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Diffusion in the matrix of granitic rock. Field test in the Stripa mine Part 1

Lars Birgersson
Ivars Neretnieks

Royal Institute of Technoloqy
Department of Chemical Engineering
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SUMMARY

A migration experiment in the rock matrix is presented. The experiment has been carried out in "undisturbed" rock, that is in rock under its natural stress environment. Since the experiment was performed at the 360 m-level (in the Stripa mine), the rock had nearly the same conditions as the rock surrounding a nuclear waste storage.

The results show that all three tracers (Uranine, Cr-EDTA and I^-) have passed the disturbed zone from the injection hole and migrated into "undisturbed" rock. At the distance of 11 cm from the injection hole 5-10 % of the injection concentration was found.

The results also indicate that the tracers have passed through fissure filling material.

These results indicates that it is possible for tracers (and therefore radionuclides) to migrate from a fissure, through fissure filling material, and into the undisturbed rock matrix.

1. BACKGROUND

The figure below illustrates our present concept of the microstructure of granite (1).

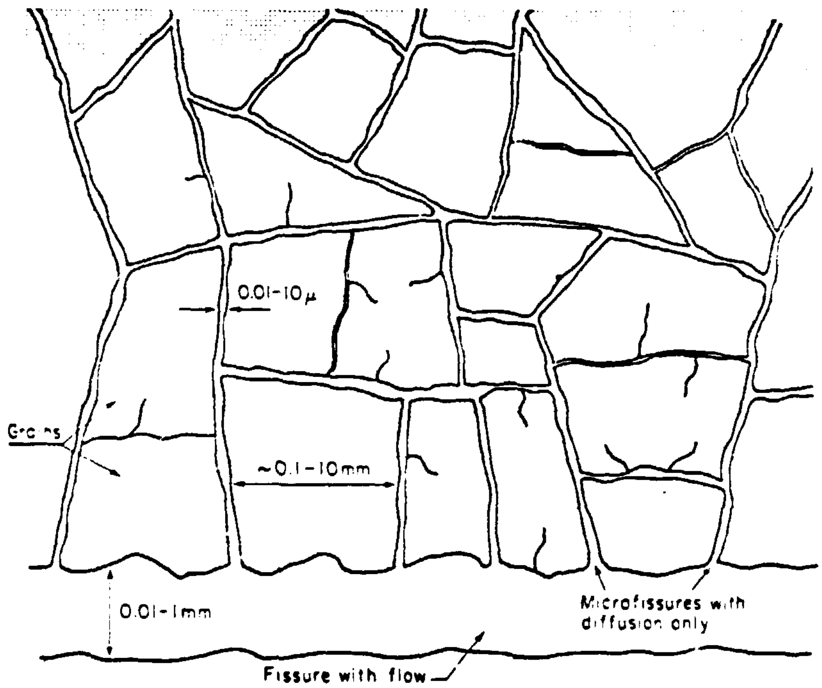


Figure 1. A twodimensional view of the microstructure in granite showing "typical" sizes of grains, microfissures and fissures.

The granite is intersected by a number of fissures where water flows. In the rock matrix, there exists a connected pore system (micro fissure system) where molecules can move by diffusion. Between the fissures and the rock matrix there exists a thin layer of fissure filling material (fissure coating material), which the molecules must pass through before they can penetrate the pore system in the rock matrix.

In the Swedish concept it is proposed that the nuclear waste shall be stored in canisters at approximately 500 m depth in the bedrock. The canisters may eventually degrade and the radio nuclides may then be transported in the fissures by the flowing water.

The radionuclides migrating with flowing water may be considerably retarded if they can diffuse into the rock and sorb on the surfaces of the micro fissures in the rock matrix (2).

The importance of matrix diffusion can be illustrated by diagram 1, where breakthrough curves for some radionuclides at a long distance from the waste storage are shown for surface reaction and surface reaction + matrix diffusion (3).

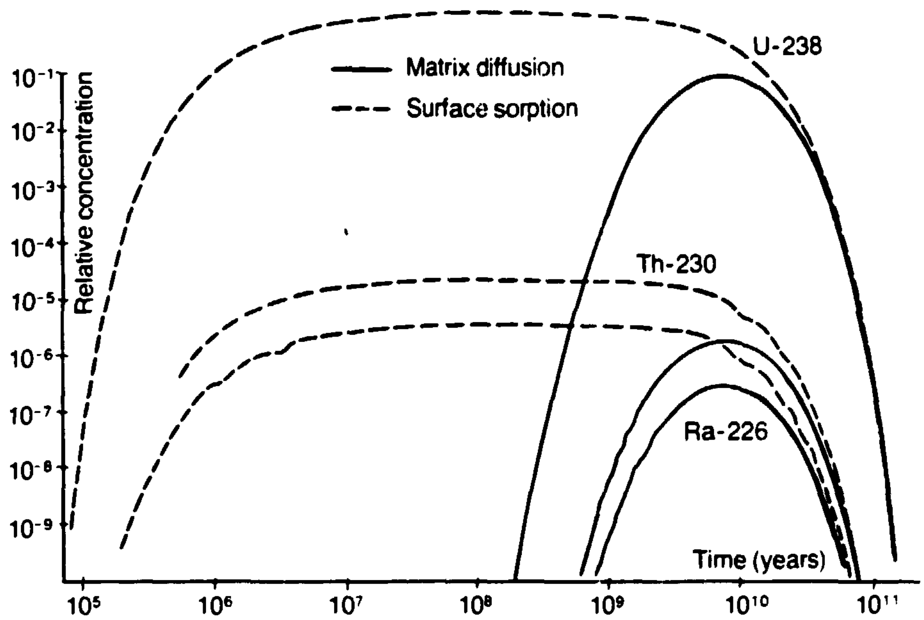


Diagram 1. The influence of matrix diffusion. $D_p \varepsilon_p = 10^{-12}\ m^2/s$

From diagram 1 and the discussion above it is obvious that diffusion into the rock matrix is a very important mechanism for radionuclide retardation. It is therefore important to ensure that this connected pore system really exists and can be utilized for diffusion.

At present there are a series of laboratory experiments being performed with the purpose to determine diffusion coefficients for various tracers in granite. These experiments show that it is possible for various kinds of tracers to migrate in the granite matrix by diffusion, but the experiments are not carried out in "undisturbed" rock. It cannot be ruled out that the reduction of the rock stresses which occur when samples are taken out have induced the micro fissures. It is thus necessary to make experiments in rock in the natural stress environment and before a first release of the stress as a recompression will not close irreversibly induced microfissures. It is also necessary to know if diffusion can occur through the fissure filling material, since the radionuclides must pass through it before they can penetrate into the rock matrix.

This experiment was performed in the Stripa mine at the 360 m-level. That will give nearly the same conditions (according to rock stresses and rock pressure) as for the planned nuclear waste storage.

2. INFLUENCE OF THE STRESS FIELD

Near drillholes and drifts, the rock stresses will be changed compared to "undisturbed" rock. A general rule in these cases is that the rock stresses are changed about 2 hole diameters out from and below the hole. That is, outside these 2 hole diameters essentially "undisturbed" rock exists (4).

