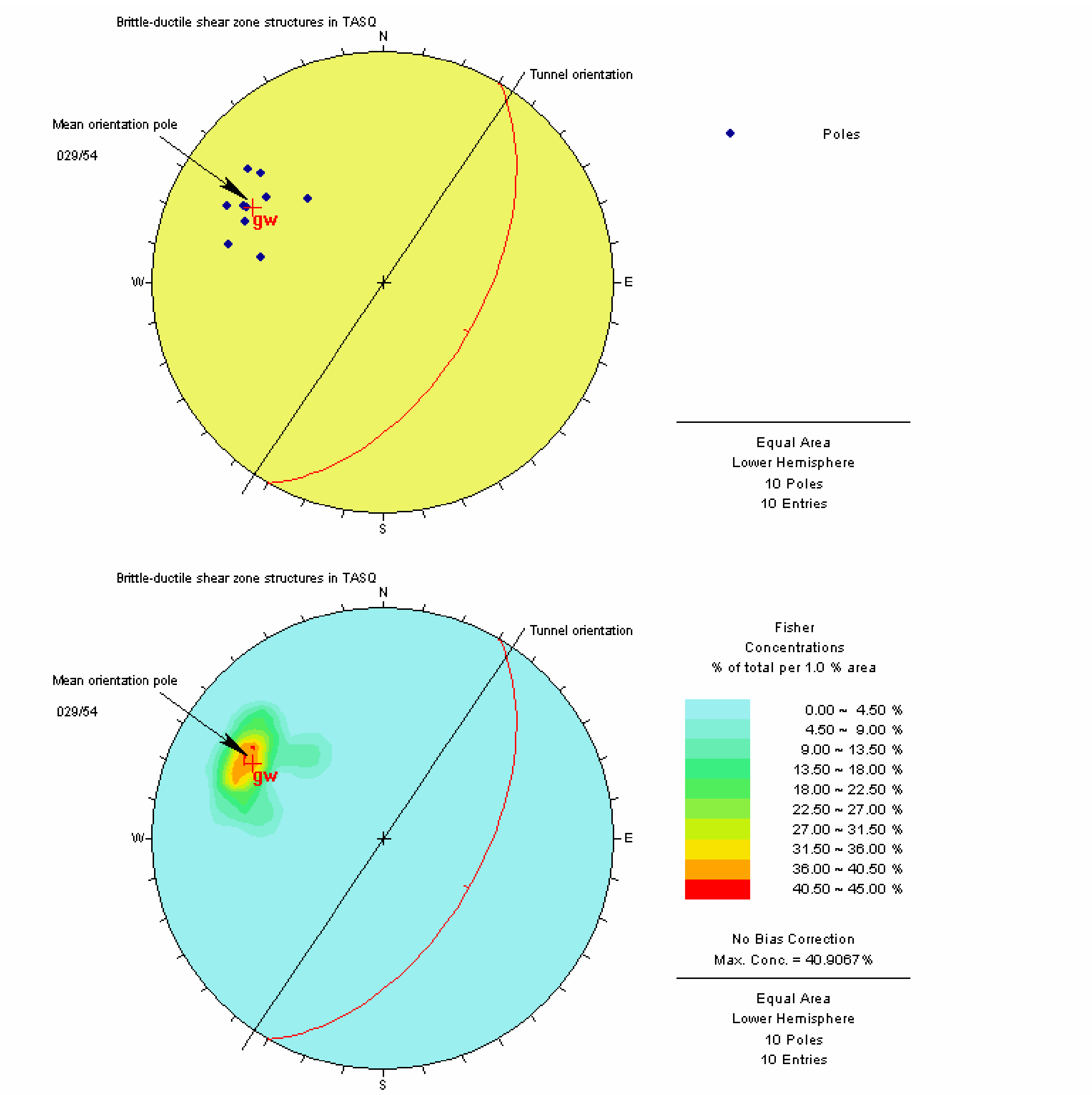


Figure 15: *Stereographic projections showing the measurements of the brittle-ductile shear zone running parallel to the Q-tunnel. Mean orientation of the measurements is 029/54. The great circle representing the mean value plane is shown, just as is the mean value pole.*

A complementary core logging focused entirely on structures was performed on a core drilled pre-excavation of TASQ and almost parallel with the tunnel (borehole KA3376B01). No consideration was taken to rock types, as the regular core log already existed. The results are presented in appendix 3. The logging shows that the shear zone was penetrated by the borehole in two main areas. Between 16 and 18 m the core has probably cut the shear zone margins, as the drill core is partly, but not entirely protomylonitic and/ or brecciated. In section 40 to 45 m the core has cut through both the zone margins and the main deformation zone, including true mylonite. Oxidation associated with the shear zone also was found in the vicinity of the sheared areas.

It is interpreted that the shear zone mapped in the TASQ may be a continuation of the deformation zone NE-2. When comparing with the Rock Visualization System model of the TASQ area, no zone has been predicted (Figure 1). However, 35-40 m to the east, in the TBM tunnel, the fracture zone NE-2 has been predicted by extrapolation to the 450 m level /Rhén, et.al, 1997/, but is not found in the tunnel. The properties and orientation of the NE-2 correlate fairly well with the shear zone mapped in the Q-tunnel, although the latter is somewhat more narrow and has a more gentle dip.

3.4 Displacements

Twelve locations of minor displacement due to faulting have been mapped. Offset is as most 0.3 m and generally 0.1-0.2 m. Offset in TASQ is generally seen on displaced fractures or dikes. As seen in stereo plots (Figure 16), no main orientation for faults can be found, but seem to be randomly distributed.

There are, however, three larger faults which were not included in the regular mapping, as they were discovered after the floor was uncovered and mapping was completed. The faults belong to the NW-SE/sub vertical set that strikes perpendicular to the tunnel. These faults are situated at 59 m, 64 m and 69 m in the tunnel and the two latter delimit the APSE test section. Amount of displacement along these faults must exceed 1-2 m, as the mylonitic shear zone has been faulted this much and after 69 m can not be seen at all. A brief and simplified map of these faults is shown in Appendix 2. Two of the fractures can also be seen in Appendix 4 (geological map of the floor at 64-69 m), even though here not indicated as faults.

