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Äspö Hard Rock Laboratory

TRUE-1 Continuation project

Fault rock zones characterisation

Review of existing structural information and construction of local RVS models of four potential experimental sites

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January 2003

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Abstract

This report presents a review of structural information relating to water-conductive structures potentially useful for the Fault Rock Zones Characterisation programme and construction of focused structural models on selected target structures. From an original set of identified target structures, four structures were retained. Geometrical models were developed in the Rock Visualisation System (RVS) which also included secondary intersecting water-conducting features as well as existing boreholes of various types. The modelled geometries of the target structures, foremost based on the Tunnel Mapping System (TMS) data base, were compared with the corresponding interpreted geometries from the Fracture Classification and Characterisation project (FCC) and geometries provided by the GEOMOD project.

Sammanfattning

Denna rapport presenterar en sammanställning av strukturell information kopplad till vattenförande strukturer längs Äspötunneln, potentiellt användbara för projektet ”Fault Rock Zones Characterisation”, och geometriska strukturella modeller för utvalda strukturer. Från en ursprunglig grupp av vattenförande strukturer valdes fyra målstrukturer ut för fortsatt analys och modellering. Modeller upprättades i RVS och innehöll även andra ordningens vattenförande strukturer liksom förekommande borrhål av olika typer. Geometrier hos modellerade målstrukturer, företrädesvis baserade på tunnelkarteringen och dess databas, jämfördes med motsvarande tolkade geometrier från FCC och med geometrier modellerade i GEOMOD.

Contents

1 Introduction

The objective of the Fault Rock Zones Characterisation programme (part of TRUE-1 Continuation Project) is to characterise a number of typical fault rock zones of variable thickness with the specific objectives to assess their pore space characteristics and the *in situ* porosity of fault gouge. This is achieved primarily by injection of epoxy resin in the structures and subsequent sampling (overcoring) and analyses. Support is provided from structural geology, mineralogy and geochemical analyses. The study is also closely coordinated with a laboratory sorption programme specifically targeted on rim zone and fault gouge material.

Four tentative structures have been identified along the main access ramp in the Äspö Hard Rock Laboratory (Äspö HRL). The process of selecting suitable candidates for this experiment was based on the FCC detailed characterization of water-bearing faults along the tunnel system (Mazurek et al 1997). This data set is the most appropriate for finding a suitable structure as it was focused on describing the geological character in great detail. However, there may be other relevant structures in the laboratory as the Mazurek et al (1995) database only concentrates on features that intersect the whole tunnel periphery, not just a part of it and the fact that there are more tunnels available at present (early 2003) than in 1995.

The requirements defined for a suitable candidate geological structure include:

- Intersection of the tunnel
- Water-conducting
- Not grouted or covered by shotcrete
- Potential candidates for sampling fault gouge

The experiment requires that the chosen structure should be possible to intercept by new short boreholes in close vicinity to the tunnel in order to sample fault gouge and enable injection of epoxy resin for pore space analysis. The projected borehole intercepts should, if possible, be minimized to a distance in the order of 5 to 15 m away from the tunnel. Also, the chosen target structure should be in such a location so that it is feasible to place a drilling rig nearby without blocking the tunnel.

A scan of the Mazurek et al (1995) database produced a series of potential candidates, cf. Table 1-1.

Table 1-1. Compilation of potential suitable candidates for the Fault Rock Zones Characterisation programme (based on the Mazurek et al. (1995) database.

Tunnel length	Geological characteristics	Geometry	Width	Water inflow to the tunnel	Comments
1600 NE-2	1-2 master faults with some // fractures and splays, 1-2 clayish and mica-rich fault breccia zones 5-20 cm	N30E/70S	<1,5 m	0,8 and 0,5 l/min	Accessible, Dry in places. Very rich in chlorite and probably clay minerals. Sample collected
1905	Several subparallel fractures, 5-10 cm	N20W/steep		0,66 l/min	Relatively small structure. Possibly too close to niche
1990	1-2 master fault, fault crush grading to fault breccia 2-10 cm	N70W/steep	0,2-1 m	2 l/min ?	Accessible, Grout in Upper part? Corresponds to 1985 sampled for REX experiments
2163	1 master fault with few splays, small lenses <10 cm, and fault crush <1 cm	N50W/steep	0,1-0,2 m	0,12 and 6,24 l/min	Accessible, Close to microbial experiments in niche
2351	1 master fault, fault breccia 1.5 cm wide	N40W/steep	0,1-0,4 m	0,3 and 2,9 l/min	Accessible, One intersecting, fracture may complicate?
2369	1 master fault, fault crush to fault breccia lenses 3-20 cm wide	N50W/steep	0,3-0,8 m	3,5 l/min	Accessible, Pre-grouting
2430	1 master fault, some splays, fault breccia with thin clayish zones 2-10 cm wide	N15W/steep	0,3-0,8 m	Drop	Accessible, Similar to #19? Sample collected
2545	1-3 slightly curved master faults, intense small scale fracturing and crush, 1-20 cm	N50W/70S	1-2 m	0,05 l/min	Accessible, Grout? Complex structure

These potential candidate structures were controlled in the field and a "Comments column" was added describing the specifics of each candidate. Finally, it was decided to construct local structural models in the Rock Visualisation System (RVS) for the four most promising candidates, cf. Table 1-2. These models will ia. be used to guide the planning of the exploration drilling to be performed.

Table 1-2. Compilation of the most suitable potential candidates on which local RVS models are to be constructed.

Model	Tunnel length	Characteristics	Geometry	Width	Water inflow to the tunnel	Comments
A	2/545 m	1-3 slightly curved master faults, intense small scale fracturing and crush, 1-20 cm	N50W/70S	1-2 m	0,05 l/min	Readily accessible, Partially grouted!? Complex structure!
B	2/430 m	1 master fault, some splays, fault breccia with thin clayish zones 2-10 cm wide	N15W/steep	0,3-0,8 m	Drop	Readily accessible, Similar to Structure #19!? Sample collected!
C	2/163 m	1 master fault with few splays, small lenses <10 cm, and fault crush <1 cm	N50W/steep	0,1-0,2 m	0,12 and 6,24 l/min	Readily accessible, Close to microbe experiments in niche
D	1/600 m	1-2 master faults with some // fractures and splays, 1-2 clayish and mica-rich fault breccia zones 5-20 cm	N30E/70S	<1,5 m	0,8 and 0,5 l/min	Fracture zone NE-2. Readily accessible, Dry in places. Very rich in chlorite and probably clay minerals. Sample collected!

The locations of these local RVS models are illustrated in Figure 1-1.

