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Äspö Hard Rock Laboratory

TRUE Block Scale project

October 1997 Structural model; Update using characterisation data from KA2511A and KI0025F

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February 1998

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Abstract

This report presents an update of the TRUE Block Scale conceptual structural model reported by Hermanson and Follin (1997) using data from borehole investigations and activities during the drilling of borehole KI0025F. All available data sources for each structure intersecting the TRUE Block Scale target volume are here presented. Further, an attempt is made to link the structural model to hydraulic information collected at the site. The presented geological indications and hydraulic responses are summarised in figures with predicted zones and observed structures in tunnel sections and in the drillcores in and around the target volume.

Sammanfattning

Denna rapport är en uppdatering av den konceptuella strukturmodellen för TRUE Block Scale presenterad av Hermanson och Follin (1997). Data har använts från borrhålsundersökningar och borrningsaktiviteter av KI0025F. All tillgänglig information för strukturer som korsar TRUE Block Scale-området presenteras. Vidare har ett försök gjorts att sammankoppla strukturmodellen med hydraulisk data samlad på platsen. De geologiska indikationerna och hydrauliska responserna summeras i figurer med zoner, observerade strukturer i tunnelsektioner och även i borrhål i och runt den aktuella blockvolymen.

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1 Introduction

This report presents an update of the TRUE Block Scale conceptual structural model presented by Hermanson and Follin (1997) using data from borehole investigations and activities during the drilling of KI0025F. It also includes new BIPS data from the newly reamed KA2511A. The updating is presented as a conceptualisation of the structural geology and geohydrology in the TRUE Block Scale target volume.

The following sources of investigation data has been utilised

- Drilling activities (core drilling protocol, Kärnborrning AB 960826))
- BIPS interpretation (CD-ROM, Stråhle, 1997)
- Borehole radar in KA2563A and KI0025F (directional antenna)(Carlsten 1997a, 1997b)
- UCM logging in KA2563A, KA3510A and KI0025F (Gustafsson, 1997a, 1997b)
- Detailed flow logging in KA2563A, KA2511A and KI0025F (Gentzschein, 1997a, 1997b)
- Pressure responses during drilling of KA2563A and KI0025F (Winberg, 1997)

The conceptual model update is based on the previous structural model presented by Hermanson and Follin (1997) and concentrates on testing the following hypotheses:

Can any of the defined structures in Hermanson and Follin (1997) be rejected?

Do we need new structures to explain observed pressure responses and drawdowns during the drillings of KA2563A and KI0025F?

Do sub-horizontal structures act as major hydraulic pathways?

An updated general geological interpretation of the TRUE Block Scale volume is given in Chapter 2. A re-interpretation of the most significant structures in the volume is presented in Chapter 3 and in Chapter 4. Co-ordinates of the structures are given in the Appendix 1, and nomenclature and classification of structures according to Rhén et al. (1997) is given in Appendix 2.

2 Structural geology of the studied block

The lithology of the studied block consists of Äspö Diorite intersected by a number of fine-grained granites and a few greenstone bodies. The abundance of fine-grained granite in relation to the host rock (diorite) is 12% and greenstone 1% which is similar to the general picture in the HRL. As seen in Figure 2-1, the lithological contacts of the fine-grained granites and greenstones are generally gently dipping implying that there is a general sub-horizontal lithology in the central area of the studied block. This pattern is also seen in boreholes KA2598A (north-western HRL) and in KA2162A (central HRL) and indicates that the lateral extent of gently dipping structures may extend beyond the limits of the block scale volume. However, from experience, the Äspö type of fine-grained granite is variable in width and is unlikely to extend as one single body at a 100 m scale. Rather, it is suggested that several bodies may occur roughly in the same plane but with limited individual extent (≈ 5-50 m?).

The impact of the inferred sub-horizontal lithology and associated possible hydraulic pathways is suggested to be a target for future focussed hydraulic tests.

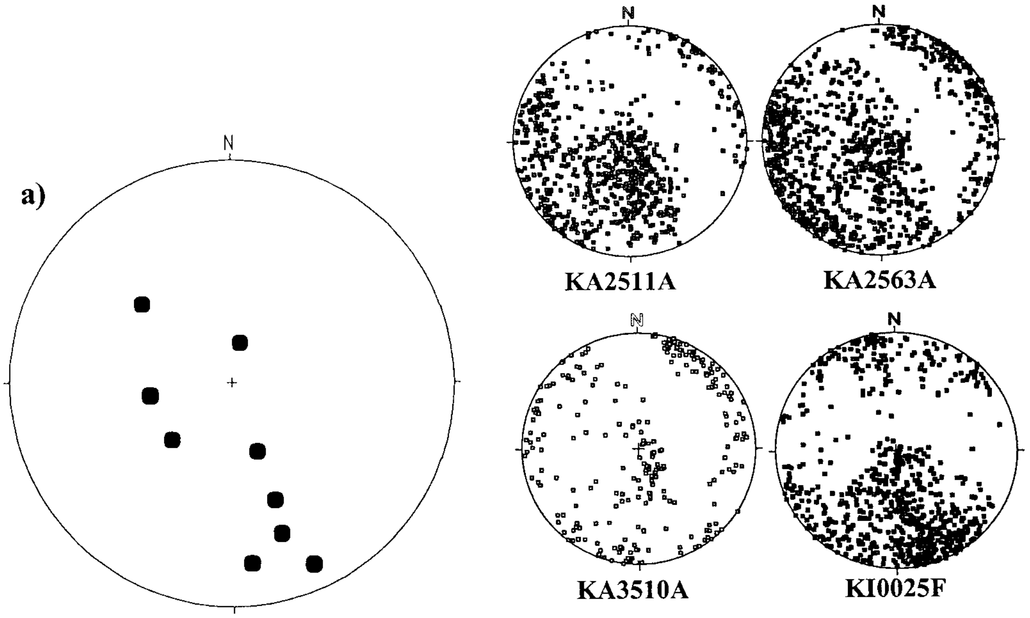

Figure 2-1 a) Fine-grained granite contacts in KA2563A. b) All mapped fractures in boreholes KA2563A, KA3510A, KA2511A and KI0025F. Poles of fracture planes projected on the lower hemisphere.

Studying the general fracturing of KA3510A, KA2563A, KA2511A one finds that there exists a pronounced sub-horizontal fracture set as well as two steep NW and NNE trending sets. The sub-horizontal fracturing is most pronounced in KA2511A, whereas few sub-horizontal fractures are intersected in KI0025F. The latter influenced by the sub-horizontal inclination of KI0025F. This is a pattern that is well known from investigations throughout the HRL. Experience from previous projects has also shown that the inflow from sub-horizontal fractures is low and usually occurs only when gently dipping fractures intersect larger steep faults (Rhén et al 1995). Instead, the flow paths between the larger NE trending zones EW-1 and NE-1 are interpreted to occur through mainly steep NW to NNW structures interconnected by NNE-N trending steep structures. However, new information from KA2511A leads to the result that sub-horizontal fractured bodies of fine grained granites exist and act as potential hydraulic pathways. It is observed that the most pronounced gently dipping zone intercepts are found in KA2511A, but also in KA2563A (limited extent). The core in KA2511A is actually dominated by sub-horizontal fractures in opposition to the other boreholes where steep structures dominate. Thus, local connectivity's may be influenced by sub-horizontal bodies.

Sections of greenstone occur in two parts of KA2563A at around 100 m and around 300 m, and at depth in KA2511A. Greenstone has been interpreted to be gently dipping large scale thin sheets from surface observations (Talbot et al. 1990). If this is true at z=-450 m, then it is possible that the bodies of fine-grained granite locally follow a gently dipping sheet of greenstone. The contact zone between greenstone and the host rock are often faulted with calcite fillings, at times idiomorphic in character. These faults may well act as hydraulic pathways.

Indications of brecciated parts of the cores tell something about location and orientation of possible zones, while tectonized sections and mylonites indicate early plastic deformation and possibly reactivated permeable zones. It is evident that both rock contacts and plastic deformation (possibly along the contacts) are gently dipping whereas brecciated parts of the cores tend to be steep. This suggests that minor brittle zones intersecting the target volume are steep. This hypothesis is also strengthened by the occurrence of steep water bearing faults in the tunnel parts that borders the investigated volume.

KA2563A, the longest of the currently drilled boreholes, does not intersect any boundary zone in the far west part of the hole. However, fairly strong seismic reflectors are seen beyond the limit of KA2563A and are interpreted as being a proposed boundary to the west of the target volume. The reliability of the existence of this element is low as well as the reliability of its orientation. No new information from the southern and northern boundary zones, NE-2 and EW-1, have been collected within the framework of the performed characterisation.

