SKB TECHNICAL REPORT 87-26

The Kymmen power station TBM tunnel Hydrogeological mapping and analysis

Kai Palmqvist[1] and Roy Stanfors[2]

[1]BERGAB
[2]Lunds University

December 1987

SVENSK KÄRNBRÄNSLEHANTERING AB
SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO

BOX 5864 S-102 48 STOCKHOLM
TEL 08-665 28 00 TELEX 13108-SKB

THE KYMMEN POWER STATION

TBM TUNNEL

HYDROGEOLOGICAL MAPPING AND ANALYSIS

Kai Palmqvist, BERGAB-Berggeologiska Undersökningar AB

Roy Stanfors, Lunds Universitet

December 1987

Information on KBS technical reports from 1977-1978 (TR 121), 1979 (TR 79-28), 1980 (TR 80-26), 1981 (TR 81-17), 1982 (TR 82-28), 1983 (TR 83-77), 1984 (TR 85-01), 1985 (TR 85-20) and 1986 (TR 86-31) is available through SKB.

ABSTRACT

The aim of the project is to make a detailed investigation of the geological conditions and the different kinds of leakages along a tunnel belonging to the Kymmen power station in the province of Värmland, Sweden.

The studies are carried out in a TBM tunnel, which due to particularly mild treatment of the bedrock during the driving process, affords unique opportunities for detailed studies of groundwater leakages.

The mapping, covers a tunnel length of 4500 m. In the drawings of the geological mapping all the continuous fissures and fissures with leakage irrespective of their length or continuity are shown. A table accompanying each section covered by the drawings indicates the character of the surface of the fissure (raw, plane, smooth, winding etc), the contents of filled fissures and any variations in the widths of fissures.

Zones in which the bedrock is more or less mechanically crushed and intersected by close fissures are marked with special screen designations in the drawings. One of the appended tables gives the extent and the type of crushing. Between varying degrees of crushing and types of mechanical crushing, 5 types of tectonic zones are distinguished for differentiation.

In the same way, based on the extent and type of alterations, 5 types of clay-alterations are distinguished.

In mapping visible leakage, 5 classes have been distinguished according to size.

In addition to mapping the location of leakage from channels which end at a point from which droplets can escape (point leakage), there are accompanying tables which indicate damp and dry sections of tunnel separately. The tables also often give detailed information about aquiferous fissures.

TABLE OF CONTENTS

1. GENERAL INFORMATION

1.1 Introduction

At the request of SKB, BERGAB-Consulting Geologists have carried out a geological mapping of a TBM tunnel belonging to the Kymmen power station in the province of Värmland, Sweden. The objective of the mapping was to document water leakage in the tunnel. The bedrock had received particularly mild treatment during the driving process, so the tunnel afforded a unique opportunity to study the presence of water in the fissures and zones of the bedrock.

This report contains an analysis of the mapping results.

1.2 Geological Mapping Report

The mapping consists of 15 drawings on a scale of 1:200. The mapping covers a tunnel length of 4500 m. As is shown in the drawing Fig. 1.1 the entire mantle surface has been mapped. This drawing is an example of how the geological information is presented on the original drawings, which have swedish text (see Fig. 1.2). The rock types found are designated with initials in the drawings.

For a detailed analysis of the bedrock, drawings in which the rock types are marked with screen designations have been made. These drawings show for instance, water leakage in boundaries between rock types, but are not included in the report since the screen designations are too difficult to read after reduction of scale.

In the drawings of the geological mapping all the continuous fissures and fissures with leakage, irrespective of their length or continuity are shown. What are referred to as "cracks" have not been mapped.

The table accompanying each section of drawings gives the strike and dip of the schistosity of the bedrock. The strike and dip of water-filled fissures as well as of joint sets is also given. Special fissure diagrams illustrate the fissures of each a 100 m section of the tunnel. The diagrams indicate the tunnel direction and fissures, with special indication of fissures along the planes of schistosity, aquiferous fissures and clay-filled fissures.

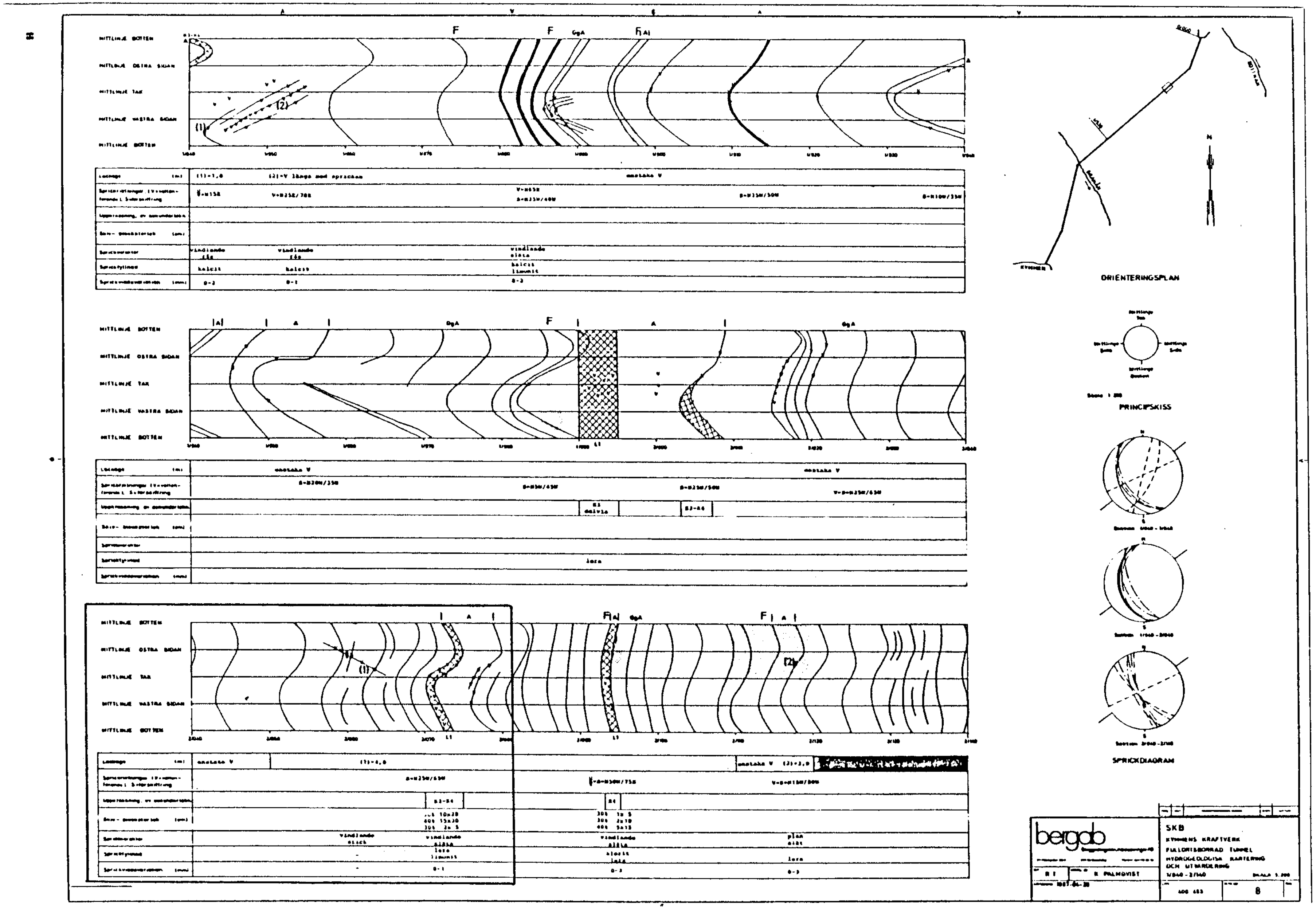
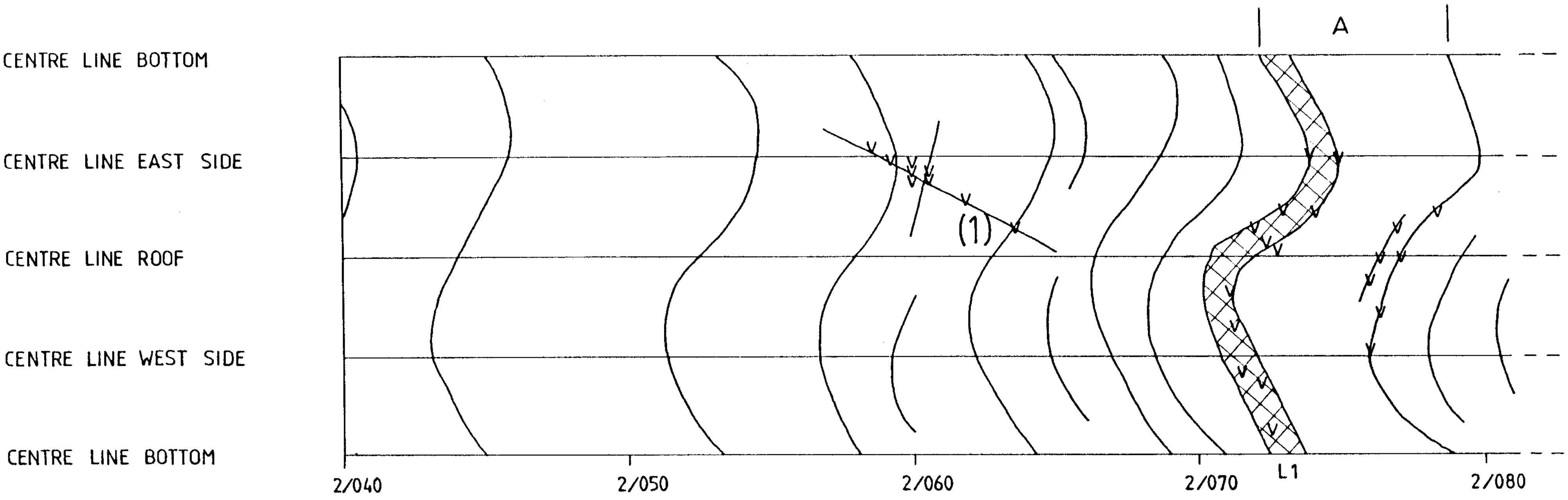


Fig 1.2 Example of an original drawing on a reduced scale (Swedish text)
The thick line shows the part presented in Fig 1.1



Leakage (m)	solitary V	(1)=4,0		
Strike and dip of fissures, (v=aquiferous fissures), S=schistosity		s=N25W/65W		
Type of crushing, Sl = secondarily cemented			K3-K4	
Thickness of plates, lengths of block edges (cm)			30% 10x20 40% 15x30 30% 2x 5	
Character of fissure surface		winding cracks	winding smooth	
Fissure filling		-	clay limonite	
Variation in fissure width (mm)		-	0-1	

Fig 1.1 Example of geological mapping with accompanying table

The table accompanying each section covered by the drawings indicates the character of the surface of the fissure (raw, plane, smooth, winding etc), the contents of filled fissures and any variations in the widths of fissures.

Zones in which the bedrock is more or less mechanically crushed and intersected by close fissures are marked with special screen designations in the drawings. One of the appended tables gives the extent and the type of crushing.

Between varying degrees of crushing and types of mechanical crushing, 5 types of tectonic zones are distinguished for differentiation:

K1: "slaty cleavage" indicates zones in which the bedrock is broken mainly along plane-parallel fissures at intervals $\geq$ 10 cm.

K2: "thin-slaty cleavage" indicates zones in which the bedrock is broken mainly along plane-parallel fissures at intervals < 10 cm.

K3: "blocky rock" indicates zones in which the bedrock is broken mainly along intersecting fissure groups demarcating blocks with edges of 20-60 cm.

K4: "partly crushed rock" indicates zones in which the bedrock is broken mainly along intersecting fissure groups demarcating blocks with edges < 20 cm.

K5: "completely crushed rock" indicates zones in which the bedrock is entirely fragmented by fissures from intersecting directions.