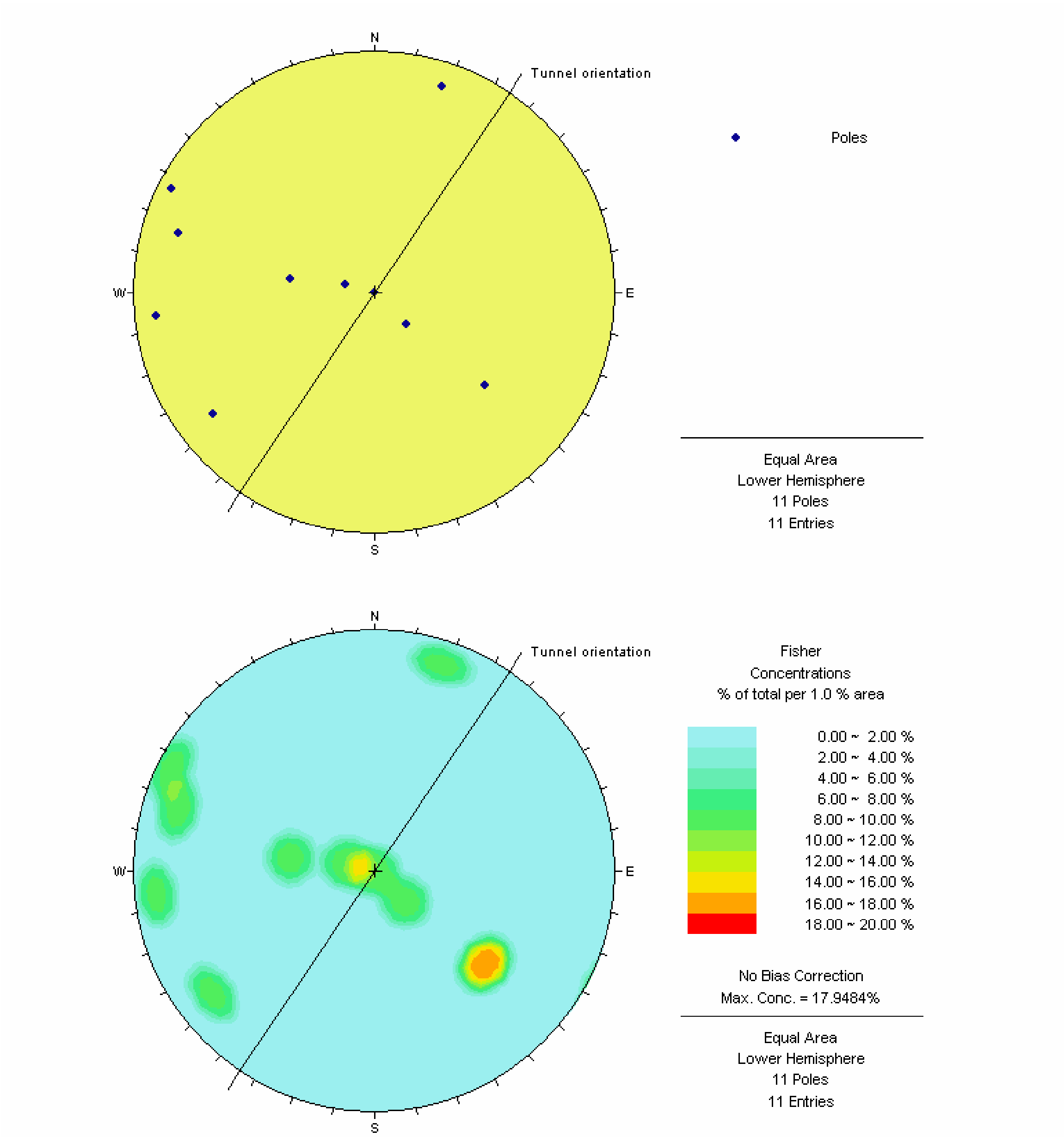


Figure 16: *Stereographic projections of all fractures in TASQ showing displacements. No main orientations can be found, small scale faulting (less than 0.3 m) appears to be random. Note that the larger scale faulting (in meter scale) along fractures oriented perpendicular to the tunnel not is shown in these projections, as they were discovered after the mapping was completed. An interpretation of these faults is instead presented in appendix 2.*

Striations

Only two striations have been measured in the Q-tunnel. Both of them trend NNE, have a gentle plunge and are found on similarly oriented surfaces (24→017 on fracture surface 017/74, 05→015 on fracture surface 014/80). Linear structures are presented as "plunge→plunge direction". Yet another striation has been found on a fracture surface similar to the two above (007/74), but could not be measured. Both the measured striations are of the type stretching lineation, which means their orientation is parallel to direction of movement. Although the striations are too few to give a reliable result, they indicate a gently plunging movement in NNE-SSW.

3.5 Water

Leakage in the TASQ is mainly caused by fractures (Figure 17). In 57 of 85 locations with leakage the water originates from fractures. Leakage from the wall rock has been mapped in 22 locations. It should be noted that the term "leakage from the wall rock" is a term used by SKB representing undefined leakage source, most probable from micro fractures. In 5 locations the leakage is caused by boreholes and in 1 location water is leaking from a fracture zone.

Water bearing fractures have been subdivided into three subgroups, v, vv and vvv, where "v" stands for moist, "vv" for dripping water and "vvv" stands for flowing water.

Fifty two (52) fractures were found to be water bearing. From these, 41 belong to the "v"-group, 8 to the "vv"-group and only three to the "vvv"-group. Every other leakage location (from wall rock, boreholes and fracture zones) only generates "v" leakage.