3 Summary of structural indications in the true block scale volume

A number of interpreted structures intersecting the TRUE Block Scale target volume can be described with different degrees of reliability. A condense table illustrating all available data sources for each structure is presented in Table 3-1. These structures represent the most prominent structures intersecting the target volume and are rated according to a relative reliability scaling of zones presented by Bäckblom (1996). It is important to note that all of the identified structures are interpreted to be groups or close networks of faults rather than single fault planes. When structures are identified in different boreholes, it is made on the simplest assumption, i.e. a planar extension in the direction of the fault planes, and identification of similar geological or hydraulic characteristics in neighbouring boreholes. However, geological structures at Äspö are known to be heterogeneous in their lateral characteristics which results in intercepts with quite varied geology, and especially hydraulic behaviour.

There is little known of what should be expected of the lateral extension of the Äspö faulting. As the foliation is constant in orientation and there are no other systematic ductile deformation, such as folds, in the rock, one would expect that brittle structures extend in a planar fashion.

Below follows short descriptions of the interpreted structures in Table 3-1;

1. A magnitude 1U radar reflector is interpreted to intersect KA2563A at L=11.9 m. This reflector is sub-parallel to a fault in KA2563A at L=16 m. Large steep water-bearing fractures in TBM tunnel sections around 2600 m, and in the F-tunnel coincide with a planar interpolation of this feature trending 127/90. It is considered as a **probable** structure.

2. A fairly steep structure (113/88) associated with fractured and oxidised core at L=11.6 m, and at L=12.8 m in KA3510A (large open fault with cavities). Similar geology is found also in KA2563A at L=68.35 m. A water-bearing fault at tunnel section L=2511 m is sub-parallel to this structure. The fracturing in the core section is characterised by a network of fractures (crush) with cavities and epidotized fillings. This feature is considered as **possible**.

3. A steep sub-parallel structure to no. 2 (113/78) intersecting KA3510A at L=39 m and KA2563A at L= 68 m. There are radar indications in both cores and a breccia in KA3510A at L=37.8 m (106/81). It is considered as a **probable** structure.

4. This feature, trending 293/77, intersects KA2563A at L= ca 93 m and is associated with an inflow of around 40 l/min. A possible intercept of this structure is located at L=12.7 m in KA3510A and could be attributed to the

same fault as structure no 2 at L=12.8 m. The intercept in KA2563A is characterised by oxidised and altered host rock with calcite filled fractures with cavities (296/76). A planar interpolation of structure 4 to KA2511A returns an intercept at L= ca 20-23 m where the rock show similar geological characteristics as in KA2563A. The section 23.08-26.6 has a recorded inflow of 30 l/min. If structure 4 is extended to intersect KA2511A, structure 5 is interpreted to intersect somewhere between KA2563A and KA2511A. Hydraulic responses in structures 4 and 5 are interpreted as coupled. This structure is considered as **probable** due to the fact that the intercepts in both boreholes have similar characteristics and orientation.

5. A structure associated with large inflows in both KA3510A, KA2563A and KI0025F. Interpreted to intersect at L=46.6 m in KA3510A, at L=102-103 m in KA2563A and at L = 4.9 m in KI0025F. The extreme inflow in KA2563A at L = 102 m (700 l/min) occur through a fault with 0.5-1 cm calcite and possible lithified gouge filling which is partly eroded. The fault has no clearly visible ductile precursor and occurs in diorite with no signs (such as decrease in grain size or chemical dissolution of minerals) of previous tectonic events. The feature consists of a smaller fracture ending at an almost orthogonal angle to the fault and could be interpreted as a splay fracture. A fair bit of displacement has occurred along the fault plane as opposite sides match badly.

   The structure seem to consist of one or a few major inter-linked fault planes with rather thick (mm to cm) calcite filling, at times with idiomorphic crystals giving the fault a high porosity. The planar extent (115/88) is striking as the structure is identified over a distance of at least 50 m and show more or less the same orientation and characteristics at all but one intercept. The extension to KA2511A is doubtful as this intercept is significantly smaller than elsewhere. Anyhow, structure 5 is so well defined that it is considered as a **certain** structure.

6. This structure is associated with inflow points in KA2563A at L=153.6 m (100 l/min), in KI0025F at L=75.7 m and possibly also in KA3510A at 58 m. A planar projection of structure 6, trending 154/84, intersects KA2511A at 95 m where there is no suitable structure. However, there exists one open fracture with parallel orientation to structure 6 (340/71) at L=100 m. In support of BIPS observations, a radar reflector in KA2511A at L=94 m is interpreted as the same structure. The structure may also interact with KA3510 through Structure 5, or a sub-parallel structure to Structure 5, intersecting at L=47.1 m in KA3510A where a fine-grained granite is intersected by 2-3 sub-parallel faults with idiomorphic calcite fillings (140/82). At L= 152-154 m in KA2563A there is 10 to 15 faults with parts of the core crushed (300/80). Fault surfaces are covered by chlorite, and possibly at a few places by lithified fault gouge, in a host rock of dark diorite with increased (sub-parallel?) foliation.

   In KI0025F the intercept is less significant and consists of a group of oxidised faults with calcite and epidote fillings. The host rock is dark diorite, but the section around the faults is reddened granite like rock. However, the nature of this structure makes any extensions over larger distances difficult. This structure is now interpreted to intersect at least three boreholes, but the non-unique geological character of the structure makes the interpretation not well defined and it is therefore considered as **probable**.

7. Interpreted to be a steep structure, trending 129/88, intersecting KA2563A at the inflow point yielding 100 l/min inflow at L= ca 151 m (as do structure 6) and KI0025FA at L= 43 m. One radar reflector found in KI0025F at L= 43 m, orientation 154/82 (alt. 210/64), supports an NW extension of this structure. Both intercepts are associated with altered oxidised diorite and fracturing (311/80 in KA2563A). The structure can also be interpreted to intersect KA2511A at L= ca 52 m. All three intercepts are associated with inflow points; 100 l/min in KA2563A, 9 l/min in KI0025F and 6 l/min in KA2511A. Structure 7 is rated as **probable**.

8. This steeply dipping structure intersects both the TBM, the F-tunnel, KA3510A and KA2563A and is considered **probable**. Steep faults in the F-tunnel and in the TBM are also clearly visible in KA3510A from 15.5 m up to 17.4 m in highly foliated, oxidised and altered diorite. The structure also intersects KA2563A at around L=220-230 m. This intercept is distributed over a larger distance, and consist of the same type of foliated and altered diorite with faults filled with epidote and calcite. Radar reflectors are interpreted in both KA3510A and KA2563A. As the intercept is more intense in KA3510A, the structure is either diverting into several smaller fault structures or diminishing beyond KA2563A.

9. This structure is currently only interpreted to intersect KA2563A and consist of a group of open faults at L = ca 265 m. It has not been possible either to locate or extend this structure to any of the other boreholes without conflict with the current conceptual model and it is therefore considered limited in extent to exist only in the surrounding of KA2563A. Current interpretation of orientation is 280/90. Structure 9 is considered **possible**.

10. Both radar and seismics in boreholes KA2563A and KA2511A define the **probable** Structure no. 10. However, this structure may occur beyond the extent of KA2563A. Orientation of the radar reflector in KA2511A (111/85) is consistent in orientation with the crosshole seismic reflector in KA2563A (282/89). Fractured fine-grained granite dominate in KA2511A. Fracturing is more intense in the contact between the fine-grained granite and the greenstone. Note that the contact is sub-horizontal as well as one of the faults in this section. The intercept in KA2511A is located at L= ca 240 m. Interpreted

11. This structure rated as **possible** is indicated by both crosshole seismic and radar and intersects KA2511A at L= ca 270 m. Indications in KA2563A

consist of a steep and a sub-horizontal open fracture in diorite. Current interpretation of orientation is 300/79.

12. A seismic reflector beyond the limit of all boreholes is interpreted as being a possible boundary zone as proposed by the previous block scale siting investigation. Orientation is 355/90. It is rated as a **possible** structure.