Secondarily cemented fissures are indicated in the table by the supplementary designation Sl.

The table also lists the percentage of distribution of different foliation and block sizes in tectonic zones.

In the mapping, certain sections of the tunnel with blocky bedrockmass which do not belong to true tectonic zones are distinguished. These sections are indicated in the table by codes given within parenthesis designating the extent and type of crushing.

"Clay-alteration" indicates alterations in the bedrock causing the formation of clay-minerals. These may be both swelling and non-swelling types. Based on the extent and type of alterations, 5 types of clay-alterations are distinguished:

L1: "clay-filled fissure" indicates occasional fissures with a width $\leq$ 10 cm.

L2: "clay-filled vein" indicates occasional fissures with a width > 10 cm.

L3: "zone with clay-alteration in the majority of fissures" indicates tectonic zones in which the bedrock itself is not weathered.

L4: "zone with clay-alteration in the majority of fissures" indicates tectonic zones in which the bedrock itself is more or less weathered.

L5: "general clay-alteration" indicates that the entire bedrock mass is altered to clay.

Clay-alteration is marked in the drawings and given a code designation in conjunction with the mapping.

In mapping visible leakage, 5 classes have been distinguished according to size:

V: "minor drip" indicates damp bedrock surfaces with occasional water droplets.

VV: "major drip - slowly running water" indicates dense water droplet formations, developing at times into running water.

VVV: "fast running water - flushing water" indicates major ground water leakage, usually caused by isolated major open fissures.

VVVV: "fast flushing water" usually indicates major leakage from channel formations.

VVVVV: "very fast flushing water" indicates gushing ground water inflow, usually from a channel formation.

In addition to mapping the location of leakage from channels which end at a point from which water droplets can escape (point leakage), there are accompanying tables which indicate damp and dry sections of tunnel separately. The tables also often give detailed information about aquiferous fissures. The number and "size" of leaks are indicated by numbers (1) which refer to geological mapping report.

The quantification of point leakage is treated under "Analysis of Hydrogeological Conditions".

Supplementary to the hydrogeological mapping, a large number of leaks have been photographed. Some of these photographs have been selected in the photo appendix. When these photos are referred to in the mapping comments, the letter F and the appropriate section length are given.

2. BEDROCK CONDITIONS

2.1 Bedrock

2.1.1 Bedrock in the Kymmen-Rottnen Area of the Province of Värmland, Sweden

Information from a geological survey of this area of Värmland, may be found in the Törenbohms survey map from 1981 and a map of the district of Värmland published in 1983 (SIND-kartan). Modern mapping of the district of Värmland has been underway for a number of years. Detailed geological information may be found in the description of what is known as the "Gräsmarksformation", (Lundegårdh, 1977).

The predominate type of rock in the tunnel is a reddish, often fine-grained granite gneiss which has passed trough at least two phases of schistosity. A minor feature of the granite gneiss is that it contains relatively large amounts of homogenous granite - often with phenocrysts.

Parallel to the schistosity of the granite gneiss in a N-NNW direction there are elongated lenses of dolerite. The dolerites are often mineralogically metamorphed (uralitizated) and are schistose. A special feature of the bedrock of this part of Värmland is the occurrence of a series of lens-shaped volcanic rock types usually grouped under the designation "Gräsmarksformationen". All of these volcanics are highly metamorphed (metavolcanics) and are often schistose. One variation of these is high in quartz and reddish in color (quartz prophyr) while the rest have a more basic composition and are darker in color (porphyrites).

These porphyrites and the schistose dolerites mentioned above, have been grouped under the designation "amphibolite" in accordance with engineering geology.

A characteristic of all the rock types described above is that they strike N-NNW and dip 40-50^{o} towards west.

2.1.2 Bedrock Along the Strech of Tunnel

As shown in drawing Fig. 2.1 the mapping distinguishes four rock types. Minor schistose granites have been designated as granite gneiss. Where the granite is densely peppered with an even distribution of metamorphed mafic intrusive bodies, the rock type has been designated as granite gneiss with amphibolite plates. Fine-grained partially gneissic quartz porphyr has been designated as leptite. Where veins of greater thickness of metamorphed mafic rock types occur they are designated as amphibolite.

The extent and distribution of the major rock types mapped are shown in table 2.1.2.1, appendix 2.1. The granite gneiss in the drawings and tables below is designated as Gg. Granite gneiss with amphibolite plates is designated as GgA, while designations L and A correspond to leptite and amphibolite. Leptite and granite gneiss with amphibolite plates each account for approximately 40% of the 4496 m mapped stretch of tunnel. Granite gneiss constitutes 13% and amphibolite 7%. Amphibolite in this case designates continuous sections $\geq$ 25 m.

2.2 Tectonics

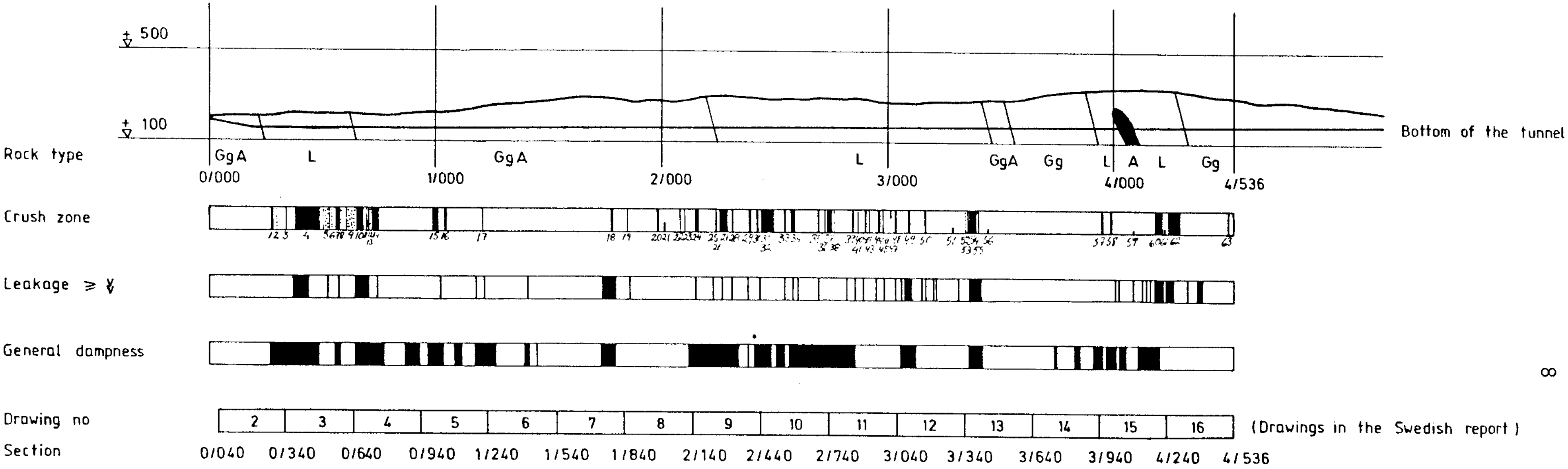
2.2.1 General Fissure Composition

The schistosity of the bedrock strikes mainly NNW. Dips at intervals of 40-60^{o}W dominate. There are however, great local variations in strike and dip.

As described above the schistosity of the granite gneiss also strikes between N50^{o}W and N30^{o}E. Dip varies between intervals of 45-80^{o}W. The corresponding measurements for leptite are strike N55^{o}W-N30^{o}E and dip 25-80^{o}W. The strike of granite gneiss with amphibolite plates varies between N65^{o}W and N15^{o}E. Dip varies between 30-80^{o}W. The strike of the amphibolites was measured at N10^{o}E and dip 50^{o}W.

Along the mapped stretch of the tunnel 63 crush zones were registered. Seven of these are lined. Of the non-shotcreted zones 48 show a parallel formation to the strike of the schistosity. The remaining 8 zones which are not plane-parallel have been formed in leptite (7) and amphibolite (1).

The majority of mapped fissures have been formed along the plane of schistosity. In addition to this joint set, there are also fissures which strike NNE-erly and have an easterly dip. In addition



Rock types:

Gg = granite gneiss

GgA = granite gneiss with amphibolite plates

L = leptite

A = amphibolite

Leakage ≥ ∀

Individual lines are not drawn to scale, so in some cases they represent leaking zones with a width of only a meter

Crush zones:

▌ crush zone

⁝ lined area

Fig 2.1 Overview profile of the hydrogeological conditions joint sets which strike NE-erly with a steep dip also occur relatively frequently in some places. This type of joint set is often formed at right angles to the strike of the schistosity planes. Steep fissures which strike N-S and E-W occur periodically.

2.2.2 Fissure Composition in Different Rock Types

In addition to fissures along the planes of schistosity, which are the most frequently formed, fissure formations also occur which are to some extent determined by rock type.

Steep fissures dominate in the granite gneiss and strike approximately E-W respectively N-S - N10^{o}E. Furthermore, steep fissures occur which strike NNW-erly.

Fissures strike in more directions in leptite than in the other rock types. Fissures with an easterly slope (50-70^{o}) occur very frequently, usually striking at intervals of N10-55^{o}W. Fissures with an eastern slope and which strike N5-50^{o}E also occur in places. Steep fissures occur striking N65-80^{o}E, NNW and NNE.

The composite picture of fissures in granite gneiss with amphibolite plates is dominated by steep fissure striking at intervals of WNW- E-W -ENE. In addition, there are steep fissures which strike N10-30^{o}E as well as easterly sloping fissures (70-80^{o}E) striking NNE-erly.

2.3 Fissure Filling

2.3.1 Mineral Alteration, Deposits, etc

The most common fissure filling is clay. The clay appears as thin clay filled fissures or clay channels, mainly along the planes of schistosity as well as in contact with amphibolite.

Fissure fillings of calcite, chlorite and quartz have been noted, but are less widespread.

Limonite deposits have been observed in fissures along the planes of schistosity as well as following other fissure directions.

No signs that calcite-cemented fissures are more common where there is a thick rock overburden have been observed. Neither are limonite deposits more common in aquiferous fissures under a thin rock overburden.

2.4 Ground Water Leakage

2.4.1 Leakage in Different Rock Types

An investigation of variations in range and intensity of visible leakage in different rock types indicates that granite gneiss sections are usually dry and show only minor isolated leaks (V). More extensive leakage occurs only in section 4/320 - 4/536.

Granite gneiss with amphibolite plates shows general dampness in < 35% of the total length of tunnel. Minor leakage often occurs sporadically, and with greater frequency in association with amphibolites and crush zones. More extensive leakage in different types of fissures appears as point leaks as well as in "drapery" form.

The leptite section of tunnel shows long stretches of general dampness (> 50% of the total length). Increased frequency of minor leaks (V) occured in places, as well as major leaks along some fissures and zones often as point leakage. "Drapery" leakage was also mapped.

The distribution of leakage ≥ V in the different rock types is presented in table 2.4.1.1 below.

Table 2.4.1.1 Leakage ≥ V divided according to rock type

Granite gneiss:	Total 640 m
	11 V on 640 m = 1,7 V /100 m
	5 VV on 640 m = 0,8 VV /100 m
Granite gneiss with amphibolite plates	Total 1891 m
	67 V on 1891 m = 3,6 V /100 m
	35 VV on 1891 m = 1,8 VV /100 m
	3 VVV on 1891 m = 0,2 VVV /100 m
Leptite	Total 1896 m
	162 V on 1896 m = 8,5 V /100 m
	95 VV on 1896 m = 5,0 VV /100 m
	3 VVV on 1896 m = 0,2 VVV /100 m
	4 VVVV on 1896 m = 0,2 VVVV /100 m

Amphibolite: Total 69 m
(larger plates)

2V on 69 m = 2,9 V/100 m

2.4.2 Leakage in Tectonic Zones

Mapped leakage in the tectonic zones is compiled in table 2.4.2.1, appendix 2.2. The table indicates the width and extent of the zones and the type of crushing, clay alteration, as well as the different plate and block sizes calculated as percentages. The direction of the zones in relation to the strike of the schistosity of the rock and the number of leaks according to size are also indicated. Where possible, the table also shows to which fissure directions leakage is related. In addition, the table indicates whether the rock surface of these particular sections was dry or damp.