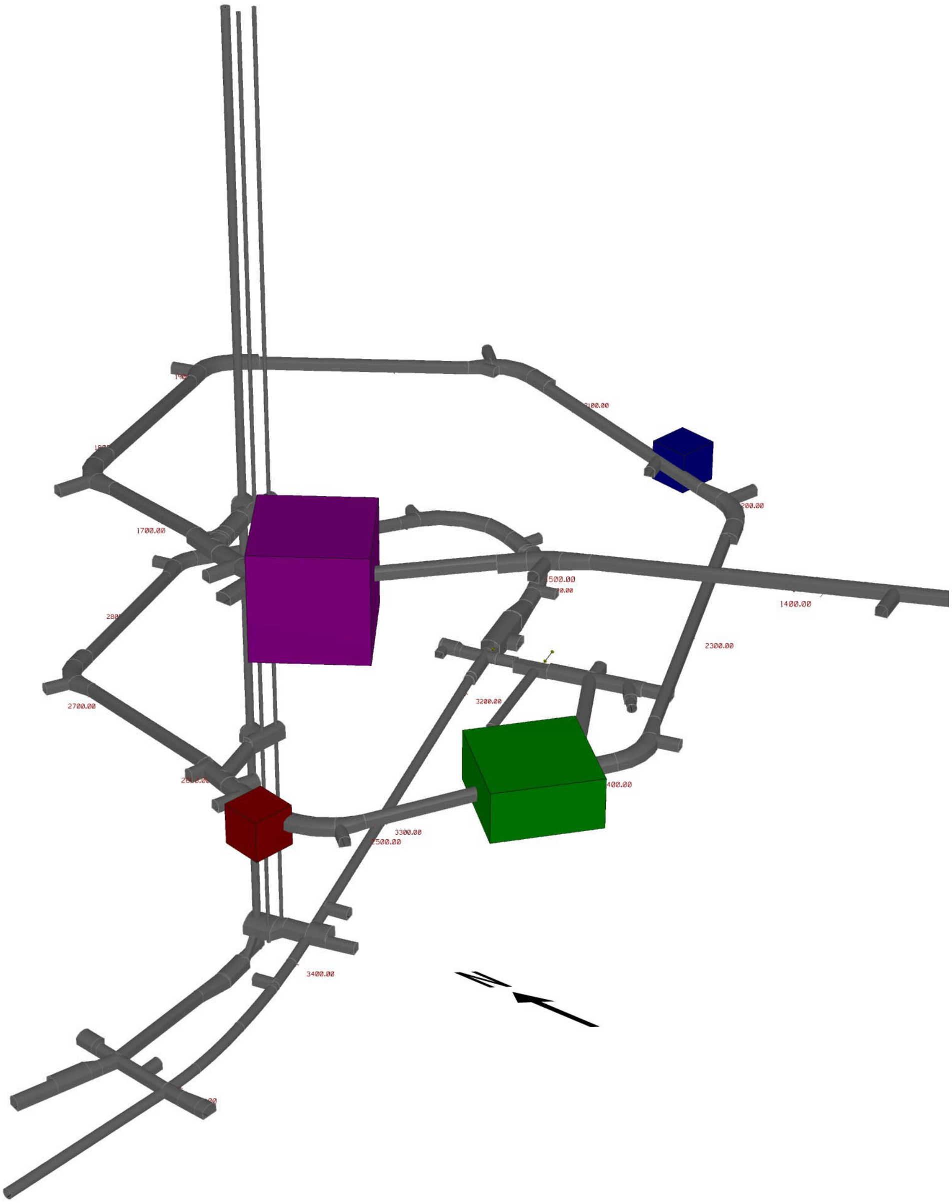

Figure 1-1 *Overview of the Äspö HRL spiral tunnel and location of tentative experimental sites for the Fault Rock Zones Characterisation programme. The boxes show the locations and sizes of the four structural RVS models. The colouring of the models A (red), B (green), C (blue) and D (purple), respectively.*

In the following sections detailed descriptions are given of each of these local RVS models. Each model was constructed to accommodate future amendments to the models and to enable use of the information in other work performed in the Äspö HRL. The modelling process used data available, not only from Mazurek et al (1995) but also the latest information from SICADA, TMS (the tunnel mapping system of Äspö HRL) and various experimental models such as TRUE Block Scale and GEOMOD models, were used. All coordinates in the text are provided in the RT90-RH70 system. The orientation of the system is the following: positive X-axis : East, positive Y-axis : North and positive Z-axis : upwards.

2 Model A, 2/545 m

2.1 Size of the model

The model is situated on the left side (outer side) of the tunnel centred at tunnel length 2545m, see Figure 1-1. The corners of the modelled cube are listed in Table 2-1, and the size of the model is 20·20·20 m^3.

Table 2-1. Coordinates defining the boundaries of Model A in the RT90-RH70 system.

RT90-RH70	Easting [m]	Northing [m]	Z [masl]
Corner 1	1551306.458	6367775.204	-328.000
Corner 2	1551326.446	6367774.506	-328.000
Corner 3	1551326.446	6367774.506	-348.000
Corner 4	1551306.458	6367775.204	-348.000
Corner 5	1551325.748	6367754.518	-328.000
Corner 6	1551305.760	6367755.216	-328.000
Corner 7	1551325.748	6367754.518	-348.000
Corner 8	1551305.760	6367755.216	-348.000

2.2 Existing boreholes in the vicinity of the model volume

There is only one borehole that intersects the model boundaries, SA2550A. This is a probe hole drilled during the excavation of the main tunnel and is associated with very little information. There is one core drilled hole (KA2563A) in the vicinity of the model apart from a few SA-holes. Figure 2-1 illustrates the existing boreholes in, and in the vicinity of, the model volume. Note that borehole KA2563A extends below the model volume. A thorough analysis of how the water-conducting sections of borehole KA2563A relates to the model volume has not been performed.