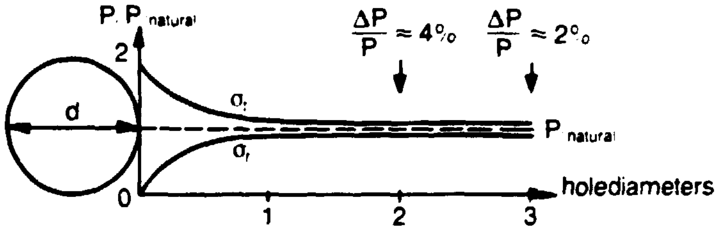


Figure 2. $\frac{\Delta P}{P}$ vs distance from a hole

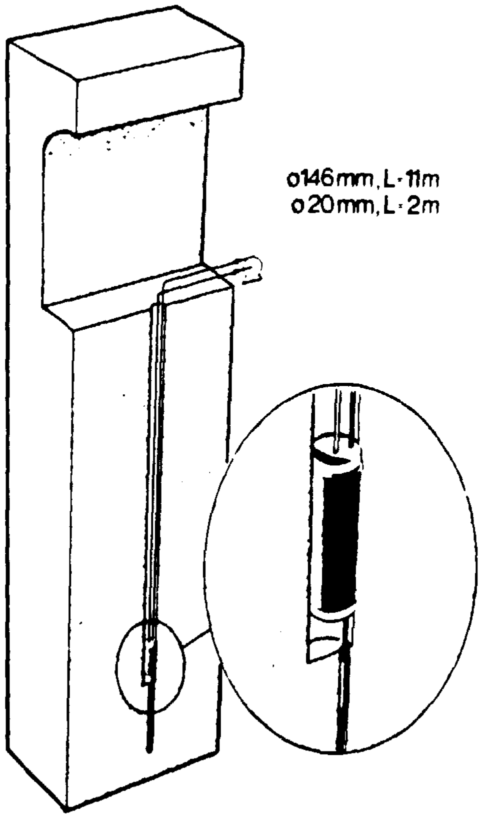


Figure 3. Drilling dimensions and packer positions

Since the diameter of the drift where the experiment has taken place was approximately 5.5 m, a 11 m deep 146 mm hole was drilled. At this distance (11 m) from the drift the changes in rock stresses due to the drift can be neglected, *i.e.* essentially "undisturbed" rock is reached. However, the existence of the 146 mm hole will cause a further change in the rock stresses approximately 0.3 m (2 hole diameters) outward and below.

Thus, in the bottom of the 146 mm hole a 20 mm hole (approximately 2 m long) was drilled. This 20 mm hole will cause a change in the rock stresses approximately 4 cm outward, but outside this disturbed zone and 0.3 m below the larger hole essentially "undisturbed" rock is reached.

With the 146 mm packer positioned just above the little hole (see figure 3), the little hole will serve as injection hole in this experiment.

If tracers can migrate from the little hole (injection hole) past the disturbed zone and into "undisturbed" rock, this experiment will indicate the existence of a connected pore system in "undisturbed" rock.

3. EXPERIMENTAL ALTERNATIVES: DIFFUSION + FLOW AND DIFFUSION

3.1 Pressure gradients

The most satisfactory way of doing this kind of experiment is to do a diffusion experiment with no over pressure in the injection hole. But since the pressure gradients for the water (tracer solution) in the little hole and the water in the surrounding rock are different, pressure differences between the little hole and the surrounding rock will occur. And since a pressure difference is the driving force for flow in a permeable media, flow will occur simultaneously with diffusion (see figure 4 and appendix 1).

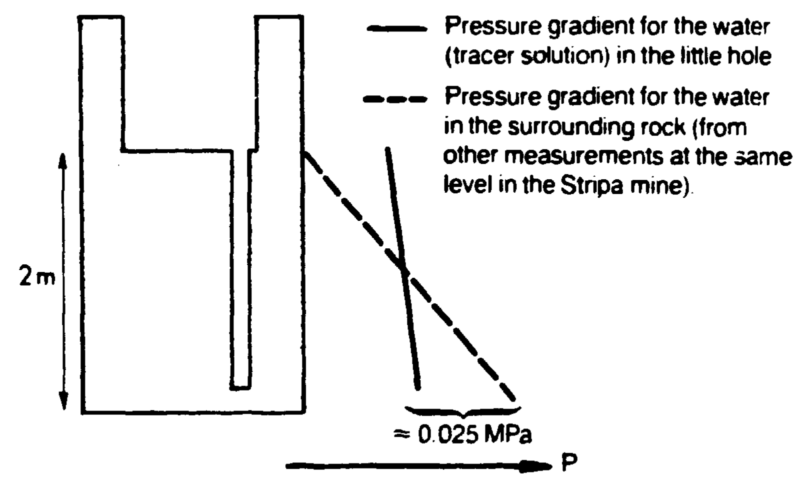


Figure 4. Pressure gradients for injection hole and surrounding rock

If the pressure gradients look like figure 4, it means that simultaneously with diffusion, flow will occur out from the little hole in the top and into the little hole in the bottom. Since there are no pressure difference in the middle of the hole, no flow will occur there.

The discussion above indicates that the diffusion profile from a diffusion experiment might be more or less displaced because of the flow.

Since the diffusion and flow may be of the same order of magnitude, it may not be possible to separate the radial concentration profile due to diffusion from that due to flow.

3.2 Diffusion. Expected travel distances.

The diffusivity of a species of low molecular weight $(M < 500)$ in water at ambient temperature is $D_v \approx 1\text{-}3 \cdot 10^{-9}\ m^2/s$. The diffusivity in the pore water in a porous body (D_p) is normally slower because of the geometrical factor δ_D/τ^2, where δ_D is the constrictivity and τ^2 the tortuosity. The relation between the diffusivities are $D_p = D_v \cdot \delta_D/\tau^2$. The ratio δ_D/τ^2 is expected to be somewhere in the interval 0.035 - 0.20, if the confining rock pressure is in the range 10 - 25 MPa (2), which is very likely at the depth where the experiment was carried out.

Expected values of D_p would then be from $0.3 \cdot 10^{-10}\ m^2/s$ to $6 \cdot 10^{-10}\ m^2/s$. In the following discussion D_p is assumed to be $10^{-10}\ m^2/s$.

The concentration, for radial diffusion from a cylindrical source, is a function of radius r and time t only. For a non-sorbing component the equation becomes:

$$\text{Diffusion equation:} \quad \frac{\partial c}{\partial t} = D_p \frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial c}{\partial r}\right) \qquad (1)$$

Solving this equation with the appropriate initial and boundary conditions gives the concentration as a function of r and t

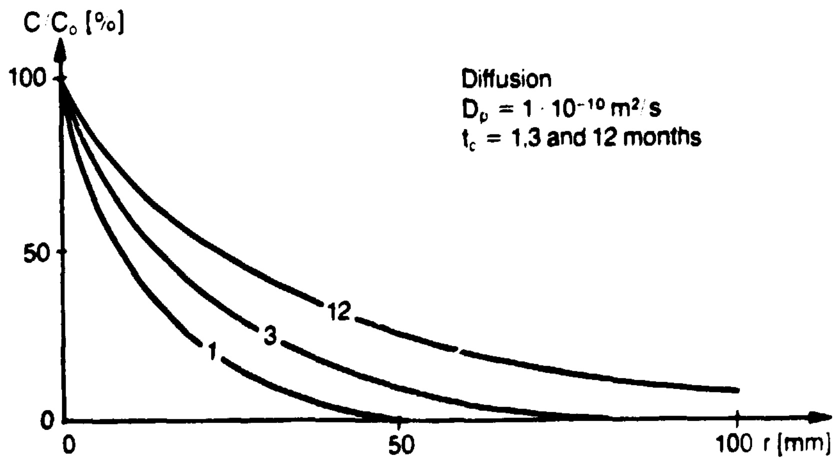


Diagram 2. DIFFUSION. c/c_o vs r, for various contact times

The dimensionless parameter that determines the shape of the curves is $D_p \cdot t_c / r_1^2$, where r_1 is the radius of the little hole (injection hole).

3.3 Flow. Expected travel distances.

In a permeable medium, flow will occur because of a pressure gradient. What significance this pressure gradient will have on the flow rate is mainly determined by the hydraulic conductivity (K_p) of the rock matrix. The equation that predicts the radial flow rate (v_r) and the radial flow distance (r_f) for a non-sorbing component is:

Radial flow equation: $$v_r = \frac{\text{const.}}{r} \qquad (2)$$

This equation can be solved to obtain the radius of a moving front at time t. Assuming that Darcy's law is valid, we obtain for stationary flow:

$$r_f = \sqrt{\frac{2 \cdot t \cdot K_p \cdot (P_1 - P_2)}{\varepsilon_p \cdot \ln r_2/r_1} + r_1^2} \qquad (3)$$

The parameters and their expected values are:

K_p - hydraulic conductivity for the rock matrix (unfractured rock), $10^{-13} - 10^{-12}$ m/s (5, 6, 7)

$P_1 - P_2$ - pressure difference between injection hole and surrounding rock

ε_p - porosity in the rock matrix, 0.345 % (8)

r_2 - distance for the pressure difference (assumed to be ≈ 4 m $\Rightarrow \ln r_2/r_1 = 6$)

With Eq.(3) and the expected values of the parameters, the radial flow distance can be calculated. Diagram 3 shows the flow distance for the highest pressure difference (0.025 MPa) that would occur between the injection hole and the surrounding rock if the experiment were carried out as a diffusion experiment (see chap. 3.1).