2.4.3 Leakage in Different Types of Fissures

As indicated above, fissure composition is determined, to some extent, by the type of rock. Table 2.4.3.1, appendix 2.3 shows ground water leakage in different kinds of fissures present in each rock type. This table presents leakage found in each homogenous section of bedrock, compiled in gradations. The designation //s found in the table stands for fissures parallel to the schistosity. Detailed reference numbers for each section are designated (0/000) and photograph reference numbers are designated (F 0/000).

Table 2.4.3.2, appendix 2.4 shows the number of leaks ≥ V/100 m of tunnel distributed according to rock type and the direction of fissure.

2.4.4 Leakage in Relation to Type and Length of Fissure

Leakage in relation to mapped fissure length has been investigated to determine whether certain fissure directions might be underrepresented as a result of the tunnel´s direction. This investigation covers those leakages within and outside the tectonic zones, which can be connected with a precise fissure. Table 2.4.4.1 indicates the number of leaks ≥ V per m of mapped fissure in the rock types present.

Table 2.4.4.1 Leakage ≥ V /m fissure in different rock types

Gg	total fissure length 1871 m	
	V : 11/1871 m =	0,59 · 10^{-2} V/m
	VV : 5/1871 m =	0,27 · 10^{-2} VV/m
GgA	total fissure length 6101 m	
	V : 67/6101 m =	1,10 · 10^{-2} V/m
	VV : 16/6101 m =	0,26 · 10^{-2} VV/m
	VVV : 3/6101 m =	0,05 · 10^{-2} VVV/m
L	total fissure length 2031 m	
	V : 77/2031 m =	3,79 · 10^{-2} V/m
	VV : 68/2031 m =	3,35 · 10^{-2} VV/m
	VVV : 2/2031 m =	0,10 · 10^{-2} VVV/m

Table 2.4.4.2, appendix 2.5, was drawn up to present the strike directions of aquiferous fissures in relation to mapped fissure lengths. It also indicates which fissure strike directions show most leakage ≥V, as well as the number of fissures in each direction and the total mapped length of fissures in each direction. Under "Observations" a brief description of the nature of the leaks is given.

Table 2.4.4.2, indicates that the amount of leakage ≥ V per meter of fissure length is, on the whole, the same in granite gneiss and granite gneiss with amphibolite plates. The amount of leakage per meter of fissure is, however, clearly greater in leptite. In addition, this table indicates that most leakage in granite gneiss is found along fissures which strike N60°W/20°S. In granite gneiss with amphibolite plates most leakage is from fissures striking parallel to the schistosity and from steep fissures striking N50°E.

Most leakage in leptite occurs in fissures striking parallel to the schistosity. Many leaks also occur from steep fissures striking N50-80^{o}E.

2.4.5 Character of fissure surface - Type of Leak

All registered fissures along the planes of schistosity are smooth and most of them are plane. Only a few of the mapped fissures found along the planes of schistosity were observed as winding. Most other investigated fissure strike directions are winding and smooth. Raw fissures often strike easterly.

Continuous fissures along the planes of schistosity are usually aquiferous. Steep fissures parallel to the tunnel often showed profuse leakage. These fissures are usually winding - en echelon formation, with both raw and smooth fissure surfaces. The largest type of leaks (4 has been found) is located at intersecting points of fissures along the planes of schistosity and crossing smooth fissures in crushed leptite.

3 ANALYSIS OF HYDROGEOLOGICAL CONDITIONS

3.1 Aquiferous Qualities

3.1.1 Aquiferous Qualities of Bedrock

Chapter 2 indicates that the different rock types, to some extent, determine their own fissure pattern. As a result the different rock types vary in the degree to which they are aquiferous. Since the rock types alternate and intersect along the entire stretch of tunnel, mapped leakage in the different rock types is determined as independent of rock overburden. There is a lack of information indicating to what extent leakage has led to sinking ground water levels. Some sinking is estimated to have taken place however, since no grouting has been done. This should particularly be true in the major tectonic zones. This may have led to somewhat reduced visible leakage in some places, but the distribution of different sizes of water leaks presented in the drawings and tables here still gives a reliable indication of the relative differences existing between the different rock types, zones and fissures.

3.1.2 Aquiferous Qualities of Different Rock Types

Section 2.4.1 indicates an interesting disparity between aquiferous fissures in different rock types. The section of granite gneiss was mostly dry with only minor isolated leakage. More extensive leakage only occurred in section 4/320-4/536 of granite gneiss. Nearly all leakage ≥⩖ is associated with fissures striking N60°W/20°S and at intersections of crossing cracks (F 4/385, F 4/396). In the only tectonic zone in granite gneiss (4/506-4/509) there was no leakage.

The more complexly formed sections containing granite gneiss and amphibolite plates show general dampness in <35% of the total length. Minor leakage (V) appears with greater frequency in conjunction with amphibolites and crush zones. Minor leakage is more widespread in intermediary sections. More extensive leakage occurs in tectonic zones as well as in different types of fissures in intermediary sections. The larger leaks appear in point leak form as well as in "drapery" form.

On the whole, the leptite section shows a higher degree of dampness in the tunnel than the other rock types (>50% of the total length). Minor leakage (V) occurs with increasing frequency in conjunction with certain tectonic zones. More extensive leakage is often in point form and occurs in solitary fissures as well as in tectonic zones. "Drapery" leakage also occurs.

Amphibolites are more widespread in sections 2/730-2/778 and 4/050-4/079. The tunnel is generally damp in these sections. There is a crush zone in the first section. Two point leaks (⩖) were mapped in the crush zone.

Table 3.1.2.1, appendix 3.1 shows the occurrence of more extensive leakage (≥⩖) in different rock types. The table clearly indicates that the leptite section is more aquiferous than other rock types. The column of number of leaks of different dimensions calculated per meter of tunnel indicates that water leakage in leptite is more than double the leakage in granite gneiss with amphibolite plates. Water leakage in granite gneiss with amphibolite plates is, in turn, more than double the leakage in granite gneiss. Comparisions of amphibolite plates must be made with great caution since the regularity of their occurence is unreliable.

The table also indicates that granite gneiss with amphibolite plates has more number of leaks outside the tectonic zones than inside the zones. The opposite applies to leptite. In granite gneiss the leakage is located outside the tectonic zone. Since this zone comprises such a small percentage of the total stretch of granite gneiss, great caution must be used in drawing any conclusions from this information.

Leakage per meter of tunnel both inside and outside the tectonic zones is greater in leptite than in granite gneiss with amphibolite plates. Granite gneiss outside the tectonic zones shows less leakage than granite gneiss with amphibolite plates.

3.1.3 Aquiferous Qualities in Tectonic Zones

As is shown in the section above the tectonic zones determine to a major extent the aquiferous qualities of the bedrock. The differences in aquiferous qualities between different zones is however great. This may be due to the type and extent of crushing, the presence of fissure filling, the nature of fissure, etc, Table 2.4.2.1 shows that the most extensive leakage occurs in zones formed in leptite. There is particularly increased leakage where the zones are wholly or partly slaty or thin-slaty. True clay alteration only occurs in contact with amphibolite and other rock types.

The table also indicates that the majority of zones are parallel to the schistosity of the bedrock and that leakage often occurs in fissures parallel to the schistosity. Inside some zones, however, leakage occurs in conjunction with other fissures striking in other directions.

Leakage inside the zones is clearly predominately point leakage located along fissures or at the intersection of two fissures.

3.1.4 Aquiferous Qualities outside Tectonic Zones

Sections 2.4.3 and 2.4.4 and adherent tables include detailed information on the aquifereous qualities of different fissure directions distributed according to rock type, meter of tunnel and meter of fissure length. Comparisons of granite gneiss and granite gneiss with amphibolite plates shows that the number of leaks $\geq$ V per meter of fissure length is approximately the same for both. The corresponding figure for leptite is more than three times greater than this.

The mapped length of fissure per meter of tunnel is 2.9 m in granite gneiss while the corresponding figure for granite gneiss with amphibolite plates is 3,5 m. The corresponding figure for leptite is 1.8 m.

The reason leakage in leptite is greater than in granite gneiss with amphibolite plates, despite the lower figure of fissure length per meter of tunnel of leptite, is probably the diffuse block structure found in some places formed by fissures and cracks, chiefly appearing in leptite.

3.2 Hydrogeological Summary

Fig. 2.1 summarizes the hydrogeological conditions in an overview profile. The drawing distinctly indicates that major tectonic zones occur in the leptite sections. The zones are often smaller and widely more disseminated in the other rock types. The location of major leaks corresponds, on the whole, to tectonic zones or appear in conjunction with tectonic zones. Even sections of general dampness in the tunnel correspond to a great extent to zone sections and/or sections of greater leakage.

As can be seen in Fig. 2.1 there are large sections (300-500 m) along the tunnel which do not have leakage ≥⩔. There are also long stretches of tunnel with leakage ≥⩔. As mentioned above, this is determined by the rock type. No effects of rock overburden and the consequent pressure of ground water have been observed.

3.3 Significance of Fissure Filling and Character of Fissure surface

3.3.1 Fissure Filling

Where it appears, fissure filling is chiefly clay. Clay filled fissures appear almost troughout as single clay filled fissures. These often occur along the planes of schistosity or in contact with amphibolites. In some cases a clay filled fissure may have the same qualities as clay-filled veins.

In some places there are also fissure fillings of calcite, chlorite and quartz.

Fissure filling both within the tectonic zones and in intermediary sections is of such minor significance that any effect it might have on aquiferous qualities would be insignificant.

3.3.2 Character of Fissure surface

Rock-fall is unusual in a full-face bored tunnel, which limits potential for detailed studies of the character of fissure surfaces.

Leakage both inside and outside tectonic zones often occurs along fissures parallel to the schistosity. These fissures are smooth throughout and mostly plane.

Leakage also often occurs along fissures more or less parallel to the tunnel. These fissures are steep, winding - "en echelon". Both raw and smooth fissure surfaces may occur.

The greatest leakage occurs at intersections of crossing fissures.

3.4 Leakage Formation

Table 3.4.1, appendix 3.2 shows the distribution of point and drapery leakage. The table indicates that there are 169 point leaks ≥VV in crush zones. The corresponding figure for drapery leaks is 12. The number of point leaks outside the crush zones is 189. The corresponding figure for drapery leaks is 17.

Table 3.4.1 also shows that drapery leaks are twice as common in granite gneiss with amphibolite plates as in leptite.

The leakages mapped here indicate that water chiefly appears in channels, either at the intersection of two fissures or along a fissure plane.

3.5 Quantification of Leakage

Where possible the leak size was measured during the mapping process. The specifications of the

mapped leaks are given below:

V = < 0,01 l/min

VV = 0,01 - 0,2 l/min

VVV = 0,2 - 1,5 l/min

VVVV = 1,5 - 6,5 l/min

VVVVV = > 6,5 l/min

3.6 Conclusions

-The rock types show the various aquiferous qualities to differing extents. Granite gneiss is chiefly dry. The more complex sections of granite gneiss and amphibolite are damp <35%. The corresponding figure for leptite is >50%.

-The frequency of major leakage (≥VV) in leptite found is more than twice that found in granite gneiss with amphibolite plates. The frequency of major leakage ($\geq$V) in granite gneiss with amphibolite plates found is, in turn, more than twice that found in granite gneiss.

-This type of water distribution may partly be attributable to the fact that leptite is more brittle than the other rock types and partly to the absence of material filling in the leptite fissures. The more extensive leakage in granite gneiss with amphibolite plates in comparison with granite gneiss may be attributable to unhomogenous qualities and fissure formations along the planes of schistosity associated with these qualities.