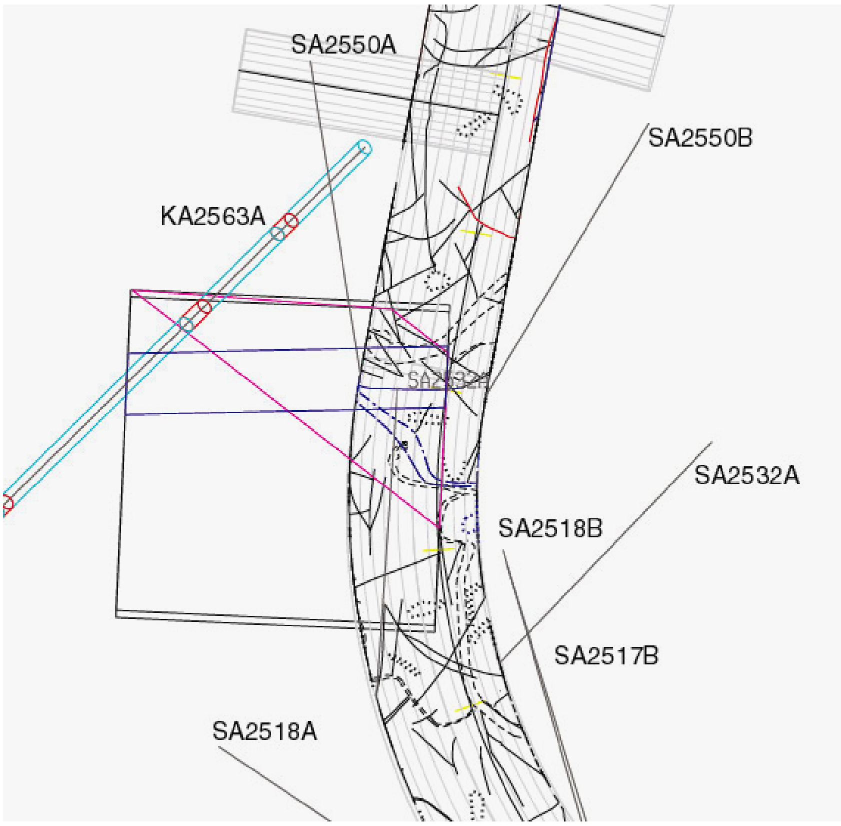

Figure 2-1 *Plan view of existing boreholes in or close to Model A.*

2.3 Water-conducting features from tunnel mapping

There are two water conductive features in the model volume according to the TMS tunnel mapping database. The main feature, in this investigation, is located at tunnel length 2545 m and is modelled to have an orientation of 307/65. The equation of the plane is 0.5454X + 0.7238Y + 0.4226Z - 5455058.113 = 0 (RT90-RH70). The second water-conducting fracture that intersects the model volume (visible in the TMS maps) is mapped at about tunnel length 2550 m. The fracture orientation is 268/78 and the equation of the plane is -0.0341X + 0.9776Y + 0.2079Y -6171762.337 = 0 (RT90-RH70). According to the TMS database no other water conductive fractures are mapped in the vicinity that can be assumed to intersect the model volume. Albeit the fact that the trace from fracture 2550 in the TMS maps is terminated against the trace from target fracture 2545, no termination is introduced on any fracture in the model, cf. Figure 2-2.

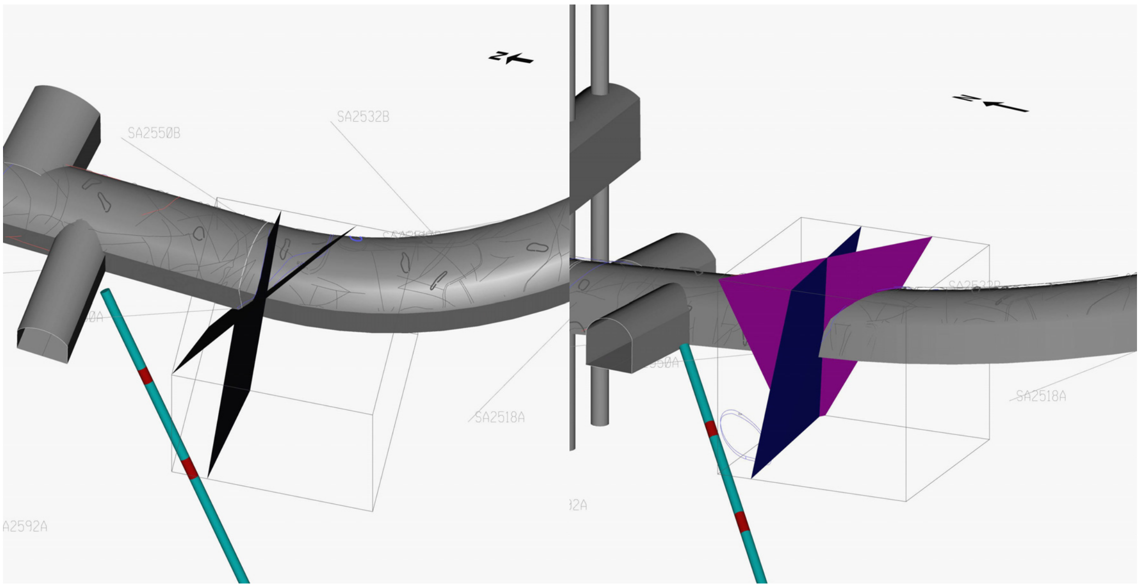

Figure 2-2 *Perspective view of the two major water-conducting structures in Model A. The purple feature is the target structure.*

2.4 Fractures from Mazurek et al (1995)

Mazurek et al (1995) do not mention any other feature than the present target structure at chainage 2545 m and this structure is attributed a geometry of 312/70˚.

2.5 Fracture zones

According to the GEOMOD model (Berglund et al., 2003), there are no zones crossing the model volume. The nearest zones identified from the geological model (Berglund et al., 2003) are the top part of HQ3 and NE-2 which is more than 20 m away from the model volume cf. Figure 2-3.

