International
Progress Report

IPR-00-35

Äspö Hard Rock Laboratory

Status Report of the Matrix Fluid Experiment
June 1998 – June 2000

Compiled and edited by:
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Conterra AB

December 2000

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Report no.	No.
IPR-00-35	
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Keywords: Matrix fluid, low transmissive features, interconected porosity, leaching, fluid inclusions, repository performance assessment

Summary

Much of the undisturbed groundwaters sampled from the Äspö site, mostly to depths of 500-600 m, have been collected from water-conducting fracture zones with high transmissivities ($T > 10^{-9}$ m^2s^{-1}) and probably attain their chemical character mostly by mixing waters of different origin. These groundwater compositions have been compiled, evaluated and interpreted to explain the hydrochemical character of the site. In contrast, little is known about groundwater compositions from low transmissive parts ($T < 10^{-10}$ m^2s^{-1}) of the bedrock. Under such conditions long residence times are characteristic and the composition of the formation waters is more dependent on water/rock reactions than mixing, and also more likely influenced to varying degrees by the rock matrix fluid chemistry. Matrix fluids are considered here to constitute the pore fluids in the rock matrix. However the accessibility of these fluids, and their ability to move through the rock matrix, will depend on whether or not the pore spaces are connected. Assuming a rock fabric of interconnected pores and fine fissures, and bearing in mind that rocks of low transmissivity constitute the major volume of the bedrock mass in any granite body, matrix fluids are suspected to contribute significantly to the chemistry of deep formation groundwaters.

In the context of deep geological disposal of high-level radioactive wastes, to model near-field repository processes requires specific knowledge of the near-field input groundwater compositions expected during the lifespan of the repository. Therefore, knowledge of the composition and origin of the matrix fluid should provide a more realistic hydrochemical input to near-field performance and safety assessment calculations, since deposition of spent fuel will be restricted to rock volumes of low transmissivity.

To address these issues, the main objectives of the Matrix Fluid Experiment are:

- to determine the origin and age of the matrix fluids,
- to establish whether present or past in- or out-diffusion processes have influenced the composition of the matrix fluids, either by dilution or increased concentration,
- to derive a range of groundwater compositions as suitable input for near-field model calculations, and
- to establish the influence of fissures and small-scale fractures (when present) on fluid chemistry in the bedrock.

This report describes and interprets the results so far available, and represents the halfway stage of the Matrix Fluid Experiment scheduled to continue to the end of 2001.

Contents

1 Background

1.1 Matrix fluids and saline groundwaters

Much of the undisturbed groundwater sampled from the Äspö site, mostly to depths of 500-600 m, has been collected from water-conducting fracture zones with high transmissivities ($T > 10^{-9}$ m^2s^{-1}). Consequently, these groundwaters probably obtain their chemical character mostly through mixing along fairly rapid conductive flow paths, determined by hydrodynamically active conditions rather than by chemical water/rock interaction. In this part of the bedrock sampled groundwaters show salinities which range generally from fresh to brackish near the surface (<2 g/L chloride) to moderately saline at 500 m (5-6 g/L chloride). Greater than 500 m, where hydrodynamic conditions are less active, the salinity progressively increases with depth to a maximum of 12.3 g/L chloride at around 1 000 m (Smellie and Laaksoharju, 1992; Smellie et al., 1995; Laaksoharju et al., 1999). On the mainland at Laxemar, borehole KLX02 records around 45 g/L chloride at 1 700 m where near-stagnant groundwater flow conditions are encountered (Laaksoharju et al., 1995).

In contrast, little is known about groundwater compositions from low transmissive parts ($T < 10^{-10}$ m^2s^{-1}) of the bedrock. Under such conditions long residence times are characteristic and the composition of the formation waters is more dependent on water/rock reactions rather than mixing, and also more likely influenced to varying degrees by the rock matrix fluid chemistry. Matrix fluids are considered here to constitute the pore fluids in the rock matrix. However the accessibility of these fluids, and their ability to move through the rock matrix, will depend on whether or not the pore spaces are connected. Assuming a rock fabric of interconnected pores and fine fissures, and bearing in mind that rocks of low transmissivity constitute the major volume of the bedrock mass in any granite body, matrix fluids are suspected to contribute to the chemistry of deep formation groundwaters. Obviously matrix fluids trapped in isolated pore spaces or in micro-fracture/fissure dead-ends will not contribute directly to the surrounding formation groundwater chemistry. Some contribution can be expected from long-term diffusion processes.

Under undisturbed conditions the matrix or pore fluids are suspected to be saline in composition. The most direct evidence for this comes from the URL site in Canada where salinities of ~90 g/L TDS have been recorded from fluids sampled from a granite matrix (Gascoyne, 1996). There are several potential sources to the salinity in the matrix fluids, for example, from ancient Proterozoic (older than ~570 Ma) seawater or basinal brines, Palaeozoic (older than ~250 Ma) basinal brines, seawater and evaporites, and young Holocene (10-0 ka) brackish waters. Additionally, rock/water interaction processes may also dissolve/leach salts in the rock; an additional source may derive from the rupture and/or dissolution of fluid inclusions located in and/or around some of the major rock-forming minerals (mostly quartz). With respect to these latter sources, it is important to be able to correlate, as close as possible, the known fluid composition with the actual mineralogy and geochemistry of the host rock. Thus, the study of fluid inclusions, a potential salinity source at Äspö, comprises an important part of the matrix experiment.

1.2 Repository performance assessment implications

The Swedish disposal concept recognises that the long-term integrity of the near-field engineered barrier system, over time periods of thousands to hundreds of thousands of years, is closely related to the long-term hydrochemical stability of the repository host rock. To model near-field processes requires therefore specific knowledge of the near-field input groundwater compositions during the expected lifespan of the repository. Based on earlier considerations, knowledge of the composition and origin of the matrix fluid should provide a realistic hydrochemical input to near-field performance and safety assessment calculations, since deposition of spent fuel will be restricted to rock volumes of low transmissivity. Under these hydraulic conditions, particularly during the post-closure period of the repository when there has been a return to hydrochemical equilibrium, chemical gradients gradually may become established between the saline rock matrix fluids and the water saturating the bentonite and bentonite/sand backfill materials. This chemical differential between backfill materials and rock matrix might well result in an increase in salinity towards the backfills such that, with time, may cause deterioration of their physical properties. This may impact on the long-term stability of the repository.

Even though it has been argued that the Swedish engineered barrier system may not be particularly sensitive to high salinity (Andersson et al., 2000), limits have been set (up to 100 g/L TDS) and the expected near-field salinities need therefore to be quantified.

1.3 Scope and objectives of the matrix experiment

Based on the above considerations the main objectives of the Matrix Fluid Experiment are:

- to determine the origin and age of the matrix fluids,
- to establish whether present or past in- or out-diffusion processes have influenced the composition of the matrix fluids, either by dilution or increased concentration,
- to derive a range of groundwater compositions as suitable input for near-field model calculations, and
- to establish the influence of fissures and small-scale fractures (when present) on fluid chemistry in the bedrock.

To successfully achieve these objectives depends on identifying a rock mass of low hydraulic transmissivity; this was successfully accomplished. Locating a suitable bedrock to drill the matrix borehole, together with the designing and construction of specialised downhole equipment to accommodate long-term sampling of matrix fluids, commenced late 1997 and continued into early 1998. The borehole was drilled and completed in June 1998.

To address the project objectives, several major areas of investigation are involved:

- drillcore studies (geochemistry, mineralogy, petrology, fluid inclusions),
- drillcore crush/leach experiments,
- matrix fluid sampling, analysis and interpretation,
- hydraulic character of the matrix, and
- hydraulic and hydrochemical characterisation of near-vicinity fractures/fissures of low hydraulic transmissivity ($<10^{-10}\ m^2s^{-1}$).

Details of the objectives, rationale and experimental set-up are presented in Smellie (1999). An international team is involved in the experiment with groups representing Sweden, Switzerland, Finland, France and Canada all participating. The experiment is scheduled to be reported by the end of December, 2001.

The responsible investigators are:

Alec Blyth	(University of Waterloo, Canada)
Joél Casanova	(BRGM, France)
Shaun Frape	(University of Waterloo, Canada)
Seppo Gehör	(Kivitieto Oy, Finland)
Erik Gustafsson	(Geosigma AB, Sweden)
Doug Hirst	(University of Waterloo, Canada)
Marcus Laaksoharju	(GeoPoint AB, Sweden)
Sten Lindblom	(Stockholm University, Sweden)
Anna Säfvestad	(SKB, Sweden)
Eva-Lena Tullborg	(Terralogica AB, Sweden)
Nick Waber	(University of Bern, Switzerland)
Bill Wallin	(Geokema AB, Sweden)

Ingvar Rhen (VIAK VBB, Sweden) has been involved in the initial planning, drilling and borehole completion activities of the programme. Technical support is provided by Patrik Hagman (SKB, Äspö) and Lars Andersson (SKB, Äspö).

2 Matrix borehole (KF0051A01)

(Based on contributions by A. Säfvestad and C. Andersson (SKB), G. Nilsson (JAA AB), Geosigma AB) and I. Rhén (VIAK VBB)).

2.1 General

Initially it was considered to drill 4-5 boreholes at Äspö in bedrock of low to intermediate hydraulic transmissivity, at different depths and in different lithologies, allowing a comparison of potential matrix fluid chemistry with: a) increasing depth, b) differing lithology, and c) the presence or absence of nearby fractures/fissures. This programme was subsequently restricted to one borehole at one site in order to test both the robustness of the sampling equipment and also to determine if the sampling of matrix fluids was altogether possible.

2.2 Location

On the basis of available data from geological, hydrological and tunnel construction activities from the Äspö HRL, and several reconnaissance trips, five potential locations were considered from tunnel sections characterised by:

- low fracture frequency; very few water-conducting fractures
- homogeneous and similar rock-types (Äspö Diorite and Småland Granite)
- low transmissivity in probeholes
- absence of grouting
- possible access to tunnel niches to facilitate drilling
- additional information, e.g. in the vicinity of earlier (or on-going) studies (e.g. TRUE Experiment; Prototype Repository Experiment; Chemlab Experiment, Microbe Experiment) where groundwater sampling has been carried out and there exist available hydrochemical data.

The selection of a first preference borehole location was based on several criteria:

- that the experiment should be conducted at repository depths (~500 m)
- that the tunnel section chosen should be dry and free from water-conducting fractures
- that the rock be homogeneous, i.e. minimum potential influence from variations in composition
- that there should be minimum future disturbance from tunnel activities
- that drilling could be carried out with minimum disturbance to tunnel activities

Five locations were considered, and their respective priorities are summarised below; Priority (1) in Tunnel 'F' was selected **(Table 2-1; Fig. 2-1).**

Table 2-1. Summary of five locations selected for consideration

Tunnel Section (m)	*Vertical Depth (m)*	*Rock-type*	*Comments*	*Priority*
2375	~ 320	Äspö Diorite	Niche at 2375 m	3
2520	~ 345	Äspö Diorite	Tunnel curve location	2
3010	~ 415	Småland Granite	Near-vicinity of True Project	4
3375	~ 445	Småland Granite	Vicinity of lift	5
L=51	~ 450	Äspö Diorite	Tunnel F	1

Priority (1) fulfilled most of the criteria listed above.

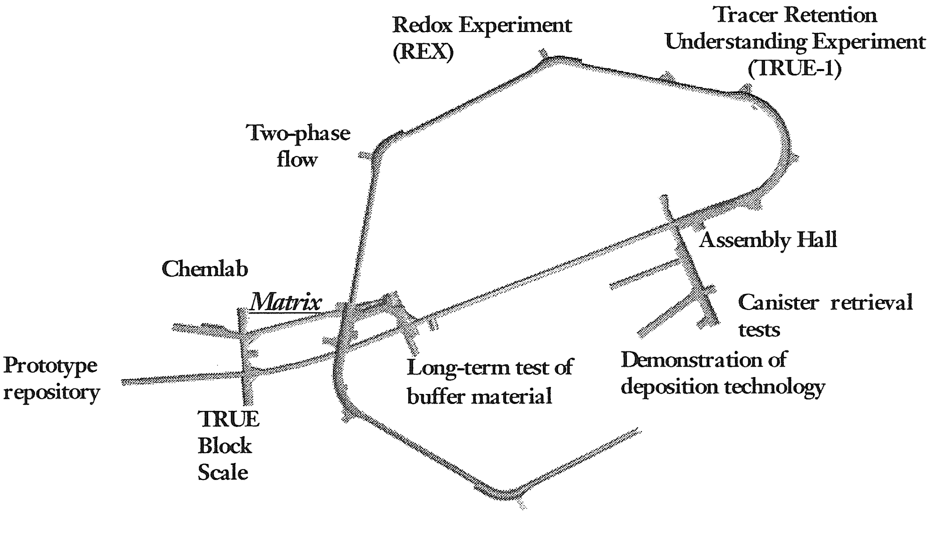


Figure 2-1. *Äspö HRL: Location of Matrix Fluid Borehole in 'F' Tunnel relative to the other experiments*

2.3 Drilling

Drilling of the borehole was carried out on 26th May, 1998, adhering as close as possible to the protocol detailed in Smellie (1999). To minimise potential groundwater contamination well characterised formation groundwater from borehole KA2598A (in the near-vicinity of 'F' Tunnel) was used as flushing water; a total of 9.7 m^3 water was used. The flushing water is normally spiked with uranine so that subsequent water samples can be evaluated for contamination incurred during drilling. Any sample with less than 1% uranine is considered acceptable. Furthermore, all borehole drilling activities were carried under pressurised nitrogen gas to maintain reducing conditions in the borehole.

The first 2.10 m of the borehole was core drilled with a diameter of 131 mm to allow the installation of a special casing that could resist the high hydraulic head at this depth. In addition, this installation would effectively seal-off any potential influence from the Excavation Damage Zone (EDZ) bordering the tunnel. The casing was first glued and bolted in position and then a valve arrangement was mounted to secure the drilling rig; core drilling with a diameter of 76.2 mm then commenced through the valve. From start to finish the drilling operation took 24 hours and a total length of 11.70 m was drilled at an upwards inclination of ~30°; at all times the borehole was under nitrogen gas pressure. Following drilling the borehole was cleaned with flushing water, purged with nitrogen and then closed by bolting a metal cover over the casing opening; special inlet valves through the anchoring plate allowed pressurised nitrogen to circulate along the borehole.

The drillcore material was mapped as soon as possible to avoid undue evaporation of matrix fluid. Long-term preservation of the core prior to mineralogical study was planned by first wrapping the drillcore in aluminium foil followed by a complete wax coating. This procedure, unfortunately, was not carried out; the core was first waxed and then wrapped in the foil.

On May 28th the borehole was reopened and TV-image logging (BIPS) was carried out, still under nitrogen gas. The borehole was then closed with continuously circulating nitrogen gas. Results of the BIPS logging and drillcore mapping **(see Appendix 1)** confirmed the chosen locality to be devoid of major open fractures and with no evidence of groundwater entering the borehole. Based on this information two borehole sections were chosen to sample matrix fluids. They were selected:

- to avoid any tunnel excavation damage zone (EDZ) beyond the 2.1 m casing length - otherwise hydraulic short-circuiting may occur around the packer systems
- to include a texturally homogeneous rock
- to avoid any kind of fractures, open or sealed

The borehole sections chosen were 4.66-5.26 m and 8.85-9.55 m respectively.

2.4 Completion

Borehole completion was carried out on June 12th, 1998; since the borehole activities two weeks earlier, continuous nitrogen gas circulation had been maintained in the borehole to minimise oxidation effects.

