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Diffusion in the matrix of granitic rock Field test in the stripa mine. Part 2

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Stockholm, Sweden March 1983

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FIELD TEST IN THE STRIPA MINE
PART 2

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DIFFUSION IN THE MATRIX OF GRANITIC ROCK

FIELD TEST IN THE STRIPA MINE

PART 2

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TABLE OF CONTENTS

Page

Summary

References

Notation

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 was subject to nearly the same conditions as the rock surrounding a nuclear waste reporitory as proposed in the Swedish concept (KBS).

The results show that all three tracers (Cr-EDTA. Uranine and I^-) have passed the zone disturbed by the presence of the injection hole and migrated into "undisturbed" rock.

These results indicates that it is possible for tracers (and therefore radionuclides) to migrate into the undisturbed rock matrix.

Diffusivities obtained in this experiment are comparable to those obtained in laboratory experiments.

1. BACKGROUND

Our present concept of the micro structure of granite is illustrated in the figure below.

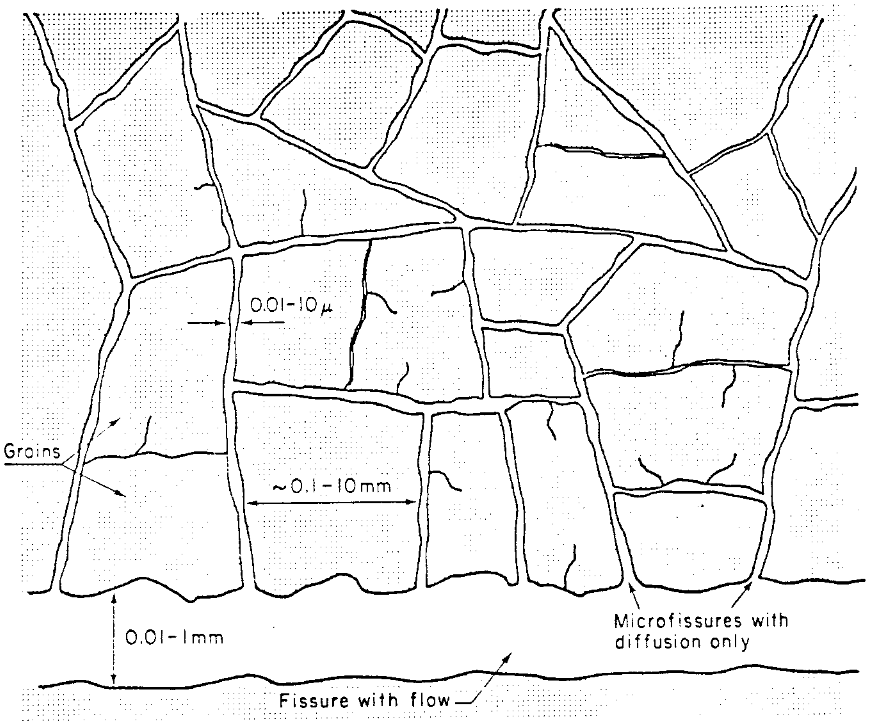


Figure 1. A two dimensional view of the microstructure in granite showing "typical" sizes of grains, microfissures and fissures.

The granite is intersected by a number of fissures where water flows. In the rock matrix. a connected pore system exists (micro fissure system) where molecules can move by diffusion. Between the fissures and the rock matrix there exists a thin layer of 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 radionuclides may then be transported in the fissures by the seeping water.

The radionuclides migrating with seeping 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 (1).

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 (2).

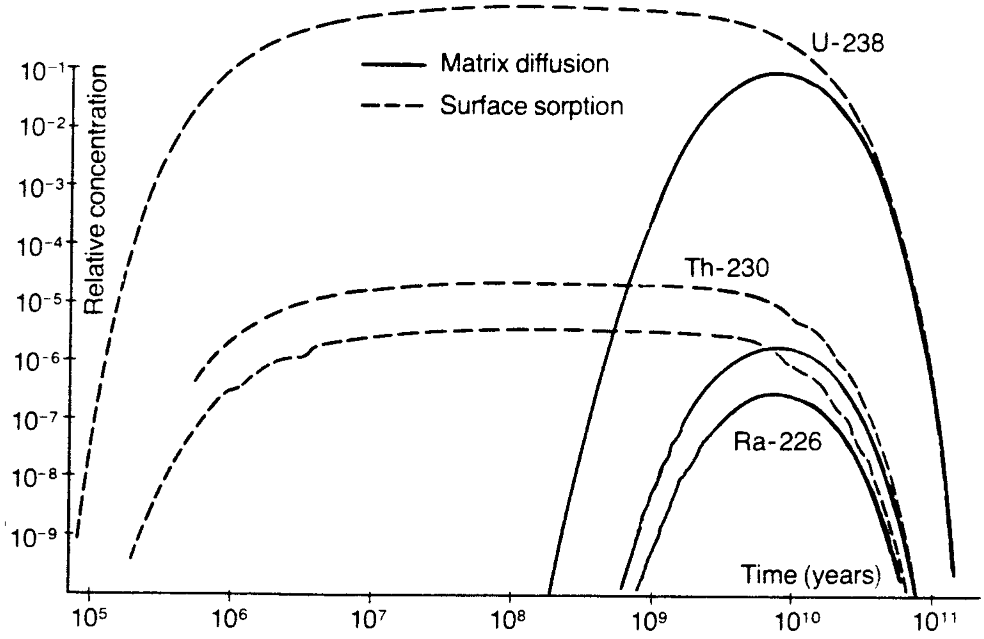


Diagram 1. The influence of matrix diffusion. $D_p \varepsilon_p = 10^{-12}$ m^2/s.