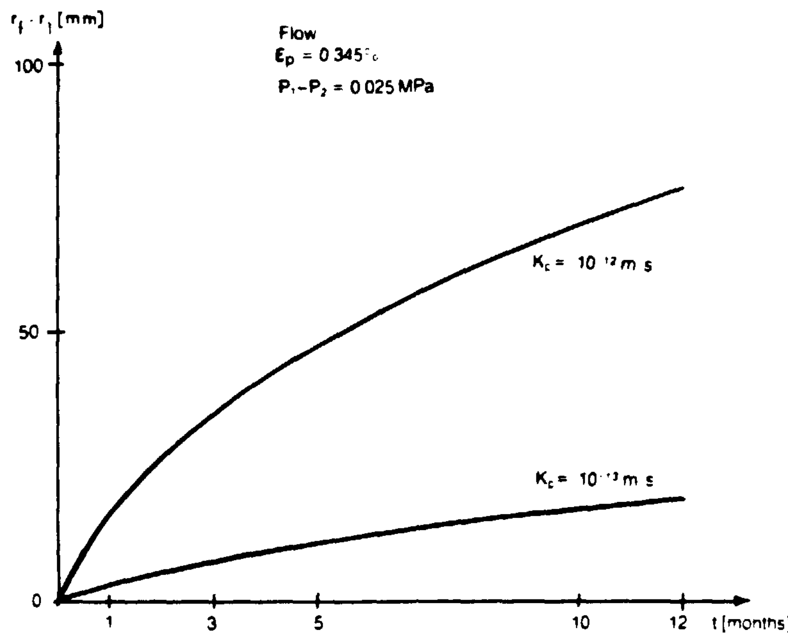


Diagram 3. FLOW. Flow distance in the rock matrix vs time, for different values on K_p. $P_1 - P_2 = 0.025$ MPa.

Diagram 3 also shows how sensitive a diffusion experiment is for leakage. If there is some leakage in the system, the pressure in the injection hole will be lower than the pressure in the surrounding rock. That would lead to flow from the surrounding rock into the injection hole.

3.4 Experimental considerations

Comparing diagrams 2 and 3, it is obvious that if the experiment is carried out as a diffusion experiment the radial flow distance because of the pressure difference is of the same order of magnitude as the expected diffusion distance, if the rock matrix (unfractured rock) has a hydraulic conductivity $K_p \geq 10^{-13}$ m/s. Another factor that would disturb the concentration profile from a diffusion experiment is the dispersion connected with the radial flow.

Because of these difficulties, it was decided to carry out the experiment with a over pressure of ≅ 1 MPa.

The chosen over pressure was high enough to eliminate the problem with the different pressure gradients, but small enough to avoid influencing the microstructure of the rock (4).

The flow distances due to this over pressure calculated with Eq. (3) are illustrated below.

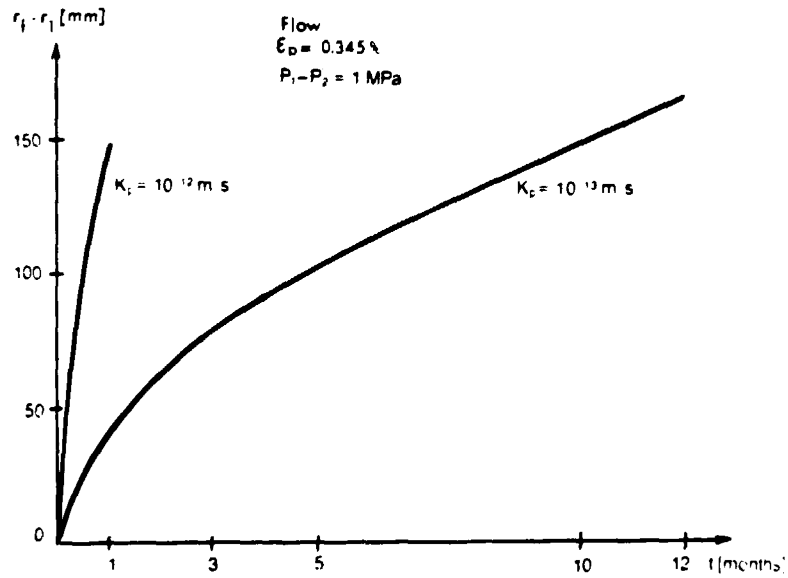


Diagram 4. FLOW. Flow distance in the roc atrix vs time, for different values on K_p.
$P_1 - P_2$ = 1 MPa.

Based on the figure above, it was decided to have an injection time of ≅ 3 months.

3.5 Flow and diffusion. Expected travel distances.

The equations that predict the migration distance when radial diffusion and flow occur simultaneously are:

$$\text{Diffusion equation:} \quad \frac{\partial c}{\partial t} + v_r \frac{\partial c}{\partial r} = D_p \frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial c}{\partial r}\right) \qquad (4)$$

$$\text{Radial flow equation:} \quad v_r = \frac{\text{const.}}{r} \qquad (2)$$

The initial and boundary conditions used imply: No tracer in the rock at start and constant concentration in injection hole all times thereafter. Steady flow.

To solve this convection - diffusion problem, the numerical model TRUMP (9) was used. In diagram 5, the results for some calculations with different K_p and D_p values are illustrated. The flow calculation is based on an over pressure ($P_1 - P_2$) of 0.9 MPa, which is the over pressure that was used in the experiment. The dispersion due to the flow is neglected in the calculations.

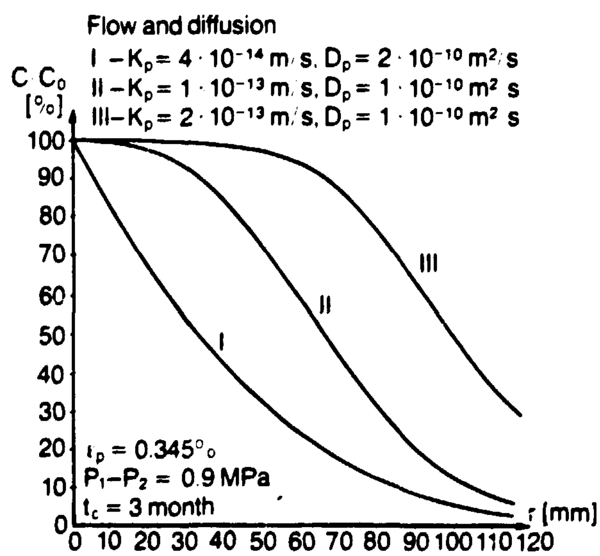


Diagram 5. FLOW AND DIFFUSION. Concentration profiles in the rock matrix vs time, for different values on K_p and D_p. $P_1 - P_2 = 0.9$ MPa

4. EXPERIMENTAL DESIGN

After drilling the holes, one small packer was placed in the little hole and one big packer was placed in the bottom of the big hole (see figure 3). The small as well as the big packer were mechanical.

The small packer was used to get a tube down to the bottom of the small hole and to close off major fractures (i.e. fractures that would increase the injection volume to unmanageable amounts).

The function with the big packer was just to close off the injection compartment from the rest of the hole.

This system, with inflow through a nylon tube in the bottom of the little hole and outflow through a tube just above the little hole, ensures a good circulation when the tracers are injected.

After the installation of the packers, the water pressure and the water flow into the little hole was monitored. The water pressure was found to be 0.73 MPa and the water flow into the little hole approximately 7 ml/h, which indicated that some water bearing fissure was intersecting the little hole.

Since the waterflow into the little hole was so small (≅ 7 ml/h), it was not necessary to close off any of the fissures that were intersecting the hole.