The designed downhole packer equipment was constructed to exclude any contact between groundwater and metal which may result in unwanted long-term reactions. All metal parts were therefore teflonised and peak tubing was used throughout; the packer material used is polyurethane to further minimise organic contamination. To reduce the dead volume space in the sampling sections, peak dummies were added **(Fig. 2-2).** Finally, to ensure a 'microbe-free' environment, all internal parts of the packer equipment and peak tubing were cleaned in the laboratory with formaldehyde, purged with ultra-pure nitrogen and then sealed prior to transport to the tunnel. The presence of microbes may give rise to unwanted iron-oxidising (and/or sulphate-reducing) reactions which may alter the chemistry of sampled fluids and may cause precipitation/clogging in the fine tubing preventing fluid flow.

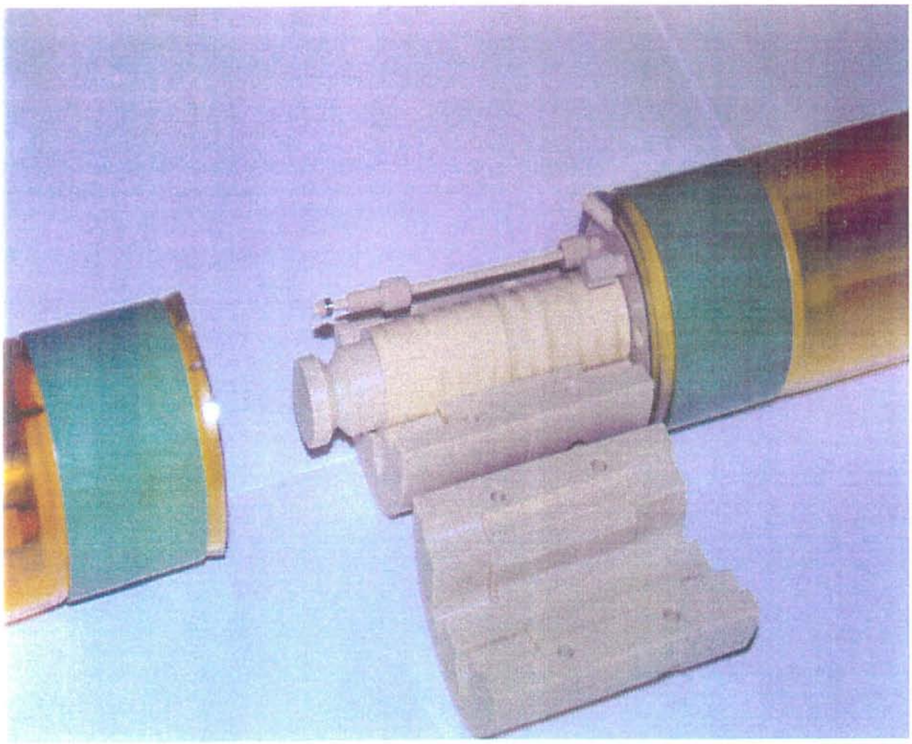


Figure 2-2. *Sampling Section 4 (0.6 m; see Fig. 2-3) showing the design of the peak dummy material to reduce the dead volume space. Packer systems at either side are of polyurethane.*

Since the main emphasis during installation of the borehole equipment **(Fig. 2-3)** was to ensure as much as possible a 'microbe-free' and 'oxygen-free' environment in the borehole, the following sequence was carried out:

- pressurised nitrogen gas was continuously circulated in the borehole during all activities,
- the borehole was first flushed with a nitrogen gas, high-pressure spray containing 30% ethanol to destroy any existing microbes,
- the external parts of the packer/sampling system were cleaned with formaldehyde,
- the packer system was quickly inserted into the borehole and the packers inflated, and
- the peak tubing ends were opened and quickly connected to the sampling and pressure monitoring cabinet.

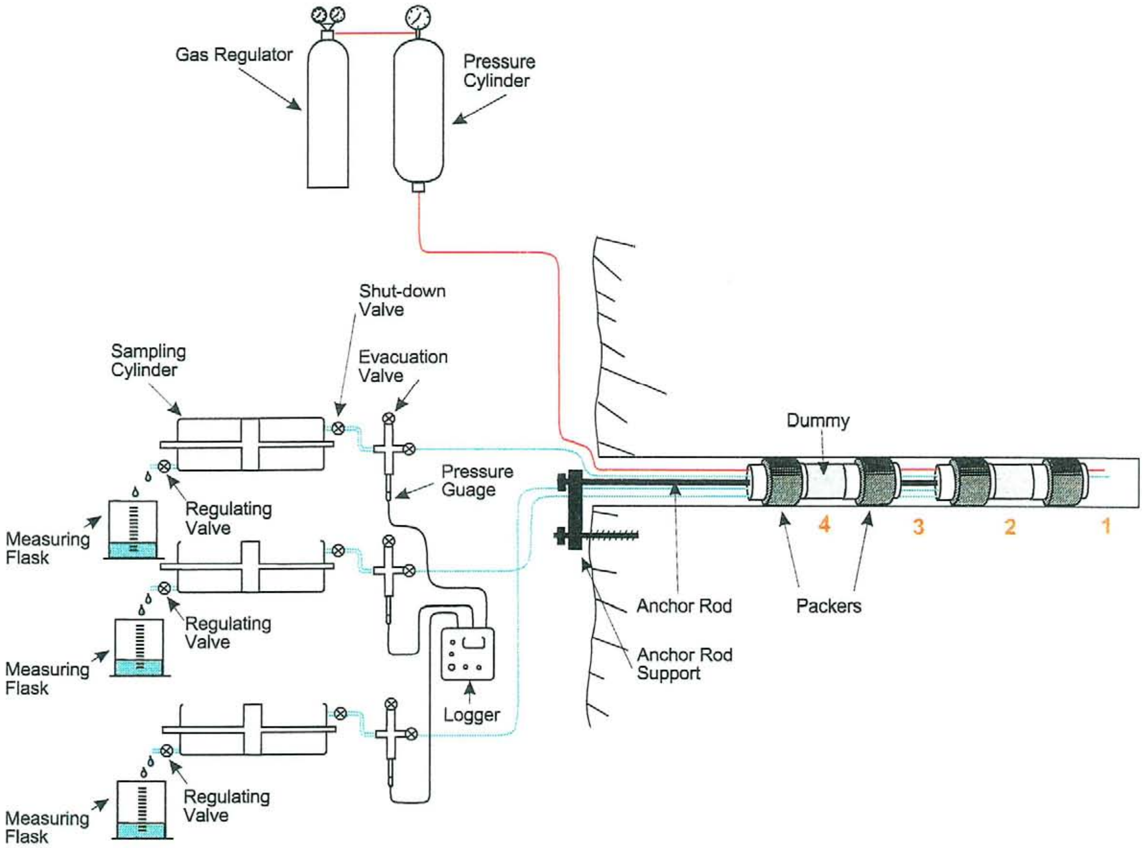


Figure 2-3. *Matrix fluid experimental set-up. Borehole sections 2 and 4 were selected to collect matrix fluid; sections 1-4 are continuously monitored for pressure.*

Table 2-2 lists the parameters of the isolated sections following borehole completion; the 160 mL volume in italics indicated for Section 4 is the volume actually sampled (this Chapter, Section 2-6).

Table 2-2. Borehole completion: Parameters of the isolated sections (P = pressure monitoring; S = sampling)

Borehole Section	S/P	Length (m)	Volume (mL)
1	S/P	10.55-11.80 (1.25)	5461
2	S/P	8.85-9.55 (0.70)	245
3	P	6.26-7.85 (1.59)	6237
4	S/P	4.66-5.26 (0.60)	210 *(160)*

2.5 Monitoring

Using a data logger (Äspö HMS), continuous monitoring of pressure in the four borehole sections, with the outlet valves to the sampling cylinders closed **(Fig. 2-3)**, commenced directly after installation of the packer/sampling equipment. Increasing pressure should indicate a build-up of gas and/or matrix fluid diffusing into the isolated borehole sections from the host rock. **Figure 2-4** shows the pressure curves from June 1998 to June 2000; the breaks in borehole Section 1 (green) and Section 4 (red) in December 1999 indicate when these sections were opened for sampling (this Chapter, Section 2-6). Because of the reduced volumes in Sections 2 and 4 due to the installation of dummies **(Fig.2-2),** these two sections would be expected to be most sensitive to pressure variations.

As indicated above, pressure increases do not necessarily indicate that fluids are accumulating. Several processes may be interacting, for example, two or three phase diffusion processes involving nitrogen (out-diffusion), and matrix gases and/or matrix fluids (in-diffusion). If these processes occur under equilibrium conditions, then little or no pressure increase would be expected in the isolated borehole sections. In any case, the out-diffusion of nitrogen, accompanied by a gradual pressure decrease, might be expected to characterise the initial stages of the experiment. This is suggested by borehole sections 1 and 4; in contrast, Section 2 shows only a brief decrease followed by an increase and then a gradual decrease. A sharp increase in the early stages is shown by Section 3 before levelling off. After March 1999, however, the system appears to have settled and, as might be expected from the section volumes, Section 4 (210 mL) shows a steady increase to a maximum in December 1999 before levelling off. At this stage the borehole section was opened and sampled for fluids (this Chapter, Section 2.6) explaining the sharp drop in pressure. Section 2 (245 mL), also demarcated for sampling, in contrast shows a much more gradual increase which is still continuing. As might be expected from the large borehole volumes, Section 1 (5461 mL) and Section 3 (6237 mL) show no variation; Section 1 was also opened in December 1999 but no fluid was sampled (this Chapter, Section 2.6).

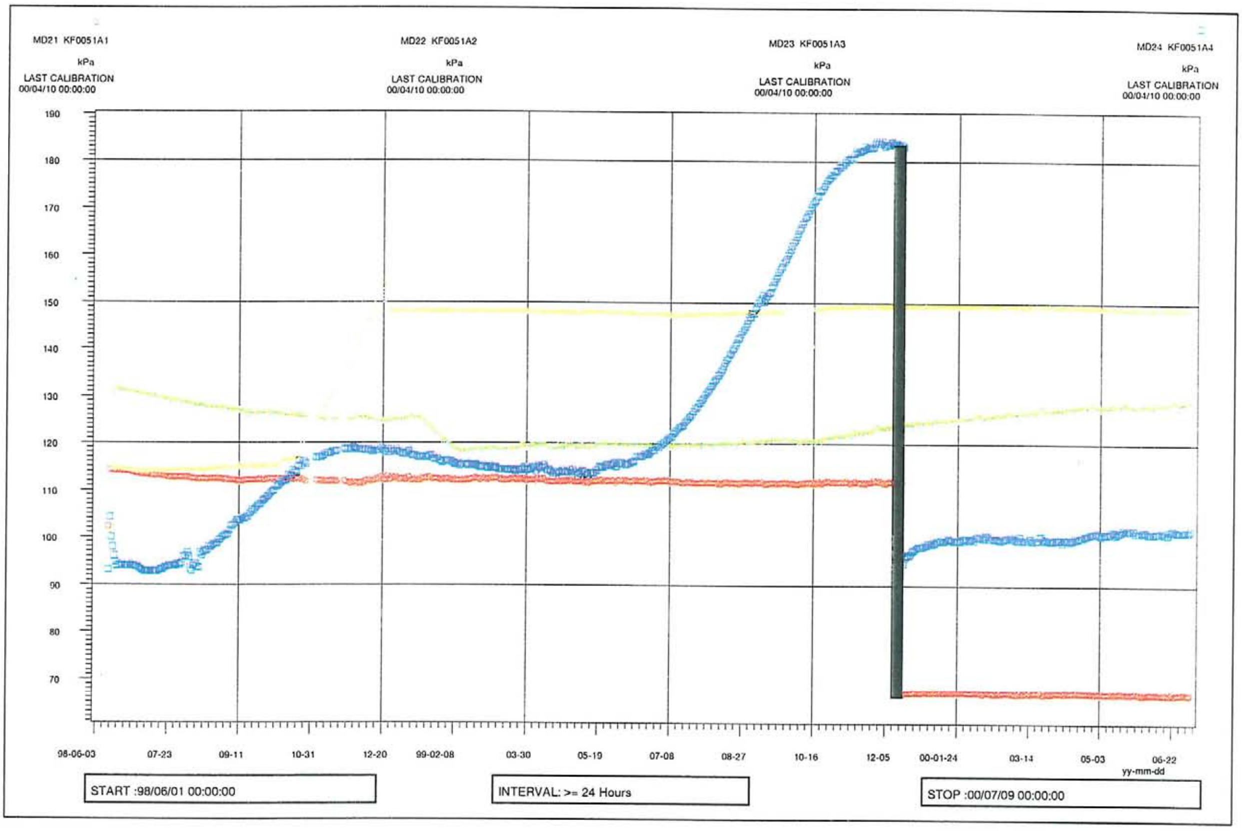


Figure 2-4. *Pressure monitoring curves for each of the four isolated borehole Sections; 1(red), 2 (green), 3 (yellow) and 4 (blue). Sections 2 and 4 are demarcated for matrix fluid sampling. The break in the curves (black line) indicates the occasion when sections 1 and 4 were opened for sampling.*

2.6 Sampling and analysis

Since the pressure curve for borehole Section 4 had begun to level off during November 1999, it was decided in December to assess the progress of the experiment after a period of 18 months. Borehole Section 1 (10.55-11.80 m), initially intended only for pressure monitoring, was opened to test if any fluid was present. No fluid emerged, only a release of gas with a distinct smell of H_2S. The absence of fluid was not altogether surprising since this borehole section is rather long and not instrumented for sampling (total volume of 5461 mL). Initially some 75 mL of fluid would need to accumulate (because of the geometry of the borehole) prior to discharging from the borehole section outlet tube.

This was followed by opening borehole Section 4 (4.66-5.26 m); after an initial emission of gas (also smelling of H_2S), some 160 mL of water were collected under an inert nitrogen atmosphere. This was out of a total borehole section volume of 210 mL **(Table 2-2)**, of which 20 mL was considered inaccessible because of the geometry of the borehole and the design of the instrumentation. The analytical protocol was prioritised according to the amount of sample available. The hydrochemical data suggest that the collected water is largely influenced by groundwater compositions from nearby fractures which has entered the sampling section via interconnected pore/fissure flow and by diffusion. True matrix fluid is also present, albeit much diluted, and this is demonstrated by comparing the 'matrix water' with typical fracture-derived groundwaters **(Table 2-3)** sampled within the Prototype Repository, TRUE Block Scale and Chemlab/Microbe 'J' niche experiments located nearby (see Chapter 5). Although the major ions Na, Ca, K and Cl are generally similar in range, Mg and SO_4 deviate markedly, in common with significant differences in pH, many of the trace elements, and in the isotopes of chloride, strontium, oxygen and deuterium. The increase of Mg in the fracture-derived groundwaters may reflect a small marine influence caused by the hydraulic drawdown during tunnel construction. The full matrix sample analysis is presented in **Appendix 2** and a detailed discussion of the chemistry is included in Section 5.3.

Microbial activity is generally evidenced and probably explained by some residual contamination in the sampled section following borehole activities (K. Pedersen, written comm., 2000). Viable counts of sulphate-reducing bacteria (SRB), which gave rise to the smell of H_2S and may explain the disparity of sulphate in Table 2-3, and iron-reducing bacteria (IRB), were both positive. Other chemical parameters possibly affected by microbial activity are S, Mn, Fe-speciation, pH and alkalinity.

For prolonged sterilisation, a sustainable bacteriocidal substance is required (e.g. mercury chloride or silver chloride). This was not considered in the initial planning phase for fear of chemically contaminating the borehole. In retrospect, this risk will have to be taken in future long-term experiments to 'avoid' undesireable microbial activity.

Borehole Section 2 (8.85-9.55 m) has been showing a small, but steady pressure increase since February 1999, with a slightly more marked increase since October 1999. This will be allowed to continue until adequate matrix fluid has accumulated (total section volume of 245 mL). Sampling will then be carried out involving a more sophisticated approach which will also include gas analysis. The much slower accumulation of fluid in this section, plus the absence of large fluid volumes in the adjacent Section 1 (already opened), may suggest a lower porosity and therefore more representative matrix fluid composition than collected from borehole Section 4 (see Chapter 4).