NE-2 This zone is NE-2 and data for this zone can be obtained from Rhén et al (1997). In the TRUE Block Scale area this zone is considered as **probable.**

EW-1 This zone is EW-1 and data for this zone can be obtained Rhén et al (1997). In the TRUE BS area this zone is considered as **certain.**

15. A radar reflector and a number of faults in KA3510A describe this structure. At 117.90-120.89 m, 15 faults intersect KA3510A in fine-grained granite. There is a cm wide sub-parallel calcite filled fracture in the middle of this group, although it is sealed (i.e. not reactivated). It seem possible that these fractures take part in the measured slow increase in inflow. However, this structure is not observed in any other borehole and the extent is therefore limited. Orientation is interpreted to 269/90. This structure is rated as **probable.**

16. Evidence for a gently dipping fine-grained granite body intersecting KA2563A at L= ca 56 m and associated with a greenstone and massive faulting in KA2511A at L = 102.5-103.5 m. This structure is also supported by a seismic crosshole reflector and the orientation of the sub-horizontal rock contacts in both KA2563A and in KA2511A and is rated as **possible.** It can be described as a fractured lithological body rather than a traditional zone. However Structure 16 may be an important hydraulic connector between steep NW trending zones.

17. This indication is also most probably a gently dipping fine-grained granite associated with greenstone in KA2563A and with an intensely deformed fine-grained granite in KA2511A. The lithological body is interpreted to follow a gently dipping cross-hole seismic reflector intersecting KA2563A at L=110.5 m and KA2511A at L=125 m. Previous seismic investigations in KA2511A also show a gently dipping reflector at this depth. There are also several sub-horizontal faults in KA2511A, in section L = 130 - 132 m, associated with altered diorite and fine-grained granite, calcite and epidote fillings. This structure is geologically more prominent than zone 16, but is not necessarily a conductive structure as the deformation (in KA2511A) is ductile, with little brittle evidence. Sub-horizontal structures is interpreted to act as hydraulic connectors, but seem to show a very heterogeneous conductive character. This structure is rated as **possible.**

18. The last identified gently dipping fine-grained granite structure is supported by both radar and seismic in KA2563A and KA2511A. It is currently interpreted to be a dry intercept even if there exist a 20 l/min inflow in KA2511A which is measured in the interval up to L=242 m. However, as

this structure intersects at L=242.5 m the inflow is not interpreted to be associated with this structure but rather to a steep structure at L=241.5 m. Inspection of the core shows a fault crush with a parallel epidotized faults in KA2511A. The main fault has chlorite and some calcite fillings and occurs in fine-grained granite (close to the contact with the diorite). The host rock in this core section (25 cm) is influenced by hydro-thermal activities. The sub-horizontal structure is considered as **probable**.

19. Structure 19 is identified in the BIPS log in three boreholes, KA2563A at L = 227 m, KI0025F at L = 166 m, and in KA2511A at L = 198 m. A larger inflow is noted in KI0025F (30 l/min). However, the zone is interpreted to be heterogeneous in its structure, with a non-conductive intercept in KA2511A. The orientation is changed slightly from the previous structural model to 334/63. This structure is considered as **probable**, but the extent is unclear as the characteristics change dramatically between the intercepts.

20. Structure 20 is found in KA2563A at L = 188.6 m as a group of faults with observable apertures on the BIPS log, and in KA2511A at L= 122 m. When drilling KI0025F, at L = 87.7 a single response was measured in KA2563A and Structure 10 is therefore extended to KI0025F L= ca 88 m. The geological characteristics are not as dramatic in KI0025F and in KA2511A as in KA2563A. In the latter boreholes, this structure is identified as an open fracture or a group of open fractures in altered diorite. No registration was made in KA2511A at the time of drilling into L= 87.7 m in KI0025F. The orientations of the fractures are similar in all intercepts, giving this structure an interpreted orientation of 318/85. It is considered **probable**, but most likely consists of a group of interconnected structures.

Z. The Z structure is a large zone, unlike all other structures found in the drilled boreholes in the TRUE Block Scale experiment as regards to its geological characteristics. This structure is identified by a large section of core crush from L = 188 m to the end of the borehole which is also confirmed by the BIPS image. During the drilling it was featured by successively increased inflow and mobilisation of unconsolidated material. A mineralogical analysis performed by Tullborg (1997, in prep) show that the characteristics of this zone is similar to the characteristics of Zone NE-1, with brecciated, crushed and faulted rock with large portions of altered host rock, (diorite and fine grained granite). The contents of fault gouge in the analysed sample was low, possibly due to that gouge may have been flushed out during drilling and uptake of the core. Geometrically, this zone is sub-parallel to NE-2, EW-3 and NE-1. However, based on the conceptual model of the site scale zones (Rhén, 1997), zone NE-1 is located over 80 m south of the Z structure, and EW-3 is approximately 30 m south of the Z structure. However, zones NE-2, EW-3 and NE-1 are not well identified in this particular part of the HRL. Splay structures and minor branches to these major zones may therefore exist. It is interpreted that the Z structure is such a branch of either EW-3 or NE-1. The characteristics of zone NE-2 is completely different, dominated by mylonites, and a few conductive faults.

Table 3-1 Identified structures in cores KA3510A, KA2863A and KA2511A

Interpreted structures	Level of probability	Intersection KA3510A (m)	Intersection KA2563A (m)	Intersection KA2511A (m)	Intersection KI0025F (m)	Strike	Dip	Seismic (#1) indication in KA2563A and KA2511A (reflector no strike/dip)	Radar indication in KA3510A (reflector no:magnitude strike/dip)
1	Probable	-	11.8	-	-	127	90	-	-
2	Possible	11.6	68.4	-	-	293	88	-	2:1U 292/90
3	Probable	38.8	67.9	-	-	113	78	-	14:1U 107/87
4	Probable	12.7	93.6	ca 23	-	293	77	-	2:1U 292/90
5	Probable	46.6	102.0	-	5.0	295	88	-	5:1U 155/88
6	Probable	58.0	153.6	(100)	75.7	334	87	-	(6:3 116/82)
7	Possible	-	150.7	52.4	43.1	129	88	-	-
8	Probable	19.0	222.4	-	-	217	90	-	17:2 52/50
9	Possible	-	265.9	-	-	280	90	6:192/79	-
10	Probable	-	-	239.6	-	126	89	10:282/89	-
11	Possible	-	-	268.8	-	300	79	1:128/66	-
12	Possible	-	-	-	-	355	90	5:175/73	-
NE-2	Probable	-	-		-	63	72	-	-
EW-1	Certain	-	-		-	241	78	-	-
15	Possible	118.3	-	-	-	269	90	-	15:1 279/68
16	Probable	-	56.4	103.5	-	205	19	2:199/19	-
17	Probable	-	108.7	132.2	-	207	29	3:206/29	-
18	probable	-	194.3	242.5	-	25	4	4:203/17	-
19	probable	-	226.8	197.8	166.1	334	63	-	-
20	probable	-	188.6	122.0	87.9	138	85	-	-
Z	probable	-	-	-	190.2	230	73	-	-

Table 3-1 (continued) Identified structures in cores KA3510A, KA2863A and KA2511A

Interpreted structures	Radar indication in KA2563A (reflector no:magnitude strike/dip)	Radar and Seismic (#2) indication in KA2511A (reflector (R or S:magnitude strike/dip)	Radar indication in KI0025F (reflector no:magnitude strike/dip)	Inflow (l/m):borehole	Geological indication of structure
1	-	-	-		Fgranite, fractured, faults, faults in the tunnel
2	25:1U 166/79	-	-		Oxidized, fractured, crush
3	25:1U 166/79	-	-		Oxidized, fractured, crush
4	24:2U 126/82	-	-	40:KA2563A	Fgranite, greenstone, crush
5	5:2 53/23	-	15:238/75 15:315/75	700:KA2563A (103m) 70:KA3510A (46.5m) 40:KI0025F (4.9m)	Fgranite, greenstone (radar), single feature
6	9:2 67/25	R:1 111/75	-	100:KA2563A (153m) 20:KA2511A (100m)	oxidized network with faults
7	23:1 123/76	-	18:154/82 18:210/64	100:KA2563A (153m) 9:KI0025F (43m) 6:KA2511A (53 m)	Oxidized, fractured, crush
8	-	-	-		faults in TBM tunnel and KA3510, KA2563A
9	-	R:2 248/71	-		Oxidized, single open faults in KA2563A at 263 to 265 m
10	22:2U 11/81	R:1 111/85	-	20:KA2511A (240 m)	Greenstone, crush (312 m), chloritisized
11	-	R:U 281/29	-		
12	-	-	-		Only seismic and radar evidence
13		-	-		NE-2
14		-	-		EW-1
15	-	-	-	40:KA3510A (118m)	Fgranite, crush (118-119m)
16	-	R:1 205/6 S:2 82/4	-		Fgrained granite, oxidized
17	5:2 53/23	-	-		Fgrained granite, greenstone
18	30:1 128/26	R:1 111/85	-		Fgrained granite
19	-	-	8:055/81 7:212/73	30:KI0025F (166m)	Faults in Finegrained granite, alteration
20	-	-	13:021/10 13:81/36	1.9:KI0025F (92 m) 8:KA2563A (187.5m)	Open fault KA2563A, other intercepts faultgroups in altered diorite
Z	-	-	10:310/64 10:24884 17:277/71		Minor branch of either EW-3 or NE-1

4 UPDATING THE STRUCTURAL MODEL WITH HYDRAULIC INFORMATION

The structural model presented in Chapter 3 is based mainly on geological indications and geophysical anomalies gathered at the experimental site. In what follows, an attempt is made to link the structural model to hydraulic information collected at the site, in particular the pressure responses recorded in the four HMS sections of KA2511A and in the seven sections in KA2563A while drilling borehole KI0025F. A series of graphical presentations of structures acting as possible pathways of pressure disturbances, created by the drilling of boreholes KA2563A and KI0025F, are presented by logical argumentation for identifying possible strategic hydraulic conductors in the structural model.