After circulating the tracers for ≅ 24 h, to get constant concentration in the system, the injection was initiated. A pressure of 1.63 MPa (i.e. 0.9 MPa over pressure) was used during the whole injection time. The over pressure was obtained by using compressed nitrogen gas.

Samples were taken of the tracer solution regularly during the injection time. The concentration for all tracers (Cr — EDTA, Uranine and I^-) was constant during the whole injection time, which indicates that there were no (or very little) sorption and chemical reaction.

5. OVERCORING AND SAMPLING

After about 3 months the injection was terminated. The packers were retrieved and the little hole was overcored. The core from the overcoring had a diameter of 132 mm and was ≅ 2.5 m long, with the injection hole (20 mm) at the side. The core was cut into ≅ 5 cm long cylinders.

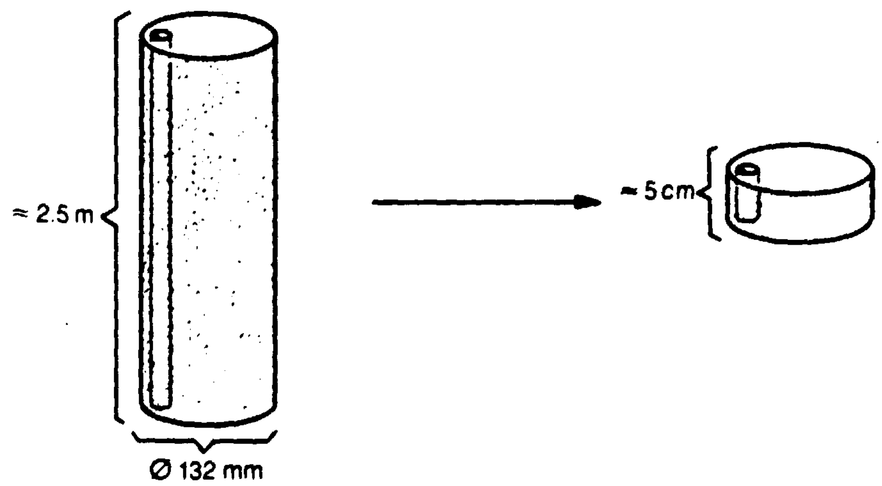


Figure 5. Sampling, step 1.

From these cylinders, a number of sampling cores (Ø 10 mm) were drilled at different distances from the injection hole. These sampling cores were leached with distilled water.

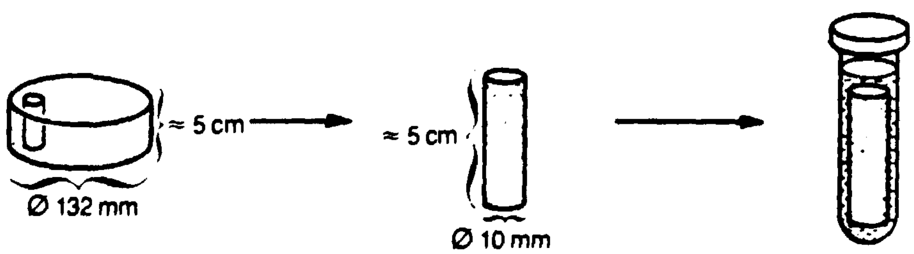


Figure 6. Sampling, step 2.

The tracer concentration in the distilled water was determined, and recalculated for the concentration in the pore water.

5.1 Migration rate from sampling core

The leach rate has been determined experimentally by impregnating a core (Ø 10 mm, L ≅ 5 cm) in a tracer solution for a long time (≅ 1 month), after which the core was placed in distilled water for leaching. The leaching was going on for 36 days and showed that > 95 % of the maximum concentration was reached after 10 days.

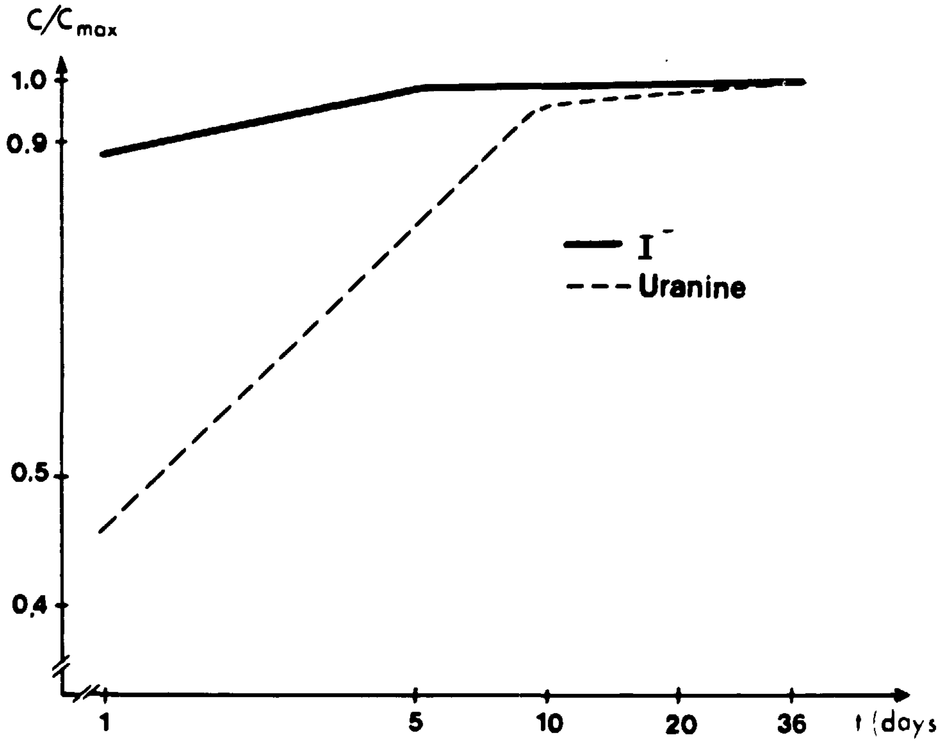


Diagram 6. Leach rate for sampling cores. $c/c_{maximum}$ vs time, for I^- and Uranine.

Based on these results it was decided to use a leach time of ≅ 20 days.

6. TRACERS AND ANALYTICAL METHODS

6.1 Tracers

Since the objective of this experiment is to investigate the existence of a connected pore system in "undisturbed" rock, a mixture of non-sorbing tracers was injected. With non-sorbing tracers the migration rate is high, which means that they will penetrate "undisturbed" rock in a "short" time.

The method of finding suitable non-sorbing tracers has been:

- o Stability test.
- o Test of sorption on the materials used in the equipment.
- o Test of sorption on crushed granite.

Cr- EDTA and Uranine was found by Abelin et al (10) to be stable and non-sorbing on materials and granite. The contact time for these tests was ≅ 20 days.

Stability and sorption has been measured for I^- with approximately 400 days contact time. I^- was found to be stable and showed no sorption on eighter materials or granite.