Table 2-3. Average values for TRUE Block Scale, Prototype and 'J' Niche (Chemlab/Microbe) experiments, compared to the Matrix data and Prototype sample KA3572G01.

Element	TRUE Block [n=8] (mg/L)	Prototype [n=7] (mg/L)	KA3572G01 [n=1] (mg/L)	'J' Niche [n=5] (mg/L)	Matrix [n=1] (mg/L)
Na	1 983	1 887	2 340	2 286	2 200
K	7.9	9.1	10.3	9.11	11.4
Mg	42.4	86.4	24.8	54.1	7.8
Ca	1 396	770	800	1 996	964
Fe	0.09	0.34	-	0.90	0.24
Si	5.7	7.9	5.4	5.7	7.6
F	1.2	1.3	1.2	-	-
Cl	5 675	4 210	4 810	6 944	5 160
Br	30.7	19.9	27.2	39.3	43.16
SO_4	363	308	617	447	26
Alkalinity	19	155	-	40	approx. 170-200
pH	8.0	7.3	7.4	7.4	6.7
	µg/L	µg/L	µg/L	µg/L	µg/L
Li	860	360	435	920	274
Sc	<0.01	0.020	0.024	0.540	0.099
Mn	280	510	-	410	890
Rb	28	30	35	29	31
Sr	19 900	10 780	15 700	33 780	18 600
Y	0.145	0.130	0.118	0.331	0.198
Cs	2.37	2.29	1.43	3.63	0.685
Ba	60.3	52.3	59.3	69.4	425
La	0.13	0.05	0.15	0.17	1.29
Ce	0.29	0.14	0.07	0.19	0.86
Nd	0.03	0.02	0.02	0.06	0.38
Th	<0.005	<0.005	<0.005	<0.004	<0.4
U	0.006	0.030	0.018	0.030	0.103
^{3}H	4.4	8.4	4.7	2.9	-
$\delta^{18}O$	-9.6	-8.0	-10.1	-10.6	-11.6
δD	-75.9	-66.7	-80.9	-79.6	-87.9
^{14}C	60	70	-	-	-
$\delta^{37}Cl$	+0.03	-0.28 to +0.16	+0.27	+0.34	+0.61, +0.59
^{10}B	47.23	45.97	51.87	-	-
^{34}S	25.3	25.6	-	-	-
$^{87}Sr/^{86}Sr$	-	0.717563	0.714990	-	0.714561

^{3}H (TU); $\delta^{18}O$ (‰ SMOW); δD (‰ SMOW); ^{14}C (pmc); $\delta^{37}Cl$ (‰ SMOC); ^{10}B (‰ CDT); ^{34}S (‰ CDT)

3 Matrix drillcore

(Based on contributions from A. Blyth, D. Hirst and S. Frape (U. Waterloo), S. Linblom (U. Stockholm), E-L. Tullborg (Terralogica AB) and N. Waber (U. Bern)

3.1 General

To interpret the origin of the matrix fluid and how it moves through the rock matrix requires a thorough understanding of the mineralogy, petrology, geochemistry and petrophysics of the rock mass. To this end the matrix drillcore, in particular those portions representing the borehole sections being sampled, are undergoing a detailed characterisation. The coordinated approach is outlined in **Figure 3-1**.

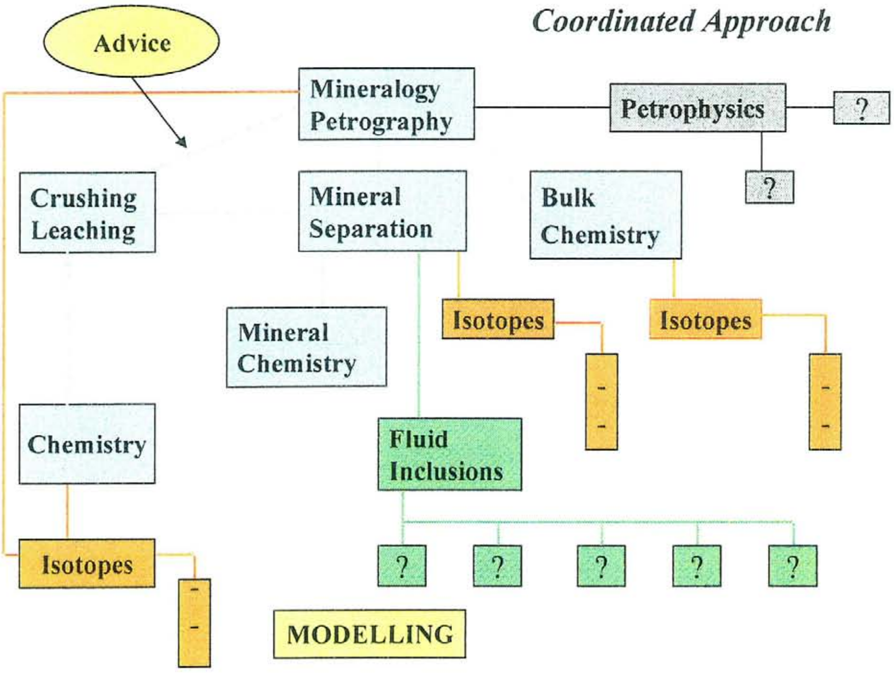


Figure 3-1. *Matrix drillcore: Investigative protocol.*

The major problem is to identify the composition of the pore fluids in the rock, in particular those within the interconnected pore system since these are the fluids which are most readily accessible from the rock matrix. If these fluids are highly saline in character they can influence the groundwater chemistry in fractures/fissures of low hydraulic conductivity. In turn these saline groundwaters may influence the repository near-field environment. Out-diffusion of saline fluids from the matrix into a backfilled tunnel or deposition hole may also directly influence the long-term stability of the engineered barrier system, namely the bentonite and/or bentonite/sand backfill materials.

The following studies of the drillcore are structured to try and differentiate between accessible and inaccessible matrix fluids and determine their composition and origin:

- Mineralogy and fluid inclusion studies should identify first where most of inaccessible fluids are located; however, fractured or decrepitated fluid inclusions may indicate past, present or on-going leakage of fluid into the interconnected pore system.

- Crush/leach experiments on whole-rock samples are being carried out in two stages: a) coarse crush and leach to get a general idea of the expected matrix fluid composition, and b) refined step-wise approach where successively finer size rock fractions (and also mineral separate fractions) are leached, ultimately hoping to determine the intergranular or interstitial fluid compositions (i.e. excluding the fluid inclusions and mineral phases with crystal matrix bound salts).

- Laboratory permeability test to try and force out unbound matrix fluid from a rock sample. The main attraction of this experiment is that it will avoid many of the inherent uncertainties associated with mineralogical interpretation and the crush/leach experiments.

- Porosity measurements will provide an important basis for the understanding of matrix fluid movement through the rock matrix.

3.2 Geochemistry, mineralogy and petrology

Drillcore samples have been selected and studied with particular attention being paid to the two sections earmarked for matrix fluid sampling (i.e. Section 2: 8.85-9.55 m; Section 4: 4.66-5.26 m). Results show that, together with other studies at Äspö and also Stripa, the mineralogy conforms to a general monzogranite-type rock. Within the matrix drillcore length two main rock-types are represented, an Äspö porphyritic diorite type adjacent to the tunnel, and an Ävrö Granite type away from the tunnel, with the transition being located between borehole Sections 2 and 4 at around 8.40-8.50 m. This is supported by the drillcore logging and the downhole BIPS images.

The main rock-forming mineral phases constituting the drillcore are, in decreasing volume amounts, plagioclase, quartz, K-feldspar, biotite, epidote, chlorite, sphene and muscovite with accessory amounts of opaque phases, apatite and zircon. **Table 3-1** gives the modal values of the major mineral phases and shows the clear distinction between the Äspö diorite and the Ärvö granite. Macroscopically this can be seen as a colour change in the drillcore **(Appendix 1).** The feldspars consist of microcline and oligoclase; microcline is sometimes perthitic. Occasionally myrmeckite is observed at the grain boundaries of oligoclase. Alteration is sometimes considerable within the feldspar grains giving it an almost opaque character under transmitted light.

There is an increase in quartz content along the drillhole representing the transition of Äspö diorite to Ävrö granite. A general feature is that quartz fills the pore space between microcline and plagioclase and it sometimes terminates in vuggy growth textures. Open vugs are still discernable and the feldspar crystals often have a perfect terminal shape towards the infilling quartz. The grain size of quartz varies; most have an equigranular texture with fluid inclusions often outlining grain boundaries. Occasional larger quartz grains occur which may be more primary. Both types have a variable content of healed fracture planes containing secondary fluid inclusions.

Evidence of small-scale tectonic effects are common. In many places the centres of quartz grains show healed fractures now outlined with fluid inclusions. Even open delimited fractures may be observed in the centre of quartz grains. A special observation was noted at 5.45 –5.55 m, where a calcite-filled veinlet is lined with protruding euhedral quartz crystals. The quartz is stress-free, but the calcites show a slight deformation expressed as a network of rhombic cleavages.

In terms of whole-rock chemistry, typical major and trace element contents of the two rock-types are given in **Table 3-2.** These data show the Äspö diorite to have higher FeO, MgO, TiO_2, CaO, Na_2O and Rb than the Ävrö granite, but is lower in SiO_2, K_2O and Ba due to its higher content of plagioclase, biotite and epidote/chlorite.

Table 3-1. Matrix drillcore: Average modal values (vol.%) of the major rock-forming minerals

Mineral	Äspö diorite	Ävrö granite
Plagioclase	45	38
Quartz	18	25
K-feldspar	5	19
Biotite	16	8
Epidote	6	3
Chlorite	4	1
Sphene	4	2
Opaques	3	2

Table 3-2. Matrix drillcore - whole-rock chemistry

Element		**Äspö Diorite** *(7.71-7.76 m)*	**Ävrö Granite** *(9.21-9.26 m)*
Al_2O_3	wt%	17.8	16.0
CaO	wt%	4.51	3.04
Fe_2O_3	wt%	5.45	2.91
K_2O	wt%	3.16	3.81
MgO	wt%	2.36	0.929
MnO_2	wt%	0.111	0.050
Na_2O	wt%	4.56	4.15
P_2O_5	wt%	0.382	0.164
SiO_2	wt%	60.9	68.9
TiO_2	wt%	0.865	0.421
LOI	wt%	0.8	0.6
Total	**wt%**	**100.1**	**100.4**
Ba	ppm	1030	1600
Be	ppm	1.93	1.73
Co	ppm	10.4	<5.51
Cr	ppm	87.2	85.4
Cu	ppm	25.8	<5.51
Ga	ppm	22.4	14.2
Hf	ppm	5.85	2.7
Mo	ppm	<2.26	<2.20
Nb	ppm	17.1	7.93
Ni	ppm	33.1	20.6
Rb	ppm	121	93.6
Sc	ppm	8.92	3.48
Sn	ppm	3	1.43
Sr	ppm	1180	1010
Ta	ppm	1.39	0.655
Th	ppm	5.83	3.68
U	ppm	2.58	2.11
V	ppm	77.7	31.4
W	ppm	0.791	0.646
Y	ppm	25.4	11.1
Zn	ppm	107	277
Zr	ppm	322	139
Ce	ppm	123	57.9
Dy	ppm	4.37	1.97
Er	ppm	2.17	0.946
Eu	ppm	1.48	0.872
Gd	ppm	5.92	2.86
Ho	ppm	1	0.395
La	ppm	44.8	22.7
Lu	ppm	0.448	0.186
Nd	ppm	58.2	24.8
Pr	ppm	16	7.11
Sm	ppm	8.25	3.23
Tb	ppm	0.934	0.375
Tm	ppm	0.541	0.197
Yb	ppm	2.08	1.03

3.3 Fluid inclusions

The nature of the matrix fluid may be influenced by leakage of saline fluids from fluid inclusions which, at Äspö, are commonly included in matrix quartz. Four research groups (Universities of Stockholm, Bern and Waterloo, together with a group from Oulu, Finland) are participating in characterising the fluid inclusions; this collaboration will also function as an interlaboratory exercise with the intention of deriving a common methodology for the description, analysis and interpretation of fluid inclusion populations.

Fluid inclusions are observed in quartz and apatite; the latter has only been observed at a few places, but inclusion fluids may have important implications for genetic/paragenetic relations. There are three types of quartz: a) large primary irregular grains, b) small, recrystallised equigranular grains in a heptagon matrix, and c) vuggy quartz. Fluid inclusions in quartz are mainly associated with the coarse-grained primary magmatic quartz and later fine-grained recrystallised quartz. They show a diverse distribution where grain boundary inclusions **(Fig. 3-2)**, and fracture bound inclusions **(Fig. 3-3)** dominate. Multi-phase liquid, solid and gas fluid inclusion types are commonly associated with the primary quartz **(Fig. 3-3)** and mostly liquid phase types with the recrystallised quartz. Three-phase inclusions have been observed with a probable calcite daughter mineral and evidence of decrepitated inclusions have also been recorded (Lindblom, 2000).

Preliminary microthermometric studies at the University of Bern show that the fluid inclusions identified in the coarse-grained magmatic quartz and the fine-grained recrystallised quartz mostly represent highly saline populations. Salinity ranges from 8.2-20.9 wt% $NaCl_{eq}$ in the former types and from 4.3-10.8 wt% $NaCl_{eq}$ in the latter types. In addition, several other fluid inclusion types containing non-fluorescent gas-rich inclusions (CO_2 or CH_4) have also been revealed.

Grain boundary fluid inclusions

Fig. 8a. Grain boundaries in equant-shaped quartz crystals outlined by irregularly shaped fluid inclusions.
(section 2:1x, MFXSL-4.105)

150 mm

Fig. 8b. Grain boundaries in quartz shown at polished surface where inclusions give 'etch'-like textures.
(section 4:1, MFXSL-7,81)

150 mm

Fig. 8c. Same view but focused 20 mm below polished surface, where fluid inclusions are seen to outline grain boundaries in quartz.
(section 4:1, MFXSL-7.81)

150 mm

Fig. 8d. Flat-lying irregular fluid inclusions showing bottom of equant quartz grain.
(section 4:1, MFXSL-7.81)

150 mm

Fig. 8e. Similar 'bottom' inclusions.
(section 2:2, MFXSL-5.42)

50 mm

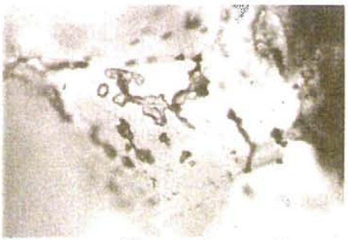
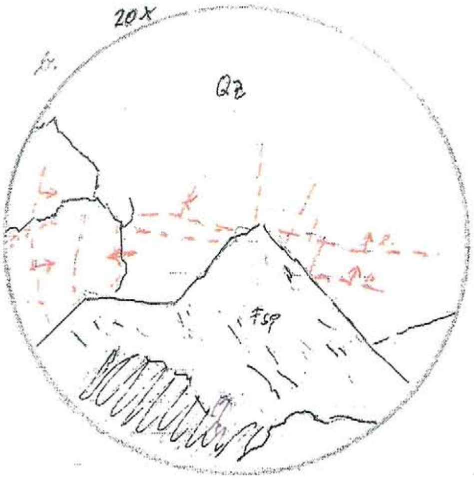


Figure 3-2. *Examples of grain boundary fluid inclusions (Äspö diorite)*

MFXSL-5.03

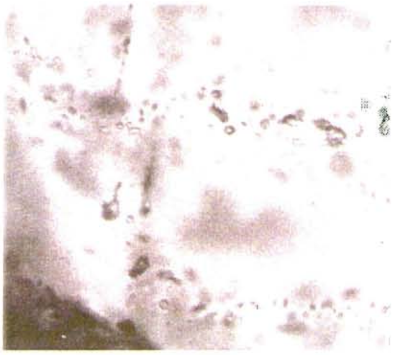
Section 1:1

Fig. 1a. Sketch of facetted feldspar crystals superceded by quartz. Dip of FIP is indicated by arrows.