-Leakage in granite gneiss with amphibolite plates $\geq$ V calculated per meter of tunnel is three times greater inside zones than outside zones. The corresponding figure for leptite is 3-4. This means that approximately 25% of leakage along the tunnel occurs in rock between the tectonic zones.

-Water leakage occurs in point leaks (channel formations) as well as in leaks along fissures (drapery form). The number of point leaks $\geq$ V located in crush zones is 169. The corresponding figure for drapery leaks is 12. Outside the crush zones the number of point leaks is 189 and the number of drapery leaks is 17.

-Drapery leakage is found to be twice as common in granite gneiss with amphibolite plates as in leptite.

-The number of leaks $\geq$ V per meter of fissure length is approximately the same for granite gneiss and granite gneiss with amphibolite plates. The corresponding figure for leptite is more than three times larger.

-The distribution of leakage $\geq$ V along the tunnel is such that larger "unbroken" sections with insignificant water-bearing capacity have been discerned.

ACKNOWLEDGEMENT

The data in this report has to a great extent been processed in order to meet the specific requirements of Professor Ivars Neretnieks and his group. With further processing, the data could be used as a basis for additional calculations and geological models etc.

It is our hope that this report will help to fill the current gap in studies of the presence of water in crystallin Swedish bedrock.

Table 2.1.2.1 Division of rock types, crush zones, shotcrete and block structures outside the crush zones.

SECTION	ROCK TYPE (m)	OF WHICH AMF	TOTAL LENGTH (m)	CRUSH+SHOTCRETE (m)	OF WHICH SHOT-CRETE	NON-CRUSH/SHOTCRETE (m)	OF WHICH BLOCK STRUCTURE
0/040-0/232	GgA	-	192	-	-	192	-
0/232-0/640	L	-	408	230	146	178	43
0/640-2/233	GgA	107	1593	132	47	1461	-
2/233-2/730	L	65	497	145	-	352	323
2/730-2/770	A	40	40	17	-	23	23
2/770-3/446	L	24	676	68	14	608	302
3/446-3/552	GgA	1	106	-	-	106	-
3/552-3/915	Gg	14	363	-	-	363	-
3/915-3/955	L	-	40	2	-	38	31
3/955-3/970	Gg	-	15	-	-	15	-
3/970-4/050	L	9	80	5	-	75	59
4/050-4/079	A	29	29	-	-	29	-
4/079-4/117	Gg 1)	8	38	- 2)	-	38	-
4/117-4/137	L	-	20	-	-	20	20
4/137-4/145	Gg	-	8	-	-	8	-
4/145-4/320	L	5	175	73	-	102	50
4/320-4/536	Gg	-	216	4	-	212	-
		302	4496	676	207	3820	851

1) with leptite cut

2) leptite cut = crush

COMPOSITION

Gg: 640 m of which amphibolite plates comprise app. 22 m total

GgA: 1 891 m of which amphibolite plates comprise app. 108 m total

L: 1 896 m om which amphibolite plates comprise app. 103 m total

A: 69 m

TABLE 2.4.2.1 LEAKAGE IN TECTONIC ZONES

ZONE NO	WIDTH (m) (SECTION)	ROCK TYPE	TYPE	PLATE-BLOCK SIZE (cm)	DIREC-TION	WATER-BEARING LEAKAGE
1.	7 (0/275-0/282)	L+amphlens	K3-K4	30% 3x5 40% 5x10 10% 10x20 20% >10x20	S+other directions	14 V evenly distributed → 2V/m zone damp
2.	7 (0/294-0/301)	-	shot-crete	-	-	3 V → 0,42V/m 1 V → 0,14V/m
3.	6 // fissures = 1.5 (0/345)	L	K2 L1	Plates <10	N80E	5 V → 3,3 V/m 3 V → 2,0 V/m
4.	29 (0/379-0/408)	L	K3-K4 shot-crete	30% 3x5 40% 5x10 10% 10x20 20% >10x20	S+other directions	~25 V evenly distributed →0,89 V/m 2V//s→ 0.07V/m damp
	47 (0/408-0/455)	L	K3	10% 5x10 50% 10x30 40% >30x60	S+other directions	7 V evenly distributed →0,15V/m 31V(most frequently N50E)→0,66V/m 6 V (N50E)→0,13 V/m damp
	25 (0/455-0/480)	L	K3-K4 shot-crete	30% 3x5 40% 5x10 10% 10x20 20% >10x20	S+other directions	damp
5.	28 (0/490-0/518)	-	shot-crete	-	-	-

ZONE NO	WIDTH (m) (SECTION)	ROCK TYPE	TYPE	PLATE-BLOCK SIZE (cm)	DIREC-TION	WATER-BEARING LEAKAGE
6.	10 (0/535-0/545)	-	shot-crete	-	-	-
7.	18 (0/557-0/575)	L	K4	40% 3x10 30% 5x20 20% 10x10 10% >10x10	S+other directions	leakage converging N50E (5V) and N55W/55N(3V+ 1V) 3 spread V 11V per 18 m → 0,61V/m 1V per 18 m → 0,05V/m damp
8.	12 (0/575-0/587)	-	shot-crete	-	-	-
9.	59 (0/595-0/654)	-	shot-crete	-	-	-
10.	23 (0/654-0/677)	GgA	K3-K4	30% 3x5 30% 5x15 30% 15x30 10% >15x30		N20E (5V) //s (≥ 1V) 31V evenly distributed →1,3V/m 9V per 23 m → 0,39V/m damp
11.	0.5 (0/698)	Contact GgA/A	K2	plates 2-10	N40W/40W //s	3V → 6V/m damp
12.	8 (0/700-0/708)	GgA+ contact+ GgA/A	K3-K4	30% 3x5 30% 5x15 40% 5x15		6V evenly distributed →0,75V/m damp
13.	8 (0/708-0/716)	-	shot-crete	-	-	
14.	22 (0/724-0/746)	GgA	K2-K4 L1	plates 2-10 blocks 2-6	//s=N40W/ 50W	leakage //s 1V →0,05V/m 7V →0,32V/m damp

ZONE NO	WIDTH (m) (SECTION)	ROCK TYPE	TYPE	PLATE-BLOCK SIZE (cm)	DIREC-TION	WATER-BEARING LEAKAGE
15.	15 (0/990-1/005)	GgA	K2-K4 L1/ shot-crete	plates 2-10 blocks 2-10	//s=N20W/ 60W	1⩔ prob. //s→ 0.07⩔ /m damp
16.	10 (1/030-1/040)	GgA	K2-K4 L1/ shot-crete		//s=N20W/ 60W	1V → 0,1V /m 1⩔ → 0,1⩔ /m 1⩔ → 0,1⩔ /m
17.	3 narrow zones 3,5 (1/207-1/217)	GgA	K2-K4	plates 2-10 blocks 2-10	//s=N10W/ 60W	leakage between zones damp
18.	8 (1/774-1/782)	GgA	K3 (part-ly)	30% 15x30 70% >15x30	//s=N15W/	leakage //s + contact amphlens 12V → 1.5V/m damp
19.	1 (1/835)	Amph-lens	K3-K4 L1	30% 3x5 30% 5x15 40% 15x30	//s=N10W/ 50W	12V evenly distributed → 12V/m
20.	5 (1/990-1/995)	A+con-tact GgA	K3/L1 (part-ly)	30% 15x30 70% >15x30	S+other joints	7V evenly distributed → 1.4V/m
21.	0-2 (2/005)	contact A/GgA	K3-K4 small cut	30% 2x5 60% 10x30 10% >10x30	//s=N25W/ 50W	6V(//s)→ 3.0V/m
22	1 (2/072)	contact GgA/A	K3-K4 L1	30% 10x20 40% 15x30 30% 2x5	//s=N25W/ 65W	12V (//s)→ 12.0 V/m
23	1 (2/094)	Amph-lens	K4 L1	30% 1x5 30% 2x10 40% 5x15	//s=N50W/ 75S	6V(//s)→6.0V/m 1⩔(//s)→1.0⩔/m

ZONE NO	WIDTH (m) (SECTION)	ROCK TYPE	TYPE	PLATE-BLOCK SIZE (cm)	DIREC-TION	WATER-BEARING LEAKAGE
24	4 (2/143-2/147)	A+con- tact GgA/A	K3-K4	20% 3x5 40% 5x10 30% 20x30 10% >20x30	//s=N45W/ 80W	7V(//s)→ 1.75 V/m damp
	6 (2/147-2/153)	GgA+ contact +GgA/A	K1-K4	30% 3x5 70% >10x20	//s=N30W/ 65W	12V(//s)→ 2.0 V/m damp
	3 (2/153-2/156)	GgA	K4	30% 3x5 30% 5x10 30% 10x20 10% >10x20	//s	10V(//s)→3.33 V/m 2 VV → 0.67VV/m damp
25.	8 (2/232-2/240)	L+con- tact	K3-K4	30% 3x5 30% 5x10 30% 10x30 10% 10x30	S+other direc- tions	32 V evenly distributed → 4.0V/m damp
26.	4 (2/244-2/248)	L	K2-K4/ K5	plates 2-6 blocks 2-4	//s=N20W/ 60W	1 VV (//s)→ 0.25 VV /m 1 VVV (//s)→ 0.25VVV/m damp
27.	11 (2/253-2/264)	L	K2-K4	plates 2-10 blocks 2-8	//s	3 VV (probably //s)→ 0.27VV/m 2 VVV (prob.//s)> 0.18VVV/m damp

	20
	(2/264-2/284)
		L+A	K2-K4/
			K5
			Clay in
			contact
				plates 2-6
				blocks 2-4
					//s	crack+N70E=1VVVV;
						//s=1 VVVV
						2VV→0.1VV/m
						
						2VVV→0.1VVV/m
						
						1VVVV→0.05VVVV/m
						
						2VVVV→0.1VVVV/m
						damp

ZONE NO	WIDTH (m) (SECTION)	ROCK TYPE	TYPE	PLATE-BLOCK SIZE (cm)	DIREC-TION	WATER-BEARING LEAKAGE
28.	9 (2/300-2/309)	L	K2-K4/ K5	plates 2-6 blocks 2-4	//s=N10W/ 70W	S+crack N40E/70-80E=1 V //s leakage direction 1V → 0.11V/m 1V→ 0.11V/m 2V→ 0.22V/m damp
29.	6 (2/380-2/386)	L	K2-K4/ K5	plates 2-10 blocks 2-8	//s=N20W/ 50-60W	2V→0.33V/m 1V→0.17V/m damp
30.	2 (2/415-2/417)	L	K2-K4	plates 2-10 blocks 2-8	//s=N10W/ 55W	1V//→ 0.5V/m damp
31.	32 (2/425-2/457)	L+A	K2-K4/ K5 L1 (the thin amph. plate crushed)	plates 2-5 blocks 50% 2x3 50% 4x6	//s=N10W/ 55W	2V→ 0.06V/m 5V→ 0.16V/m 2V → 0.06V/m damp
32	20 (2/465-2/485)	L+con-tact L/A	K4-K5 Clay in contact	40% 2x3 40% 4x6 20% >4x6	//s	1V→ 0.05V/m 1V→ 0.05V/m damp
33	10 (2/530-2/540)	L+con-tact L/A	K4 L1	40% 4x6 40% 8x12 20% >8x12	//s=N60W/ 70S	3V→ 0.3V/m (//s) fukt
34	15 (2/570-2/585)	L	K2-K4	plates 2-8 blocks 2-6	//s=N60W/ 70S	1V→0.07V /m 4 V→0.27V/m fukt