4.1 Hypothesis on hydraulic connectivity of the target block

The potentiometric pressure in KA2511A while drilling KA2563A and KA3510A was monitored in four sections, P1-P4, connected to the HMS monitoring system. The hydraulic properties of the four packed-off sections are described in Olsson (1994), cf. Table 4-1. Similarly, when drilling KI0025F, pressure was monitored in the HMS sections in KA2511A and in seven sections in KA2563A

Table 4-1 Positions of the HMS sections in KA2511A (after Olsson, 1994) and KA2563A (after Winberg, 1997).

	KA2511A		**KA2563A**
Sect.	**Depth, m**	**Sect.**	**Depth, m**
P1	171-293 m	P1	266-363
P2	81-170 m	P2	197-265
P3	31-80 m	P3	187-196
P4	6-30 m	P4	146-186
		P5	113-145
		P6	76-112
		P7	6-75

Winberg (in prep) presents a pressure response matrix which lists the potentiometric pressure in the monitored sections of KA2511A while drilling KA2563A and also in KA2511A and KA2563A while drilling KI0025F. These pressure responses have been visualised in 3D for a number of major inflow points in both KA2563A and in KI0025F. The visualisations have been made in order to investigate alternative hypotheses for connectivity involving interpreted structures in order to explain the response pattern in the rock volume. The following important hydraulic intercepts have been chosen for visualisations and accompanying conceptual discussion:

- KA2563A at L = 99 m (response pattern same as at L = 103 m)
- KA2563A at L = 156 m
- KI0025F at L = 4.9 m
- KI0025F at L = 87.7 m
- KI0025 F at L = 166 m
- KI0025F at L = 187 m

4.1.1 KA2563A L = 99 m (Structure 4)

When drilling into the structure at L = 99 m and at L = 103 m, (Structure 5), pressure responses are recorded in all four sections in KA2511A with draw downs in excess of 150 kPa in section P2, P3 and P4 (Winberg 1997). After the drilling of both KA3510A, and KI0025F, the major part of the L=99 m inflow can be attributed to Structure 5, and Structure 4. The spread of the pressure disturbance in the volume is large and must incorporate a good part of the fracture network. An analysis of which major structures that may take part in this distribution reveals four candidates. The simplest conceptual model incorporates four sub-vertical structures, Structures 4, 5, 6 and 7, c.f. Figure 4-1. Structure 5 is together with structure 4 identified in all boreholes. Structure 6 is identified in KA2563A, KA3510A and KI0025F and possibly also at L=100 m in KA2511A. However, structure 6 is a structure that should be part of a focused hydraulic testing campaign to evaluate its hydraulic importance. The top illustration in Figure 4-1 requires that Structure 7 is active to explain the response in KA2511A, P3. The bottom illustration in Figure 4-1 suggests that the sub-horizontal Structure 16 interacts with structures 6 and/or 7. Structure 16 is identified in KA2511A in section P2 and is associated with gently dipping fine grained granite and greenstone.

4.1.2 KA2563A L = 156 m (Structures 6 and 7)

When drilling into the structure in KA2563A at L = 156 m, c.f. Figure 4-2, pressure responses are recorded in all four sections of KA2511A (Winberg, in prep), although about 100 kPa lower than the intercept at L = 99 m. Again the whole fracture network seems to be invoked in the distribution of pressure. A conceptual model based on the identified major structures in the volume show that at least seven structures are needed to explain the disturbance pattern. If sub-horizontal structures are invoked, Structure 8 may not be needed as a connector between the NW trending steep structures. The simplest solution is to invoke only Structures 5, 6, 20, 10 and 18.

4.1.3 KI0025F at L = 4.9 m (Structure 5)

The intercept at L= 4.9 m is featured by an inflow of 40 l/min and is identified by radar reflectors at L=3 m trending WNW to NW with a steep dip. The intercept of this structure gives rise to pressure responses in all instrumented sections of KA2511A and KA2563A (Winberg, in prep). In addition, weak responses are observed in some sections in KA1751A, KA1754A and KA2162A. The March 1997 structural model (Hermanson and Follin, 1997) predicted Structure #5 to be intercepted in KI0025F at approximately L=3 m. With the addition of this new intercept, Structure #5 is interpreted to be identified in three boreholes; KA3510A, KI0025F and KA2563A. In Figure 4-3, the pressure responses are visualised in the top left illustration. A conceptual model of possible sub-vertical structures that may take part in the response pattern (top right) incorporates at least Structures 5, 6 and 7. However, we know that Structure 7 does not intersect KA2511A. Invoking sub-horizontal structures 16 and 17 helps explaining responses in KA2511A in both section P2 (together with Structure 6) and P3.

4.1.4 KI0025F at L = 87.7 m (Structure 20)

The intercept at L=87 - 92 m is identified by an inflow of 1.9 l/min, radar reflectors trending NE and E-W, respectively, and fractures oriented in 336/77. The geology of this section is characterised by a few faults surrounded by altered, oxidised host rock (diorite and greenstone). Mineralisations of epidote is visible. It should be noted that the rock contact between the diorite and the greenstone is not fractured in the drill core.

A draw-down event with a magnitude of 11 m is recorded in KA2563A section P3 (L=187-196) when the structure is intersected. Curiously enough, the pressure regains its original level when Structure #19 is intersected at L=165-167.5 m. The explanation of such a recovery of the pressure in section KA2563A:P3 is not trivial unless the pressure in KI0025F shows a similar pressure increase. A possible matching structure is noted in borehole KA2563A at L=188.7 m with an orientation 316/82. This structure occurs inside section P3 in KA2563A and is most probably responsible for a large part of the inflow within this section. The detailed flow logging revealed a flow of over 8 l/min for this section and if it is the only conductive structure in the section, its interpreted transmissivity is around 6x10-7 m^2/s. Up till this point this intercept has not been attributed to any known structure. The geological imprint is not considered to be similar for the three intercepts, L=87.5 in KI0025F, L=188.7 in KA2563A and L = 122 m in KA2511A although the intercept in the latter borehole is suggested to be non-conductive. Connectivity exist and may be attributed to either an indirect connectivity through Structure #9 or Structure #6, or direct through Structure 20. Figure 4-4 shows the interpreted orientation of Structure 20, and how it intersects in KA2563A, section P3.

4.1.5 KI0025F at L = 166 m (Structure 19)

The intercepted Structure at L=165-167.5 m is indicated by an inflow of about 10 l/min (initial inflow prior to intersection with the structure at L=186-193.88 m was around 30 l/min). The structure is featured by two equally possible radar reflectors trending NE with a steep dip, and a group of faults identified in the BIPS images and the drillcore, trending NNW with a 60-75° dip. The geological characteristics of the structure in KI0025F are faulting, brecciation and large pores with idiomorphic calcite crystals. The host rock is altered diorite. The structure is interpreted to intercept KA2511A at L = 197.8 m. This intercept is similar to Structure 20, considered "dry". It should be noted that the relevant part of KA2511A is located approximately 100 m above KI0025F, L=165-167.5 m. There exists a hydraulic connection between the intersected structure and the innermost 4 sections in KA2563A, c.f. Figure 4-5, whereas no connectivity exist with KA2511A. There are several possible explanations for such a response pattern:

1. Structure #19 is a NNW trending structure, intersecting KA2563A and is, through either Structure 8 and/or Structure Z, connecting to Structures 20 and 6. (sub-vertical solution)
2. Structure #19 is a NNW trending structure intersecting KA2564A, and the sub-horizontal structure 18 which connects to other steep NW trending structures, (sub-horizontal solution).