0.5 mm

Fig. 1b. Two parallell FIP are shown, cut by a FIP emanating from plagioclase crystal face.



75mm

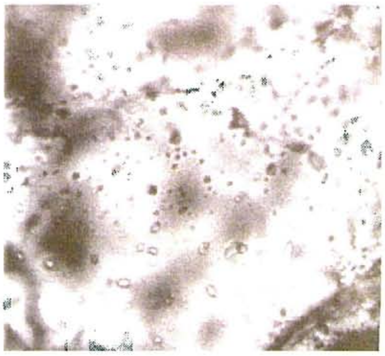
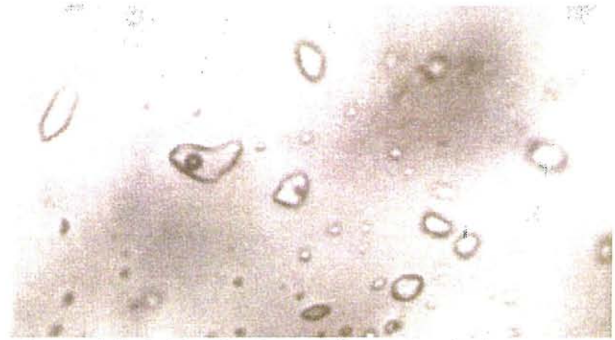


Fig. 1c. Fluid inclusion occurrence in quartz. Enlargement show mixture of one-phase and two-phase inclusions. The size of large two-phase inclusion is 15 um long.

100 mm



50mm

Figure 3-3. Examples of fracture bound fluid inclusions (Äspö diorite)

3.4 Crush/leach experiments

3.4.1 General

A drillcore length of Äspö diorite (3.25-3.77 m), close to borehole Section 4 (4.66-5.26 m) was split into two subsections; one split was investigated by the University of Bern (3.60-3.77 m) and the other by the University of Waterloo (3.25-3.60 m). Since two different drillcore sections were studied and two different approaches were employed, comparison of results (e.g. calculated salinity of the matrix pore water) can only be qualitative at best. The crush/leach experiments are therefore reported separately.

The faulty preservation of the drillcore material following drilling and mapping by applying beeswax directly on the drillcore instead of first wrapping in aluminium foil, may have contributed to some contamination of the experiments. This was not the case for the University of Bern as the outer 5 mm core margin containing the wax was removed as an initial step. The University of Waterloo sample, however, was initially heated to remove the wax which may not have been complete. As a precaution the wax was analysed separately and the data indicate that contamination was minimal **(Table 3-3)**.

Table 3-3. Analysis of beeswax coating material

Element	ppm
Al	8.8
Ba	0.1
Pb	0.02
B	4
Br	5
P	1
Fe	1.5
Ca	10
K	25
Si	8
Cu	0.1
Cr	0.1
Li	0.2
Mg	1.4
Mn	0.05
Mo	0.02
Na	22
Ni	0.08
Sr	0.06
Sn	0.04
Zn	0.3
	mg/L
Cl	<1
SO_4	<2

3.4.2 University of Bern

Experimental

Sample preparation, crushing and aqueous extraction were all carried out in a glove-box under an oxygen-free N_2-atmosphere to prevent any possible oxidation of sulphide minerals. The outermost 5 mm of core (included the wax coating) was removed and the central portion then crushed and milled to a grain size of < 63μ. On two aliquots of the powdered rock material aqueous extracts and Ni-ethylenediamin (Ni-en) extracts were carried out at four different rock/water ratios. To control the degree of inevitable water/rock interactions the extraction time in both cases was set to seven days to allow for full equilibration of the extract solution with calcite (present up to 1 wt%). A further control was to extract at different water/rock ratios since the concentration of a chemical constituent that behaves in a conservative (or non-reactive) manner should show a linear dependence to the different water/rock ratios. Moreover, a linear relationship with sulphate is a measure of the lack of atmospheric contamination in the system.

Both extracts were analysed for major ions and trace elements; chloride isotopes (at Waterloo) and strontium isotopes (at Bern) were analysed on one extract **(Appendix 3).**

The porosity was calculated from gravimetrically determined water loss at 150°C measured on an undistrubed aliquot of each sample.

Results

A linear relationship of both chloride and sulphate **(Figs 3-4, 3-5)** to the different water/rock ratios indicated: a) that the extractions had been successfully accomplished, b) there was little or no atmospheric contamination (also supported by pH and alkalinity corrected for calcite saturation), and c) the extracted sulphate belongs to the true pore water.

Using the water-loss porosity values of 0.1vol% and 0.2 vol% for the two samples, the chloride extract concentrations can be converted into chloride concentrations per litre of *in situ* pore water using the following procedure:

(1-porosity) x (density/porosity) x (Cl concentration of aqueous extract)

The chloride concentrations ranged from around 61 000 to 89 000 mg/L chloride. In addition to indicating the high potential source of salinity to the matrix pore water in the Äspö diorite, these extractions show also how sensitive the calculated salinity is to small variations in the true porosity and the accuracy of porosity measurements respectively.

Finally, combining the results from the crush/leach experiments with the preliminary fluid inclusion data (Chapter 3.3), the aqueous extracts yield salinities in the range of the highly saline fluid inclusions. These results, together with Br/Cl and Sr-isotope data,

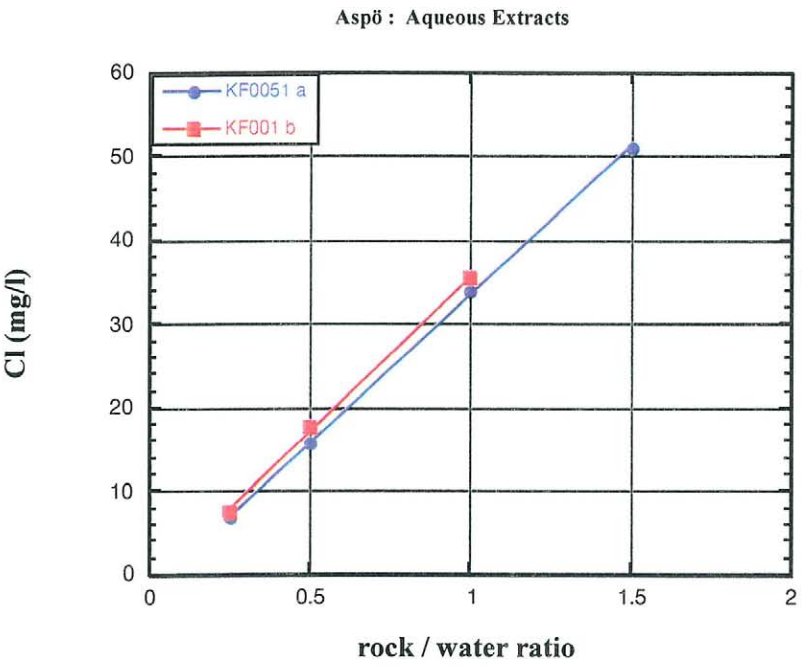


Figure 3-4: *Cl-concentrations in aqueous extracts at different water/rock ratios*

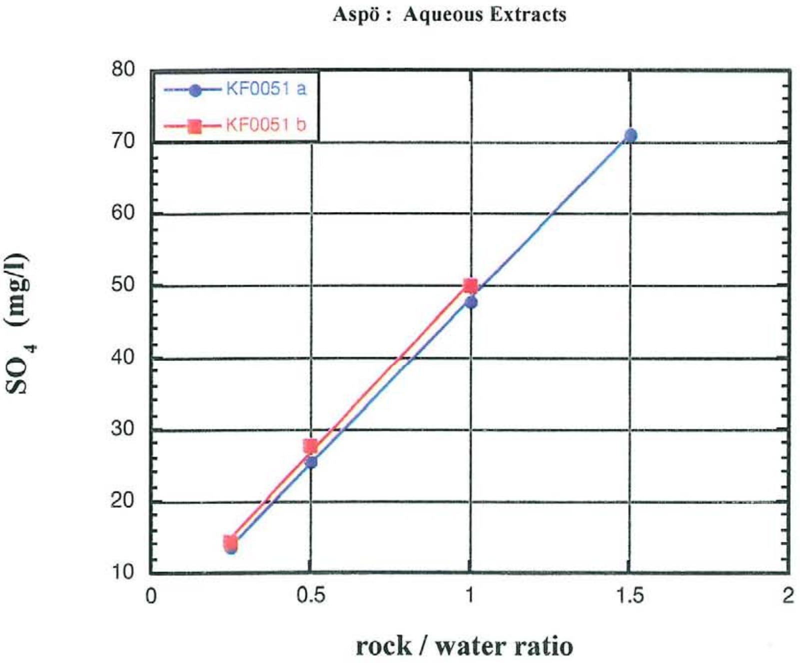


Figure 3-5: SO_4-concentrations in aqueous extracts at different water/rock ratios

indicate that a mixture of interstitial water and fluid inclusion fluid could act as a high salinity source, potentially explaining the presence of deep, highly saline groundwaters at Äspö.

3.4.3 University of Waterloo

In contrast to Bern, who ground down the drillcore sample to less than 63 μ and carried out one leach on two aliquot splits, the approach of Waterloo was stepwise, using three separate leaches on one ground down drillcore sample.

Experimental

The wax coating on the 3.60-3.77 m section of the drillcore was first largely removed by scraping and heating the surface with a heat gun. The core was then coarse crushed in a jaw crusher and then pulped in a corundum shatter box. One litre of Ultrapure water was added to the pulped sample and the water and rock mixture shaken and leached for 24 hours at room temperature. The sample was coarse filtered (#4 filter paper) or centrifuged, followed by vacuum flask filtering through a 0.45 μm filter paper. The remaining rock mixture was dried and the above procedure repeated a second and a third time.

Following each leach, the filtered water was analysed for chloride isotopes using the VG Sira 9, Dual Inlet mass spectrometer. Accuracy for ^{37}Cl was ±0.12‰ SMOC (2Φ). In addition two sub-samples were analysed for major ion chemistry by ICP, one at Waterloo and the other at the SKB Äspö Laboratory.

Results

1. Major ion chemistry

The major ion chemistry of the leachates is presented in **Table 3-3.**

Table 3-3. Major ion chemistry

	U. Waterloo Analytical Lab. Analytical Concentration (mg/L)							Äspö Laboratory Analytical Concentation (mg/L)						
Sample	**Cl**	**Br**	**SO_4**	**Ca**	**Mg**	**Na**	**K**	**Cl**	**Br**	**SO_4**	**Ca**	**Mg**	**Na**	**K**
Leach 1	31.8	<DL	15.1	7.5	12.4	58.1	41.5	NA	0.3	NA	7.3	13	69	47
Leach 2	20.5	NA	NA	NA	NA	NA	NA	NA	0.48	NA	3.4	1.2	42	24
Leach 3	9.7	NA	NA	NA	NA	NA	NA	9.0	NA	NA	NA	NA	NA	NA

<DL - less than detection limit; NA - not analysed or not yet available

Based on these data, the concentration of the major ions in the rock were calculated as shown in the following example:

Leach 1

Cl analysis: 31.8 mg/L
1L of Ultrapure water was added to 1472.28 g of powdered rock

Assuming all the chloride comes out of the rock:

$$\frac{31.8mg/L(Cl)\times 1L}{1472.28g(rock)\times 1000mg/g} = 2.16\times 10^{-5}\frac{mgCl}{mgRock} = 21.6ppm$$

Table 3-4 shows the calculated concentrations of major ions in the rock based on the analysed elements for each of the leach experiments.

Table 3-4. Calculated concentrations of major ions per kg rock

	U. Waterloo Analytical Lab. Calculated Concentration in ppm kg^{-1} rock							Äspö Laboratory Calculated Concentation in ppm kg^{-1} rock						
Sample	**Cl**	**Br**	**SO_4**	**Ca**	**Mg**	**Na**	**K**	**Cl**	**Br**	**SO_4**	**Ca**	**Mg**	**Na**	**K**
Leach 1	21.6	<DL	10.3	5.1	8.4	39.5	28.2	NA	0.2	NA	5.0	8.8	46.9	31.9
Leach 2	14.3	NA	NA	NA	NA	NA	NA	NA	0.3	NA	2.4	0.8	29.4	16.8
Leach 3	6.9	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

<DL - less than detection limit; NA - not analysed or not yet available

2. ^{37}Cl isotope analysis

The source of chloride in this rock section is thought to be from fluid inclusions (primary, secondary and grain boundary). By crushing and leaching the rock, the isotopic signature of this chloride was obtained. **Table 3-5** presents the ^{37}Cl isotopes for successive leaches.

Table 3-5. ^{37}Cl for successive leaches

Sample	**^{37}Cl ‰ SMOC**	**Repeat**
Leach 1	0.26	-
Leach 2	0.35	0.40
Leach 1	0.11	0.47

3. Comments

Chloride leaching from the powdered rock was incomplete, as shown by the Cl concentration analysis. Chloride concentrations dropped from 31.8 mg/L in the first leach, to 20.5 mg/L in the second leach, to 9.7 mg/L in the third leach. The samples were dried and re-powdered in the shatter box between leaching, so it is possible that finer powdering occurred, thereby releasing more fluid inclusion chloride to be leached.

^{37}Cl isotope values obtained are similar within the accuracy of the method (±0.12‰ SMOC (2Φ)) for leach 1 and 2. Leach 3 chloride concentrations were lower and the values obtained are less reliable. There was insufficient sample left to duplicate the analyses.

Further related experiments using drillcore material of varying composition from other localities at Äspö are in progress. Step-wise crushing and leaching at increasingly smaller grain-size fractions will be carried out. These data should provide a more reliable basis to interpret the results from the matrix drillcore.

3.5 Permeability test

Since August 1999 a high pressure experimental set-up has been operating at the University of Waterloo **(Appendix 4)**. This experiment is essentially trying to force double distilled (Ultrapure) water through a drillcore portion (100x50 mm) in order to extract unbound, intragranular matrix fluid. The drillcore portion, selected adjacent to Section 4, has been mounted in a moisture proof membrane with an applied hydrostatic stress of 11.7 MPa (i.e. equivalent to the lithostatic stress at the Matrix Borehole location in Tunnel 'F') and a pore pressure of 6 MPa has been applied to the distilled water. Up until October 1999 no movement was observed and the pore pressure was accordingly increased to 9.5 MPa. Some activity was observed in November, 1999 which subsequently slowed down. Monitoring is continuing.

3.6 Petrophysical measurements (porosity)

3.6.1 General

The total or physical porosity in a crystalline rock is the volume not occupied by mineral grains. It therefore incorporates the presence of micro-fractures, porous minerals (often secondary minerals) and fluid inclusions.

In most experiments and modelling exercises the interconnected physical porosity (the effective hydraulic porosity) is the parameter required. Interconnected porosity is determined in the laboratory using injection or saturation techniques. At Äspö, rock physical porosity has been measured at several localities as an integral part of other on-going experiments (Mazurek et al., 1997; Sundberg and Gabrielsson, 1999; Johansson et al., 1998) and during the tunnel construction (e.g. Stanfors et al., 1993 a and b). The method most commonly employed has been water saturation, but He-gas expansion and Hg injection porosimetry have been tested. Despite that a comparison of the different methods revealed only very small differences (Mazurek et al., 1997), caution is required since the total porosity is very small and the error of the methods quite large. Small measurement errors may reflect large descrepancies in subsequent calculations of pore fluid compositions (i.e. salinities). This underlines the necessity to use one common technique for all determinations; at least the measurement error will be the same for all samples thus allowing direct comparison.

3.6.2 Methodology

Measurements of connected physical porosity are being carried out at the Swedish National Testing and Research Institute. The samples (5 cm pieces of drillcore) are first dried at 110 °C until a constant weight is reached (minimum 24 h), then they are stored at room temperature under controlled conditions for 24 hours and a dry weight is measured. The sample is then water saturated until stable conditions are achieved after which the sample is reweighed. Following this, the samples are dried a second time and a new dry weight determined.