ZONE NO	WIDTH (m) (SECTION)	ROCK TYPE	TYPE	PLATE-BLOCK SIZE (cm)	DIREC-TION	WATER-BEARING LEAKAGE
35.	8 (2/690-2/698)	L	K2-K4	plates 2-8 blocks 2-6	//s=N40W/ 50-60W	2V→ 0.25 V/m 2V→ 0.25 V/m damp
36.	1 (2/722)	L+A	K2-K4	plates 2-10 blocks 2-8	//s=N40W/ 50-60W	1V//s = 1V/m damp
37.	18 (2/730-2/748)	A+con-tact A/L	K2-K4 L1	plates 2-10 blocks 2-8	//s=N40W/ 50-60W	2 V =N20E→ 0.11V/m damp
38.	4 (2/821-2/825)	A+con-tact A/L	K2-K4 Clay in contact	plates 5-8 blocks 5-10	//s=N40W/ 50-60W	3V//s→ 0.75 V /m damp
39.	2 (2/837)	L	K2-K4 Clay in contact	plates 5-8 blocks 5-10	//s	3V//s→ 1.5 V/m damp
40.	1 (2/845)	L	K4	30% 6-8 70% 10-15	//s=N40W/ 50W	1V//s→ 1.0 V/m 2V//s→ 2.0 V/m damp
41.	1 (2/851)	L	K1	plates 10-15	//s=N40W/ 50W	2V//s→2.0 V/m 1V//s→1,0 V/m damp
42.	5 (2/890-2/895)	L	K1-K2	plates 5-15	//s=N35W/ 55W	1V//s→0.2V/m 3V//s→0.6V/m 2V//s→0.4V/m
43.	1 (2/901)	Amph-lens in L	K1 Clay in contact	plates 15	//s=N35W/ 55W	1 V//s→1.0V/m

ZONE NO	WIDTH (m) (SECTION)	ROCK TYPE	TYPE	PLATE-BLOCK SIZE (cm)	DIREC-TION	WATER-BEARING LEAKAGE
44.	2 (2/945-2/947)	L	K1	30% 6x8 60% 20x30 10% >20x30	//s	3 VV//s→1.5VV/m 1 VVV//s→0.5VVV/m
45.	1 (2/962)	L	K3-K4	30% 6x8 60% 20x30 10% >20x30	//s=N40-50W/ 50-60W	1 V//s→1.0 V /m
46.	1 (2/966)	L	K3	30% 6x8 60% 20x30 10% >20x30	//s	-
47.	0-1,5 (3/010)	L	K3-K4 (on one side)	30% 2x5 30% 10x20 40% 15x30	//s	2V//s→1.3V/m
48.	2 (3/022-3/024)	L	K2-K4 L1	plates 5-8 blocks 5-10	//s	1V//s→0.5V/m 1VV//s→0.5VV/m
49.	7 (3/075-3/082)	L thin amph lens	K2-K4 Clay in contact	plates 2-8 blocks 5-10	//s=N45W/ 40-50W	3V//s→0,43V/m 3VV//s→0.43VV/m damp
50.	4 (3/153-3/157)	L thin amph lens	K4-K45 Clay in contact	30% 2x3 60% 6x8 10% >6x8	//s	1VVV//s→0.25VVV/m
51.	0-2 (3/290-3/292)	L	K2 SL L1	plates 5-12	//s=N25W/ 50W	5 V
52.	14 (3/345-3/359)	-	shot-crete			1V
53.	0-3 (3/359-3/362)	L	K4 (on one side)	30% 1x5 30% 2x10 40% 5x15	//s= N45W/ 45W	1V//s→0.33V/m damp

ZONE NO	WIDTH (m) (SECTION)	ROCK TYPE	TYPE	PLATE-BLOCK SIZE (cm)	DIREC-TION	WATER-BEARING LEAKAGE
54.	18 (3/362-3/380)	L	K3-K4	30% 3x5 30% 5x20 30% 20x30 10% >20x30	//s	~45Vspread→ 2.8V/m 1VV=N25E→0.05VV/m 1 VV =N25W/50E→ 0.05VV/m 1 VV =N25W/50E→ 0.05VV/m damp
55.	1-4 (3/393-3/394)	L	K3-K4 L1-L2	30% 3x5 30% 5x20 30% 20x30 10% >20x30	//s	5 V//s→ 1.5V /m 6 VV//s→ 2.0 VV/m damp
56.	18/2 (3/430-3/445)	L	K3 (on one side)	30% 3x10 30% 10x20 30% 20x30 10% >20x30	diffe-rent direc-tions	isolated
57.	2 (3/948-3/950)	L	K4-K5 L1	50% 2x3 50% 6x8	//s=N10W/ 60-70W	damp
58.	4 (3/978-3/982)	L	K4-K5 K1	-	diffe-rent direc-tions	1VV=N10-30E→ 0.25VV/m damp
59.	0-3 (4/090)	L i Gg + A	K4-K5 Cut	20% 0x2 40% 3x5 40% 5x15	V=crack	2VV in crack
60	18 (4/188-4/206)	L	K4 L1	30% 3x5 40% 5x10 20% 10x20 10% >10x20	//s=N50W/ 70S	N50W/70S //s N30E/70W ~40V→2.2 V/m 7VV→0.39 VV/m 5VV→0.28 VV/m damp
	5 (4/206-4/211)	L	K1 L1	plates 20	//s=N50W/ 70S	7V//s→1.4V/m

ZONE NO	WIDTH (m) (SECTION)	ROCK TYPE	TYPE	PLATE-BLOCK SIZE (cm)	DIREC-TION	WATER-BEARING LEAKAGE
61.	11/2 (4/219-4/229)	L	K4 on one side	50% 3x5 50% 5x10	//s=N5W/ 60W	N30E/65E //s 18 V 1 ⩔
62.	12 (4/241-4/253)	L+A	K4 part-ly K4	30% 3x5 40% 5x10 30% 10x20	//s=N5W/ 80W	N80E/70S //s ~21V → 1.75V/m 1⩔ → 0.08 ⩔/m
	19 (4/253-4/272)	L+A	K4	10% 2x5 20% 3x10 30% 5x10 40% 10x20	//s=N10W/ 50-70W	N45E //s ~24V→1.26 V/m 1⩔→ 0.05 ⩔/m
	8 (4/272-4/280)	L	K1	20% 10x10 80% plates>20	//s=N25W/ 60W	3V (//s ?) →0.38 V/m
	6 (4/280-4/286)	L	K4	10% 2x5 20% 3x10 30% 5x10 40% 10x20	//s=N-S/ 55W	4 V(//s ?) →0.67 V/m
63.	4 (4/506-4/509)	Gg	K2 SL	-	//s=N50W/ 60S	-

Table 2.4.3.1 Ground Water Leakage in different types of fissures

SECTION	ROCK TYPE	AQUIFEROUS QUALITIES - FISSURE DIRECTIONS
0/040-0/232	GgA	isolated V
0/232-0/640	L	V: //s N65E N80 N50E VV: //s N65E N80E N50E N55W/55N N50E/50S VVV: //s N65E N80E N30E/50S N50E N55W/55N TOTAL: 66 VV per 408 m = 16,2 /100 m 12 VVV per 408 m = 2,9 /100 m Dampness outside the crush zone: 81,5 m → 20% of which inside "block structures": 21,5 m Dampness in crush/shotcr: 139,5 m → 34,2%
0/640-2/233	GgA	V: isolated spread V very frequent often in association with amphibolites (there are exceptions) and crush zones. N75W=2.0 m Several V along N15E and N25E/70E form long stretch of leaks N65E leakage along the entire fissure following the strike of schistosity

SECTION	ROCK TYPE	AQUIFEROUS QUALITIES - FISSURE DIRECTIONS
		VV: //s (e.g. 3,0 m) N50E N20E N30E/70W 0,3 - 1 m N75W = 2 m N55E N10E/70E E-W N 60-70°E = 4,5 m
		VVV: //s N50E crack = 1 m N-S/65E 0,3 - 1 m N55E N10E/70E E-W N60-70E = 4 m
		VVVV: //s
		TOTAL: 67 VV per 1593 m = 4,2 /100 m 35 VVV per 1593 m = 2,2 /100 m 3 VVVV per 1593 m = 0,2 /100 m
		Dampness outside crush zone: 454,5 m → 28% of which in "block structures": - Dampness in crush zone: 115 m → 7,2%
2/233-3/446	L +40,0 m continous amphi- bolite	V: isolated spread V very frequent in some zones Several long leaks //s+ N40E
		VV: //s N50E N5E/70-80E N55W/30N N10-25E several long leaks N25E = 1,0 m N75W/60S
		VVV: //s (e.g. 2,0 m) N5E/70-80E N25W crack N50E Horizontal joint N20E

SECTION	ROCK TYPE	AQUIFEROUS QUALITIES - FISSURE DIRECTIONS
		VVV: //s intersection of fissure following strike direction and N50E N25W/50E 2 major point leaks 1-2 l/min in the same fissure
		VVVV: //s crack + N70E crack + N40E/70-80E
		TOTAL: 85 V per 1213 m = 7,0 /100 m 68 VV per 1213 m = 5,6 /100 m 3 VVV per 1213 m = 0,2 /100 m 4 VVVV per 1213 m = 0,3 /100 m
		Dampness outside crush zone: 403,5 m → 33,3% of which in "block structure": 317,5 m Dampness in crush zone/shotcr: 214 m → 16,8%
3/446-3/552	GgA	V: //s, several along an amphibolite body; isolated spread V along the stretch
3/552-3/915	Gg	Dry with few isolated V following the strike of schistosity Major fissures following the strike of schistosity + amph → several V and dampness Dampness outside crush zone: 38,5 m → 10,6%
3/915-3/955	L	V: //s Dampness outside crush zone: 38,5 m → 96,3% of which in "block structure": 25,0 m Dampness in crush zone/shotcr: 1,5 m → 3,7%

SECTION	ROCK TYPE	AQUIFEROUS QUALITIES - FISSURE DIRECTIONS
3/955-3/970	Gg	Dry
3/970-4/050	L	V: only few V, //s and N50E, N10-30E VV: //s VVV: //s (e.g. 0,5 m) N20E TOTAL: 2 VV per 80 m -> 2,5 /100 m 5 VVV per 80 m -> 6,3 /100 m Dampness outside crush zone: 63,5 m -> 79,4% of which in "block structure": 49,0 m Dampness in crush zone/ shotcr: 5,0 m -> 6,3%
4/050-4/079	A	Dampness outside crush zone: 9,5 m -> 32,7%
4/079-4/117	Gg with leptite cut	2 VVV: crack in leptite cut Isolated V, often following the strike of schistosity
4/117-4/137	L	V: //s VVV: //s TOTAL: 1 VVV per 20 m -> 5 /100 m Dampness outside crush zone: 20,0 m -> 100% of which in "block structure": 20 m
4/137-4/145	Gg	Dry

SECTION	ROCK TYPE	AQUIFEROUS QUALITIES - FISSURE DIRECTIONS
4/145-4/320	L	V: //s N10E/60E N80E/70S N45E = 5,0 m VV: //s (e.g. 4,0 m) N30E/65E = 0,5 m N80E/70S N45E N10W/35-60W VVV: //s (e.g. 2x0,5 m) N30E/70W = 0,5 m TOTAL: 11 VV per 175 m = 6,3 /100 m 7 VVV per 175 m = 4,0 /100 m Dampness outside crush zone: 44,0 m → 25,1% of which in "block structure": 44,0 m Dampness in crush zone/shotcr 23,0 m → 13,1%
4/320-4/536	Gg	V: //s, N50E, N85E/75N, N50W VV: //s intersection S + N50E N60W/20S 0,2, 4,0 and 0,6 m N15W/25W = L1 VVV: N60W/20S 0,2, 4,0 and 6,0 m E-W TOTAL: 11 VV per 216 m → 5,1 /100 m 5 VVV per 216 m → 2,3 /100 m

Table 2.4.3.2 Leakage ≥ ∨∨/100 m of tunnel of fissure directions of different rock types