Water bearing fractures in total are concentrated to the set striking NW-SE and dipping sub vertically (Figure 18). Looking at the "vv" and "vvv" leaking fractures they exclusively belong to this set perpendicular to the tunnel. Thus, the pattern in TASQ follows the pattern of the whole Äspö HRL, where this set of NW-SE/sub vertical structures is associated with leakage. The "v" group spread more, but still shows some concentration to the same orientation.

A few fractures between 20 and 30 m displayed heavy leakage during mapping shortly after excavation, but subsequently ceased leaking. For example, fracture 5 (Appendix 1), striking WNW-ESE and dipping sub vertically, was leaking more than 1 litre/minute immediately after excavation, 1 litre/minute during mapping and was completely dry one week after mapping. The same pattern goes for fracture 4 in the same section. It has the same orientation as fracture 5, perpendicular to the tunnel.

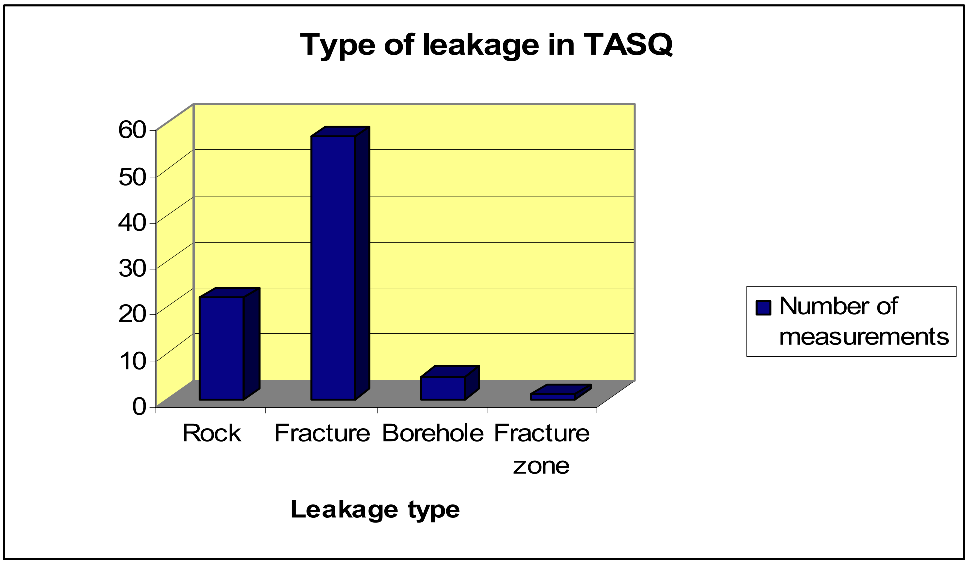


Figure 17: *Origin of water leakage in TASQ. The group of leakage from "rock" is more correctly ascribed to micro fractures. For mapping practical reasons, the water origin is however in these cases ascribed to the rock itself.*