3.6.3 Results and discussion

From earlier measurements carried out from several experimental sites at Äspö, cf references above), the average total or physical interconnected porosity values characteristic for the Äspö area (based on between 50 to 100 measurements) are:

Fine-grained granite	0.2 vol% ±0.1
Ävrö granite	0.35 vol% ±0.1
Äspö diorite	0.45 vol% ±0.1

There is a distinct difference in interconnected porosity between all three major rock-types. Altered Äspö diorite and Ävrö granite show higher porosity values than the corresponding fresh rock and these show large variations related to the type and extent of the alteration. Such variations can span 0.15 to 1.5 vol%. However, significant alteration is not a feature of the matrix borehole vicinity as indicated by the petrological studies.

In these present studies both total and interconnected porosity are being addressed. Caution has to be exercised since detailed investigations used in diffusion experiments (Johansson, 2000 and references therein) show that the distribution and character of the porosity show large differences over short distances and may, for example, be significantly lower perpendicular to the foliation in the rock. To this end structurally oriented samples are being investigated, both parallel and perpendicular to the regional foliation.

Determination of effective or connected porosity on 5 samples from the Äspö diorite portion of the matrix drillcore and 4 samples from the Ävrö granite portion gave average values of 0.32 vol% and 0.35 vol% respectively; the average densities are correspondingly 2756 and 2679 kg/m^3. The variation in density is, however, larger for the diorite (2721-2752) than the granite (2675-2679) indicating the greater heterogeneity (and greater mafic content) of the Äspö diorite.

Compared to the average Äspö porosity values quoted above, the matrix Ävrö granite is similar but the matrix Äspö diorite differs markedly (0.32 vs 0.45 vol%). This may reflect the structural orientation of the measured rock section; as suggested above, the interconnected porosity may be expected to be somewhat less when measured perpendicular to the foliation. To resolve this issue, oriented samples (i.e. parallel and perpendicular to the foliation) are presently being measured. Furthermore, attempts are being made to determine the non-connected porosity in relation to the measured interconnected porosity, and consideration is also being given to assessing the potential effect of destressing following removal of the drillcore.

3.7 Summary and conclusions

As noted at the beginning of the chapter, the major problem is to separate and analyse the pore fluids in the interconnected pore system of the rock matrix. Pore fluids are important to characterise since accessibility of these fluids not only influences the chemistry of the formation groundwaters, but the fluid chemistry can also to be influenced by the formation groundwaters by out- and in-diffusion processes respectively. The inaccessible fluids in closed-off pore spaces, at microfracture/fissure dead-ends, and contained in fluid inclusions play very little role unless tectonic stresses induce connected porosity and cause fracturing of the fluid inclusions. These effects may also be caused by water-rock interaction (i.e. dissolution) over long time periods. In both cases pore fluids and fluid inclusion fluids become accessible via the interconnected porosity and may be further transported through the rock by diffusion and, in some cases, ultimately by advective flow via micro fissures/fractures. If these fluids are highly saline, they can contribute to increasing salinity of the formation groundwaters and may also pose a problem if they come in contact with the bentonite and/or bentonite/sand materials backfilling the deposition holes and access tunnels respectively. Highly saline water may cause a deterioration in the backfill swelling properties.

The matrix drillcore studies to date indicate that the interconnected physical or total rock porosity is similar throughout the drillcore length studied even though two rock types (Äspö diorite and Ävrö granite) have been identified. Crush/leach experiments have indicated that the total fluid content in the rock (e.g. from fluid inclusions, pore fluid, interstitial fluid etc.) is highly saline and most of this can be explained by the influence of the fluid inclusions. However, the specific chemistry of the accessible pore fluid is still not known. The permeability experiment has tried to address this by attempting to force out the connected pore fluids by pressurising deionised water through the core. This has still not yielded any results after almost 2 years.

4 Hydraulic character of the rock matrix

(Based on contributions from E. Gustafsson (Geosigma AB))

4.1 General

The Äspö Matrix Fluid Experiment aims to sample matrix fluids from crystalline rock of low hydraulic transmissivity ($T < 10^{-10}$ m^2s^{-1}) at a depth of 450 m. The matrix borehole KF0051A is a "dry" borehole with no water inflow recorded during drilling, and no evidence of water-bearing fractures (see Chapter 2). Based on knowledge from other "dry" locations at the Äspö HRL the hydraulic transmissivity of the rock surrounding the matrix borehole is expected to be in the range of 10^{-14}-10^{-11} m^2s^{-1}.

Available information which is useful in estimating the hydraulic properties of the rock matrix includes:

- changes in pressure recorded from each of the four isolated borehole sections of interest over a period of two years (Chapter 2.5; Fig. 2-3),
- after a period of 18 months borehole sections 1 and 4 were opened; Section 1 was dry but Section 4 gave 160 mL of water out of a total volume of 210 mL (Chapter 2.6),
- petrological data have located a fine fracture intersection with the borehole at 4.035 m were a packer is located; this intersection is some 56.5 cm from Section 4 towards the tunnel, and
- mineralogical data (E-L. Tullborg, per. comm., 2000) have suggested that the Äspö diorite may be more porous than the Ävrö granite, although this is presently not reflected in the measured connected porosity (Chapter 3.6).

4.2 Predictions

At an early stage in the experiment, estimated times to accumulate 250 mL matrix fluid (approximating to the respective volumes of Sections 2 and 4 earmarked for sampling) were predicted based on a range of hydraulic conductivity values. Both radial and spherical Darcian flow were considered assuming differential pressures within 10–35 bar and a radius of influence 5–10 m. The results of the predictions are shown in **Figure 4-1.** At a conductivity of $1 \cdot 10^{-13}$ ms^{-1} an accumulation of 250 mL matrix fluid would require 2–9 months, and at a conductivity of $1 \cdot 10^{-14}$ ms^{-1} it would need from 16 months to 7 years. Contrastingly, at a conductivity of $1 \cdot 10^{-12}$ ms^{-1} only 5 days to one month would be required. The increase in pressure in borehole Section 4 after 15 months **(Fig. 2-4)** suggests that the hydraulic conductivity in the matrix rock block lies somewhere around 10^{-14}-10^{-13} ms^{-1}.

Following the opening of the two borehole sections in December 1999, when 160 mL of water was recovered from Section 4, out of a maximum of about 180 mL (around 20 mL residual volume was inaccessible due to packer/borehole geometry), further calculations were made. From the measured inflow rate, the actual pressure in the borehole section, and an estimate of pressure in the surrounding rock creating differential pressures within 10-35 bar and radius of influence 5-10 m, the hydraulic conductivity of the matrix rock block was calculated. Even though there are uncertainties in estimated pressure and the assumed flow regime, both radial and spherical Darcian flow, the calculated hydraulic conductivity of $1 \cdot 10^{-14}$-$6 \cdot 10^{-14}$ ms^{-1} of the matrix rock block is judged reasonable and in accordance with the earlier predictions.

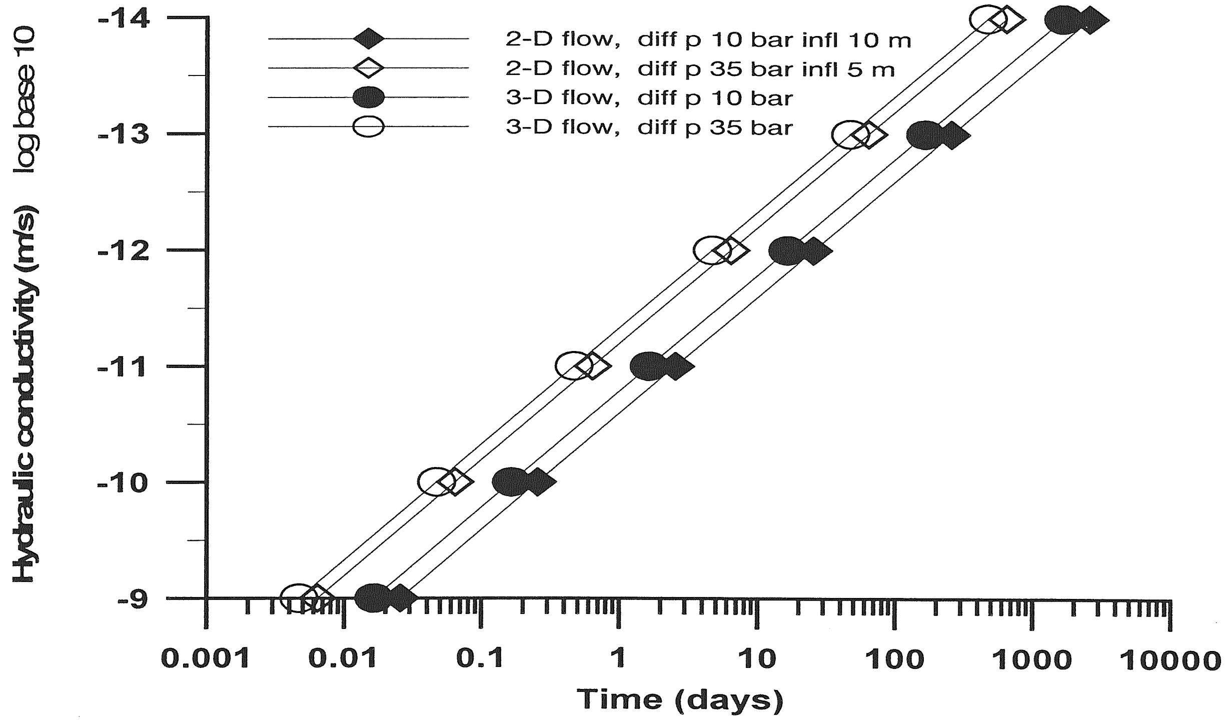


Figure 4-1. *Predicted times to accumulate 250 mL of matrix fluid, based on a range of hydraulic conductivities, considering both radial and spherical Darcian flow and assumed differential pressure within 10–35 bar and radius of influence 5–10 m.*

4.3 Fluid movement

The chemical analysis of the sampled fluid from borehole Section 4 (see details in Chapter 2.6) showed a water composition more typical of conductive minor water-bearing fractures in the near-vicinity of the matrix borehole (e.g. transmissivites of 10^{-10}-10^{-5} m^2s^{-1}; see Chapter 5) than what was expected from the matrix fluid. Hence, the existence of preferential "flow paths" in the matrix rock, closely located to minor water-bearing fractures seems possible. The distance to a water-bearing fracture, feeding some tiny connected micro-scale fractures eventually entering or passing close by borehole

Section 4 can be estimated. Assuming that the hydraulic conductivity in Section 4 is due only to flow in micro-scale fractures, simple mass balance calculations were made based on 1–3 fractures with transmissivities ranging from $1 \cdot 10^{-14}$ -$1 \cdot 10^{-13}$ m^2s^{-1} and an accumulated volume of 180 mL. If most of the accumulated water in Section 4 originates from a minor water-bearing fracture, estimates show the distance to such a feature does not exceed 3–7 metres. Of interest, and as mentioned earlier, a very fine, semi-permeable fracture/fissure intersecting the borehole was located recently on the BIPS image some 56.5 cm from Section 4; microscopic characterisation of this fracture is forthcoming.

Alternatively, 180 mL of matrix fluid can be extracted from quite a small homogeneous block of porous rock. Therefore, if it is assumed that the matrix rock block consists of a homogeneous porous media with connected pores, a 50 litre volume of such a block is enough to extract 180 mL fluid, considering a porosity of 0.35 vol% for the Äspö diorite (see Chapter 3.6). This small rock volume can be contained easily within a sphere of 23 cm radius, or a cylinder with a radius of 17 cm, if the length is 60 cm, i.e. equivalent to the sampled Section 4.

The forgone discussion has focussed on the Äspö diorite; what about the borehole section in the Ävrö granite? The BIPS image log, microscopic studies and porosity data all suggest that the Äspö diorite is more 'open' to water movement. This is also supported by the fact that borehole Section 4 in the diorite has already accumulated water and been sampled after 18 months, and indications are it has begun to fill up again, whilst Section 2 hosted by the Ävrö granite has yet to be sampled. Consequently, Section 2 may reveal a water which is more typical of matrix fluid (at least more influenced by) than Section 4. Based on the monitoring pressure data, Section 2 (volume of 245 mL) may be ready for sampling sometime in 2001, after an approximate duration of at least 3 years. In comparison with the Äspö diorite, this is more in accordance with the early predictions discussed in Chapter 4.2.

To summarise the hydraulic nature of the matrix bedrock environment, a preliminary conceptual model is presented in **Figure 4-2**. The solid arrows in the figure indicate advective groundwater flow and the broken arrows represent mainly in- and out-diffusion processes through the rock matrix.

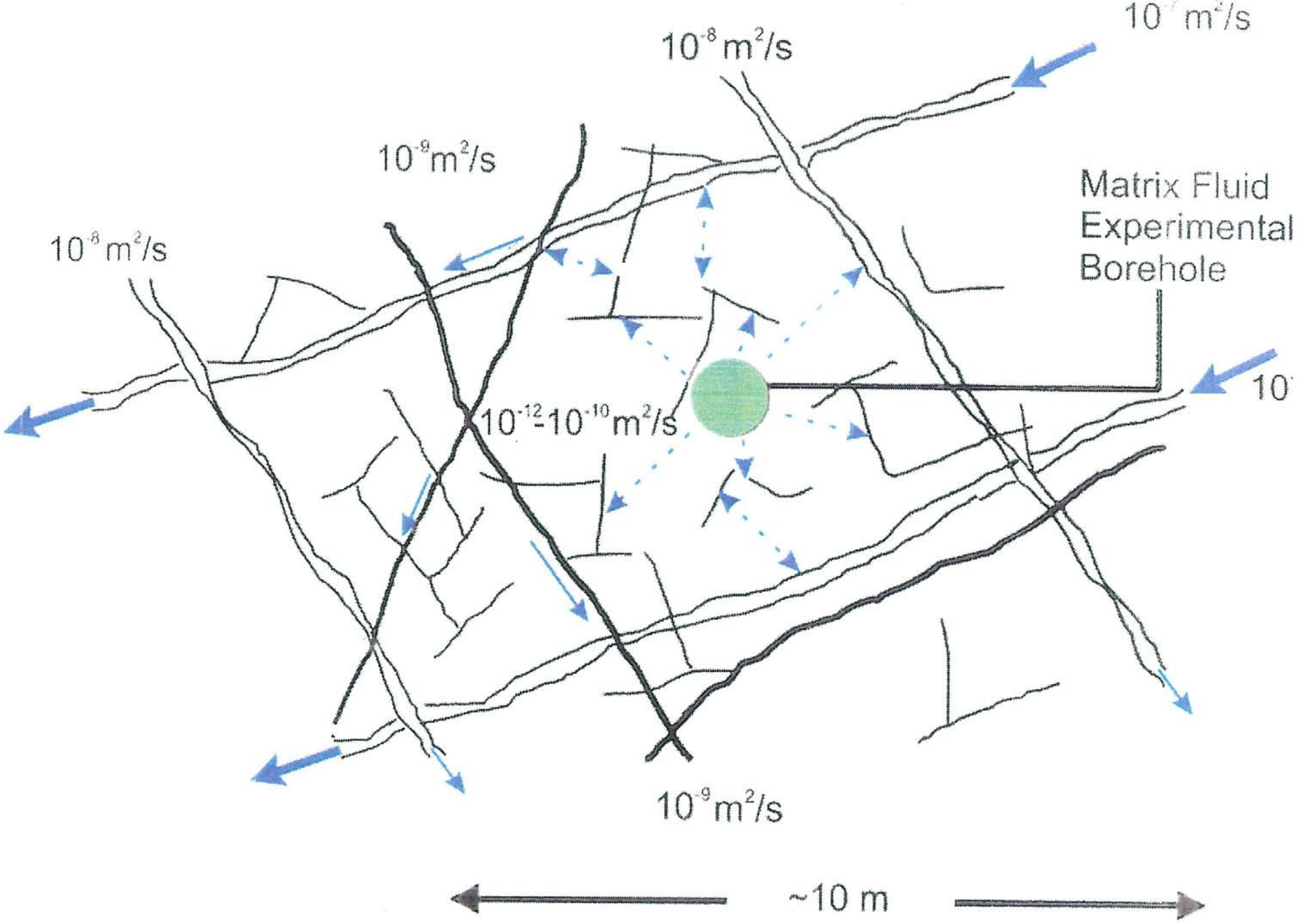


Figure 4-2. *Schematic conceptualism of the hydraulic character of the bedrock environment adjacent to the matrix borehole. (Solid arrows represent advective groundwater flow; broken arrows represent mainly in- and out-diffusion processes)*

5 The surrounding hydrochemical environment of the matrix borehole

(Based on contributions by J. Casanova (BRGM), S. Frape (U. Waterloo), M. Laaksoharju (GeoPoint AB), A. Sävestad and C. Andersson (SKB), I. Rhén (VIAK VBB), J. Smellie (Conterra AB) and B. Wallin (Geokema AB))

5.1 General

The major conclusions from undisturbed groundwater investigations at the Äspö site (e.g. Smellie and Laaksoharju, 1992; Smellie et al., 1995; Laaksoharju et al., 1999) are that much of the water chemistry down to 800 m (0.5-8 g/L chloride) can be related not only to known palaeo-events such as infiltration of glacial melt water (or cool climate recharge) periodically during the last 10-100 ka and different marine stages during the last 8-0 ka, but also to infiltration of relatively recent meteoric water (3-0 ka). Below 800 m depth the salinity increases markedly to 12.5 g/L chloride, probably approaching brine in composition at still greater depths as indicated at Laxemar (1700 m), where ancient near-stagnant groundwater (45 g/L chloride) has been dated to 1.5 Ma (Louvat et al., 1999). At these depths water/rock interactions and matrix fluids probably play an increasingly important role.