4.1.6 KI0025F at L = 187 m (Structure Z)

The structure intercepted in section 186-192.88 m, denoted Structure Z, is the largest identified structure in TRUE Block Scale so far as regards its geological characteristics. During the drilling it was featured by successively increased inflow and mobilisation of unconsolidated material, The final inflow is in the order of 70 l/min according to the UCM flow log. It consists of brecciated, crushed and faulted rock with large portions of fault gouge, and heavily altered host rock, (diorite and fine grained granite). Three possible major zones may be interpreted to be associated with this intercept, namely Zones NE-2, NE-1 and EW-3. A geometrical analysis of the three zones in relation to the intercept in KI0025F reveals that NE-2, according to the Site Scale structural model described by Rhén et al. (1997), does not extend far enough to allow intersection by the borehole. Further, the distance to the core of Zone EW-3 is projected to be in excess of

60 m, and correspondingly the distance to the core of Zone NE-1 is approximately 80 m. The identified structure in KI0025F can thus be related to any of the three major structures. It should be mentioned that NE-2 is not known to exhibit similar geological characteristics to those found in Structure Z. Mineralogical analyses suggest that this structure can be interpreted as an offspring to either Zones EW-3 or more likely, NE-1. Individual fracture orientations in the zone are sub parallel to NE-2 (232/68). However, the rock is partly crushed and fracture orientations therefore may vary quite a bit.

The response pattern show pressure responses in KA2563A, sections P1 to P4 (Winberg, in prep). A conceptual model based on sub-vertical identified structures need to invoke the structures Z, 20, 6, possibly 7 and 19, c.f. Figure 4-6. Structure Z is, based on its structural characteristics, a potential hydraulic conductor, and could well act as the connective structure which distribute the disturbance through the steep NW trending structures. However, the distance to the responding sections in KA2563A is dramatically shortened if a sub-horizontal structure, such as no 18 or 17 is included.

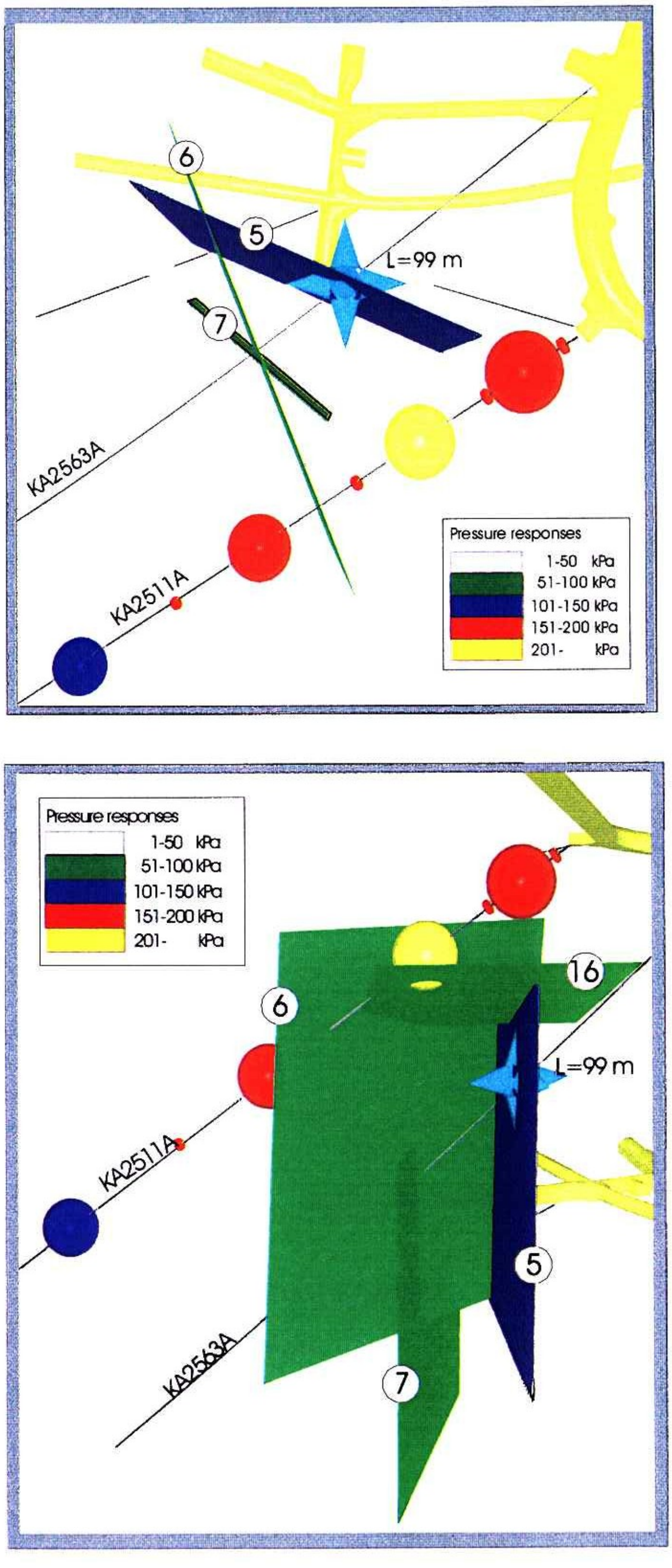

Figure 4-1 Graphical presentation of the deterministic structures likely to be associated to the pressure responses when drilling into L = 99 m in KA2563A. The two illustrations show top view and side view. Spheres indicate pressure responses (kPa) colour coded in monitored sections of KA2563A and KA3510A. The different colours of the structures are only used to enhance the visibility in 3D.

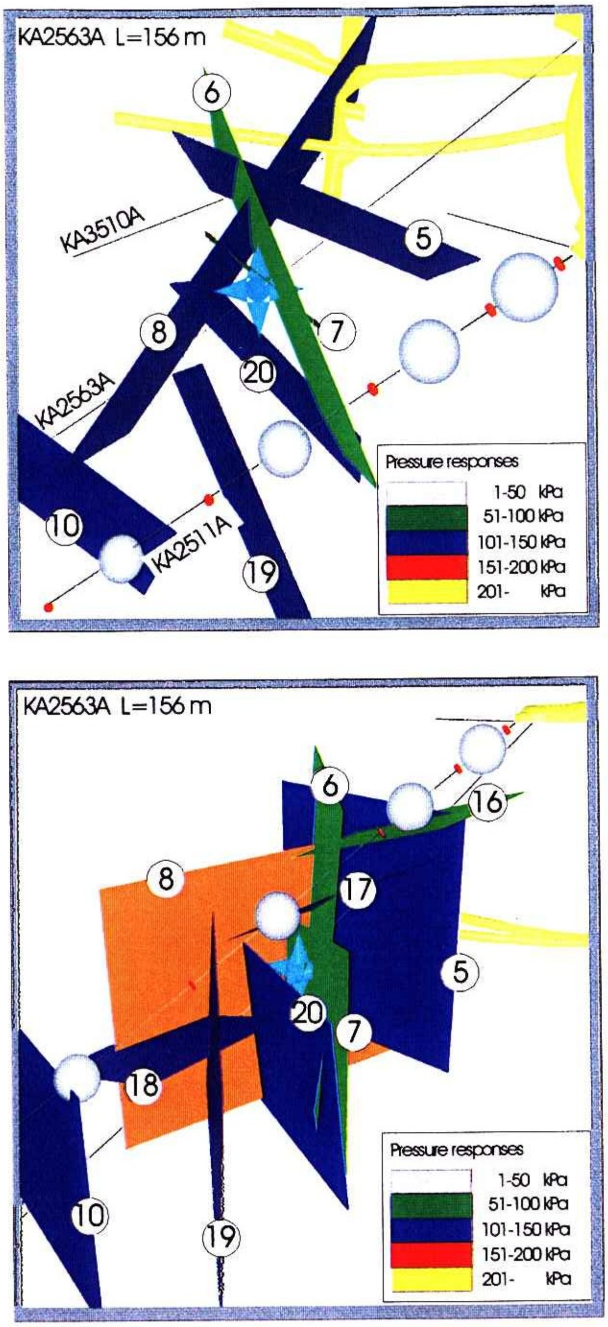

Figure 4-2. Graphical presentation of the deterministic structures likely to be associated to the pressure responses when drilling into L = 156 m in KA2563A. To explain the wide spread response pattern by vertical structures, Structure 8 is needed to connect the NW structures. A side view (bottom) shows that Structure 8 can be replaced by sub-horizontal structures.