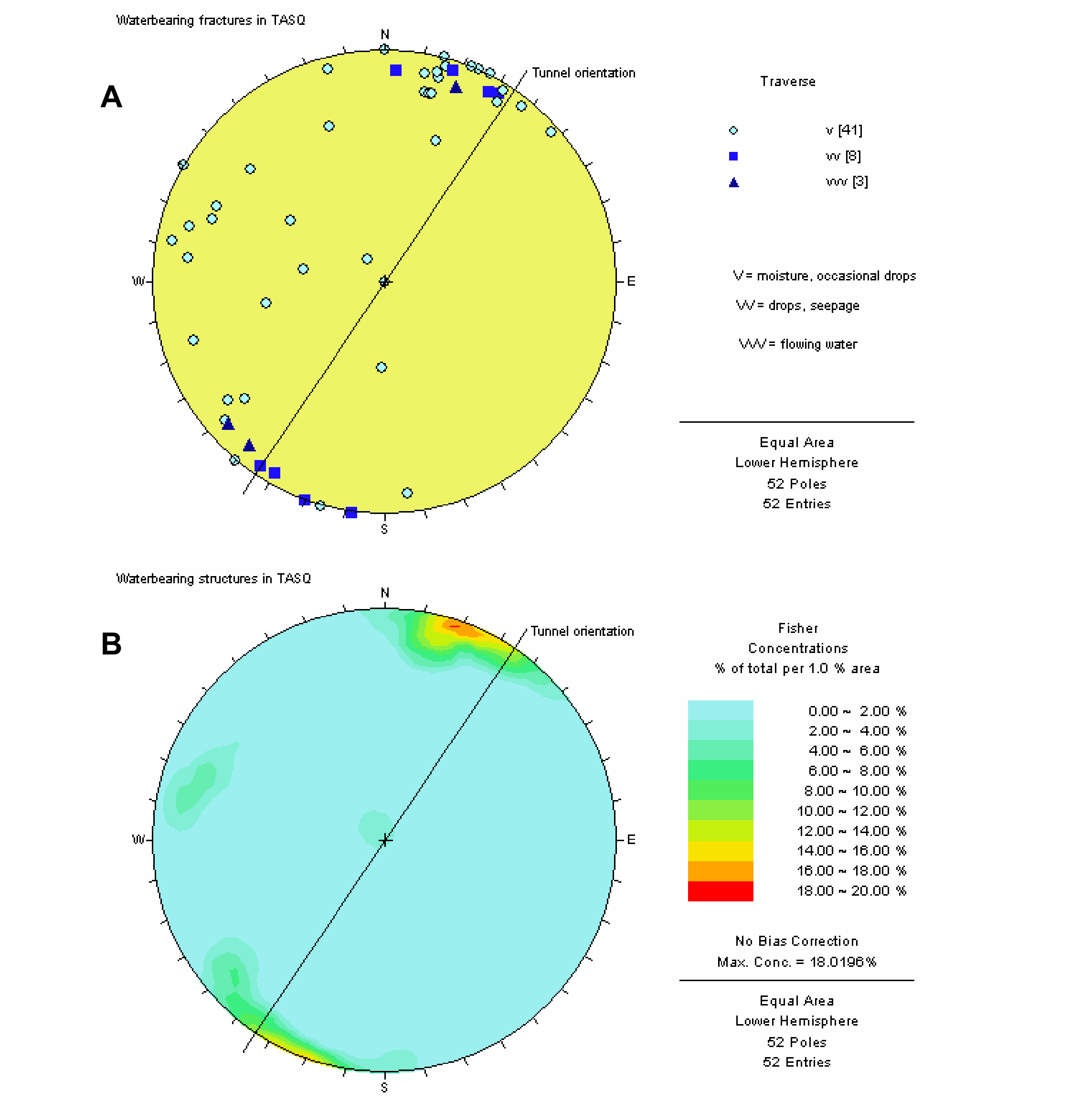


Figure 18: *A/ Stereographic projection showing water leakage in TASQ. Water flow has been separated into three classes depending of amount of water, see figure for definition of the classes. B/ Contoured stereographic projection showing all water bearing fractures in TASQ.*

4 References

Fransson, Å., 2003: Äspö Pillar Stability Experiment. Core boreholes KF0066A01, KF0069A01, KA3386A01 and KA3376B01: Hydrogeological characterization and pressure response during drilling and testing. SKB IPR-03-06

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

Staub, I., Janson, T., Fredriksson, A., 2003: Geology and properties of the rock mass around the experiment volume. Äspö Pillar Stability Experiment. SKB IPR-03-02

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

Appendices

Appendix 1

Geological map of the TASQ.

Contacts: $K_{\text{ID-NUMBER}}$ and dashed lines.

Fractures: ID-NUMBER and continuous lines.

Blanks: ID-NUMBER (included in fractures) and dotted lines.

Fracture zones: $Z_{\text{ID-NUMBER}}$ and dash dotted lines.

Water: Capital letter and v-vvv (v = moisture, vv = drops seepage, vvv = flowing).

Not that each mapping cell has its own set of numbers.

Mapping cells: 10-20m, 20-30m, 30-35m, 35-40m, 40-45m, 45-60m, 60-70m, 70-80m, 80m front

Appendix 2

Brief observations of faulting of the shear zone (red lines) presented on layout map from the tunnel floor at 55-73 m. No true orientations have been measured, merely approximated. There is no doubt about, however that it is the same zone that has been mapped in the left tunnel wall along the major part of the tunnel, as approximated orientations as well as other characteristics are the same as in the rest of the shear zone.

Appendix 3

Complementary structural logging of drillcore KA3376B01. Note that lithologies have been previously logged, only structures have been added. Figure by Pär Kinnbom.

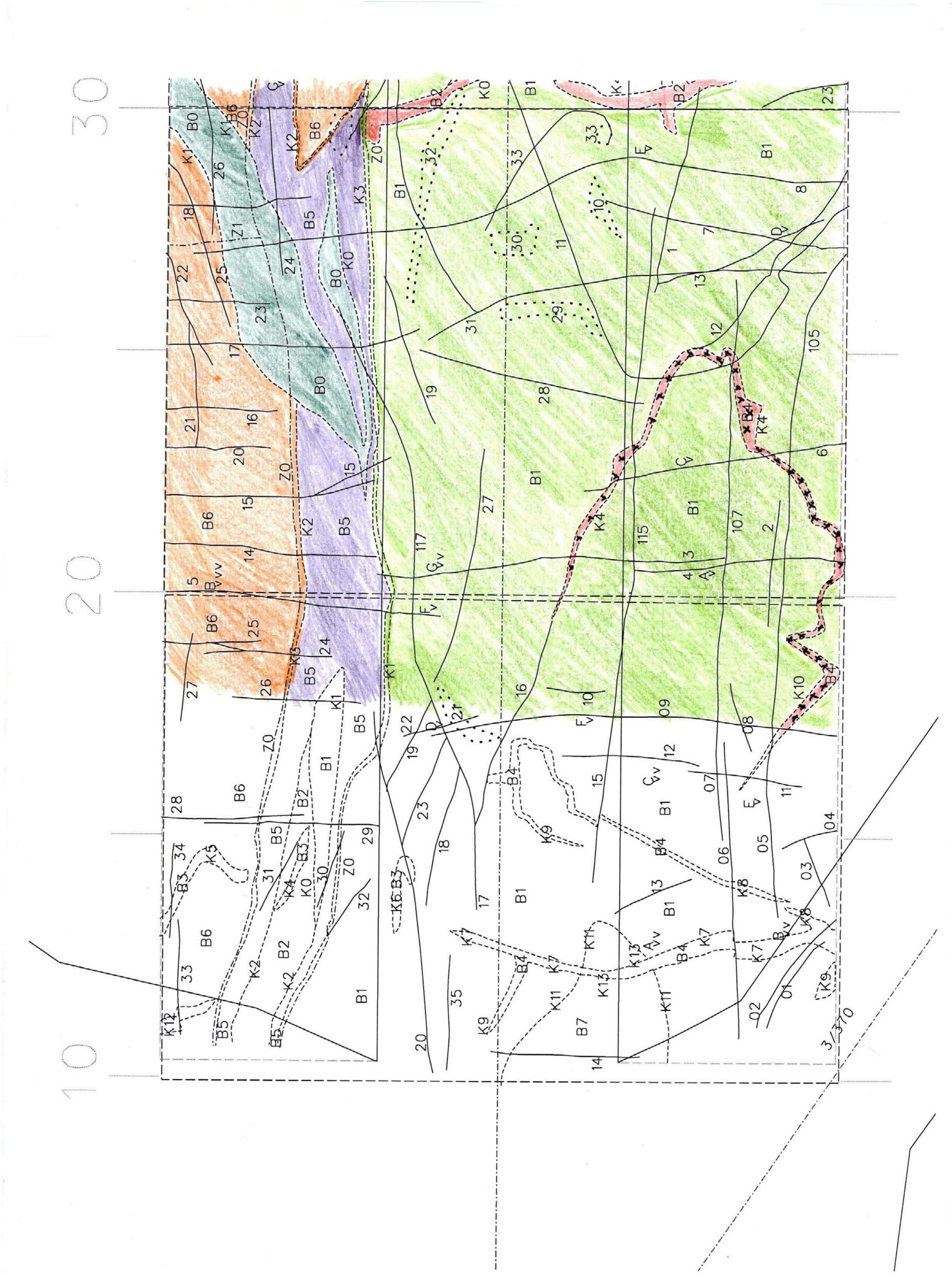
Appendix 4

Geological map of the floor at 64-69m. Mapping performed by Christer Andersson.