The main bulk of groundwater at Äspö is the result of mixing along flow paths of groundwaters of different origin, e.g. palaeowaters (saline, glacial) and modern meteoric waters. Chemically, the groundwater down to 500 m is altered mainly by rapid reactions (some microbially mediated) and less by long-term water/rock reactions due to the relatively low temperatures. At greater depths (>1000 m), due to temperature increase with depth and long residence times, water/rock reactions play a more dominant role in modifying the groundwater composition. The position of the sampling points, in relation to depth (shallow/deep), geographical location, (under land/sea), fracture orientation (towards land/sea), reactions with fracture minerals, and present/palaeo groundwater systems, is generally determining, or at least influencing to varying degrees, the obtained groundwater compositions.

The hydraulic transmissivity determines the speed the hydrochemical regime will react to the prevailing hydraulic conditions. A fracture with high hydraulic conductivity responds faster than a fracture with low hydraulic conductivity, such that the groundwater composition will be mainly a product of mixing rather than water/rock interaction. Contrastingly, a low hydraulically conducting fracture will react slowly (very low conducting features may not react at all) leading to longer groundwater residence times with significant water/rock interaction processes and, potentially, a rock matrix fluid component.

As noted in Chapter 3, matrix fluids are here considered to constitute the pore fluids in the rock matrix. However, the accessibility of these fluids, and their ability to move through the rock matrix, will depend on whether or not the pore spaces are interconnected. Assuming interconnected pore spaces, it is important to try and relate the matrix fluid chemistry to the chemistry of groundwaters present in nearby minor fracture zone(s) of low hydraulic transmissivity (T= 10^{-12}-$10^{-9}m^2s^{-1}$), since it will be these groundwaters that will come in contact eventually with the engineered barrier materials following repository closure. As noted above, these fracture zones, since they represent variations in transmissivity, orientation and also represent different geographical locations, may also be characterised by different hydrochemical signatures. These signatures may be the result of one or any combination of the following processes occurring within and close to the fracture zones:

- water/rock interaction during long residence times,
- mixing of palaeowaters from past marine stages,
- mixing of palaeowaters from past glacial periods,
- mixing of modern groundwater components, and
- evolution of groundwater chemistry by out-diffusion of pore fluids from the rock matrix into fracture zones, or *vice versa*, in-diffusion of fracture waters to the matrix.

These are important points to be addressed, and to deal with them adequately a reliable hydraulic and hydrochemical database is required. To build up such a database of fracture groundwater chemistry, related to hydraulic conductivity and at equivalent depths to the matrix fluid experiment, three sets of suitable data **(Fig. 5-1)** have been used:

- data from fractures present in the near-vicinity of the matrix fluid chemistry experiment borehole, i.e. from the 'J' niche as part of the on-going CHEMLAB and Microbe experiments,
- data from the TRUE Block Scale Experiment programme, and
- data from the deposition holes (and their surroundings) resulting from the Prototype Repository Experiment.

It is hoped that the evaluation of these data might provide some link between hydraulic transmissivity and groundwater chemistry which hitherto has not been addressed quantitatively in the Äspö programme mainly because of the difficulty in measuring low transmissivities and also the time-consuming nature of sampling from such hydraulic features. This Matrix Fluid Experiment provides the opportunity to progress a little further.

5.2 Hydraulic parameters

5.2.1 General

The detail of available hydraulic data from sampled fracture zones varies depending on the main objectives of the respective experiments. Quantitative data are available from the TRUE Block Scale and Prototype experiments, whilst data from the CHEMLAB and Microbe experiments from the 'J' niche are only qualitative at best **(Fig. 5-1)**.

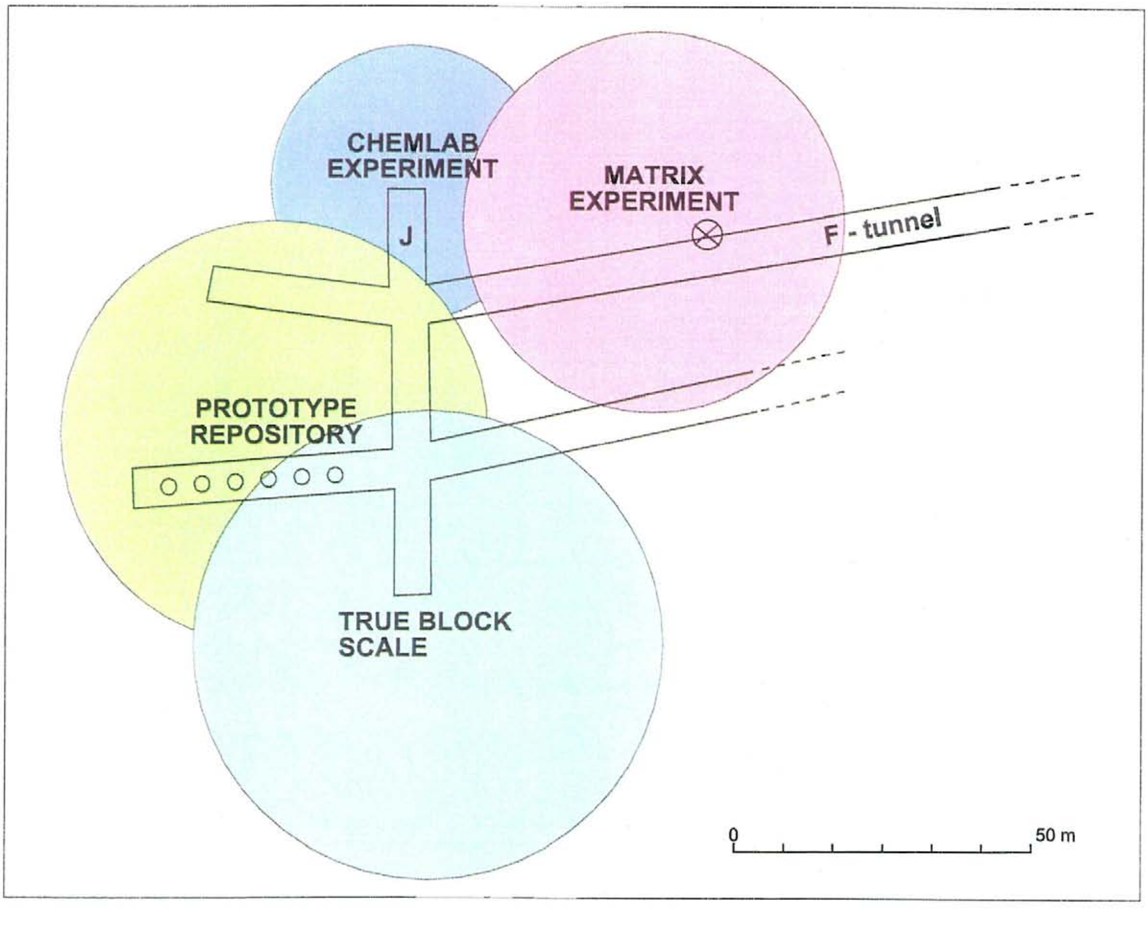


Figure 5-1. *The three areas of available hydraulic and hydrochemical data in the near-vicinity of the Matrix Fluid Experimental borehole.*

5.2.2 Available data

The hydraulic data from the TRUE Block Scale experiment is well documented in Olsson et al. (1994) and Hermanson and Doe (2000) where the measured hydraulic transmissivities of the sampled fractures **(Table 5-1)** range from 10^{-8}-10^{-5} m^2s^{-1}.

Table 5-1. Hydraulic parameters of hydrochemically characterised fractures from the TRUE Block Scale Experiment.

Borehole	Section (m)	T'missivity (m^{2}s^{-1})	T'missivity (m^{2}s^{-1})	Structure
KA2511A	52-54	4E-5[*]	-	#?
	92-109	>3E-5[*]	-	#6
KA2563A	187-190	-	8.7E-7[¤]	#20
KI0023B	41.45-42.45	1.8E-5[+]	4E-5[¤]	#7
	70.95-71.95	8.1E-7[+]	-	#21
	84.75-86.20	5.8E-8[+]	3.2E-7[¤]	#13
KI0025F	86-88	5.1E-7[+]	8.5E-7[¤]	#20
	164-168	1.1E-5[+]	2.9E-5[¤]	#19(21?)

[*] from Fig. 3-16 (Olsson et al., 1994); [+] from flow and pressure build-up tests; [¤] from x-hole pump tests

Hydraulic data from the Prototype Experiment are documented in Rhén and Forsmark (1998a,b). In close collaboration with the Prototype experiment, several borehole sections were selected for quantitative hydrochemical characterisation (Class 5 protocol). The choice of boreholes, with emphasis on intersecting low-conductive fractures, was based on:

- geological homogeneity
- structural simplicity
- structural isolation from the excavated tunnel floor and walls
- low transmissive values
- estimated low water flow rates
- measured low water flow rates

The hydraulic characteristics of the chosen borehole sections are presented in **Table 5-2.**

No quantitative hydraulic data are available from the 'J' niche but measured groundwater flow rates (0.6-4.0 mL/min) from packed-off intervals in boreholes KJ0044FO1, KJ0050F01, KJ0052F01, KJ0052F02, KJ0052F03 (Microbe Experiment) would suggest transmissivities in the range of 10^{-8}-10^{-7} m^{2}s^{-1}.

Table 5-2. Hydraulic parameters of selected borehole sections from the Prototype Experiment.

Borehole	Section (m)	T'missivity (m^2s^{-1})	Estimated Flow (L/min)	Measured Flow (L/min)	Time Exchange (Days)	
KA3566G01	12.3-19.8	1.00E-7	0.13	0.3	0.08	
	20.8-30.0	1.00E-8	0.02	0.023	1.27	*
KA3566G02	1.3-6.8	5.00E-10	0.0015	0.003	5.85	*
	7.8-11.3	1.00E-9	0.006	0.0005	23.4	*
	12.3-18.3	1.00E-7	0.12	0.4	0.05	*
	19.3-30.0	5.00E-9	0.04	0.033	1.03	*
KA3572G01	1.3-5.3	1.0E-9	0.0015	0.001	13.31	*
KA3578G01			0.00005	0.0005	14.40	
KA3590G02	8.3-16.3	1.00E-8	0.032	0.16	0.16	
	17.3-22.3	5.00E-9	0.037	0.25	0.06	*
KA3593G	1.3-7.3	3.00E-8	0.2	0.074	0.27	

* Samples subsequently chosen for Class 5 hydrochemical characterisation.

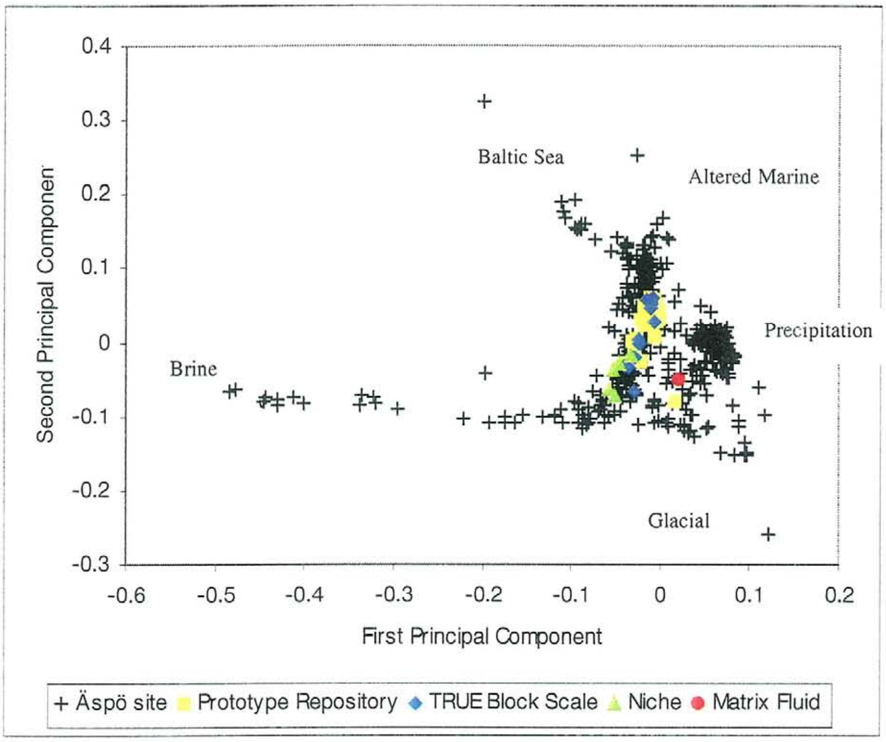
5.3 Hydrochemistry

5.3.1 General

To facilitate comparison of the various data sets, most of the hydrochemical data presented below for discussion have been of Class 5 standard and quality assured (e.g. Andersson and Säfvestad, 1999, 2000). Averaged analytical data from the TRUE Block Scale, Prototype and 'J' niche experiments, compared to the Matrix data, are reproduced in **Table 5-3** (see Chapter 2, Table 2-3). The full Matrix Fluid analysis is presented in **Appendix 2**.

5.3.2 Evaluation and discussion

The general chemical character of the groundwaters from each of the sampled sites can be seen from the PCA plot in **Figure 5-2**. The exact location of the 'matrix' sample is uncertain as all the chemical and isotopic parameters are not known due to the small volume of water obtained. Priorities had to be set, and this excluded tritium isotope determinations; furthermore the alkalinity value is uncertain because of microbial influences during titration and the carbon-14 values are not reported as the sample was inadvertently contaminated. Nevertheless, substituting some groundwater chemical values from the 'J' niche borehole KJ0052F03 (section 9.23-9.43 m), located near the matrix experimental site and potentially a source for some of the 'matrix' water collected, a good approximate location has been plotted.