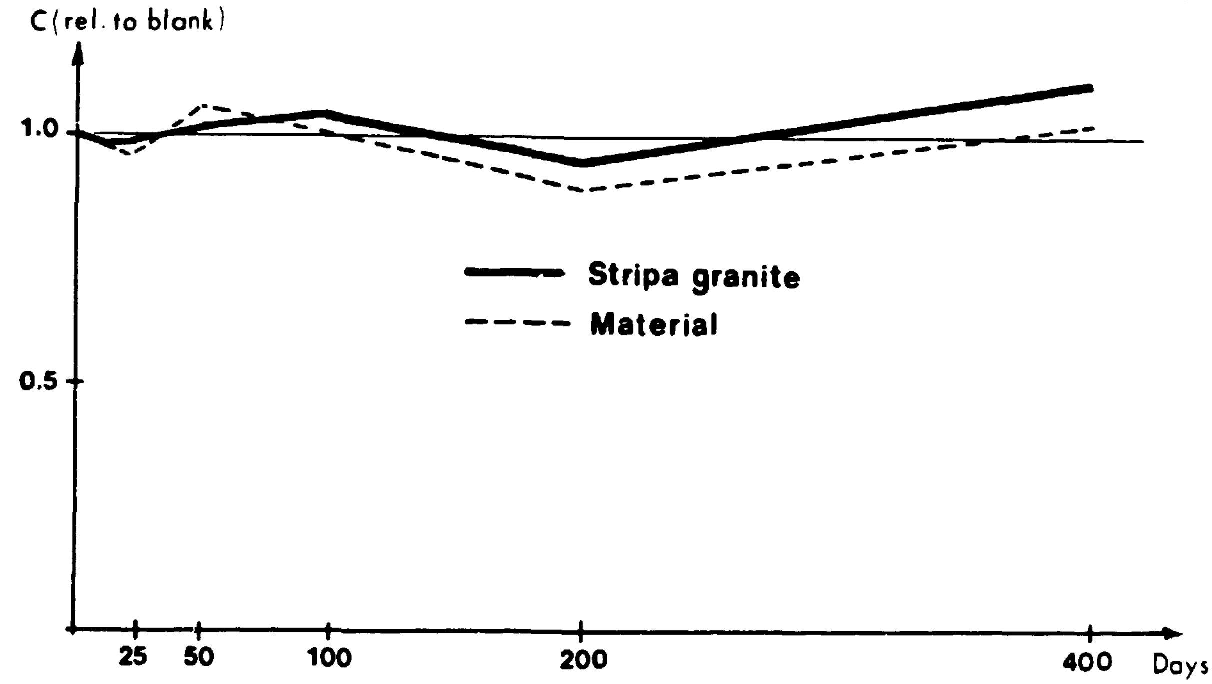


Diagram 7. Sorption test on I^-. c (relative to blank) vs time.

Since a mixture of Cr-EDTA, Uranine and I^- didn't show any chemical reaction, which also was confirmed during the experiment (see chap. 4), it was decided to use a mixture of these three tracers.

6.2 Analytical methods

The tracers were analysed with three different methods. This will decrease the risk to get a systematic error due to the analys equipment.

Tracer	Molecular weight	Analytical method	Injection concentration
Cr-EDTA	344	Atomic absorption	≅ 5 000 ppm
Uranine (Na-Fluorescein)	376	Spectrophotometer	≅ 20 000 ppm
I^-	127	Ion selective electrode	≅ 100 000 ppm

Table 1.

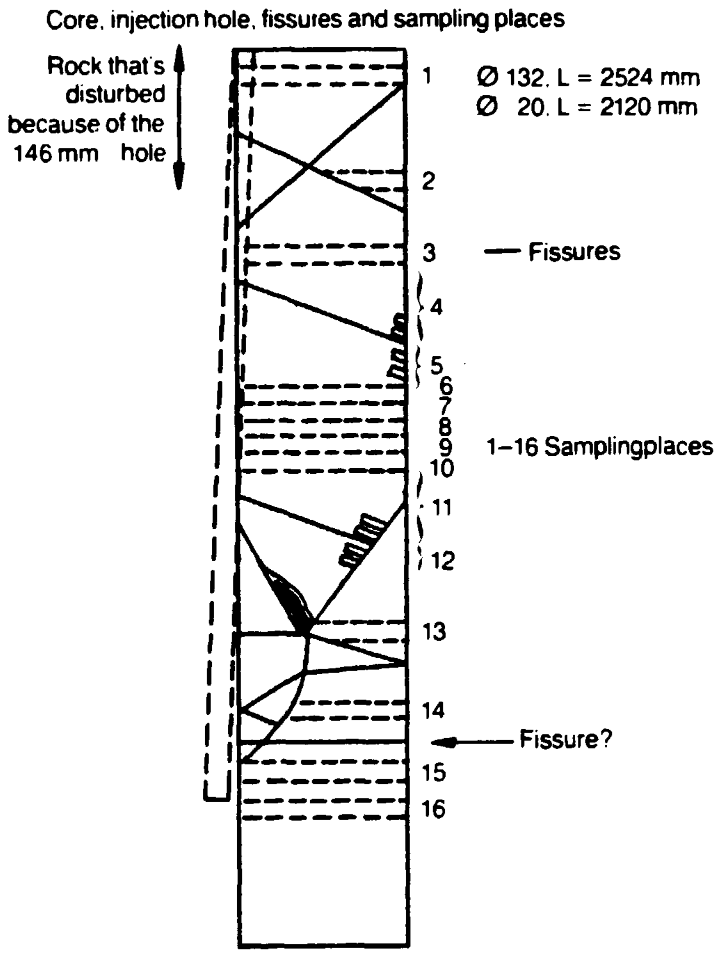
The Cr-EDTA concentration could be analysed directly on the "distilled" water. Since the absorbance for Uranine is very pH-dependent in the region pH 4-8 (11), pH was increased to pH 8.5-9.5 by addition of a solid buffer before Uranine was analysed. Before the I^- concentration could be analysed, the ionic strength had to be increased by addition of a small amount 5 M $NaNO_3$.

$$\text{Cr-EDTA} \xrightarrow{\text{Solid buffer}} \text{Uranine} \xrightarrow{\text{5M NaNO}_3} I^-$$

The addition of solid buffer didn't influence the I^- measurement.

Since the tracers were diluted 500-1000 times during the leaching, the injection concentration had to be very high (see table 1). The concentration of tracers in the injection mixture was high enough to follow the concentration profile down to at least $c/c_o = 0.01$ for all tracers. The accuracy was about +/- 0.1 for all tracers at the lowest concentration.

7. CORE DESCRIPTION



The core from the overcoring of the injection hole was intersected by several fissures. Since there was an inflow of water into the little hole (see chapter 4), at least one of them must have been waterbearing.

Therefore a number of samples were taken close to the fissures, in order to see if there was any indication of tracers having migrated first into the fissure by water flow, and then through the fissure filling material and into the rock matrix by diffusion.

Figure 7. Core description

Comments to the sampling places:

3, 6-10, 15 and 16	-	Investigation of the concentration profile in the rock matrix.
4, 5, 11 and 12	-	Samples taken far from the injection hole and close to a fissure. Could indicate diffusion through fissure filling material.
13 and 14	-	Samples taken behind a fissure. If tracers are found here they must have passed through the fissure filling material.

8. CONCENTRATION PROFILES IN THE CORE

The concentration profiles in the pieces where migration had taken place in the rock matrix (i.e. "far" from any fissures), showed the same results. All tracers have passed the disturbed zone (approximately 4 cm) and migrated a distance into "undisturbed" rock.

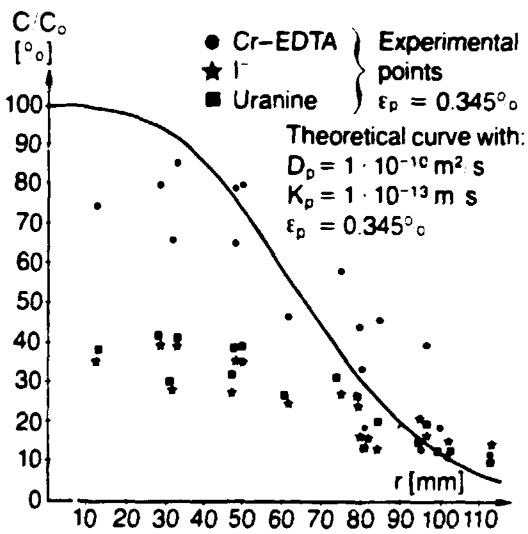


Diagram 8. Tracer concentration vs distance from injection hole for piece No. 10 and a theoretically calculated curve.

As an example, the concentration profile from piece No. 10 and a theoretical curve (9) is shown. All experimental points are based on a uniform porosity of 0.345 % in the rock matrix (see chapter 10.2).

All three tracers passed the disturbed zone and migrated into "undisturbed" rock.

At least one of the concentration profiles (Cr-EDTA) can be explained by simple convection - diffusion migration without chemical interaction.

9. INFLUENCE OF FISSURES

Since there was at least one water bearing fissure intersecting the little hole, the investigation of points 4, 5, 11 and 12 could have indicated migration through the fissure filling material and into the rock matrix if the concentration had been higher close to the fissure and lower a little way out. Unfortunately there is not enough data to show this.