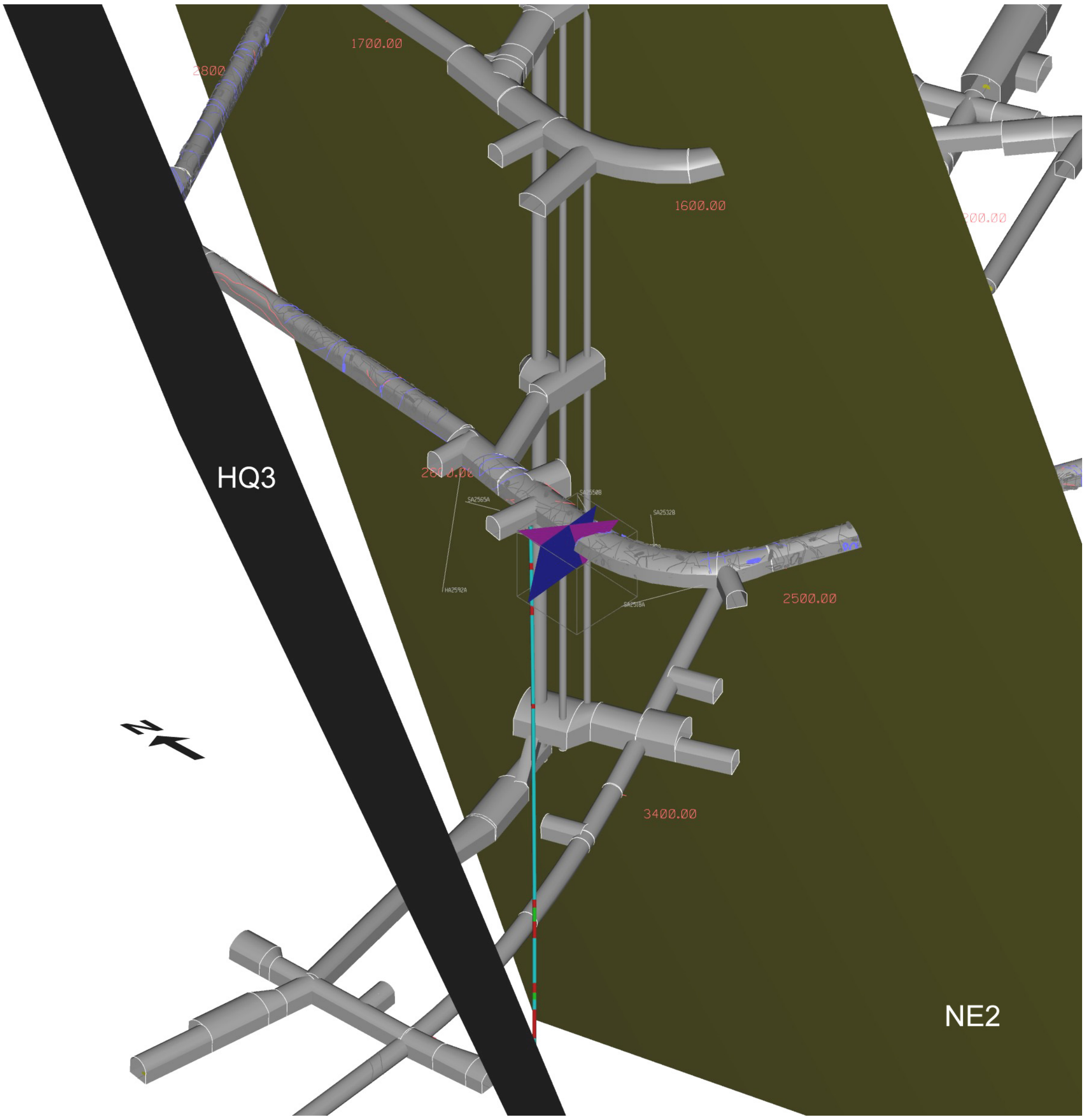

Figure 2-3 *The two major fracture zones NE-2 and HQ3 (Berglund et al., 2003) are close to the modeled volume.*

3 Model B, 2/430 m

3.1 Size of the model

The model is centred on the tunnel with its centre point at tunnel length 2430m, see Figure 1-1. The corners of the modelled cube are listed in Table 3-1. The model volume is $50{\cdot}50{\cdot}25\ m^3$.

Table 3-1. Coordinates defining the boundaries of Model B in the RT90-RH70 system.

RT90-RH70	Easting [m]	Northing [m]	Z [masl]
Corner 1	1551371.913	6367682.261	-310.000
Corner 2	1551398.409	6367724.663	-310.000
Corner 3	1551398.409	6367724.663	-335.000
Corner 4	1551371.913	6367682.261	-335.000
Corner 5	1551440.811	6367698.167	-310.000
Corner 6	1551414.315	6367655.765	-310.000
Corner 7	1551440.811	6367698.167	-335.000
Corner 8	1551414.315	6367655.765	-335.000

3.2 Boreholes

The only boreholes found inside the model volume are probe holes drilled during the excavation of the tunnel. These boreholes are SA2401A, SA2403B, SA2420A, SA2420B, SA2436A, SA2436B, SA2453A and SA2453B. Boreholes outside, but within 50 m from the model volume are, except from the SA holes, core holes KA2377A01 and KAS05 (collared at the surface) cf. Figure 3-1.

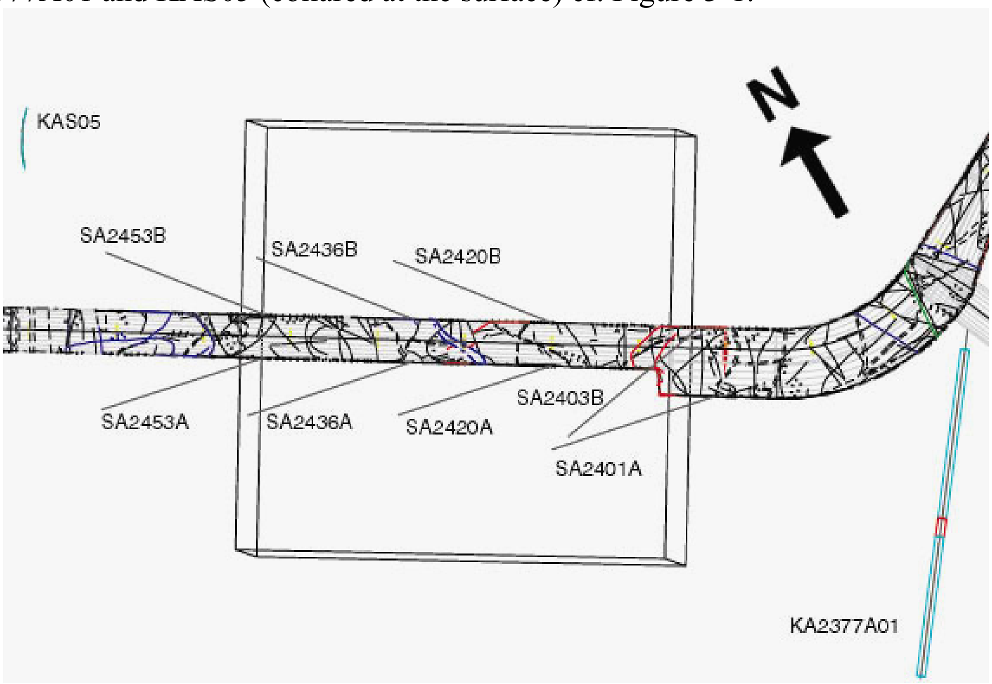

Figure 3-1 Illustration of the boreholes inside or in the vicinity of the Model B volume.

3.3 Water-conducting features from tunnel mapping

There is only one water-conducting feature in the model volume according to the TMS maps of this tunnel section. This feature is located at tunnel length 2430 m, and is modelled (based on the trace in TMS) to have a geometry of 341/87˚. The equation of the plane is -0.9442X + 0.3251Y -0.0524Z -3535087.964= 0 in RT90-RH70.

There are three minor water-conducting fractures, immediately below the model volume, that may intersect the model. The associated fractures are only affecting the west boundaries of the model (Chainage 2460) and are not intersecting the target feature 2430 within the volume.