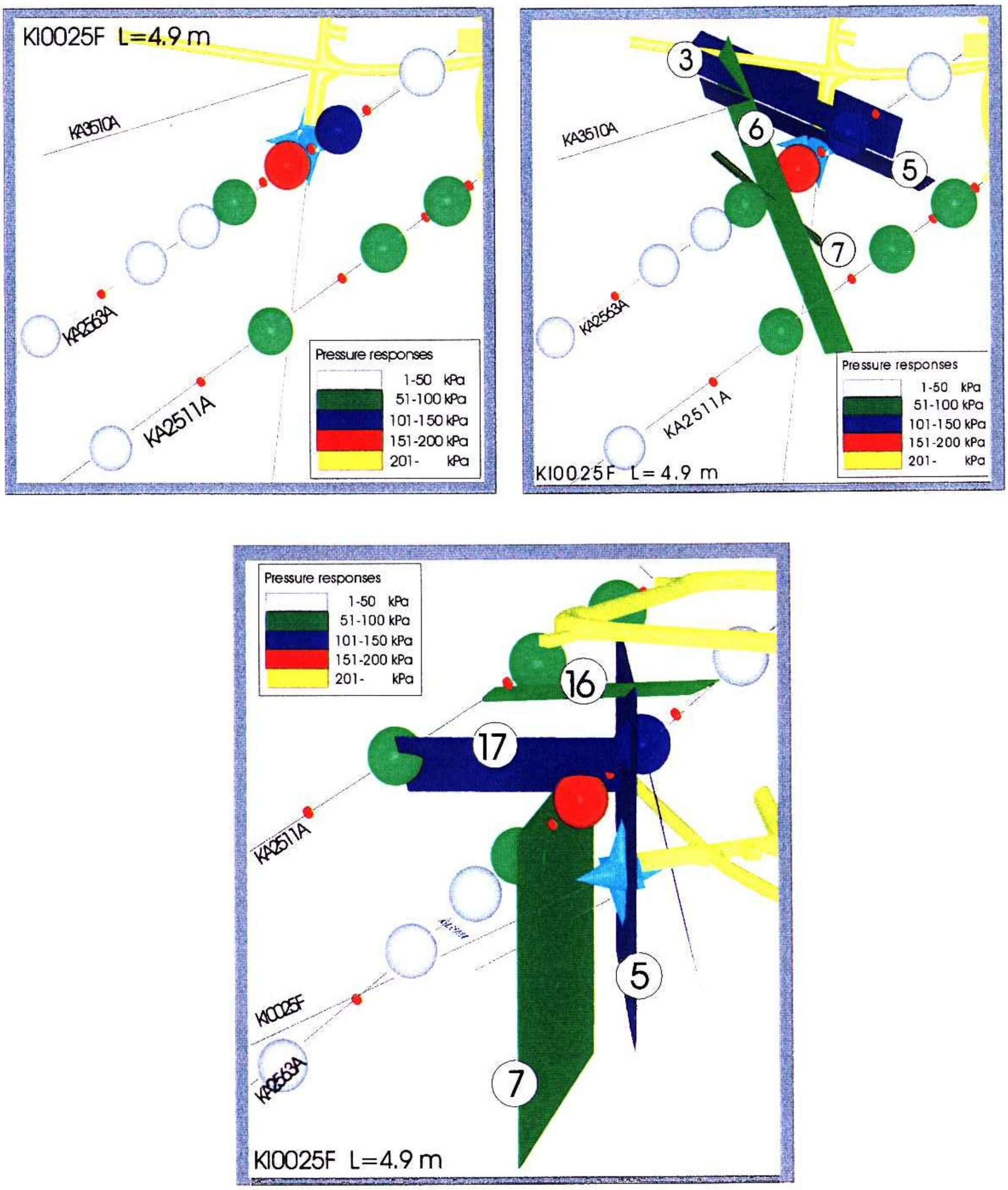

Figure 4-3 Graphical presentation of the deterministic structures likely to be associated to the pressure responses when drilling into L = 4.9 m in KA0025F. The top left illustration shows the response pattern in KA2563A and in KA2511A. Top right shows the simplest configuration of the known structures. Bottom shows additional sub-horizontal zones illustrating an optional conceptual model where Structure 6 is not necessary to explain the observed responses.

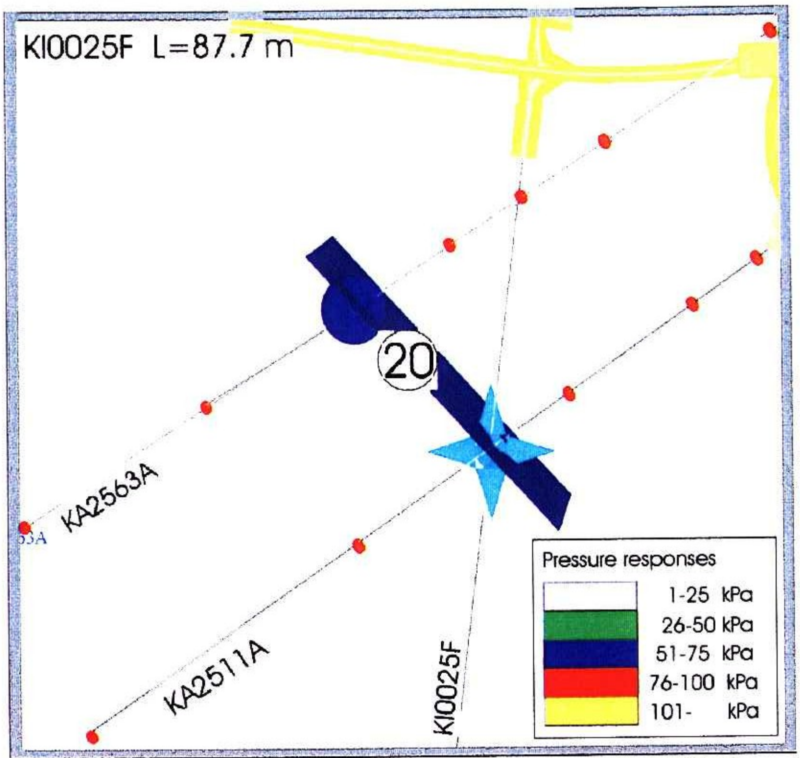

Figure 4-4 Graphical presentation of the deterministic structures likely to be associated to the pressure responses when drilling into L = 87.7 m in KI0025F. The response is distinct and singular, (110 kPa) in a 9 m section in KA2563A, implying a single structure only.

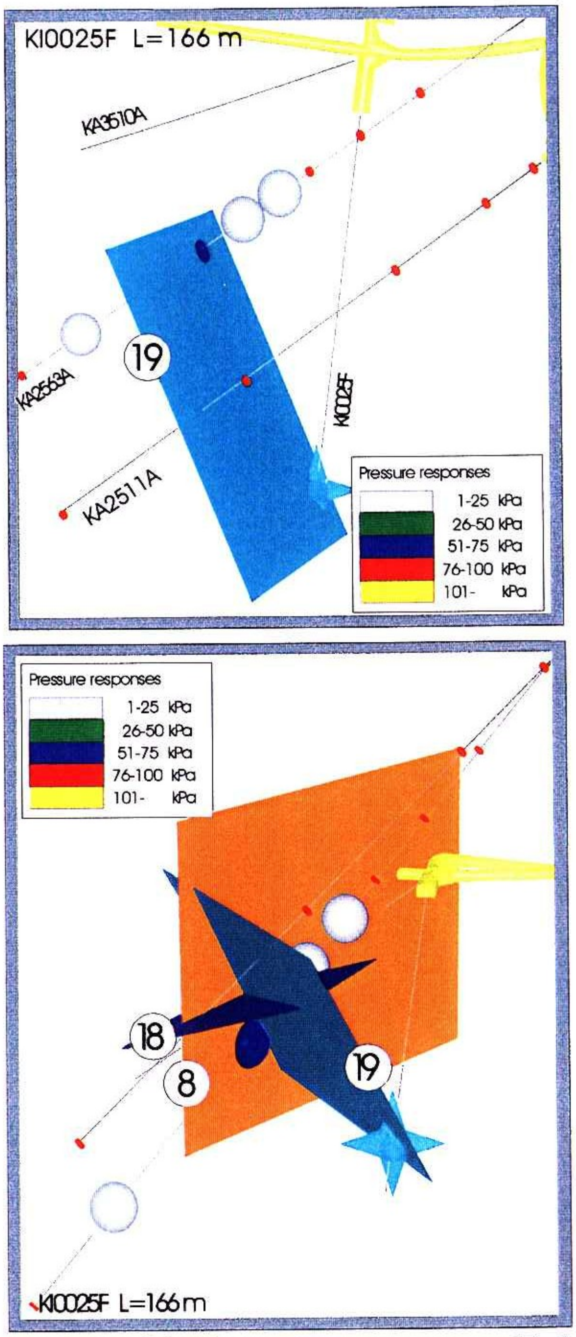

Figure 4-5 Graphical presentation of the deterministic structures likely to be associated to the pressure responses when drilling into L = 166 m in KI0025F. Structure 19 is interpreted to be structurally heterogeneous, which may explain the recorded draw-down in KA2563A (P2, 65 kPa), but not in KA2511A (P1). The responses in KA2563A, section P1, P3 and P4 can also be explained by Structures Z, 20, 10, and 6 in addition to the illustrated structures.