First Principal Componet = - 0.49[Na] - 0.03[K] - 0.01[Ca] - 0.03[Mg] + 0.13[HCO_3] + 0.24[Cl] + 0.16[SO_4] - 0.17[^2H] + 0.75[^{18}O] + 0.25[^3H]
Second Principal Component = - 0.25[Na] + 0.35[K] + 0.04[Ca] + 0.45[Mg] + 0.31[HCO_3] - 0.69[Cl] - 0.18[SO_4] - 0.09[^2H] + 0.06[^{18}O] - 0.003[^3H]

Variance:
Comp. 1 = 40%
Comp. 1+2 = 70%

Matrix Fluid sample, chemical composition:
Na = 2200; K = 11.4; Ca = 964; Mg = 7.76; HCO_3 = 185; Cl = 5180; SO4 = 26;
^2H = -87.9; ^{18}O = -11.6; ^3H = 0

Note: Matrix Fluid sample; HCO_3=185 mg/L mean value (HCO_3 ranges 170-200 mg/L) and ^3H= 0

Figure 5-2. *PCA plot showing distribution of groundwaters from the TRUE Block Scale, Prototype Repository and 'J' niche experimental sites. These data are related to the overall Äspö database and to the approximate position of the 'Matrix Fluid' sample.*

Table 5-3. Average values for TRUE Block Scale, Prototype and 'J' Niche (Chemlab/Microbe) experiments, compared to the Matrix data and Prototype sample KA3572G01.

Element	TRUE Block [n=8] (mg/L)	Prototype [n=7] (mg/L)	KA3572G01 [n=1] (mg/L)	'J' Niche [n=5] (mg/L)	Matrix [n=1] (mg/L)
Na	1 983	1 887	2 340	2 286	2 200
K	7.9	9.1	10.3	9.11	11.4
Mg	42.4	86.4	24.8	54.1	7.8
Ca	1 396	770	800	1 996	964
Fe	0.09	0.34	-	0.90	0.24
Si	5.7	7.9	5.4	5.7	7.6
F	1.2	1.3	1.2	-	-
Cl	5 675	4 210	4 810	6 944	5 160
Br	30.7	19.9	27.2	39.3	43.16
SO_4	363	308	617	447	26
Alkalinity	19	155	-	40	approx. 170-200
pH	8.0	7.3	7.4	7.4	6.7
	µg/L	µg/L	µg/L	µg/L	µg/L
Li	860	360	435	920	274
Sc	<0.01	0.020	0.024	0.540	0.099
Mn	280	510	-	410	890
Rb	28	30	35	29	31
Sr	19 900	10 780	15 700	33 780	18 600
Y	0.145	0.130	0.118	0.331	0.198
Cs	2.37	2.29	1.43	3.63	0.685
Ba	60.3	52.3	59.3	69.4	425
La	0.13	0.05	0.15	0.17	1.29
Ce	0.29	0.14	0.07	0.19	0.86
Nd	0.03	0.02	0.02	0.06	0.38
Th	<0.005	<0.005	<0.005	<0.004	<0.4
U	0.006	0.030	0.018	0.030	0.103
^{3}H	4.4	8.4	4.7	2.9	-
$\delta^{18}O$	-9.6	-8.0	-10.1	-10.6	-11.6
δD	-75.9	-66.7	-80.9	-79.6	-87.9
^{14}C	60	70	-	-	-
$\delta^{37}Cl$	+0.03	-0.28 to +0.16	+0.27	+0.34	+0.61, +0.59
$\delta^{11}B$	47.23	45.97	51.87	-	-
^{34}S	25.3	25.6	-	-	-
$^{87}Sr/^{86}Sr$	-	0.717563	0.714990	-	0.714561

^{3}H (TU); $\delta^{18}O$ (‰ SMOW); δD (‰ SMOW); ^{14}C (pmc); $\delta^{37}Cl$ (‰ SMOC); $\delta^{11}B$ (‰ CDT); ^{34}S (‰ CDT)

Figure 5-2 shows a clear separation of the 'J' niche and Prototype Repository samples with the TRUE Block Scale samples extending over the full range of both groupings; the 'Matrix' sample and that of KA3572G01 (Prototype Experiment) are clearly different. The distribution of the plotted data is controlled by variation of the saline, glacial and Baltic Sea components; the greater the Baltic component, the less the glacial (and saline) component. This may be due to the hydraulic drawdown initiated by the tunnel excavation, whereupon modern Baltic Sea and meteoric precipitation components are introduced at these depths and may have diluted or displaced the older glacial and saline components.

A modern Baltic Sea water component is supported by the moderate tritium values (7-11 TU) and higher Mg in the Prototype Repository groundwaters, which contrasts with lower Mg and tritium (1.0-4.4 TU) and more negative ^{18}O values and higher Cl content (greater glacial and saline components?) in the 'J' niche groundwaters **(Table 5-3).** The TRUE Block Scale waters show broadly similar hydrochemical trends to the 'J' niche samples with an even lower Mg content. These features would suggest that the 'J' niche waters and the TRUE Block Scale waters are less influenced by the tunnel construction than the Prototype Repository samples, even though the sampling locations for the Prototype groundwaters represent a lower range of transmissivity. This may be explained partly by the fact that most of the Prototype sampling points are close to the excavated tunnel (1-30 m; **Table 5-2**), whilst the TRUE sample locations (40-190 m; **Table 5-1**) and to a lesser extent the 'J' niche locations (9-44 m) are further into the surrounding bedrock where drawdown effects (leading to contamination by modern waters) may be less pronounced.

In this context it is interesting to note that one of the Prototype samples (KA3572G01) appears to be less influenced by drawdown effects. It is characterised by a greater glacial water component and a reduced Baltic Sea component (lower Mg) than the others. Comparison of the chemistry **(Table 5-3)** shows this sample to be quite similar to the 'J' niche and TRUE data with respect to deuterium [-80.9‰ (-79.6‰)], ^{18}O [-10.1‰(-10.6‰)] and SO_4 [617 mg/L (447 mg/L)] (average 'J' niche values in brackets). Furthermore, it differs from the rest of the Prototype samples by, for example, a more positive ^{37}Cl value, lower $^{87}Sr/^{86}Sr$ ratio, higher Na, Sr, SO_4, Cl, Br and ^{11}B, and lower Mn.

The matrix sample, as mentioned earlier (Section 2-6), when compared with the other data, is characterised by lower pH, Mg and SO_4, more negative stable isotope signatures, lower Sr-isotope ratio, higher ^{37}Cl and generally higher trace element contents with the exception of Li and Cs. The low pH and SO_4 may be a result of microbial activity. Microbe studies (K. Pedersen, written comm., 2000) revealed 900 000 cells per mL (i.e. typical for shallow Äspö groundwaters) of which 110 were sulphate-reducing bacteria and 35 were iron-reducing types.

5.4 Conclusions

To date the general conclusion from these studies is that over the range of hydraulic conductivity represented by the sampled fractures, most show little obvious correlation with groundwater chemistry. The data indicate an influx of a modern groundwater component, such as Baltic Sea and meteoric precipitation waters, associated with the hydraulic drawdown caused by tunnel construction, to the detriment of older saline and glacial melt water components which have been diluted or removed. This has been particularly apparent with the Prototype samples, despite the generally low transmissive character of the sampling locations, probably due to their near-vicinity to the excavated tunnel opening. Nevertheless there are indications that at least one of the lower transmissive fractures (KA3572G01; 10^{-9} m^2s^{-1}) has been less influenced by the drawdown due to a longer response time, retaining a lower Mg content and more negative ^{18}O signature, together with an overall higher TDS content. This may reflect a different fracture orientation than the other sampled fractures.

Drawdown effects are less evident from the 'J' niche and TRUE Block Scale sites probably due to the sampling locations being further from the excavated tunnel opening. It would appear therefore that to achieve a more sensitive correlation between hydraulic properties and groundwater chemistry, smaller ranges of hydraulic transmissivity (e.g. 10^{-12}-10^{-10} m^2s^{-1}) need to be investigated at greater distances away from these open tunnel conditions.

The 'matrix' sample, whilst reflecting a generally similar major ion character to nearby fracture compositions (with the exception of SO_4 and Mg), exhibits anomalous chlorine isotope and strontium isotope signatures and higher contents of most trace elements which may be more characteristic of a 'true' matrix component. Interestingly, the anomalously low $^{87}Sr/^{86}Sr$ ratio (0.714561) is similar to the Prototype sample KA3572G01 (0.714990); both $^{87}Sr/^{86}Sr$ ratios are significantly lower than all other measured groundwaters at Äspö. Furthermore, these two samples record the lowest Mg values (7.8 vs 24.8 mg/L) which may further support that so far they have been least affected by the drawdown Baltic Sea component which figures strongly in the other samples. This would certainly be expected from the matrix sample. Finally, a more negative oxygen-18 value (-11.6 ‰) for the matrix sample, similar to the average for the 'J' niche samples (-10.6 ‰), which are characterised by low tritium contents (i.e. very little modern Baltic sea or meteoric water component), would also support that an older glacial water component has been present in the matrix prior to tunnel construction.

It is hoped that the sampling from borehole Section 2 scheduled for later later this year will shed more light on the matrix fluid chemistry and its origin.

6 Future activities and milestones

The following activities planned for the immediate future will include:

- continuation of drillcore crush/leach experiments with specific emphasis on lithological variation and porosity profiles,
- continuation of the permeability test,
- continuation of fluid inclusion mineralogical/petrographical charaterisation and chemistry,
- expand coverage of drillcore porosity measurements (some integrated with the crush/leach experiments) to achieve a better idea of large-scale heterogeneity or homogeneity in the matrix block, and also to further characterise the Ävrö granite rock type,
- detailed study of 1-2 micro-fractures/fissures with respect to in- or out-diffusion processes. This will include whole-rock measurements of the U-decay series, ^{37}Cl, ^{11}B, ^{86}Sr and ^{87}Sr along profiles perpendicular to the fracture intersection with the drillcore,
- simple leaching of drillcore material using distilled water,
- scoping study to locate further examples of low transmissive features already characterised to increase the hydrogeological/hydrochemical database, and
- eventual sampling of borehole Section 2 (and possibly a second sampling of Section 4) when indications show that enough water has accumulated.

The Matrix Fluid Experiment, as presently planned, is scheduled to be reported by December 31, 2001. Before then, the following milestones are envisaged:

- International Technical Documents to be completed by February 28th, 2001
    - Borehole KF0051A01: Selection of Sampling Locality: Drilling and Characterisation
    - Borehole KF0051A01: Installation of Equipment and Presampling Protocol
    - Borehole KF0051A01: Mineralogical, Geochemical and Petrophysical Studies
    - of Drillcore Material
    - Characterisation of Fluid Inclusions
    - Crush/Leaching Experiments
    - Low-conducting Fractures at Depth 415-450 m: Hydraulic and Hydrochemical Database.

- Matrix Fluid Workshop (September 25/26, SKB, Stockholm)
- Minutes from Final Matrix Fluid Workshop (October, 31st, 2000)
- International Technical Documents:
    - Analysis of Fluid Inclusions (April, 30th, 2001)
    - Permeability Test (Summer 2001)
- Opening and sampling from Sections 2 and 4 of the Matrix Borehole (Autumn, 2001)
- International Technical Document on Matrix Fluid Chemistry (December 31st, 2001)
- Final Report: Synthesis and Summary of the Project Results (March, 2002)

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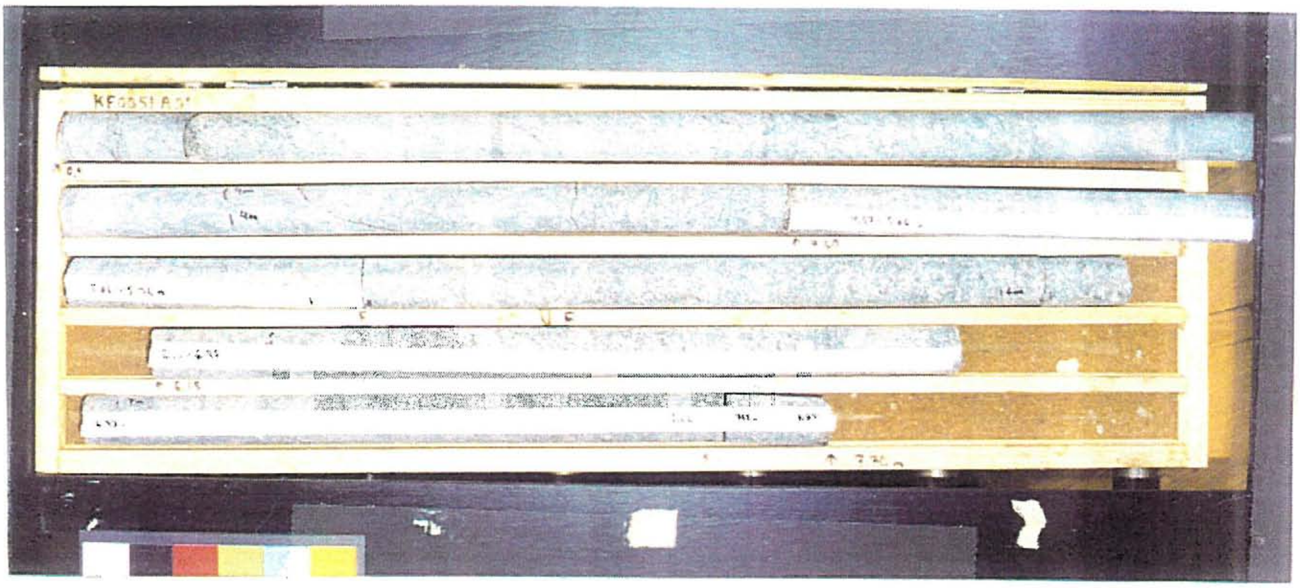
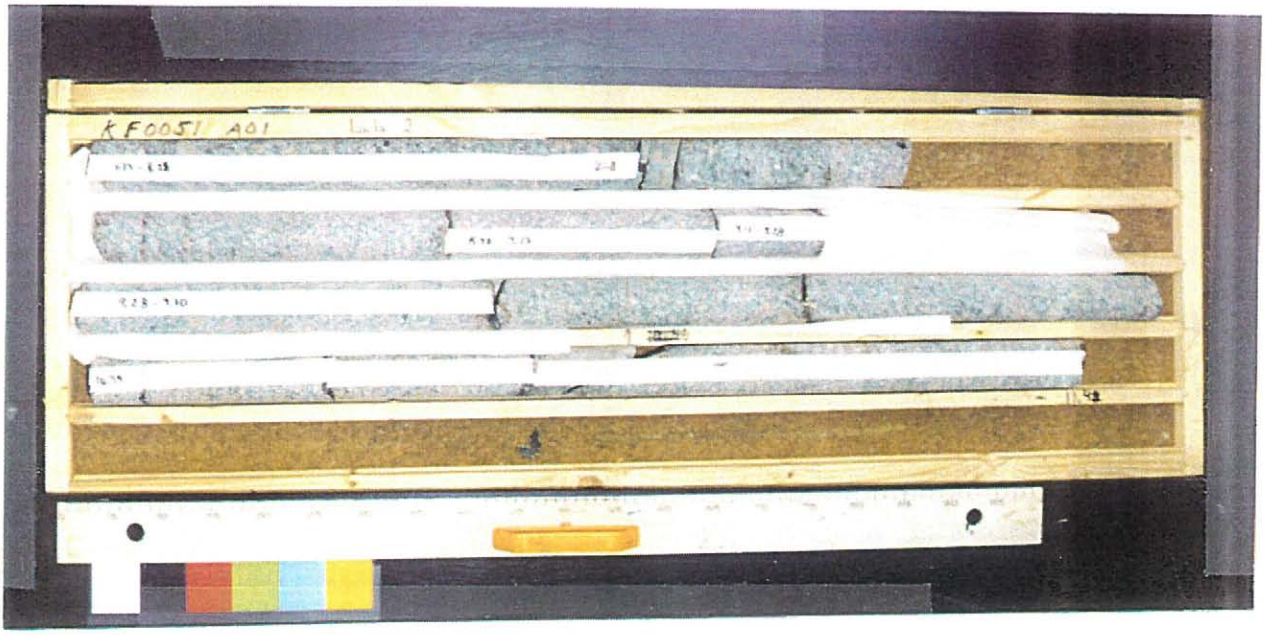
Appendix 1