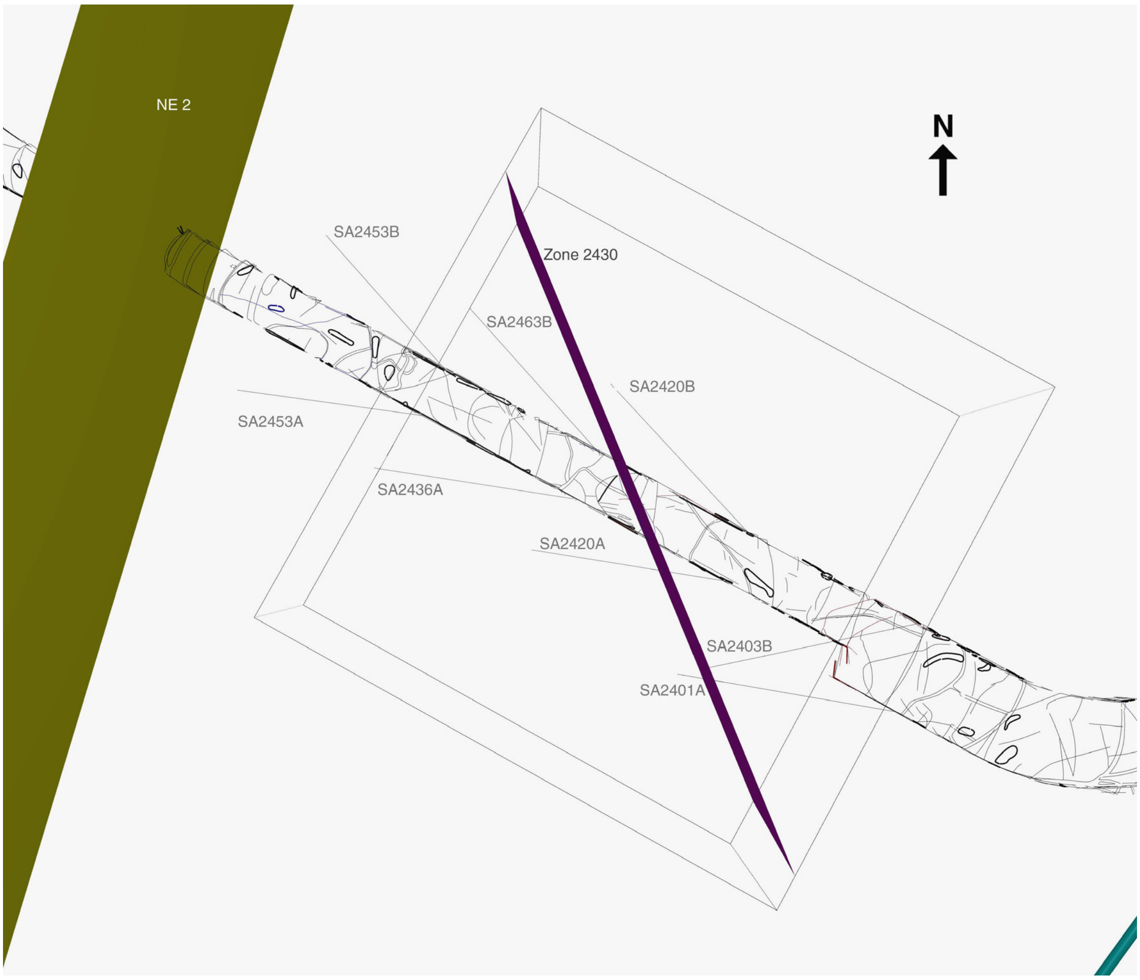

Figure 3-2 *The water conductive feature at 2430 m (purple), and the nearby deformation zone NE-2 (green).*

3.4 Fractures from Mazurek et al (1995)

Mazurek et al (1995) describes only the target feature at 2430 with an orientation of 345˚ and dipping between 85 to 90˚.

3.5 Fracture zones

According to the simplified planar geometry included in the GEOMOD model (Berglund et al., 2003), fracture zone NE-2 is passing about 15 m outside the volume (see figure 3-2). The accuracy of this interpretation at this level in the laboratory is presently unknown.

4 Model C, 2/163 m

4.1 Size of model

The model is situated on the left side (outer side) of the access tunnel with its midpoint at 2163 m, see Figure 1-1. The coordinates of corners of the modelled cube is listed in Table 4-1. The size of the model is 20·20·20 m^3.

Table 4-1. Coordinates defining the boundaries of Model C in the RT90-RH70 system.

RT90-RH70	Easting [m]	Northing [m]	Z [masl]
Corner 1	1551606.977	6367803.447	-279.000
Corner 2	1551626.965	6367802.749	-279.000
Corner 3	1551626.965	6367802.749	-299.000
Corner 4	1551606.977	6367803.447	-299.000
Corner 5	1551626.267	6367782.761	-279.000
Corner 6	1551606.279	6367783.459	-279.000
Corner 7	1551626.267	6367782.761	-299.000
Corner 8	1551606.279	6367783.459	-299.000

4.2 Boreholes

Only two probe holes from the excavation are intersecting the model volume. These are probe holes SA2142A and SA2160A and are not associated with data in a resolution that can be used to determine extensions of single fractures. There is only one cored borehole in the vicinity, namely KA2162B. This borehole is directed away from the model volume cf. Figure 4-1.

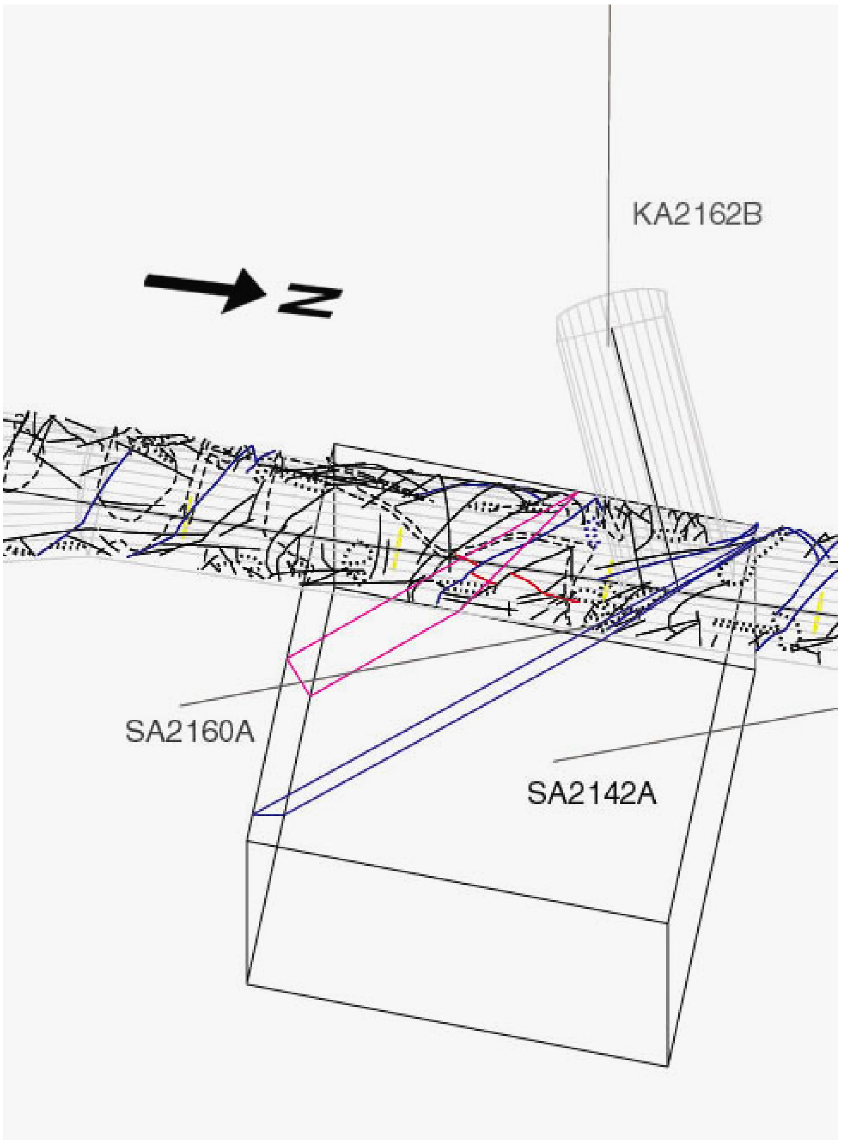

Figure 4-1 *Perspective view from the east of the the two probe holes present in Model C and also showing borehole KA2162B, directed away from the model volume . The main target feature at 2163 m is illustrated in blue outline and another water-conducting structure at 2154 m is shown in red outline.*

4.3 Water-conducting features from tunnel mapping

There are at least two, almost parallel, water conductive features in the model volume according to the TMS maps. The target feature, for this investigation, is located at tunnel length 2163 and is modelled, based on the TMS trace map, to have a geometry of 139/79˚. The equation of the plane is described by $-0.7408X -0.6440Y + 0.1908Z + 5250280.238 = 0$ in RT90-RH70 cf. Figure 4-2.