Gg	N15W/25W	0,15	∨∨/100 m
	//s+N50E	0,15	∨∨/100 m
	N60W/20S	0,11	∨∨/100 m
		0,06	∨∨∨/100 m
	N25E/65E	0,15	∨∨/100 m
	E-W	0,15	∨∨/100 m
		0,15	∨∨∨/100 m
GgA	//s	1,48	∨∨/100 m
		0,69	∨∨∨/100 m
		0,16	∨∨∨/100 m
	N50E	0,95	∨∨/100 m
		0,32	∨∨∨/100 m
	crush	0,32	∨∨/100 m
		0,26	∨∨∨/100 m
	crack	0,05	∨∨∨/100 m
	N30E/70W	0,26	∨∨/100 m
		0,32	∨∨∨/100 m
	E-W	0,21	∨∨/100 m
		0,05	∨∨∨/100 m
	N10E/70E	0,21	∨∨/100 m
		0,05	∨∨∨/100 m
	N60-70E	0,16	∨∨/100 m
		0,05	∨∨∨/100 m
A	N20E in crush	2,90	∨∨/100 m

L	//s	1,85	V/100 m
		1,90	V/100 m
		0,11	V/100 m
		0,21	V/100 m
	N65E	0,74	V/100 m
		0,05	V/100 m
	crush (usually //s)	4,60	V/100 m
		2,00	V/100 m
	N80E (=K2)	0,26	V/100 m
		0,16	V/100 m
	N55W/30-55N	0,26	V/100 m
		0,05	V/100 m
	Horizontal	0,05	V/100 m
	N20-25E	0,05	V/100 m
		0,21	V/100 m
	N50E crack	0,05	V/100 m
	N25W crack	0,05	V/100 m
	crack	0,42	V/100 m
		0,32	V/100 m
	N25W/50E	0,05	V/100 m
		0,05	V/100 m
	N75W/60S	0,05	V/100 m
	N10E/60E	0,05	V/100 m
	N30E/70W in crush	0,16	V/100 m
		0,11	V/100 m
	N30E/65E in crush	0,05	V/100 m
	N45E in crush	0,05	V/100 m

Table 2.4.4.2

ROCK TYPE	MAPPED STRETCH (m)	FISSURE DIRECTION	NUMBER OF FISSURES	TOTAL FISSURE LENGTH (m)	LEAKAGE ∨	∨∨	∨∨∨	∨ /m	∨∨/m	∨∨∨ /m	OBSERVATIONS
Gg	640	//s	81	1333	2			$0{,}2\cdot10^{-2}$			Generally dry - minor leakage
		N10-20E	10	160							
		N60W/20S		200	7	4		$3{,}5\cdot10^{-2}$	$2{,}0\cdot10^{-2}$		Drapery 0,2 - 4 m
		E-W	crack	4	1	1		$25{,}0\cdot10^{-2}$	$25{,}0\cdot10^{-2}$		
		N50E		30	1			$3{,}3\cdot10^{-2}$			
		N70-80E	9	144							Minor leakage
				1871	11	5		$0{,}6\cdot10^{-2}$	$0{,}3\cdot10^{-2}$		
GgA	1891	//s	304	5430	30	14	3	$0{,}6\cdot10^{-2}$	$0{,}3\cdot10^{-2}$	$0{,}1\cdot10^{-2}$	Mostly point leaks, but also a single drapery leak = 3 m
		N50E	18	120	18	6		$15{,}0\cdot10^{-2}$	$5{,}0\cdot10^{-2}$		Point leak
		E-W	15	360	4	1		$1{,}1\cdot10^{-2}$	$0{,}3\cdot10^{-2}$		Point leak
		N30E/70E		45	5	6		$11{,}1\cdot10^{-2}$	$13{,}3\cdot10^{-2}$		Several 0,3 - 1 m long leaks
		N60-70E		35	3	1		$8{,}6\cdot10^{-2}$	$2{,}6\cdot10^{-2}$		Point leak + 4 m long drapery leak
		N15-25E		40							Dense droplets
		N10E/70E	1	16	4	1		$25{,}0\cdot10^{-2}$	$6{,}3\cdot10^{-2}$		Point leak
		N75-85W	3	54	3			$5,\ \cdot10^{-2}$			Drapery leak 0,2 - 2 m
		crack		1		1			$100{,}0\cdot10^{-2}$		Drapery leak 1 m
				6101	67	30	3	$1{,}1\cdot10^{-2}$	$0{,}5\cdot10^{-2}$	$<0{,}1\cdot10^{-2}$	

Appendix 2.5

ROCK TYPE	MAPPED STRETCH (m)	FISSURE DIRECTION	NUMBER OF FISSURES	TOTAL FISSURE LENGTH (m)	LEAKAGE V	VV	VVV	V /m	VV /m	VVV /m	OBSERVATIONS
L	1896	//s	115	1590	45	52	1	$2,8 \cdot 10^{-2}$	$3,3 \cdot 10^{-2}$	$0,1 \cdot 10^{-2}$	Several minor leaks, mostly point - but also drapery
		N50E		51	5	6		$9,8 \cdot 10^{-2}$	$11,8 \cdot 10^{-2}$		Several minor leaks, point and drapery = 4 m
		N10-20E		143	1	4		$0,7 \cdot 10^{-2}$	$2,8 \cdot 10^{-2}$		Several minor leaks, point and drapery
		N25E	1	15	1			$6,7 \cdot 10^{-2}$			Seval minor leaks
		N65E		50	9	1		$18,0 \cdot 10^{-2}$	$2,0 \cdot 10^{-2}$		Point leaks
		N80E	6	130	5	3		$3,8 \cdot 10^{-2}$	$2,3 \cdot 10^{-2}$		
		N25W/50E	1	18		1	1		$5,6 \cdot 10^{-2}$	$5,6 \cdot 10^{-2}$	
		N55W/55N	1	7	9			$128,6 \cdot 10^{-2}$			Drapery
		N55W/30N	crack								1 m long drapery with V
		N25W	crack	7		1		$14,3 \cdot 10^{-2}$			
		different directions	crack		1						Several minor leaks
		N10W/35-60W	1	20	1			$5,0 \cdot 10^{-2}$			
				2031	77	68	2	$3,8 \cdot 10^{-2}$	$3,3 \cdot 10^{-2}$	$0,1 \cdot 10^{-2}$	
A	69	N10E	2	32							Minor leaks

Table 3.1.2.1

ROCK TYPE	TOTAL LEAKAGE	LEAKAGE IN ZONES	LEAKAGE OUTSIDE ZONES	TOTAL STRETCH (m)	OF WHICH AMPHI-BOLITE (m)	LENGTH CRUSH SHOT-CRETE (m)	LENGTH OUTSIDE CRUSH (m)	TOTAL LEAKAGE $\cdot 10^{-2}$	IN ZONES $\cdot 10^{-2}$	OUTSIDE ZONES $\cdot 10^{-2}$
Gg	11 V 5 VV		11 V 5 VV	640	22	4	636	1,73 V/m 0,79 VV/m		1,73 V/m 0,79 VV/m
GgA	67 V 35 VV 3 VVV	13 V 9 VV 2 VVV	54 V 26 VV 1 VVV	1891	108	132	1759	3,54 V/m 1,85 VV/m 0,16 VVV/m	9,85 V/m 6,82 VV/m 1,52 VVV/m	3,07 V/m 1,48 VV/m 0,06 VVV/m
L	162 V 95 VV 3 VVV 4 VVVV	103 V 46 VV 2 VVV 4 VVVV	59 V 49 VV 1 VVV	1896	103	519	1377	8,54 V/m 5,01 VV/m 0,16 VVV/m 0,21 VVVV/m	19,85 V/m 8,86 VV/m 0,39 VVV/m 0,77 VVVV/m	4,28 V/m 3,56 VV/m 0,07 VVV/m
A	2 V	2 V		69		17	52	2,90 V/m	11,76 V/m	

Appendix 3.1

Table 3.4.1 Distribution of point- and drapery leaks

A. Point leaks (number):

V : 106 in crush zones
118 outside crush zones

VV : 55 in crush zones
69 outside crush zones

VVV : 4 in crush zones
2 outside crush zones

VVVV : 4 in crush zones

B. Drapery leaks:

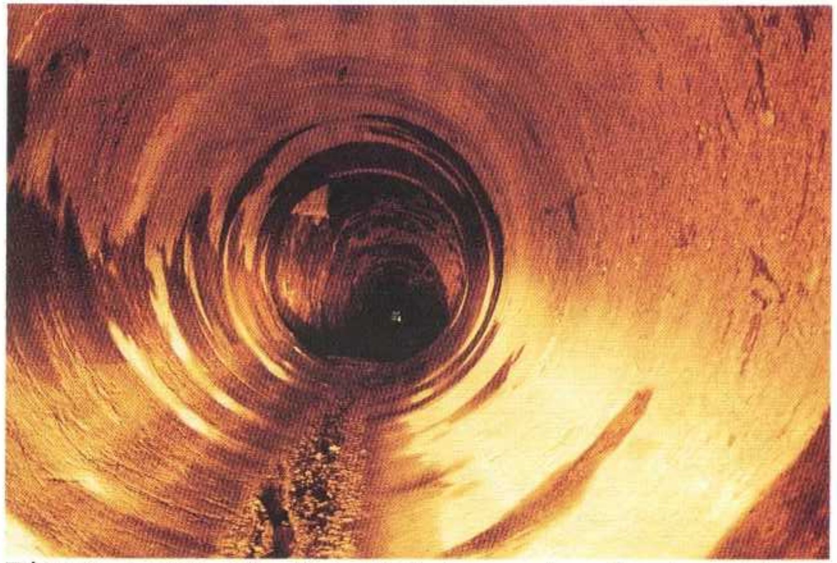
TYPE	NUMBER	LENGTH (m)	ROCK TYPE	AQUIFEROUS FISSURE DIRECTIONS
V in crush zones	5	2,0	L	N55W/55N
	2	1,5	GgA	s=N30W/65W
	1	0,5	GgA	N30E/70W
	2	0,5	GgA	s=N50W/70S
	1	4,0	GgA	s=N50W/70S
	1	0,5	GgA	N30E/65E
V outside crush zones	1	0,5	GgA	N50E
	1	0,2	GgA	N85W
	1	3,0	A/GgA	s=N15W/80W
	1	1,0	L	N55W/30N
	2	4,0	Gg	N60W/20S
VV outside crush zones	1	1,0	GgA	N50E
	3	1,0	GgA	N-S/65E
	2	2,0	L	s=N45W/45W
	1	4,0	L	s=N50W/50S
	1	0,5	L	N10W/65W
	2	6,0	Gg	N60W/20S
	1	0,2	Gg	N60W/20S

TYPE	NUMBER	LENGTH (m)	ROCK TYPE	AQUIFEROUS FISSURE DIRECTIONS
V *) in crush zone		1,0 5,0		
V *) outside crush zone		0,3-1,0	GgA	Intersecting directions
		2,0	GgA	N75W
		0,2	GgA	crack
		1,0	GgA	N15E
		1-12	GgA	N25E/70E
		4,0	GgA	N65E
		along entire fissure ~16	GgA	s=N30W-15E/70W
		2,0	L/A	s=N40W/45W
		3,0	L/A	s=N40W/45W
		6,0	Amphlens	s=N40W/45W
		4,0	L	N40E
		1,0	L	N10-25E

*) The number of V containing drapery leaks has not been counted

Open cut Granån. Thin slaty fracture zone= K2 in leptite.

Open cut Granån. Winding fissures, irregular intensity of crushing in leptite.