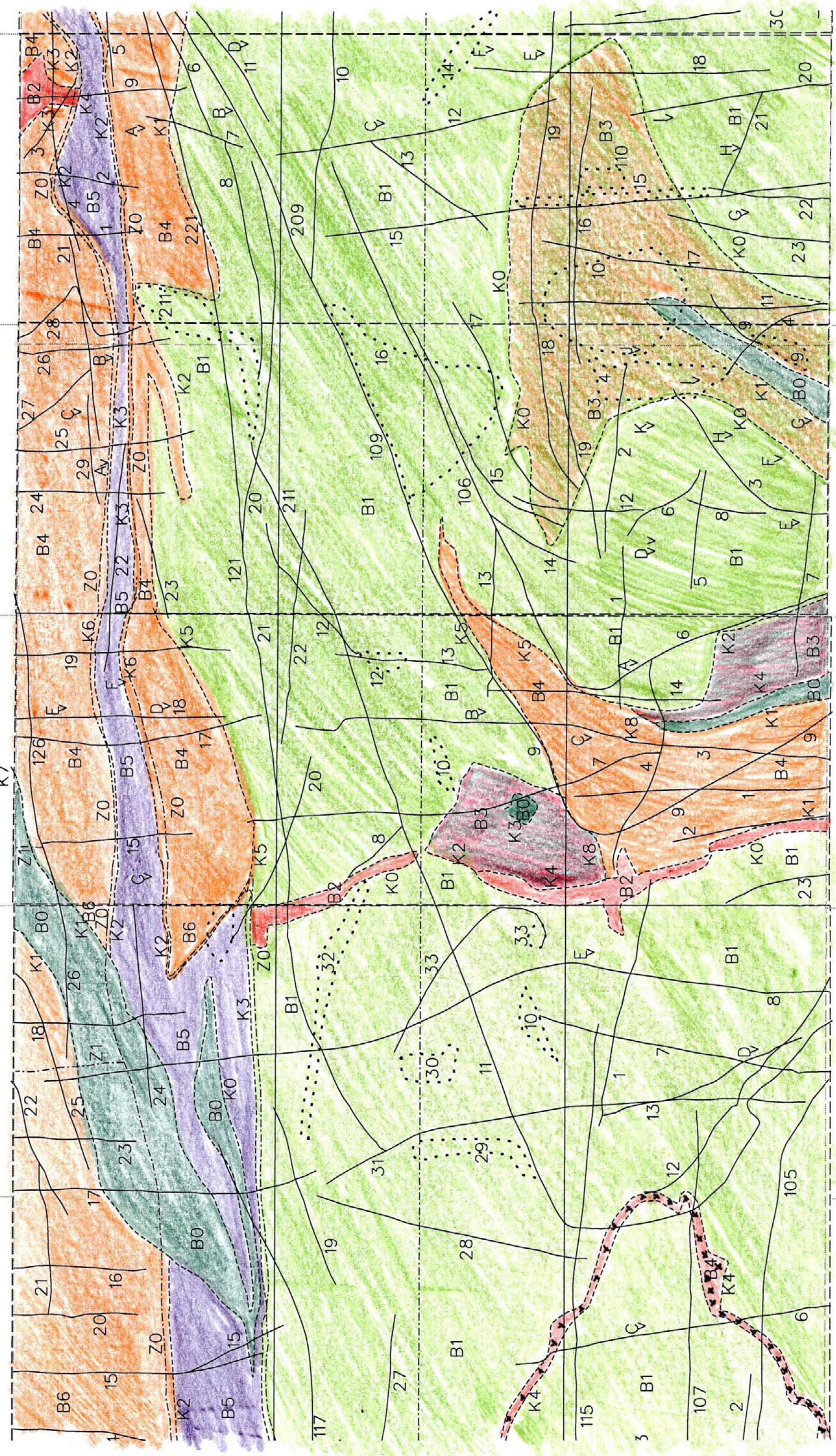
Rock types:
B1: Unaltered Äspödiorite
B2: Oxidized Äspödiorite
B3: Fine-grained granite
B5: Mylonite

Contacts, fractures, blanks and fracture zones are presented in the same way as in appendix 1.