The second water-conducting fracture in the model volume is mapped at about tunnel length 2154m. The fracture geometry is 140/75º and the equation of the plane is described by $-0.7399X -0.6209Y + 0.2588Z + 5101866.1 = 0$ in RT90-RH70 cf. Figure 4-2.

There is a third short trace that has not been modelled since it terminates immediately inside the model volume. Another water-conducting fracture intersects the tunnel just outside the model volume at a tunnel length of about 2158 m. This fracture is striking NNW and is running almost parallel to the tunnel. It will intersect the model volume but its orientation is not a concern for the experiment. Therefore this fracture is not modelled.

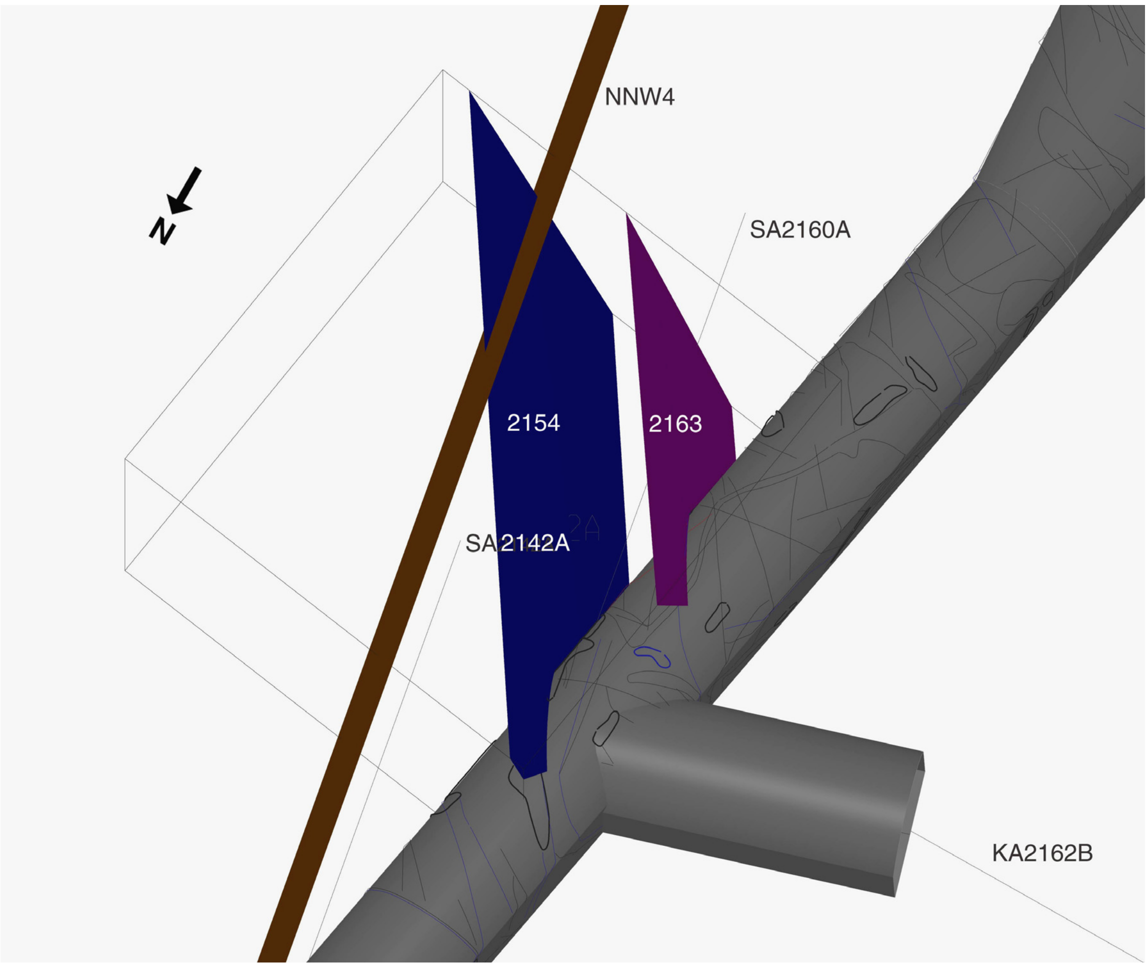

Figure 4-2 *The three major conductive features in the C-model. The NNW4 (brown) is present according to the GEOMOD model (Berglund et al., 2003).*

4.4 Fractures from Mazurek et al

Mazurek et al (1995) defines 3 fracture traces in the tunnel close to Model C at 2159, 2154 and 2163 m, respectively. The fracture at 2163 m has a geometry of 128/90˚ according to Mazurek et al (1995). This should be compared with the modelled geometry 139/79˚, based on the TMS maps. The fracture at 2154 has an orientation of 136/84˚ according to Mazurek et al. (1995) which most likely corresponds to the geometry as modelled in this study (140/75˚). The structure mapped by Mazurek et al at 2150 (120/90˚) is probably outside the model volume.

4.5 Fracture zones

According to the GEOMOD model (Berglund et al., 2003) fracture zone NNW-4 crosses right through the modelled volume cf. Figure 4-2. In this case, this is not considered as data from the TMS database does not support this interpretation.

5 Model D, 1/600 m

5.1 Size of model

The model is centred on the tunnel with its centre point at tunnel length 1600m, see Figure 1-1. The corners of the model cube are listed in Table 5-1. The size of the model is 50·50·50 m^3.

Table 5-1. Coordinates defining the boundaries of Model D in the RT90-RH70 system.

RT90-RH70	Easting [m]	Northing [m]	Z[masl]
Corner 1	1551301.804	6367751.679	-194.922
Corner 2	1551339.064	6367785.020	-194.922
Corner 3	1551339.064	6367785.020	-244.922
Corner 4	1551301.804	6367751.679	-244.922
Corner 5	1551372.406	6367747.759	-194.922
Corner 6	1551335.145	6367714.418	-194.922
Corner 7	1551372.406	6367747.759	-244.922
Corner 8	1551335.145	6367714.418	-244.922

5.2 Boreholes

This model volume contains a number of boreholes. Excluding the 8 probe holes that intersect the volume (SA1564A/B, SA1581A/B, SA1597A/B, SA1614A/B), there are also the percussion-drilled holes HA1591A, HA1613B, and the cored holes KAS05 and KA1623A.