From the two pieces taken behind a fissure the samples from piece No. 13 showed no or very low concentration (c/c_o < 2 % for all tracers). Samples from piece No. 14, however, showed that tracers had migrated into that piece. The distance from the injection hole to the fissure filling material was ≅ 70 mm, which means that the fissure was situated in "undisturbed" rock. There are three ways for tracers to reach piece No. 14.

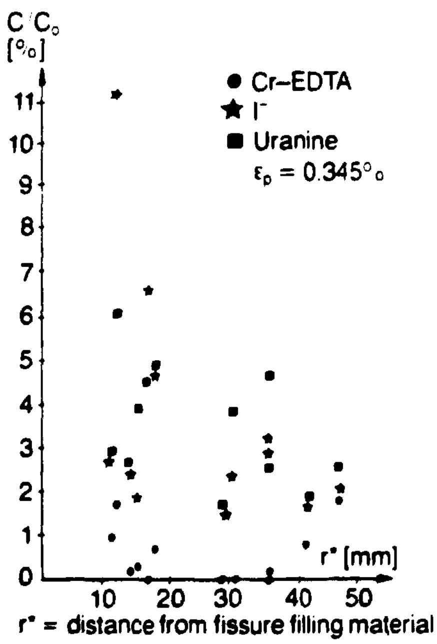


Diagram 9. Tracer concentration vs distance from fissure filling material for piece No. 14.

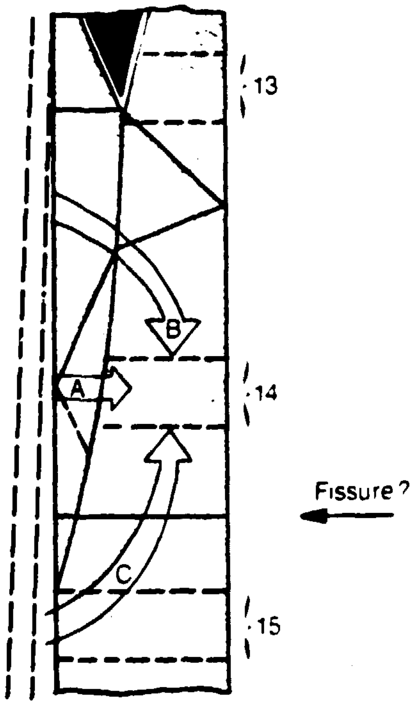


Figure 8. Possible migration path ways to piece No. 14.

A and B - Migration through the rock matrix (and/or in the fissure) and through the fissure filling material.

C - Migration outside the fissure. But this alternative can be excluded, since no (or very little) cracers were found in piece No. 15. That is probably because the bottom of the injection hole was filled with granite particles from the drilling.

The discussion above means that the existence of tracers in piece No. 14 indicates migration through fissure filling (coating) material that is under its natural stress environment.

It can be seen from diagram 9 that the relative concentration (c/c_o) behind the fissure is low, compared to the relative concentration at the same distance for migration in the rock matrix (diagram 8). That could be explained by a number of factors, for example:

- The tracers are transported through the rock matrix and to the fissure, where they are diluted because of the natural water content in the fissure.

- When the tracers reaches the fissure, they are transported away by the water flow.

- The fissure is connected to a fissure system that is under lower pressure. This means that the whole (or at least the major) pressure drop occures between the injection hole and the fissure. In this case the tracers would migrate from the injection hole to the fissure by flow and diffusion, and into the matrix of piece No. 14 by just diffusion.

- The fissure filling material decreases the migration rate.

Although the tracer concentration was relatively low in piece No. 14 (and No. 13), which can be explained by either one or a combination of the factors above, the fact remains that tracers were found in the rock matrix behind the fissure filling material.

10. DISCUSSION

10.1 Source of errors

In this kind of experiment, where the objective is to investigate the migration in the rock matrix, a number of errors will naturally occur. The most important sources of errors are listed below.

Source of errors.

I- Pressure release	Before the overcoring was done, the pressure was released and the packers were taken up. Released pressure means that the tracers could migrate to the injection hole from the surrounding rock by flow and diffusion. The time between pressure release and overcoring was ≅ 1 week.
II- Overcoring	During the overcoring, the core was flushed with water and the tracers could migrate out from the core by diffusion. The overcoring took ≅ 3 h.
III- Sampling	During the sampling (cutting into pieces and drilling of sampling cores) the core was flushed with water. This means diffusion out from the core during ≅ 5 minutes (cutting) respective ≅ 2 minutes (drilling).
IV- Analysis	The accuracy on the analysis was about +/- 0.1 for $c/c_o = 0.01$ and < +/- 0.1 for higher concentrations.
V- Porosity, ε_p	All points are based on a uniform porosity in the rock matrix on $\varepsilon_p = 0.345$ %. Since $c/c_o \cdot \varepsilon_p = \text{const.}$, this may be the major source of error if the rock matrix is inhomogeneous.

VI- Inhomogeneity

If the rock matrix is homogeneous, the concentration profile would look exactly the same in all directions out from the injection hole. But it can be seen from figure 9 that the migration rate is different in different directions.

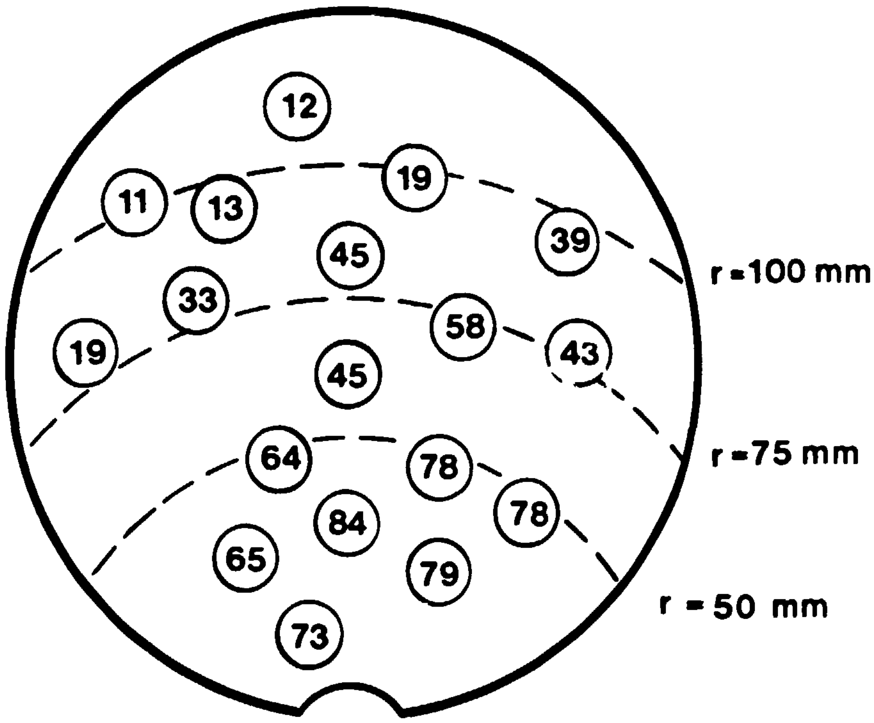


Figure 9. Concentration distribution for Cr-EDTA in the sampling cores from piece No. 10. The numbers represent the relative concentration in per cent.

Notice that points I, II and III will decrease the concentration in the sampling cores. Therefore, the concentration in the core may have been higher than indicated in diagram 8 and 9.

Since the relation between relative concentration (c/c_o) and porosity is $c/c_o \cdot \varepsilon_p$ = const., an error in ε_p can decrease or increase the c/c_o-value.

The inhomogeneity (point VI and figure 9) gives an explanation to the fact that the c/c_o-values in diagram 8 and 9 are so scattered.

10.2 Influence of porosity

From the concentration profiles in diagram 8, it can be seen that the profile for Cr-EDTA can be explained with a theoretical curve, while c/c_o does not reach higher than 40-50 % for I^- and Uranine. The magnitude of c/c_o for a sample is determined by the porosity and the calculations of c/c_o for all three tracers are based on a uniform porosity of 0.345 % in the rock matrix.

The porosity in our granite has been measured in three different ways.