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 and other crystalline rocks. These laboratory experiments show that it is possible for tracers to migrate in the granitic 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 necessarily close irreversibly induced micro fissures.

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 esssentially "undisturbed" rock exists (3).

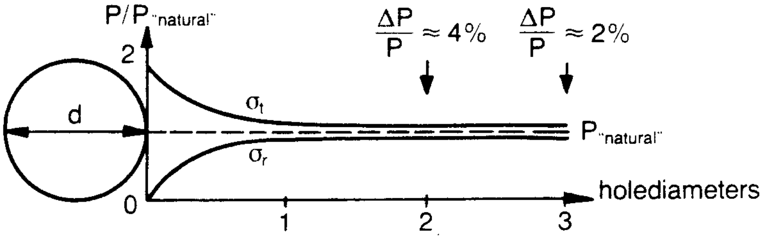


Figure 2. $\frac{\Delta P}{P}$ vs distance from a hole.

Since the objective with this experiment is to do a migration experiment in "undisturbed" rock, the experiment had to take place more than 2 drift diameters below the drift.

A 15 m long 146 mm hole was drilled. At this distance from the drift the changes in rock stresses due to the drift can be neglected, i.e. essentiallly "undisturbed" rock is reached. At the depth of 15.5 - 17.5 m a rock stress measurement was performed by the Swedish State Power Board, which confirmed that "undisturbed" rock was reached.

However, even if the changes due to the drift can be neglected, 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 the bottom of the hole.

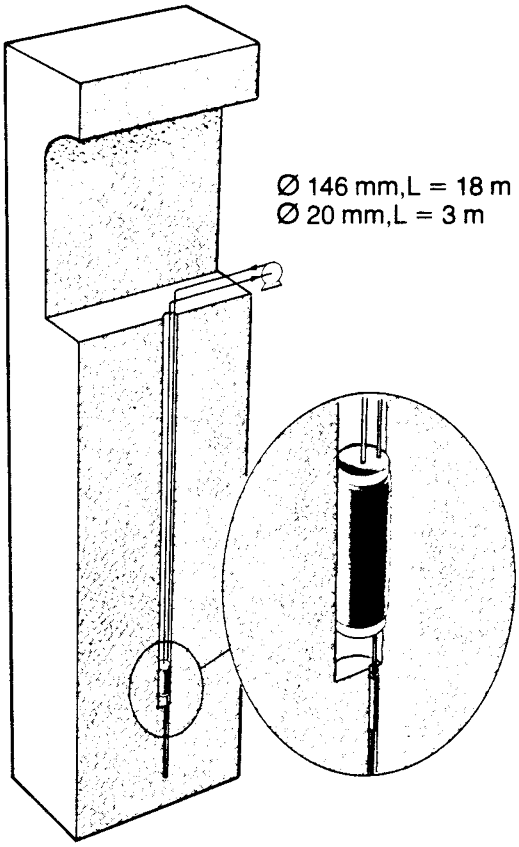


Figure 3. Drilling dimensions and packer.

Thus. in the bottom of the 146 mm hole a 20 mm hole (approximately 3 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 litte 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 DESIGN

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

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

The small packer was used to get a nylon tube down to the bottom of the small hole, in order to get a good circulation when the tracers were injected.

After the installation of the packers, the water flow into the little hole and the water pressure was monitored. Since there was no measurable inflow of water into the injection compartment, no reliable value on the water pressure could be found.

According to other measurements in the Stripa mine at the same level and only ≈ 100 m from the drift where this experiment has been performed the water pressure 18 - 21 m below the drift is expected to be between 1.0 and 1.4 MPa.

A pressure of 1.5 MPa (i.e. 0.1 - 0.5 MPa overpressure) was used during the whole injection time. This small overpressure ensured that the tracers would migrate by flow and diffusion out from the injection hole and into the pore system of the rock matrix. The overpressure was obtained by using compressed nitrogen gas.

4 OVERCORING AND SAMPLING

After about 6 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 ≈ 3.5 m long. with the injection hole (Ø 20 mm) at the side. The core was cut into ≈ 5 cm long cylinders.