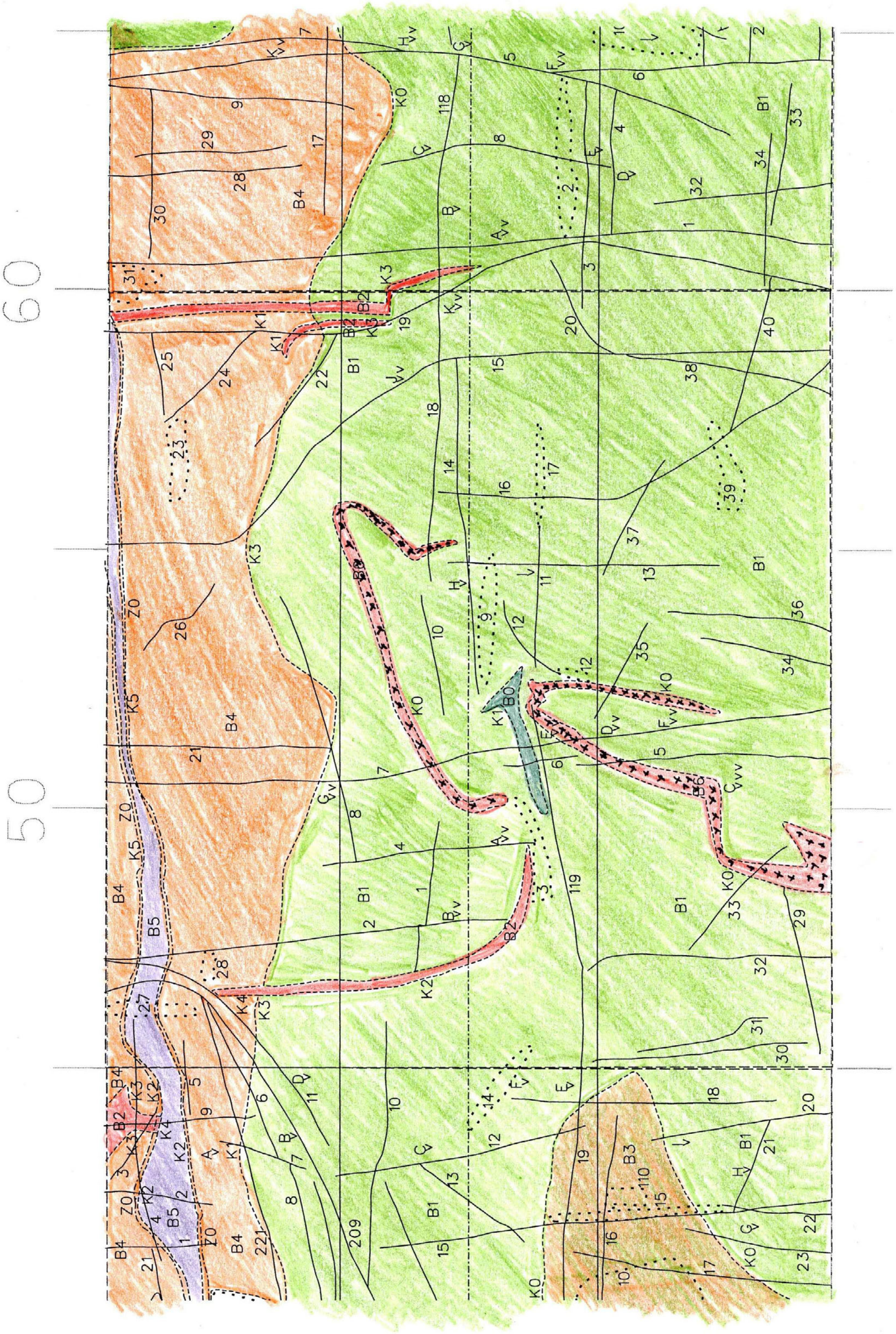
Appendix 1



Appendix 1 continuation

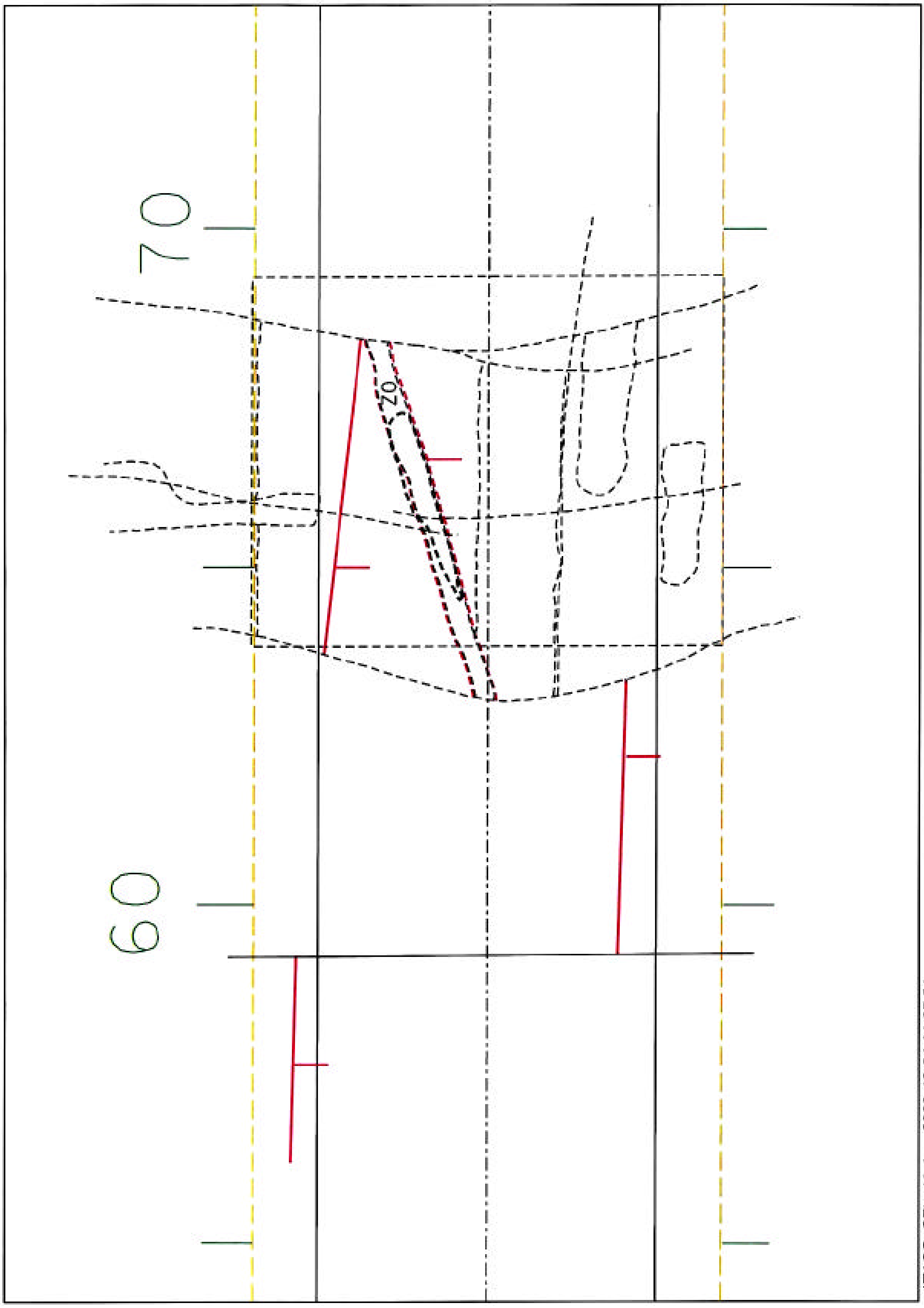


Appendix 1 continuation



Appendix 1 continuation

Appendix 2



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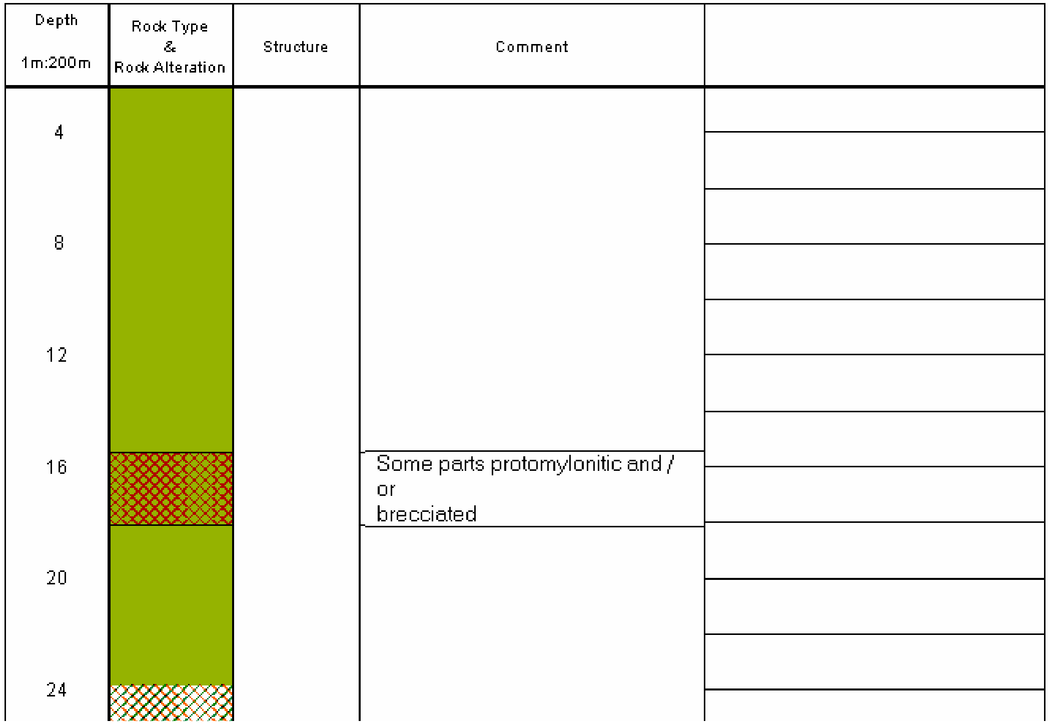
Title GEOLOGY KA3376B01

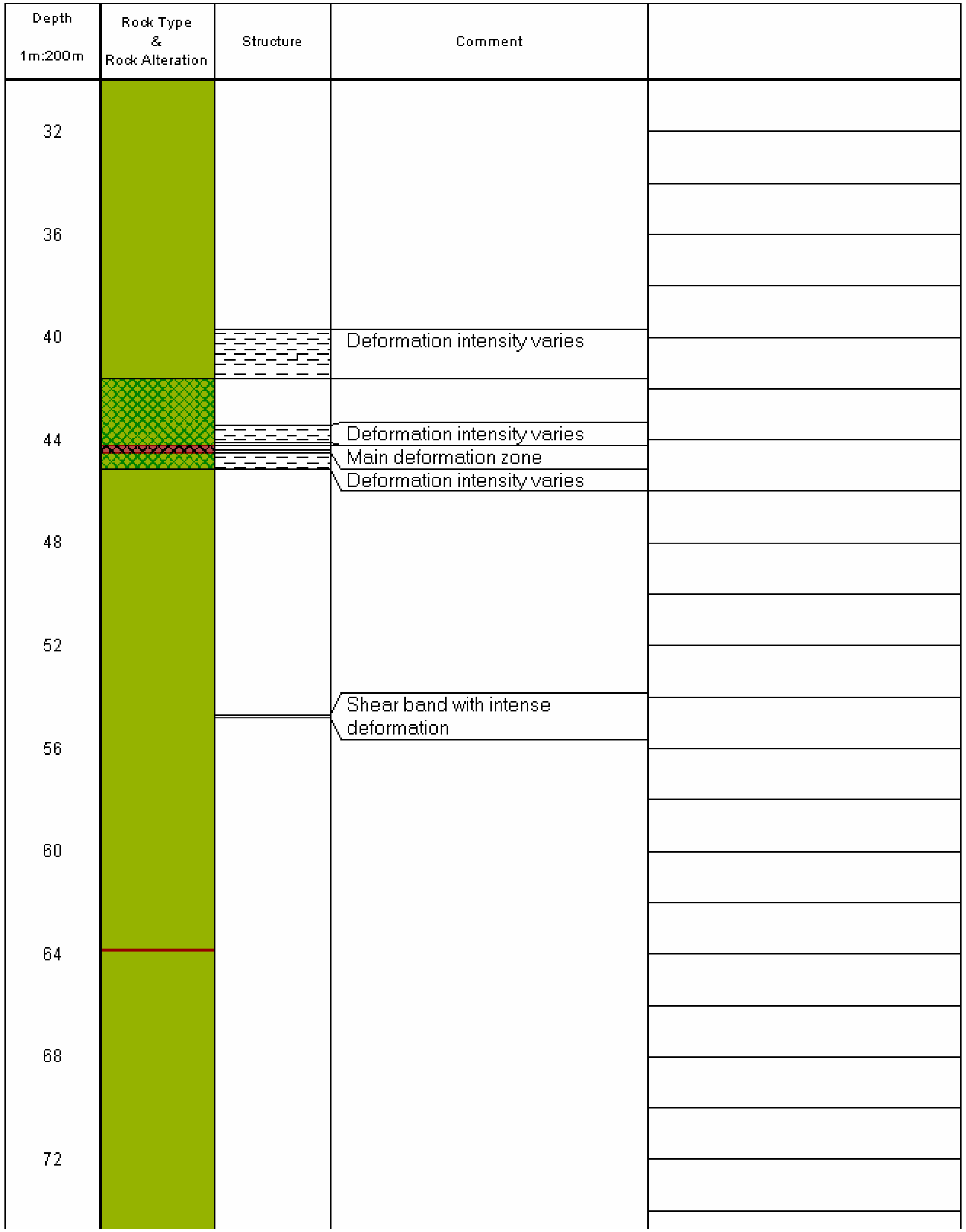
Site	ÄSPÖ	**Coordinate System**	RT90-RHB70
Borehole	KA3376B01	**Northing [m]**	6367810.222
Diameter [mm]	0.076	**Easting [m]**	1551377.107
Length [m]	80.19	**Elevation [m]**	-445.51
Bearing [°]	45.5362	**Drilling Start Date**	2002-11-08 15:22:00
Inclination [°]	-0.8962	**Drilling Stop Date**	2002-11-26 15:39:00
Remark		**Plot Date**	2003-12-09 09:28:18