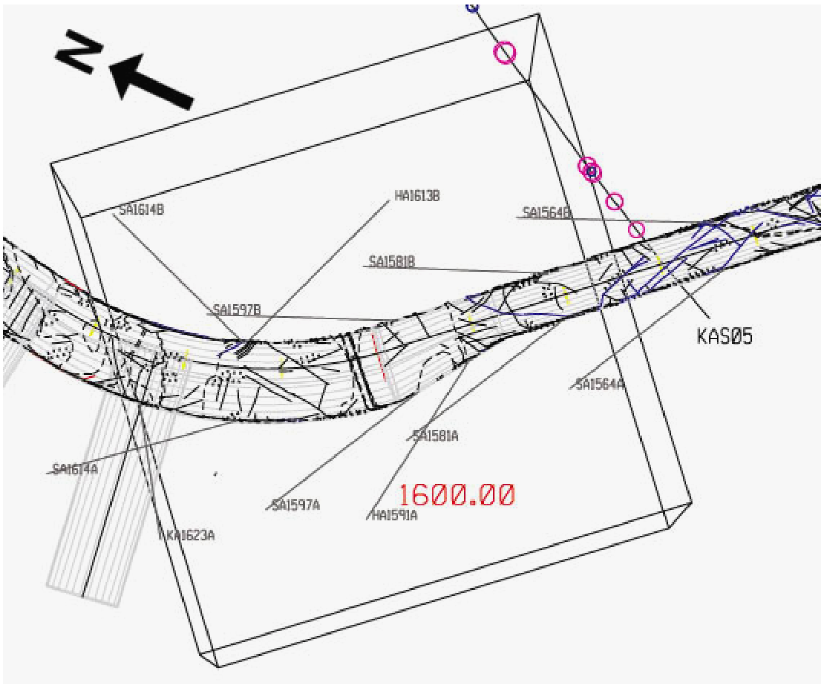

Figure 5-1 *View from above showing all boreholes in, or partly, within Model D.*

5.3 Water-conducting features from tunnel mapping

There are three traces of interpreted water-conducting features that complete the tunnel perimeter and several small traces that only cover a minor portion of the perimeter. Only the features that are seen around the whole tunnel perimeter are modelled since the size of the fractures corresponding to the ones with incomplete traces are hard to estimate cf. Figure 5-2.

The main target feature is situated at tunnel length 1600m and corresponds to the interpreted fracture zone NE-2. From the TMS tunnel mapping it is interpreted to have a geometry of 44/85˚. This differs somewhat from other interpretations, see section 5.4 and 5.5. The plane is described by the equation 0.7166X - 0.6920Y + 0.08715Z + 3294938.162 = 0, in RT90-RH70 coordinates.

The second feature intersects the tunnel at a tunnel length of about 1575m. It has a geometry of 100/85˚. The equation of this plane is described by -0.1730X - 0.9811Y + 0.0872Z + 6515508.468 = 0. The latter structure is interpreted to be terminated at the main feature, NE-2. Several traces from the TMS maps located immediately outside the model volume are sub-parallel to the 1575m feature and inbetween them there are a few water-conducting features (perpendicular to the primary orientation) that truncates against the features sub-parallel to the 1575 feature.

The third feature is located at about tunnel length 1585m and is interpreted to be terminated against both of the above mentioned features. It has an interpreted geometry of 340/67˚. The equation of the fracture plane is described by;
0.8649X + 0.3150Y + 0.3908Z -3347399.498 = 0.

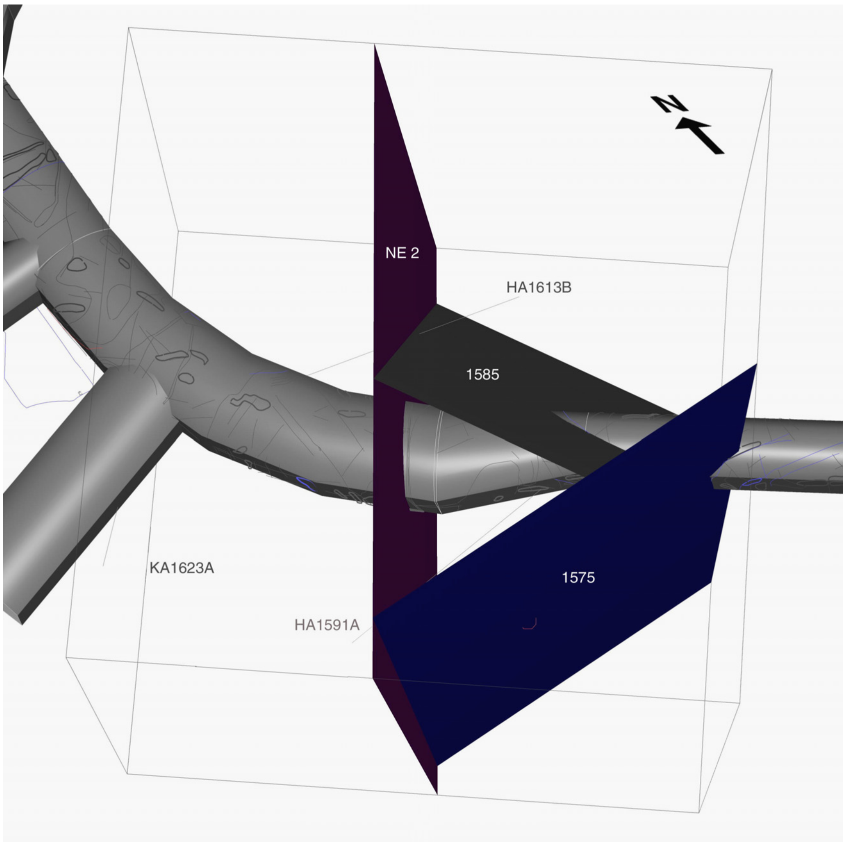

***Figure 5-2** Perspective view of the three major conductive features within Model D.*

5.4 Fractures from Mazurek et al

The three features described in Section 5.3 are also described in Mazurek et al. (1995) at 1602, 1594 and 1575 m. Mazurek et al suggests that fracture zone NE-2 should be attributed a geometry of 30/70˚. This should be compared to the orientation of the zone as modelled here (44/85˚). It is difficult to model this structure as its areal coverage in the TMS maps is wide and very irregular in shape, varying from one side to the other in the tunnel.

The feature at 1594 m in Mazurek et al is most likely the feature here modelled at 1585 m. The geometry of the feature as modelled here is 340/67 while Mazurek et al suggests 0/80. The third feature at 1575 m is suggested by Mazurek et al to have a geometry of 100/85 which is equivalent to how it is modelled in this study.