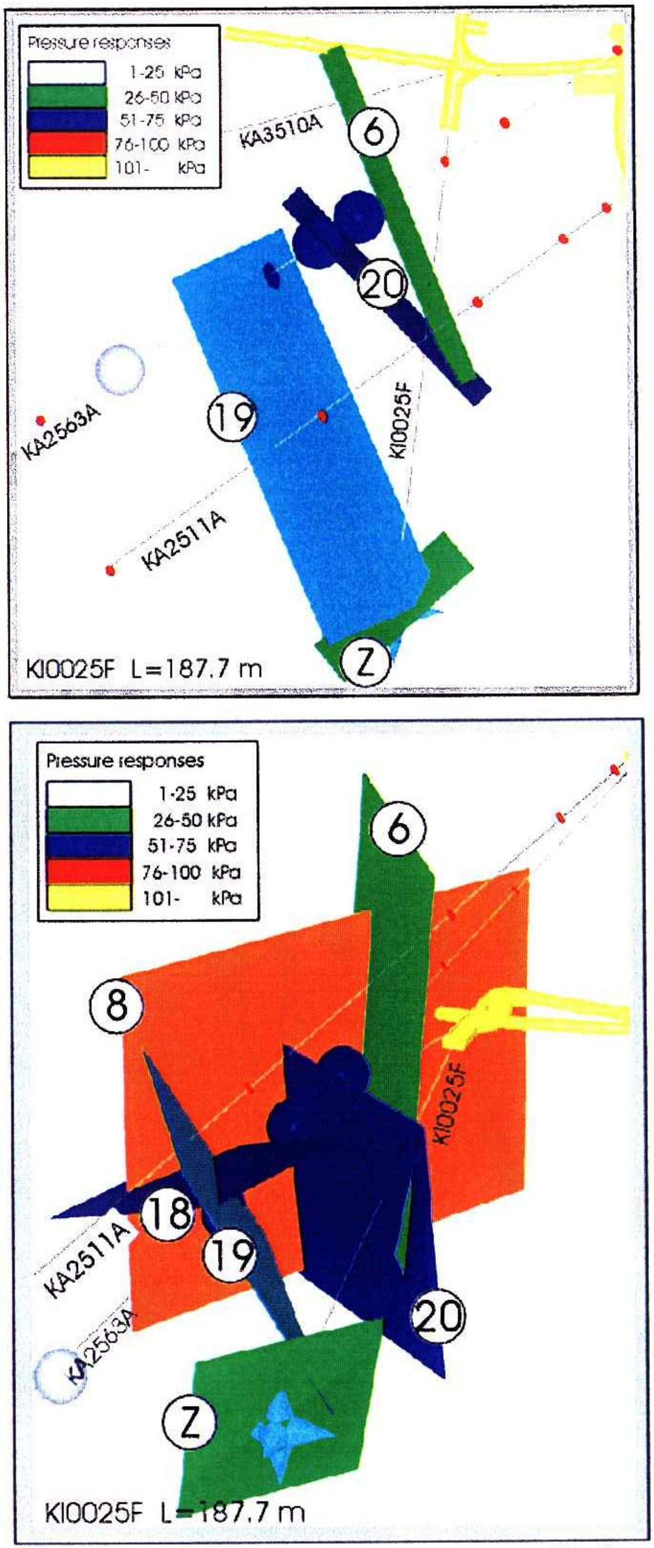

Figure 4-6 Graphical presentation of the deterministic structures likely to be associated to the pressure responses when drilling into L = 187 m in KI0025F. Structure Z is part of either NE-2, EW-3 or NE-1 and probably has a large lateral extent in the NE direction. It is therefore interpreted to primarily activate sub-vertical NW trending structures.

4.2 Structural model

The presented geological indications and hydraulic responses for the TRUE Block Scale volume are summarised in Figure 4-7 presented as a planar view with predicted zones and observed structures in tunnel sections and in the drillcores in and around the target volume. Colouring of the structures represent the degree of reliability as presented in Hermanson & Follin (1997).

The main geological findings in the target volume are;

- None of the existing structures in Hermanson and Follin (1997) could be rejected after drilling KI0025F
- The extent of Structures 9, 7, 6, 5 and 4 were better defined
- Structure 9 is only defined in one intercept KA2563A at L = 266 m not substantiated by hydraulic information.
- The extent of Structure 7 is limited to boreholes KA2511A, KA2563A and KI0025F.
- Structure 6 is observed in possibly all boreholes. However the intercept in KA2511A is weakly defined. The extent and importance as a hydraulic structure is yet not fully understood.
- Structure 5 is now defined in all boreholes except KA2511A. It is interpreted to be closely coupled, both geologically and hydraulically to Structure 4.
- Structure 4 intersects KA2511A at around 23 m which implies that Structure 5 may intersect Structure 4 somewhere between KA2511A and KA2563A.
- Sub-horizontal structures are interpreted to be an important part of the connectivity in the TRUE Block Scale target volume
- Three new structures were found after the drilling of KI0025F, structures 20, 19 and Z
- Structure 20 is interpreted to intersect KA2563A (section P3), KA2511A (P2, non-conductive intercept) and KI0025F (P4).
- Structure 19 is interpreted to intersect KA2563A (P2), KA2511 (P1, non-conductive intercept) and KI0025F (P2)
- Structure Z intersecting KI0025F at L = 187 m is probably a minor branch of either NE-1 or EW-3. The single largest geological structure in the block.