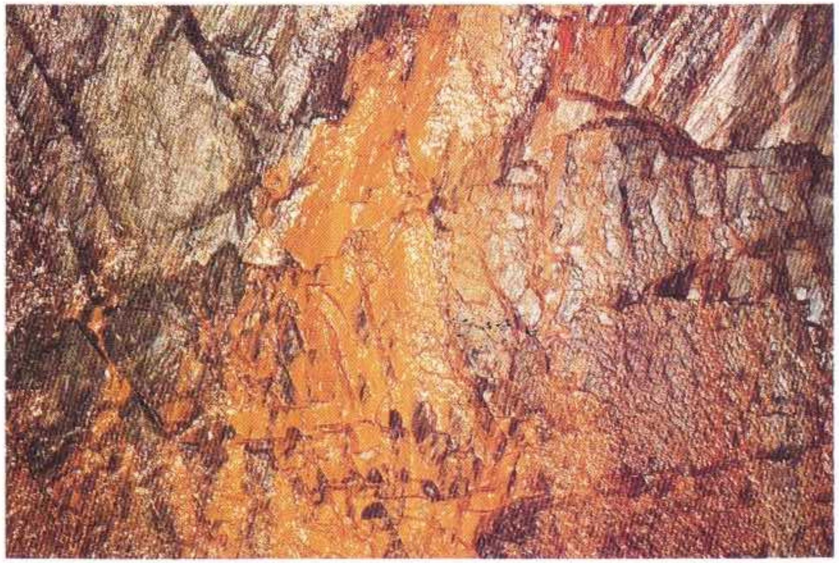


First part of the TBM-tunnel, facing the conventional drill and blast-tunnel. Good rock quality with only minor dampness in granite gneiss. 4/530

Minor point leakages in the contacts between amphibolite, granite gneiss (left) and leptite (right). 0/870

Dry granite gneiss with amphibolite plates. 1/875

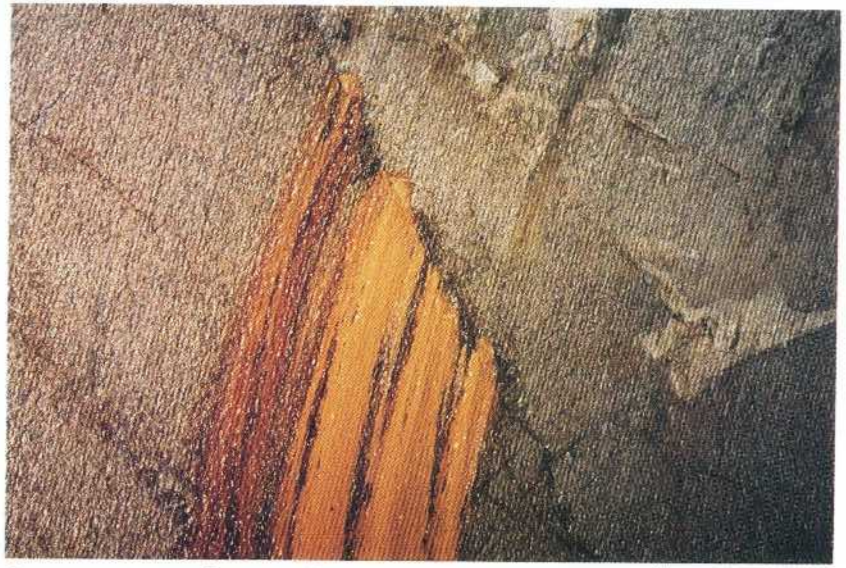
Crush zone with diffuse leakages from the roof and limonite deposition in leptite. 0/435



Several diffuse leakages with extensive limonite deposites in crush zone in leptite. 4/226

Point leakages (↓) from the schistosity intersected by cracks in granite gneiss. 4/373

Several point leakages from a fissure en echelon, in the contact leptite - amfibolite. 4/258



One meter long drapery leakage (vvv) from a crack in granite gneiss. 1/090

Extensive point leakages (v-vvv) from steep fissure parallell to the tunnel in leptite. 0/316

Strong point leakage (vvv) from fissure parallell to the schistosity in thin amphibolite plate in granite gneiss.

Point leakage (v) from thin amphibolite plate parallell to the schistosity. The amphibolite is partly altered to clay and surrounded by granite gneiss. 0/785

Drapery leakage (⩔) 0,5 m long from fissure not parallell to the schistosity in crushed leptite. 4/228

Point leakage (⩔) from a contact leptite/ amphibolite in a crush zone. 4/248

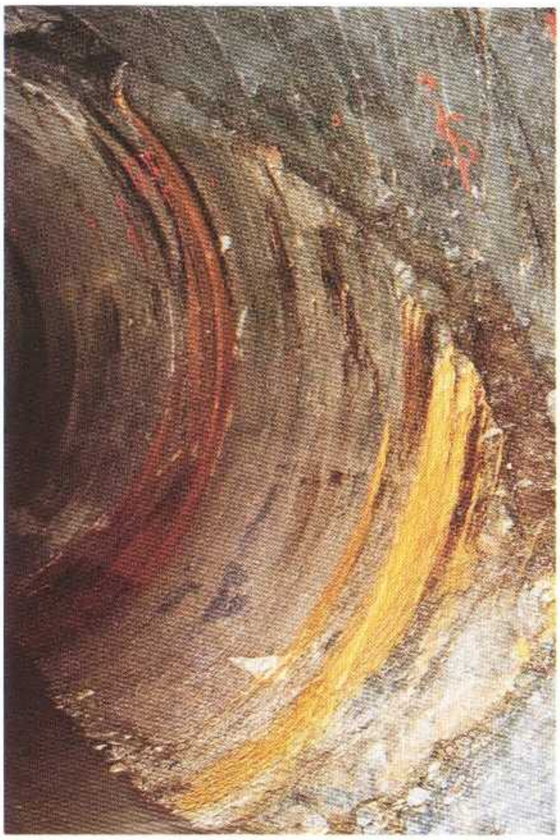
Several point leakages (v-⩔) from steep cracks parallell to the tunnel in leptite. 4/030

Strong point leakage (⩔) from crack in crush zone in leptite. 2/272

Point leakage (⩔) from fissure perpendicular to the schistosity in leptite. 2/665

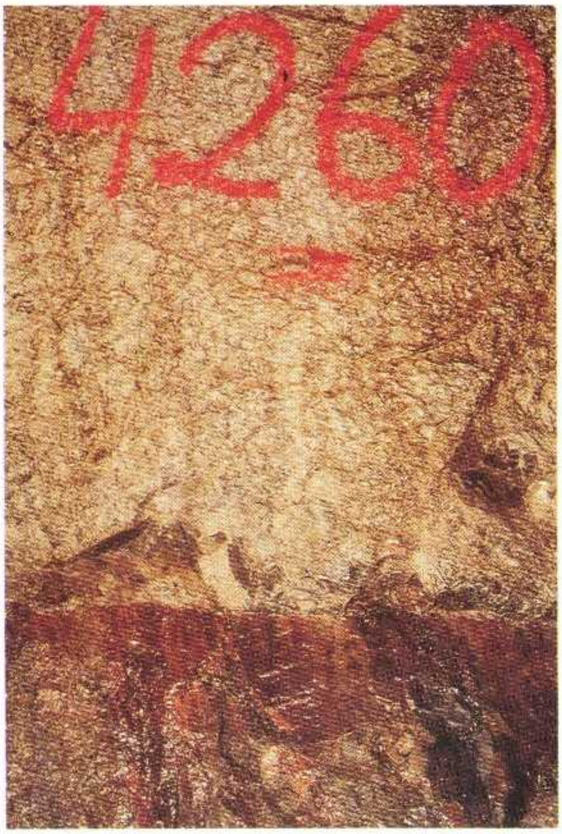
Point leakage (⩔) from crushed amphibolite plate parallell to the schistosity. The amphibolite is surrounded by leptite. 2/828

Strong point leakage (2 l/min) from fissure in thin amphibolite not parallell to the schistosity, developed in the surrounding leptite. 3/380

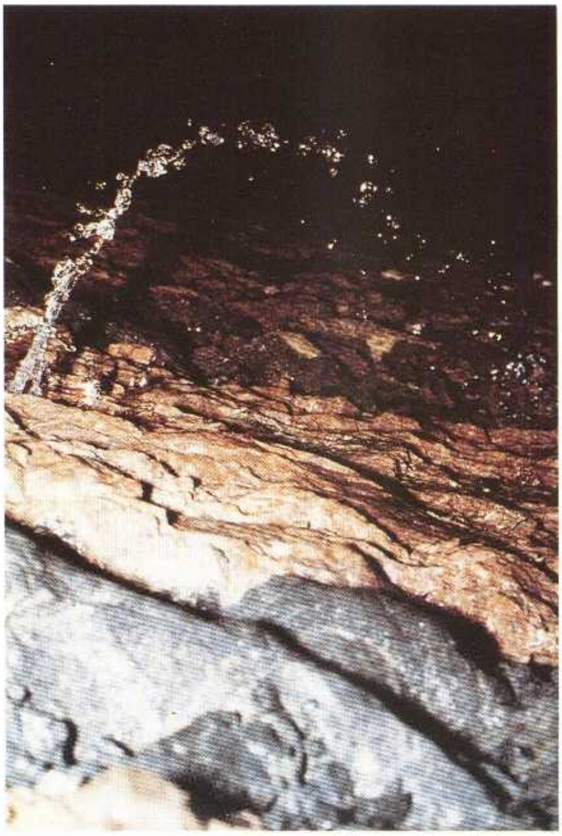


Several point leakages (v-⩡) in the contact to a small crush zone parallell to the schistosity in granite gneiss with amphibolite plates.1/778

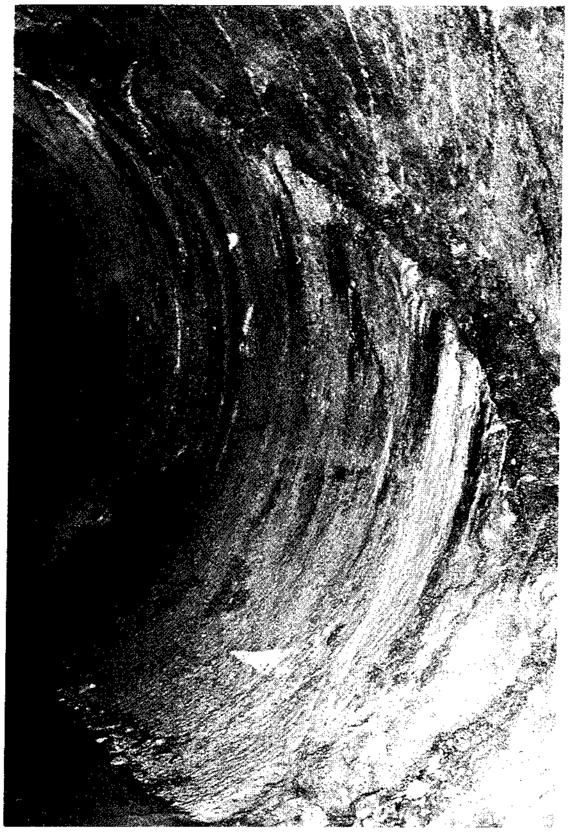
Several point leakages (v-⩡) in an irregular crush zone in granite gneiss in connection to amphibolite. 4/090



Detail of 5 m long drapery leakage (v-⩡) from steep fissure parallell to the tunnel, and in the contact to a crush zone. 4/260

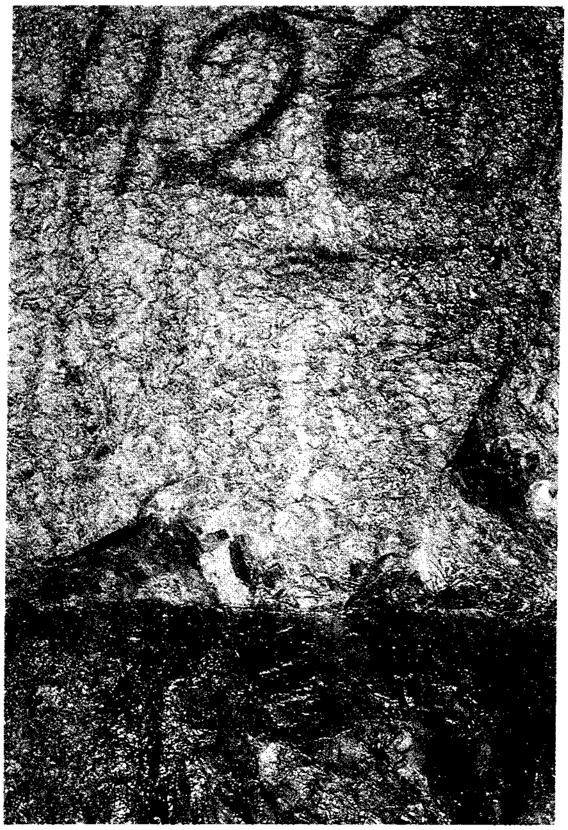


One of several point leakages (⩡) from a fissure parallell to the schistosity in the contact to a slaty cleavage zone in leptite. 2/948