ROCKTYPE SIMPEVARP
- Diorite
- Hybride Rock

ROCK ALTERATION
- Oxidized

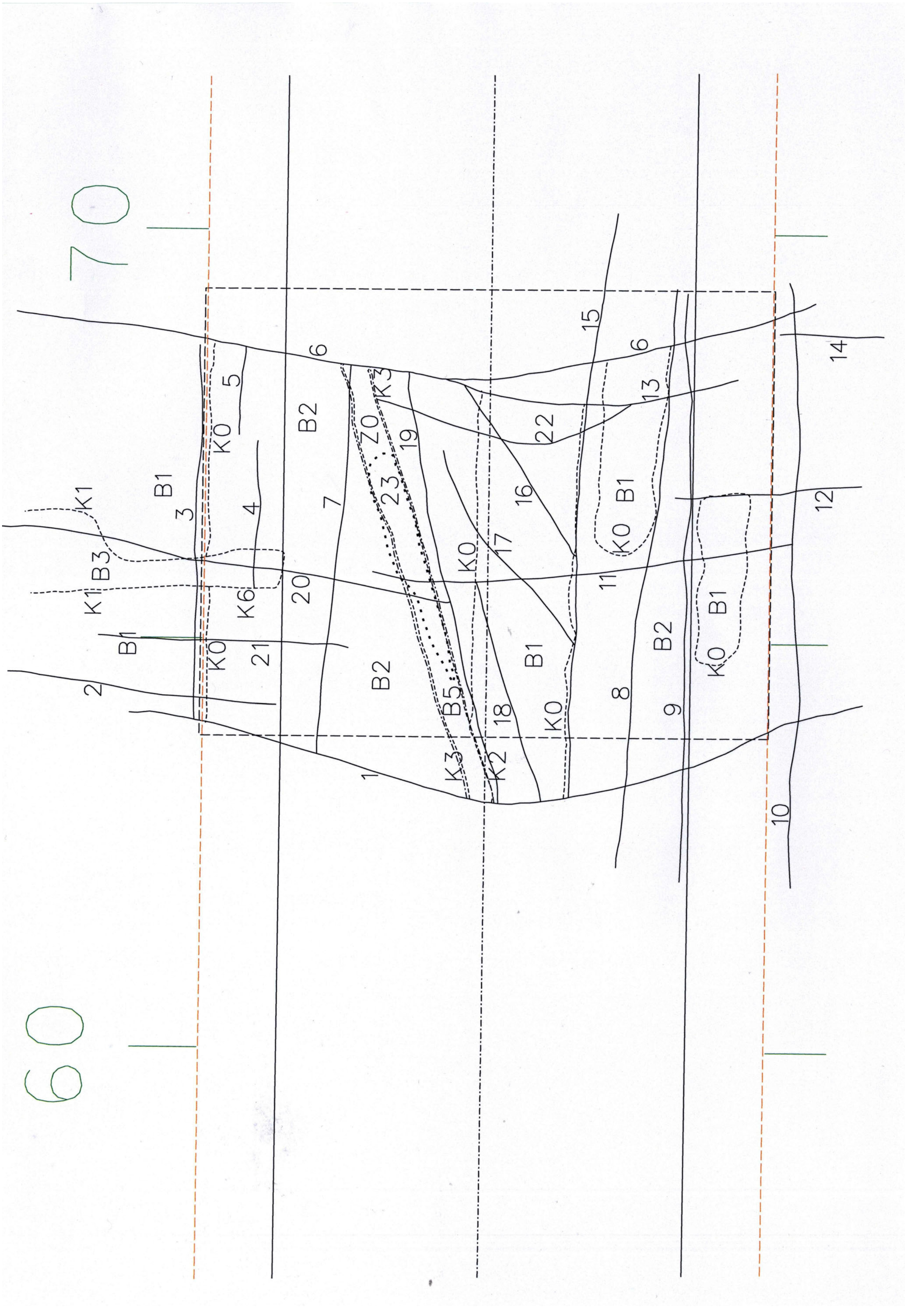
STRUCTURE





Appendix 3

Appendix 4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