- Mercury penetrometry using approximately 100 MPa. This measurement gave a porosity of 0.345 % (8).

- Comparing the weight for dry and wet granite. These measurements gave approximately the same porosity as the method above.

- Impregnating a sample with 1 M NaI and leaching in distilled water. This method gave a porosity of approximately 0.15-0.20 %, i.e. approximately half as much as the methods above.

If the concentration profiles for I^- and Uranine are calculated with the porosity that was obtained from the impregnating-leaching experiment with I^- (0.345 % /2) instead of 0.345 %, the curves for I^- and Uranine will reach the same level as the curve for Cr-EDTA!

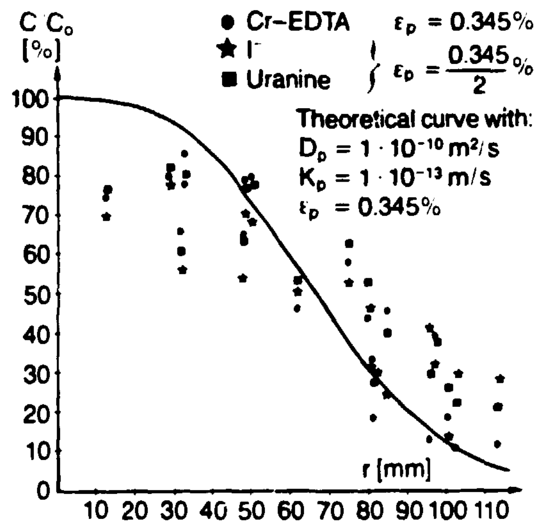


Diagram 10. Tracer concentrations based on different porosities vs distance from injection hole for piece No. 10 and a theoretical curve.

At present, we have no explanation for the fact that the concentration profiles must be calculated with different porosities for different tracers, in order to fit a theoretical curve.

11. CONCLUSION

The conclusions from this experiment are:

- Tracers have migrated through the disturbed zone and a distance into "undisturbed" rock.

- Tracers have passed through fissure filling material.

The results indicate that it is possible for tracers (and therefore radionuclides) to migrate from a fissure, through fissure filling material, and into the undisturbed rock matrix.

12. CONTINUATION

The second part of the field experiment has already been started. Experiments similar to the finished one, are now carried out in two holes.

Hole 1 - Continued experiments in the hole that was used in part 1 (finished experiment). The drilling depths are now 18 m with Ø 146 mm + 3 m with Ø 20 mm. The drilling arrangements are similar to part 1 (see figure 3).

Hole 2 - A new hole approximately 5 m from hole 1. The drilling depths are 15 m with Ø 146 mm + 3 m with Ø 20 mm. Drilling arrangements similar to part 1.

A mixture of the same non-sorbing tracers as were used in part 1 (Cr-EDTA, Uranine and I^-) is injected in both these "new" holes.

A rock stress measurement was done in hole 1 at 15.6 m - 17.4 m depth, to ensure that the experiment is carried out in rock that is under its natural stress environment.

The difference between the experiments in progress and the finished experiment is mainly that a lower over pressure is used for the injection. A lower over pressure will decrease the risk that the microstructure of the rock is influenced. But since a lower over pressure will decrease the migration rate, the injection time are increased to 6 respectively 12 months (second part) compared to 3 months (first part).

REFERENCES

1. Neretnieks, I.
Diffusion in the Rock Matrix - An important Factor in Radionuclide Migration
Handout at the American - Swedish Minisymposium on Chemistry and Geochemistry, October 11-13, 1979
Berkeley, California

2. Neretnieks, I.
Diffusion in the Rock Matrix: An important Factor in Radionuclide Retardation?
J. Geophys. Res., 1980, 85, p 4379

3. Rasmuson, A., Neretnieks, I.
Model for Far Field Migration
Presented at Fifth International Symposium on the Scientific Basis for Radioactive Wast Management, June 7-10, 1982
Berlin (West)

4. Stephansson, O.
Personal communication
Division of Rock Mechanics, University of Luleå, Sweden, 1981

5. Brace, W.F., Walsh, J.B., Frangos, W.T.
Permeability of Granite under high Pressure
J. Geophys. Res., 1968, 73, p 2225

6. Heard, H.L., Trimmer, D., Duba, A., Bonner, B.
Permeability of Generic Repository Rocks at Simulated In Situ Condition
Lawrence Livermore Laboratory, UCRL-82609, April 1979

7. Freeze, R.A., Cherry, J.A.
Groundwater, Prentice - Hall, 1979

8. Müller - Vonmoos, M.
Personal communication, Institut für Grundbau und Bodenmechanik, Eidgenössische Technische Hochschule, Zürich, 1981

9. Edwards, A.L.
TRUMP: A computer program for transient and steady state temperature distributions in multidimensional systems
National Technical Information Service, National Bureau of Standards, Springfield Va., 1972

10. Abelin, H., Neretnieks, I.
Migration in a Single Fracture
Preliminary experiments in Stripa, Internal report 81-03,
Nucl. Fuel Safety Proj., Stockholm, Sweden, 1981

11. Knutsson, G.
Spårämnen som hjälpmedel vid grundvattenundersökningar
Nordstedts, Stockholm, Sweden, 1970 (Swedish)

12. Wilson, C.
Macropermeability Experiment in Stripa (draft report)
Earth Science Div., Lawrence Berkeley Laboratory, Berkeley, California, 1981

NOTATION

c	concentration in liquid	mol/m^3
c_{max}	maximum concentration in liquid	mol/m^3
c_o	injection concentration	mol/m^3
D_L	diffusivity in water	m^2/s
D_p	diffusivity in water in pores	m^2/s
K_p	hydraulic conductivity in the rock matrix	m/s
L	length	m
P	pressure	Pa
$P_{\text{"natural"}}$	natural pressure in the rock	Pa
P_1-P_2	pressure difference between injection hole and surrounding rock	Pa
r	radial distance	m
r_f	radial distance for flow	m
r_1	radius of injection hole	m
r_2	radial distance for pressure difference	m
t	time	s
t_c	contact time	s
v_r	radial velocity	m/s

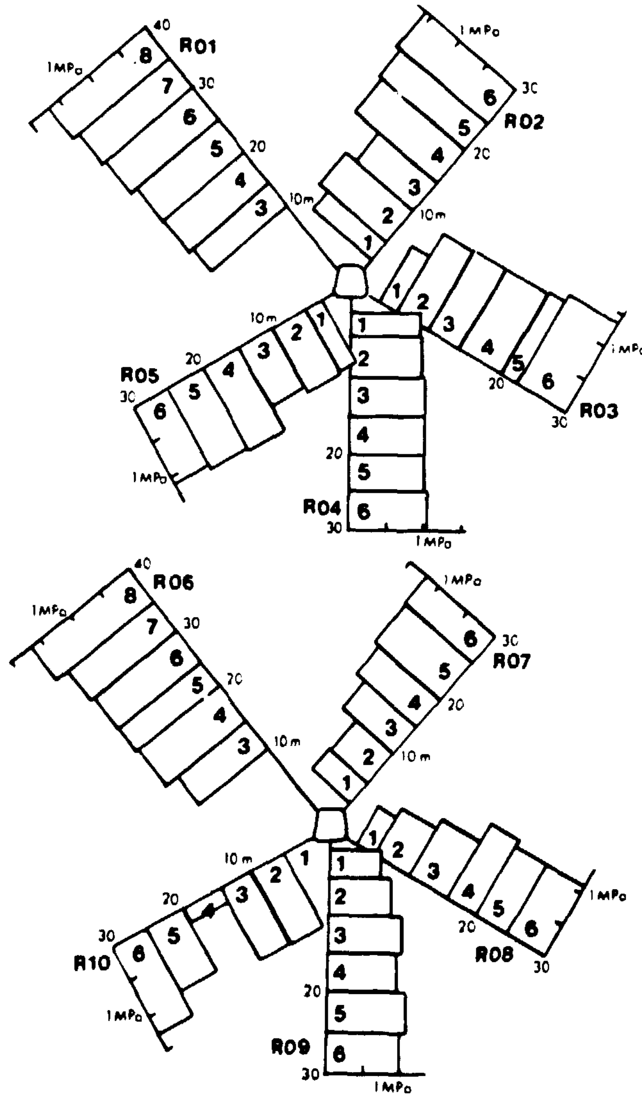
Δ	difference	
δ_D	constrictivity for diffusion	
ε_p	porosity of unfractured rock, matrix porosity	m^3/m^3
σ_r	radial tension	Pa
σ_t	tangential tension	Pa
τ	toruosity	
Ø	diameter	m