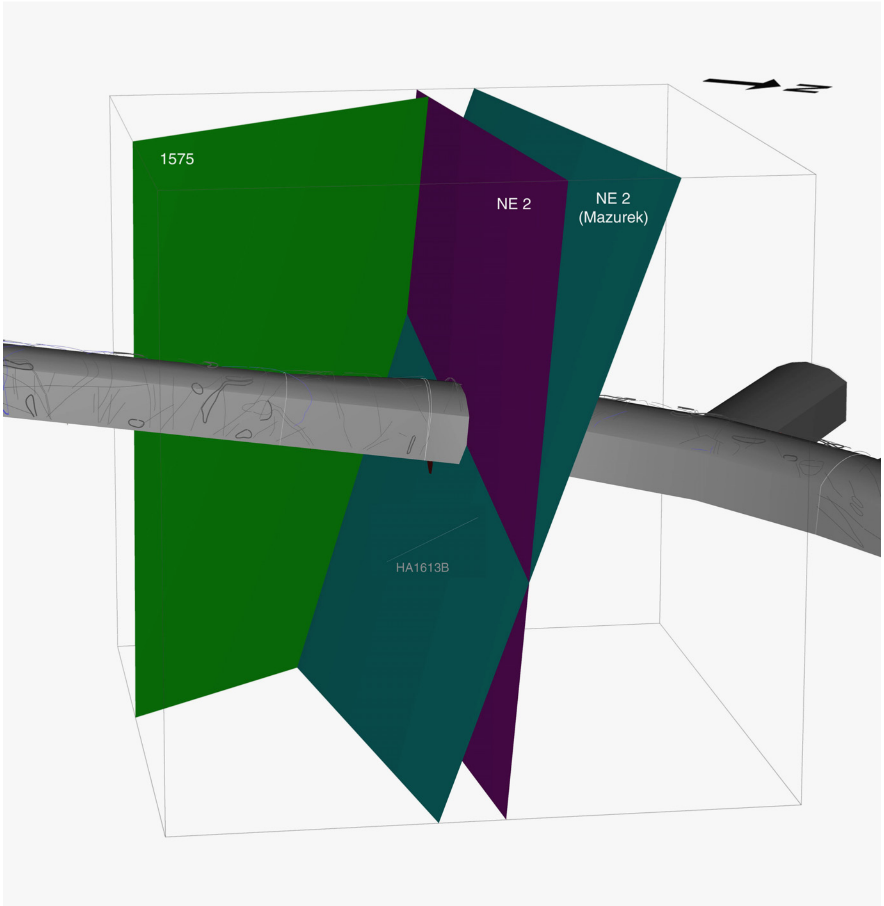

Figure 5-2 *Perspective view showing fracture zone NE-2 (target structure 1600) as modelled in this study (blue) and the Mazurek et al (1995) interpretation (dark green).*

5.5 Fracture zones

According to the GEOMOD model (Berglund et al., 2003), NE-2 intersects the model, but at a tunnel length of 1593m, i.e. displaced some 7 m towards the tunnel entrance. This is most probably an effect of the zone being modelled as a plane while the actual intercepts at different depths show a more undulating behaviour of the zone. The zone according to GEOMOD is also quite different in terms of its local orientation compared to the zone as modelled in this study. This is also evident in the TMS maps where the zone traces are found to be highly irregular at the various tunnel intercepts.

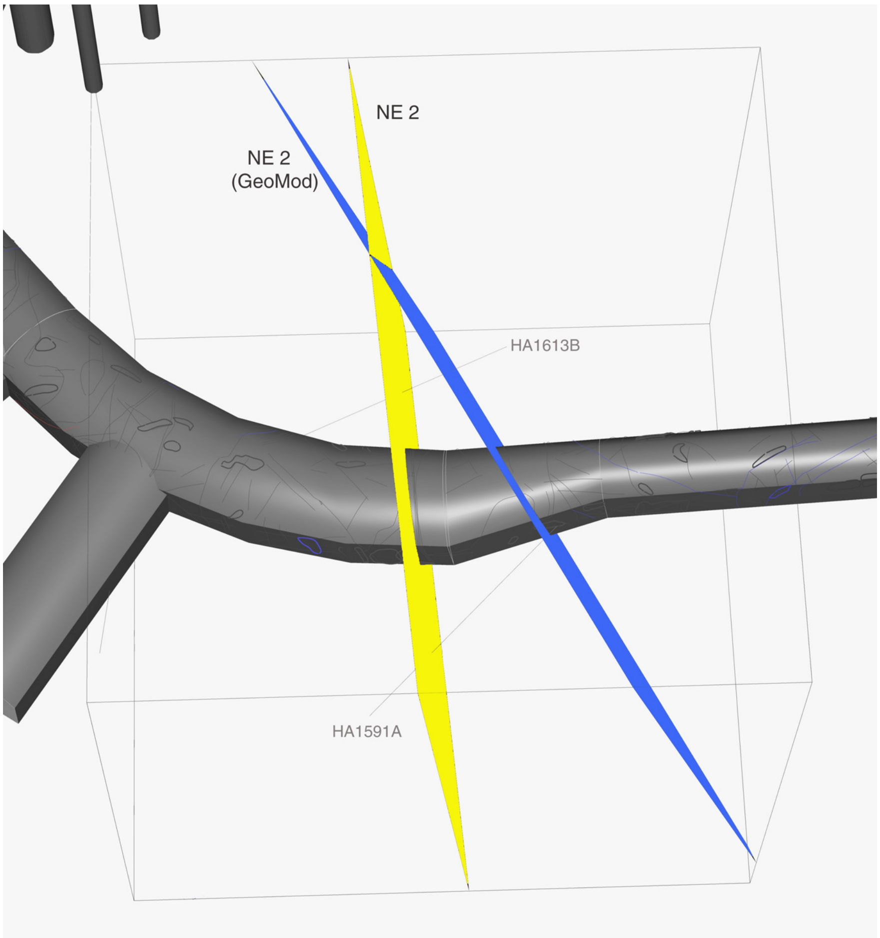

Figure 5-3 *The geometry of NE-2 as modelled in this study (yellow), and the geometry according to the GEOMOD study (blue).*

6 References

Berglund, J., Curtis, P, Eliasson, T., Olsson, T., Starzec, P., and Tullborg, E-L. : 2003. Äspö Hard Rock Laboratory – Update of the geological model 2002. International Progress Report, IPR-03-34. Swedish Nuclear Fuel and Waste Management Company.

Mazurek, M., Bossart, P and T. Eliasson 1995. Classification and characterization of water—conducting features at Äspö: Results of phase I investigations. SKB Äspö Hard Rock Laboratory, Progress Report 25-95-03. Swedish Nuclear Fuel and Waste Management Company.

Mazurek, M., Bossart, P and T. Eliasson 1997. Classification and characterization of water—conducting features at Äspö: Results of investigations on the outcrop scale. SKB Äspö Hard Rock Laboratory, International Cooperation Report ICR-97-01. Swedish Nuclear Fuel and Waste Management Company.