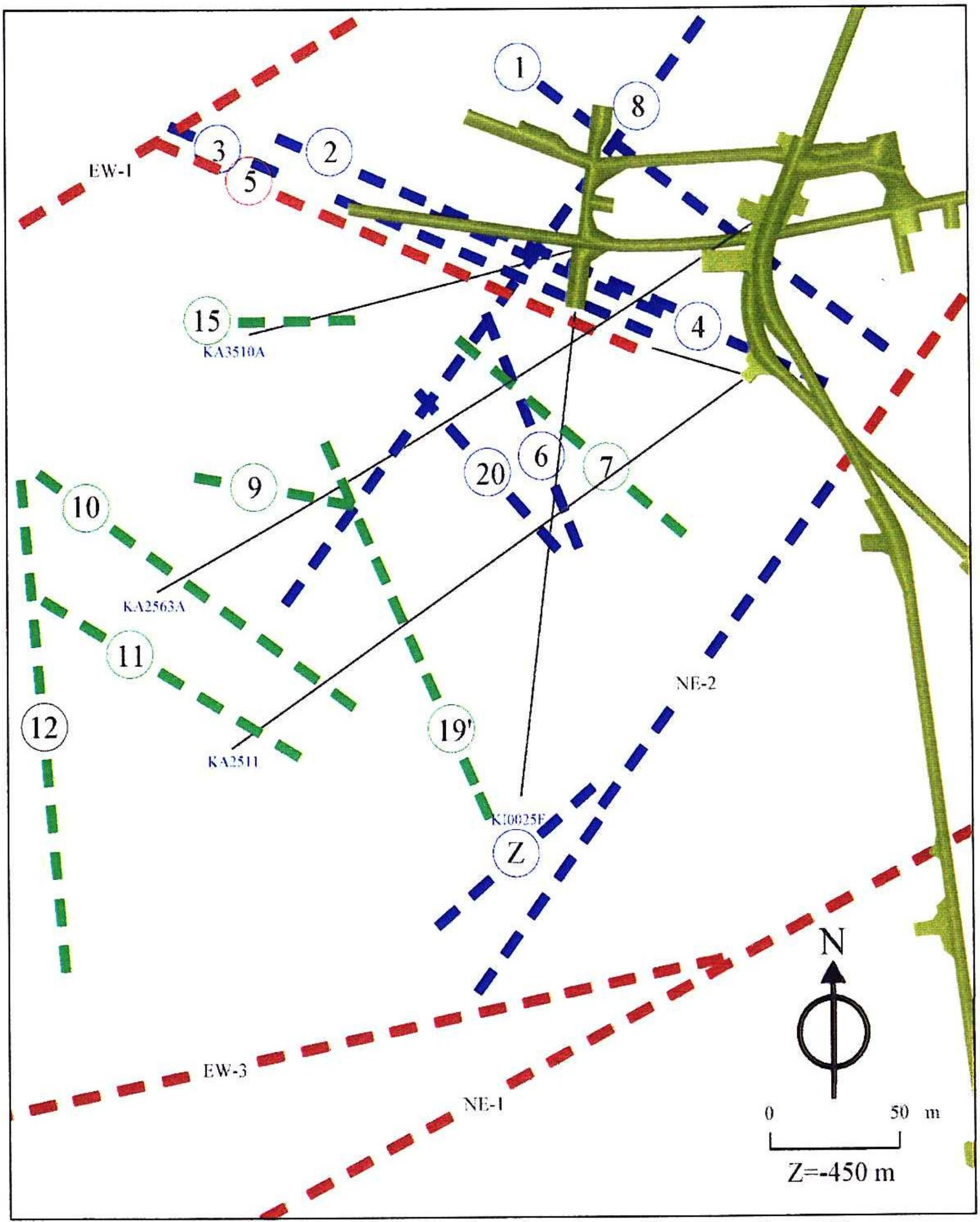

Figure 4-7 Structural model of the TRUE block scale volume. Planar section at Z=-450 m. Different colours represent different degrees of reliability. Red = certain, blue = probable green = possible structures.

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Appendix 1 Coordinates of identified structures

Table A-1. Interpreted structures given as the equation of the plane. Note that the calculated equations of the plane are based on best estimates of the interpreted borehole intercepts where boreholes have been simplified to straight lines, i.e. intercept co-ordinates have not been calculated by using borehole deviation measurements.

Zone ID	A	B	C	D	Strike	Dip
1	5.98E-01	8.01E-01	0.00E+00	-7.03E+03	127	90
2	-3.90E-01	-9.20E-01	3.51E-02	7.45E+03	113	88
3	-3.80E-01	-9.03E-01	2.01E-01	7.37E+03	113	78
4	-3.74E-01	-8.98E-01	-2.33E-01	7.14E+03	293	77
5	-4.15E-01	-9.10E-01	2.69E-02	7.40E+03	115	88
6	-8.91E-01	-4.42E-01	1.05E-01	4.95E+03	154	84
7	5.24E-01	8.46E-01	-1.02E-01	-7.16E+03	129	88
8	7.98E-01	-6.03E-01	0.00E+00	2.83E+03	217	90
9	-1.71E-01	-9.85E-01	0.00E+00	7.38E+03	280	90
10	5.88E-01	8.08E-01	-1.75E-02	-6.84E+03	306	89
11	4.97E-01	8.45E-01	1.98E-01	-6.80E+03	300	79
12	9.96E-01	8.91E-02	0.00E+00	-2.37E+03	355	90
15	1.50E-02	-1.00E+00	0.00E+00	7.21E+03	269	90
16	2.55E-01	4.49E-02	-9.66E-01	-1.20E+03	205	15
17	3.07E-01	-1.50E-01	-9.40E-01	9.45E+01	206	20
18	-5.90E-02	2.75E-02	-9.98E-01	-5.54E+02	25	4
19	-8.01E-01	-3.89E-01	-4.56E-01	4.08E+03	334	63
20	7.40E-01	6.68E-01	8.21E-02	-6.18E+03	318	85
Z	6.16E-01	-7.31E-01	-2.94E-01	3.82E+03	230	73
EW-1	4.79E-01	-8.55E-01	1.99E-01	5.47E+03	61	78
EW-3	-1.99E-01	9.61E-01	-1.91E-01	-6.41E+03	78	79
NE-1	-4.38E-01	8.47E-01	3.01E-01	-4.91E+03	243	72
NE-2	7.88E-01	-5.73E-01	2.25E-01	2.59E+03	36	77

APPENDIX 2 NOMENCLATURE AND CLASSIFICATION ON FRACTURES AND FRACTURE ZONES (after Rhén et al, 1997)

The nomenclature and classification according to Bäckblom /1989/ treats aspects for use of nomenclature for site investigations and addresses how geological, geophysical, geohydrological results should be named. A special section is devoted to the uniqueness and completeness of investigations.

According to Bäckblom /1989/ a fracture zone is a fracture zone - if only and only - if geological field evidence supports zones with the characteristics that the intensity of natural fractures is at least two times higher than in surrounding rock. Completely disintegrated and/or chemically altered rock is included in the definition of fracture zone.

The definition of fracture zone can be expanded by additional characteristics. A fracture zone can thus be 'a hydraulically conductive fracture zone' or a 'non-conductive fracture zone'.

During mapping in the tunnel it was found that this definition would, however, designate most fine-grained granites as fracture zones. Thus, it was necessary to add a tectonic/kinematic constraint to the definition of *'fracture zone'* such as shearing, faulting and clay alteration. Sections in the tunnel with >5 fractures/m, with no obvious tectonic/kinematic influence were mapped as zones with 'increased fracturing'.

The term fracture swarm has also been used and is defined as a zone with relatively high fracture frequency, but not so high as a proper fracture zone /Wikberg et al, 1991/ with fractures essentially parallel to the orientation of the swarm boundary /Hermanson, 1995/.

The term '*major fracture zone'* was used for a feature more than about 5 m wide and extending several hundred metres. Features less than about 5 m and more than 0.1 m wide and of lesser extent were called 'minor fracture zones'.

Persistent, several metres long fractures mostly steep and estimated to be significant hydraulic conductors were called 'single open fractures'.

Classification : Discontinuity domains, level of reliability

A fracture zone is a more or less two-dimensional feature. Its extension and direction is 'certain' after investigations or measurements in several points.

To define a *'level of reliability'* three separate definitions were used.

Possible is the lowest level of confidence. By additional studies the level of reliability can be raised to Probable or Certain.

Three basic cases were considered:

A Fracture zones expressed at surface, Table A2-1.

B Fracture zones not expressed at surface, Table A2-2.

C Fracture zones expressed at surface and in borehole(s) and/or under-ground caverns (tunnel(s) shaft(s), raise (s), Table A2-3.

Table A2-1 is applied to the early phase of investigations and in regions where drilling/tunnelling is not carried through.

Table A2-2 is applied to zones not observed at surface, whereas Table A2-3 should be applied to zones that have both surface and sub-surface expressions.

Increased fracture intensity in Tables A2-1, A2-2 and A2-3 is defined as a section where the intensity of natural fractures is at least two times greater than in surrounding rock.

Table A2-1. Zones observed at surface.

Reliability	Observation*
Possible	Geophysical anomaly with extensiveness or increased fracture intensity in one outcrop.
Probable	Zone with increased fracture intensity in at least two outcrops reasonably close, or geophysical anomaly with increased fracture intensity in one outcrop.
Certain	Zone with unique characteristics between at least two fractured outcrops or exposed zone of increased fracture intensity.

* Statements on dip shall be substantiated by field evidence (i.e. dip measurements on exposed zone or geophysical measurements like VLF)

Table A2-2. Zones not observed at surface.

Reliability	Observation
Possible	Increased fracture intensity in a section of a core, interpolation between at least two boreholes with sections of increased fracture intensity.
Probable	Interpolated fracture zone with some additional unique characteristics observed (geophysical, hydrogeological, geological or geochemical) in two boreholes. Sections with increased fracture intensity in one borehole and one tunnel and with some additional unique characteristics observed.
Certain	Fracture zone with unique characteristics in three or more holes or fracture zone in two boreholes with (seismic or radar) connection in between. Sections with increased fracture intensity in two tunnels and with some additional unique characteris-tics observed.

Table A2-3. Zones observed at surface and in sub-surface.

Reliability	Observation
Possible	Lineament from surface investigations and geophysical anomaly (radar) in borehole.
Probable	Zone with increased fracture intensity at one outcrop interpolated with sections of increased fracture inten-sity in at least one borehole (tunnel) or other unique characteristics interpolated with section of increased fracture intensity in at least one borehole (tunnel) reasonably close.
Certain	Fracture zone at surface with observed direction of dip at surface and unique characteristics in at least two boreholes or tunnels.

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