APPENDIX 1

Water pressure measurements in the Stripa mine

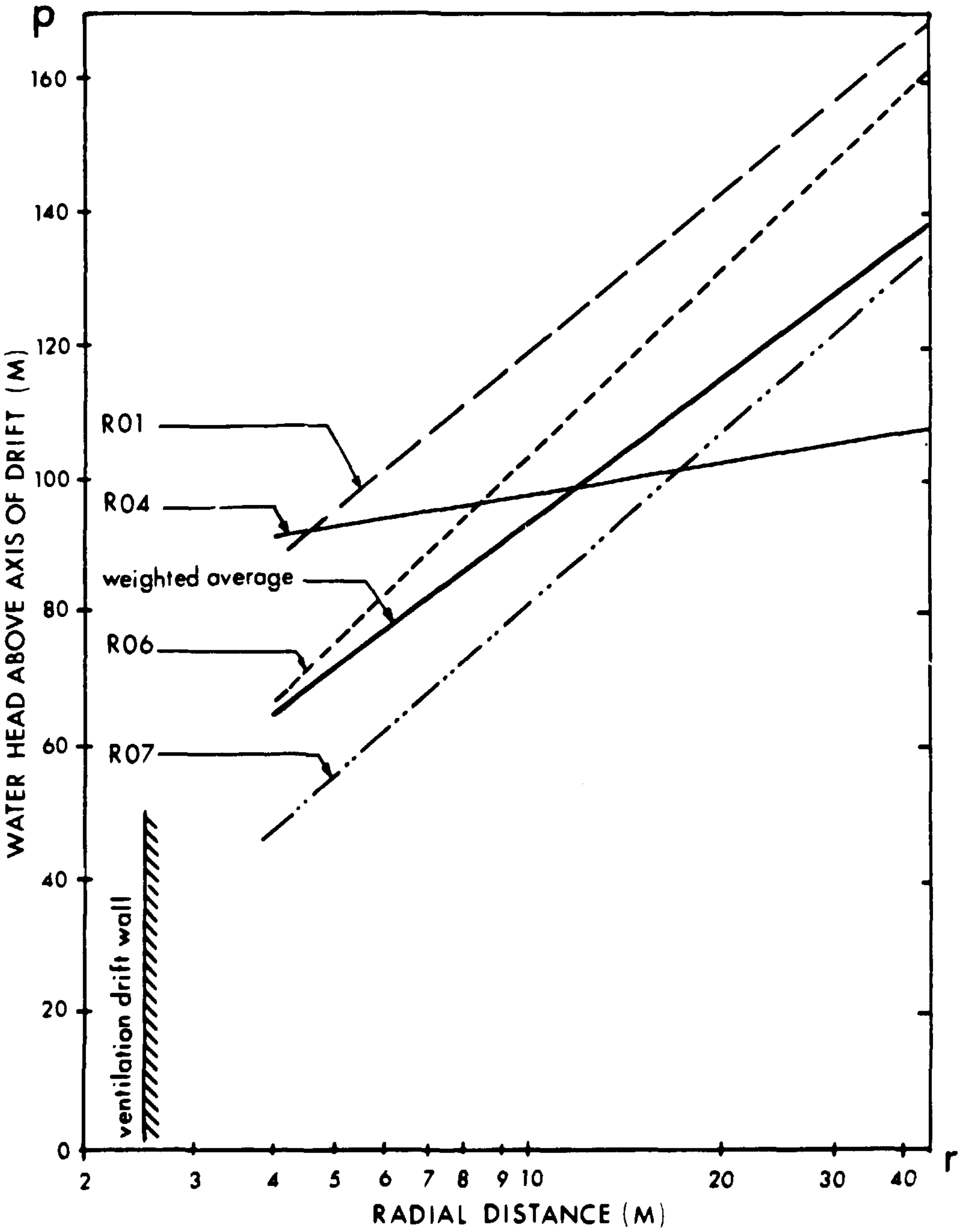
A number of water pressure measurements have been done by Lawrence Berkeley Laboratory in the ventilation drift in the Stripa mine (12). Since the diffusion experiment has been carried out in a drift (extensiometer drift) that is on the same level (360 m-level) and only approximately 100 m from the ventilation drift, it is assumed that the results from the ventilation drift are valid also for the extensiometer drift.

The results from the water pressure measurements are illustrated below.



Water pressure in the R-holes in the ventilation drift.

If the water head above axis of drift is plotted as a function of radial distance in a lin - log diagram, a number of straight lines is received.



A straight line in a lin - log diagram means that:

$$P = C_1 + C_2 \cdot \lg r \qquad \text{Eq. (1)}$$

Where C_1 is the intercept and C_2 the slope of the line. Differentiation of Eq. (1) gives the pressure gradient as a function of r:

$$\frac{dP}{dr} = \frac{C_2}{r \cdot \ln 10} \qquad \text{Eq. (2)}$$

The slope for the weighted average curve is $C_2 = 75$, which gives:

$$\frac{dP}{dr} = \frac{33}{r} \ \text{m/m} \qquad \text{Eq. (3)}$$

This means that the difference between the pressure gradients for the little hole and the surrounding rock is ≈ 2.5 m/m (≈ 0.025 MPa/m) at the distance from the drift where the experiment has taken place.

The only way to avoid the difficulties with the different pressure gradients and make a diffusion experiment, is to drill a very deep hole, so that $\frac{dP}{dr} \longrightarrow 0$. This is unpractical.

FÖRTECKNING ÖVER KBS TEKNISKA RAPPORTER

1977-78

TR 121 KBS Technical Reports 1 - 120.
Summaries. Stockholm, May 1979.

1979

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

1980

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

1981

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

1982

TR 82-01 Hydrothermal conditions around a radioactive waste repository
Part 3 - Numerical solutions for anisotropy
Roger Thunvik
Royal Institute of Technolcgy, Stockholm, Sweden
Carol Braester
Institute of Technology, Haifa, Israel
December 1981

TR 82-02 Radiolysis of groundwater from HLW stored in copper canisters
Hilbert Christensen
Erling Bjergbakke
Studsvik Energiteknik AB, 1982-06-29

TR 82-03 Migration of radionuclides in fissured rock: Some calculated results obtained from a model based on the concept of stratified flow and matrix diffusion
Ivars Neretnieks
Royal Institute of Technology
Department of Chemical Engineering
Stockholm, Sweden, October 1981

TR 82-04 Radionuclide chain migration in fissured rock - The influence of matrix diffusion
Anders Rasmuson *
Akke Bengtsson **
Bertil Grundfelt **
Ivars Neretnieks *
April, 1982

* Royal Institute of Technology
Department of Chemical Engineering
Stockholm, Sweden

** KEMAKTA Consultant Company
Stockholm, Sweden

TR 82-05 Migration of radionuclides in fissured rock - Results obtained from a model based on the concepts of hydrodynamic dispersion and matrix diffusion
Anders Rasmuson
Ivars Neretnieks
Royal Institute of Technology
Department of Chemical Engineering
Stockholm, Sweden, May 1982

TR 82-06 Numerical simulation of double packer tests Calculation of rock permeability
Carol Braester
Israel Institute of Technology, Haifa, Israel
Roger Thunvik
Royal Institute of Technology
Stockholm, Sweden, June 1982

TR 82-07 Copper/bentonite interaction
Roland Pusch
Division Soil Mechanics, University of Luleå
Luleå, Sweden, 1982-06-30

TR 82-08 Diffusion in the matrix of granitic rock Field test in the Stripa mine
Part 1
Lars Birgersson
Ivars Neretnieks
Royal Institute of Technology
Department of Chemical Engineering
Stockholm, Sweden, July 1982