Borehole KF0051A01: Extracted drillcore, geological logging of drillcore and downhole TV-imaging analysis


KF0051 A01


KF0051 A01
Låda 2

Title

Site	ÄSPÖ	Coordinate System	Local
Borehole	KF0051A01	Northing	7298.89
Diameter	76 mm	Easting	2012.60
Length	11.43 m	Elevation	-451.38
Bearing	310.3 °	Completion Date	1998-05-27
Inclination	29.9 °	Mapping Date	1998-06-12

Remark

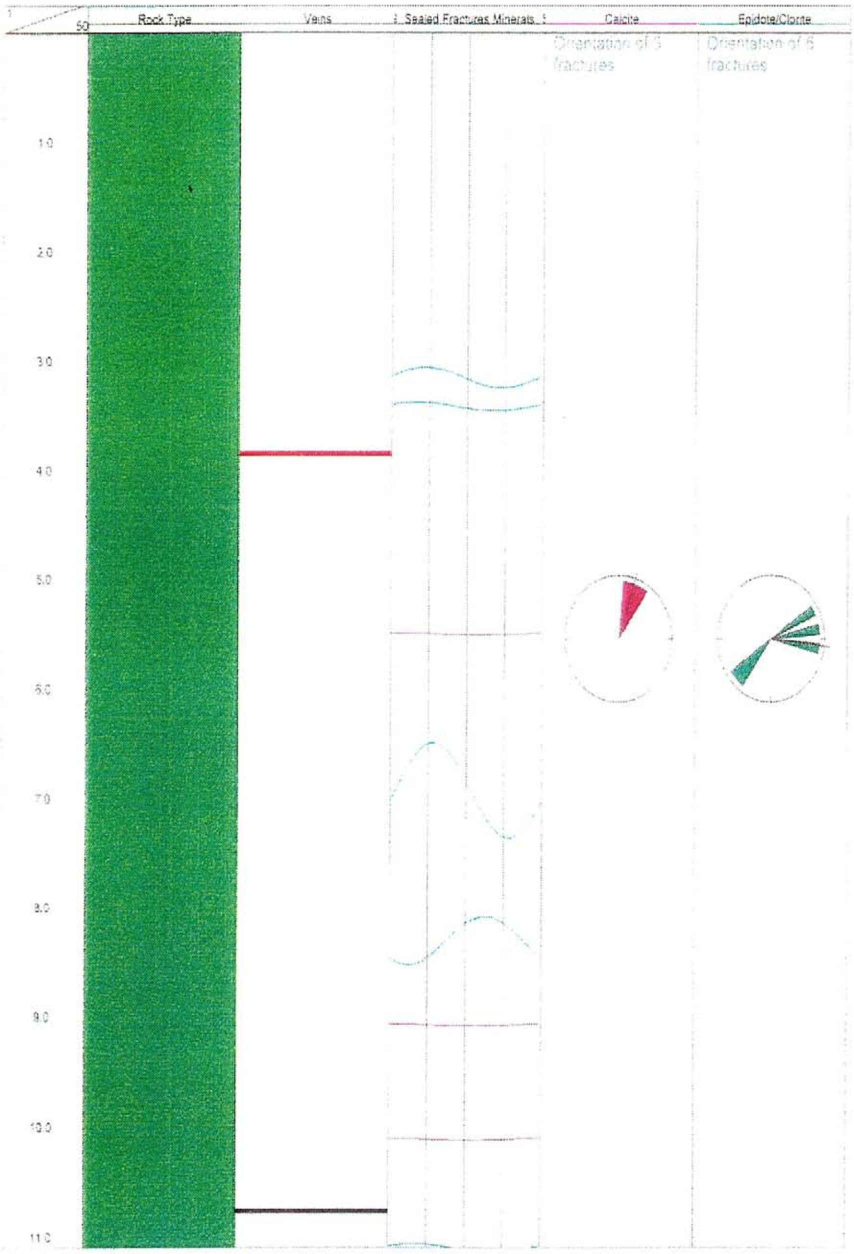


Figure 1. Geology standard-plot of borehole KF0051A01 in scale 1:50.

Appendix 2

Borehole KF0051A01: Chemistry of the ‘matrix’ groundwater

Element	**Matrix (mg/L)**
Na	2 200
K	11.4
Mg	7.8
Ca	964
Fe	0.24
Si	7.6
F	-
Cl	5 160
Br	43.16
SO_4	26
Akalinity	approx. 170-200
pH	6.7

	µg/L
Li	274
B	1110
Al	27.7
P	<100
S	3 240
Sc	0.099
V	1.08
Cr	7.27
Mn	890
Co	0.207
Ni	1.46
Cu	<2.0
Zn	<4.0
As	2.75
Rb	31
Sr	18 600
Y	0.198
Mo	0.256
Cd	<0.10
In	<0.02
I	377
Cs	0.685
Ba	425
La	1.29
Ce	0.86
Pr	0.067
Nd	0.38
Sm	<0.02
Eu	<0.02
Gd	<0.02
Tb	<0.02
Dy	<0.02
Ho	<0.02
Er	<0.02
Tm	<0.02

Yb	<0.02
Tl	<0.02
Th	<0.4
U	0.103
^{3}H	-
$\delta^{18}O$	-11.6
δD	-87.9
^{14}C	-
$\delta^{37}Cl$	+0.61, +0.59
$\delta^{11}B$	-
^{34}S	-
$^{87}Sr/^{86}Sr$	0.714561

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^{3}H (TU); $\delta^{18}O$ (‰ SMOW); δD (‰ SMOW); ^{14}C (pmc); $\delta^{37}Cl$ (‰ SMOW); $\delta^{11}B$ (‰ CDT); ^{34}S (‰ EN-1)

Appendix 3

Drillcore crush/leach experiment: Leachate analysis and preliminary modelling of data

(Nick Waber, University of Bern)

SAMPLE DESCRIPTION

Borehole	***KF0051 A01***	***KF0051 A01***	***KF0051 A01***	***KF0051 A01***	***KF0051 A01***	***KF0051 A01***	***KF0051 A01***	***KF0051 A01***	***KF0051 A01***
Type of sample	Aqueous Extract	Aqueous Extract	Aqueous Extract	Aqueous Extract	Aqueous Extract	Aqueous Extract	Aqueous Extract	Aqueous Extract	Aqueous Extract
Sample designation	A-KF a	A-KF a	A-KF b	A-KF 1st leach	A-KF 2nd leach	A-KF 3rd leach	A-KF 1st leach	A-KF 2nd leach	A-KF 3rd leach
Depth	3.60-3.77	3.60-3.77	3.60-3.77	3.25-3.60	3.25-3.60	3.25-3.60	3.25-3.60	3.25-3.60	3.25-3.60
Date collected									
Lab Extract	UniBe	UniBe	UniBe	UniWaterloo	UniWaterloo	UniWaterloo	UniWaterloo	UniWaterloo	UniWaterloo
Lab Chemistry	SGAB	UniBe	UniBe	SGAB	SGAB	SGAB	SGAB	SGAB	SGAB
Water /Rock Ratio	1:1	1:1	1:1	1:1.47228	1:1.443068	1:1.41603	1:1.47228	1:1.443068	1:1.41603
Comments				W/R uncorrected	W/R uncorrected	W/R uncorrected	W/R corrected 1:1	W/R corrected 1:1	W/R corrected 1:1

MISCELLANEOUS PROPERTIES

pH (lab)	9.99	9.99	9.95						
Electrical Conductivity (lab)									
m-Value (SK 4,3) mmol/l	1.7	1.7	1.7						
Pt Elec Potential vs SHE (field)									
Sample Temperature									
Density									

DISSOLVED CONSTITUENTS	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/kg**	**mg/kg**	**mg/kg**
CATIONS									
Lithium (Li+)	0.031			0.042	0.021	0.017	0.029	0.015	0.012
Sodium (Na+)	66	66.7	66.7	69	42	23	46.9	29.4	16.2
Potassium (K+)	42	46.9	39.1	47	24	22	31.9	16.8	15.5
Rubidium (Rb+)	0.088			0.11	0.027	0.024	0.075	0.019	0.017
Cesium (Cs+)	0.0093			0.061	0.0022	0.0043	0.0414	0.0015	0.0030
Ammonium (NH4+)	0								

Magnesium (Mg+2)	7.5	8.5	4.9	13	1.2	1.84	8.8	0.8	1.3
Calcium (Ca+2)	3.8	2.44	1.36	7.3	3.4	4.7	5.0	2.4	3.3
Strontium (Sr+2)	0.081	0.12	0.09	0.13	0.045	0.048	0.088	0.031	0.034
Barium (Ba+2)	0.12			0.21	0.078	0.038	0.143	0.055	0.027
Nickel (Ni+2)	0.013			0.041	0.0021	0.0028	0.0278	0.0015	0.0020
Cobalt (Co+2)	0.039			0.01	0.00048	0.00069	0.00679	0.00034	0.00049
Copper (Cu+2)	0.005			0.015	0.012	0.0025	0.0102	0.0084	0.0018
Chromium (Cr+6)	0.014			0.021	0.0012	0.0016	0.0143	0.0008	0.0011
Zinc (Zn+2)	0.055			0.11	0.014	0.012	0.075	0.010	0.008
Lead (Pb+2)	0.005			0.013	0.0009	0.002	0.0088	0.0006	0.0014
Cadmium (Cd)				0.00011	0.00005	0.00004	0.00007	0.00003	0.00003
Manganese (Mn tot)	0.35			0.63	0.028	0.042	0.428	0.020	0.030
Iron (Fetot)	15			24	0.92	1.6	16.30	0.64	1.13
Arsenic (As tot)	0.0017			0.0026	0.0045	0.00087	0.0018	0.0031	0.0006
Selenium (Se tot)	0.002			0.0006	0.007	0.00041	0.0004	0.0049	0.0003
Titanium (Ti tot)	0.81			1.1	0.054	0.061	0.747	0.038	0.043
Aluminium (Al tot)	11			18	1	2.1	12.2	0.7	1.5
Uranium (U tot)	0.0015			0.0043	0.0078	0.0051	0.0029	0.0055	0.0036
ANIONS									
Fluoride (F-)		5.9	5.7						
Chloride (Cl-)		33.8	35.4	31.8	20.5	9.7	21.6	14.3	0.0
Bromide (Br-)	0.36	0.28	0.28	0.3	0.48	0.077	0.204	0.336	0.054
Iodide (I-)	0.0014			0.0032	0.03	0.0069	0.0022	0.0210	0.0049
Sulfate (SO4-2)	47.9	47.9	50.1	22.2	12.9	5.4	5.0	3.0	1.3
Phosphate (P)	0.28			0.42	0.44	0.044	0.285	0.308	0.031
Nitrite (NO2-)									
Nitrate (NO3-)									
Alkalinity (HCO3-)	103.7	103.7	103.7						

NEUTRAL SPECIES									
Tot. Sulphide (H2S,HS-,S2-)									
Silica (Si)	24			27	5.6	7.5	18.3	3.9	5.3
Boron (B)	0.12			0.1	0.058	0.033	0.068	0.041	0.023
Total Organic C (TOC)									
Total Inorganic C (TIC)									
CHARGE BALANCE									
Difference / Sum %	18.33	11.3	4.03						
IONIC STRENGTH	4.697E-03	5.418E-03	5.146E-03						
SAMPLE DATA									
Borehole, Test Number									
Nagra Data Base Number									
Type of sample									
Date Sampled									
CARBONATE SYSTEM MEASURED VALUES									
pH	9.99	9.99	9.95						
Alkalinity	1.700E-03	1.700E-03	1.700E-03						
MODELLED USING MEASURED pH									
Total Dissolved CO_2	1.174E-03	1.173E-03	1.213E-03						
SI (CALCITE)	0.62	0.41	0.16						
log P(CO_2)	-5.37	-5.38	-5.30						

MODELLED USING pH ADJUSTED FOR CALCITE SATURATION

pH	8.96	9.23	9.60
Total Dissolved CO_2	1.607E-03	1.573E-03	1.401E-03
log $P(CO_2)$	-4.02	-4.33	-4.79

MINERAL SATURATION INDICES

CALCITE	0.00	0.00	0.00
DOLOMITE_ORD	0.59	0.84	0.87
MAGNESITE	0.01	0.26	0.29
FLUORITE	-0.62	-0.85	1.16
ANHYDRITE	-3.77	-3.53	-3.79
GYPSUM	-3.53	-3.29	-3.55
STRONTIANITE	-1.18	-0.80	-0.65
WITHERITE	-1.91		
CELESTITE	-3.48	-2.87	-2.98
BARITE	-0.09		
CHALCEDONY	0.16		
QUARTZ	0.60		

Appendix 4

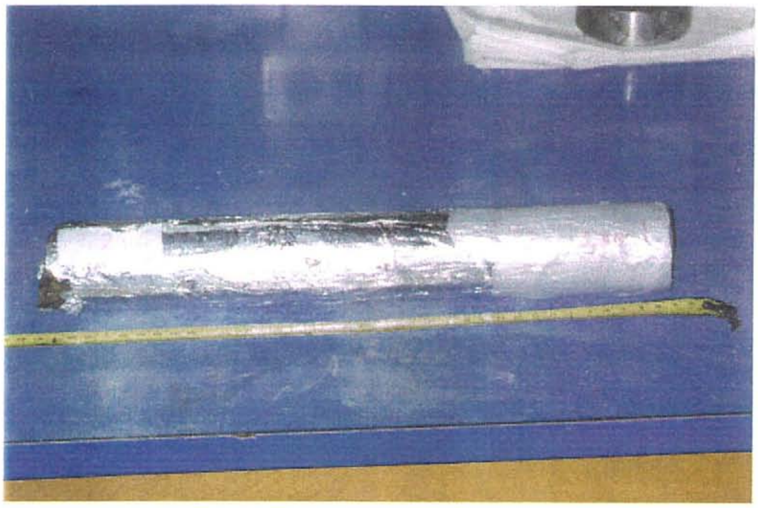
Permeability Test: Experimental set-up and explanation as presented at the September 1999 Matrix Fluid Experiment Workshop

(Doug Hirst, University of Waterloo)

Äspö Rock Matrix Experiment

Experimental Procedure for Permeability Test

1) Sample was received waxed and covered with tin foil. The wax was removed using a heat gun at low setting (to avoid thermal damage to core).



2) Sample was visually inspected for fractures or cracks.
3) Sample from the interval 3.38-3.475 m was cut on a rock saw and the ends were ground parallel to within 1 mm of each other.
4) Sample measurements were recorded and calculated:

Sample Height (mm)	100
Sample Width (mm)	50
Sample Mass (g)	565.81
Sample Volume (cc)	193.344
Sample Density (g/cc)	2.93

5) Sample was inserted into a moisture proof membrane that was located on the lower platen of the triaxial cell.
6) Filter paper was placed on top and bottom of platen.
7) The upper playen was then placed on top of the sample and stainless steel hose clamps were tightened around the membrane so they made contact with the o-rings to ensure a competent seal.

8) A pore pressure supply line was attached to the upper platen and a syringe was attached to the bottom platen.
9) A seating stress of 0.5 Mpa was applied to the top platen.
10) A corresponding stress of 0.5 Mpa was applied in the confining port of the cell.
11) This procedure was repeated until the pre-determined hydrostatic stress of 11.7 Mpa was achieved. The sample was then allowed to equilibrate.
12) Pressures remained stable and no axial displacement was detected so a small pore pressure was added to the sample.
13) A pore pressure of 6 Mpa was added to the sample using double distilled (Ultrapure) water.
14) To date no axial displacements have been measured and no fluid has entered the syringe.