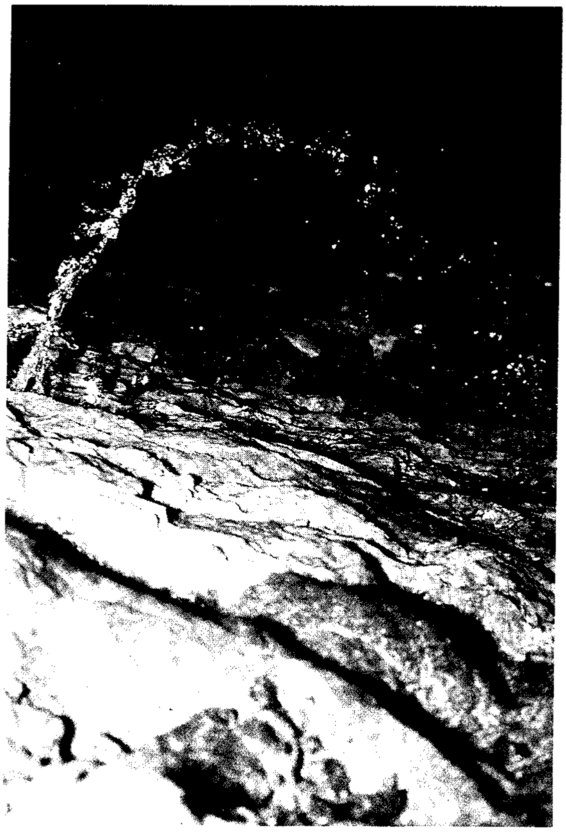


Several point leakages (v-$\overset{\vee}{\vee}$) in the contact to a small crush zone parallell to the schistosity in granite gneiss with amphibolite plates. 1/778

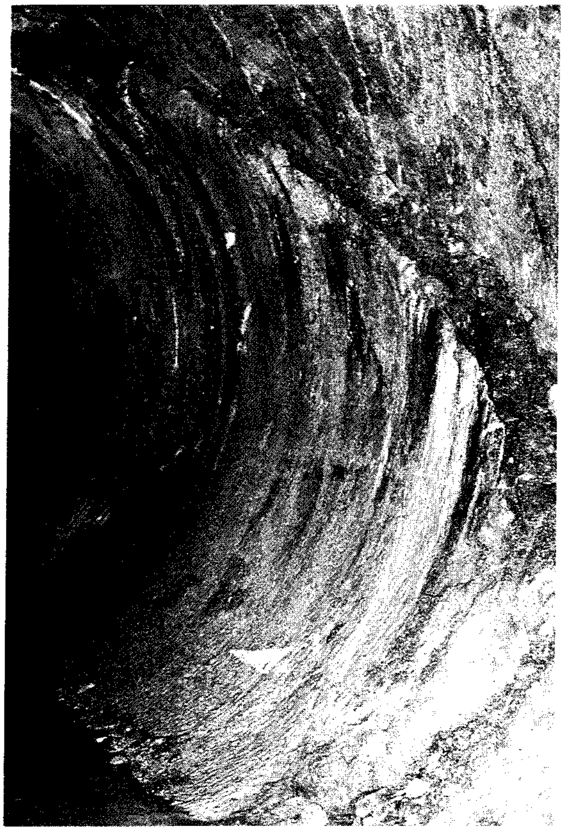
Several point leakages (v-$\overset{\vee}{\vee}$) in an irregular crush zone in granite gneiss in connection to amphibolite. 4/090



Detail of 5 m long drapery leakage (v-$\overset{\vee}{\vee}$) from steep fissure parallell to the tunnel, and in the contact to a crush zone. 4/260



One of several point leakages ($\overset{\vee}{\vee}$) from a fissure parallell to the schistosity in the contact to a slaty cleavage zone in leptite. 2/948



Several point leakages (v-V) in the contact to a small crush zone parallell to the schistosity in granite gneiss with amphibolite plates. 1/778

Several point leakages (v-V) in an irregular crush zone in granite gneiss in connection to amphibolite. 4/090

Detail of 5 m long drapery leakage (v-V) from steep fissure parallell to the tunnel, and in the contact to a crush zone. 4/260

One of several point leakages (V) from a fissure parallell to the schistosity in the contact to a slaty cleavage zone in leptite. 2/948

List of SKB reports

Annual Reports

1977–78
TR 121
KBS Technical Reports 1 – 120.
Summaries. Stockholm, May 1979.

1979
TR 79–28
The KBS Annual Report 1979.
KBS Technical Reports 79-01 – 79-27.
Summaries. Stockholm, March 1980.

1980
TR 80–26
The KBS Annual Report 1980.
KBS Technical Reports 80-01 – 80-25.
Summaries. Stockholm, March 1981.

1981
TR 81–17
The KBS Annual Report 1981.
KBS Technical Reports 81-01 – 81-16.
Summaries. Stockholm, April 1982.

1982
TR 82–28
The KBS Annual Report 1982.
KBS Technical Reports 82-01 – 82-27.
Summaries. Stockholm, July 1983.

1983
TR 83–77
The KBS Annual Report 1983.
KBS Technical Reports 83-01 – 83-76
Summaries. Stockholm, June 1984.

1984
TR 85–01
Annual Research and Development Report 1984
Including Summaries of Technical Reports Issued during 1984. (Technical Reports 84-01– 84-19)
Stockholm June 1985.

1985
TR 85-20
Annual Research and Development Report 1985
Including Summaries of Technical Reports Issued during 1985. (Technical Reports 85-01-85-19)
Stockholm May 1986.

1986
TR86-31
SKB Annual Report 1986
Including Summaries of Technical Reports Issued during 1986
Stockholm, May 1987

Technical Reports

1987
TR 87-01
Radar measurements performed at the Klipperås study site
Seje Carlsten, Olle Olsson, Stefan Sehlstedt, Leif Stenberg
Swedish Geological Co, Uppsala/Luleå
February 1987

TR 87-02
Fuel rod D07/B15 from Ringhals 2 PWR: Source material for corrosion/leach tests in groundwater
Fuel rod/pellet characterization program part one
Roy Forsyth, Editor
Studsvik Energiteknik AB, Nyköping
March 1987

TR 87-03
Calculations on HYDROCOIN level 1 using the GWHRT flow model
Case 1 Transient flow of water from a borehole penetrating a confined aquifer
Case 3 Saturated-unsaturated flow through a layered sequence of sedimentary rocks
Case 4 Transient thermal convection in a saturated medium
Roger Thunvik, Royal Institute of Technology, Stockholm
March 1987

TR 87-04
Calculations on HYDROCOIN level 2, case 1 using the GWHRT flow model
Thermal convection and conduction around a field heat transfer experiment
Roger Thunvik
Royal Institute of Technology, Stockholm
March 1987

TR 87-05
Applications of stochastic models to solute transport in fractured rocks
Lynn W Gelhar
Massachusetts Institute of Technology
January 1987

TR 87-06
Some properties of a channeling model of fracture flow
Y W Tsang, C F Tsang, I Neretnieks
Royal Institute of Technology, Stockholm
December 1986

TR 87-07
Deep groundwater chemistry
Peter Wikberg, Karin Axelsen, Folke Fredlund
Royal Institute of Technology, Stockholm
June 1987

TR 87-08
An approach for evaluating the general and localized corrosion of carbon steel containers for nuclear waste disposal
GP March, KJ Taylor, SM Sharland, PW Tasker
Harwell Laboratory, Oxfordshire
June 1987

TR 87-09
Piping and erosion phenomena in soft clay gels
Roland Pusch, Mikael Erlström,
Lennart Börgesson
Swedish Geological Co, Lund
May 1987

TR 87-10
Outline of models of water and gas flow through smectite clay buffers
Roland Pusch, Harald Hökmark,
Lennart Börgesson
Swedish Geological Co, Lund
June 1987

TR 87-11
Modelling of crustal rock mechanics for radioactive waste storage in Fennoscandia—Problem definition
Ove Stephansson
University of Luleå
May 1987

TR 87-12
Study of groundwater colloids and their ability to transport radionuclides
Kåre Tjus* and Peter Wikberg**
*Institute for Surface Chemistry, Stockholm
**Royal Institute of Technology, Inorganic Chemistry Stockholm
March 1987

TR 87-13
Shallow reflection seismic investigation of fracture zones in the Finnsjö area method evaluation
Trine Dahl-Jensen
Jonas Lindgren
University of Uppsala, Department of Geophysics
June 1987

TR 87-14
Combined interpretation of geophysical, geological, hydrological and radar investigations in the boreholes ST1 and ST2 at the Saltsjötunnel
Jan-Erik Andersson
Per Andersson
Seje Carlsten
Lars Falk
Olle Olsson
Allan Stråhle
Swedish Geological Co, Uppsala
1987-06-30

TR 87-15
Geochemical interpretation of groundwaters from Finnsjön, Sweden
Ignasi Puigdomènech[1]
Kirk Nordstrom[2]
[1]Royal Institute of Technology, Stockholm
[2]U S Geological Survey, Menlo Park, California
August 23, 1987

TR 87-16
Corrosion tests on spent PWR fuel in synthetic groundwater
R S Forsyth[1] and L O Werme[2]
[1]Studsvik Energiteknik AB, Nyköping, Sweden
[2]The Swedish Nuclear Fuel and Waste Management Co (SKB), Stockholm, Sweden
Stockholm, September 1987

TR 87-17
The July — September 1986 Skövde aftershock sequence
Conny Holmqvist
Rutger Wahlström
Seismological Department, Uppsala University
August 1987

TR 87-18
Calculation of gas migration in fractured rock
Roger Thunvik[1] and Carol Braester[2]
[1]Royal Institute of Technology
Stockholm, Sweden
[2]Israel Institute of Technology
Haifa, Israel
September 1987

TR 87-19

Calculation of gas migration in fractured rock – a continuum approach

Carol Braester[1] and Roger Thunvik[2]
[1]Israel Institute of Technology
Haifa, Israel
[2]Royal Institute of Technology
Stockholm, Sweden
September 1987

TR 87-20

Stability fields of smectites and illites as a function of temperature and chemical composition

Y Tardy, J Duplay and B Fritz
Centre de Sédimentologie et de Géochimie de la Surface (CNRS)
Institut de Géologie Université Louis Pasteur (ULP)
1 rue Blessig, F-67084 Strasbourg, France
April 1987

TR 87-21

Hydrochemical investigations in crystalline bedrock in relation to exesting hydraulic conditions: Klipperås test-site, Småland, Southern Sweden

John Smellie[1]
Nils-Åke Larsson[1]
Peter Wikberg[3]
Ignasi Puigdomènech[4]
Eva-Lena Tullborg[2]
[1]Swedisch Geological Company, Uppsala
[2]Swedisch Geological Company, Göteborg
[3]Royal Institute of Technology, Stockholm
[4]Studsvik Energiteknik AB, Nyköping
September 1987

TR 87-22

Radionuclide sorption on granitic drill core material

Trygve E Eriksen and Birgitta Locklund
The Royal Institute of Technology
Department of Nuclear Chemistry
Stockholm
November 1987

TR 87-23

Radionuclide co-precipitation

Jordi Bruno and Amaia Sandino
The Royal Institute of Technology
Department of Inorganic Chemistry
Stockholm
December 1987

TR 87-24

Geological maps and cross-sections of Southern Sweden

Karl-Axel Kornfält[1] and Kent Larsson[2]
[1]SGU, Lund
[2]Softrock Consulting, Genarp
December 1987

TR 87-25

The Bolmen tunnel project
Evaluation of geophysical site investigation methods

Roy Stanfors
December 1987