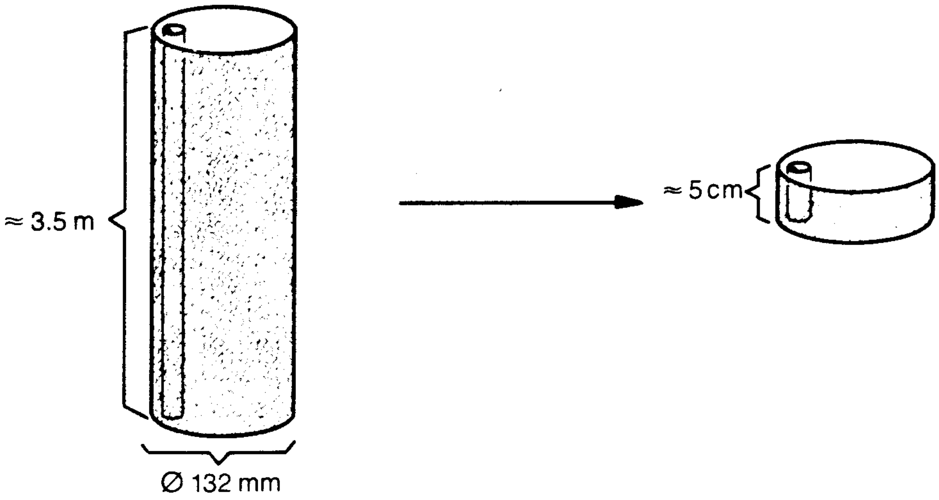


Figure 4. Sampling. step 1.

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 in distilled water.

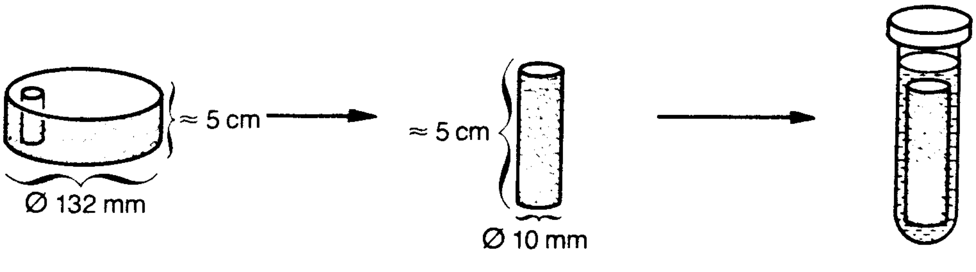


Figure 5. Sampling, step 2.

The tracer concentration in the distilled water was determined and recalculated for the concentration in the pore water. The recalculated concentration is based on the porosity that was obtained for every individual sampling core. Porosity is obtained from the weight difference between wet and dry core. After this overcoring, which made it possible to study the concentration profile approximately 11 cm outward. another hole was drilled (see figure 6).

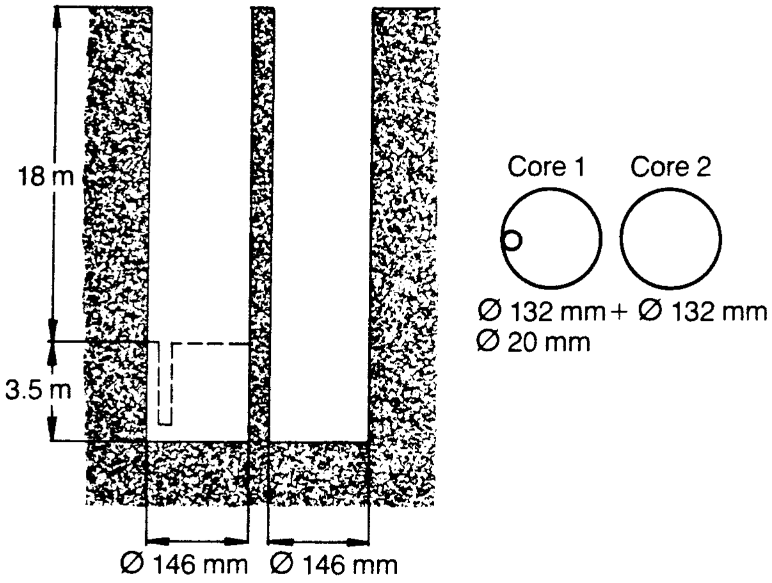


Figure 6. Overcoring arrangements

The distance between the cores was ≈ 19 mm (i.e. ≈ 5 mm between the holes) at the depth of interest (18 - 21 m).

With this "extra core". the concentration profile could be studied approximately 25 cm outward from the injection hole.

The sampling procedure for core 2 was the same as for core 1. A total number of ≈ 650 sampling cores were drilled (≈ 400 from core 1 and ≈ 250 from core 2).

5. TRACERS AND ANALYTICAL METHODS

5.1 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

These tests showed that Cr-EDTA, Uranine and I^- are stable and do not sorb on either the construction materials or granite. and since a mixture of these three tracers did not show any chemical reaction, it was decided to use them in the experiment (for more information, see Birgersson and Neretnieks (4)).

5.2 Analytical methods

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

Tracer	Molecular weight	Analytical method	Injection concentration
Cr-EDTA	344	Atomic absorption	≈ 10 000 ppm
Uranine (Na-Fluorescein)	376	Spectrophotometer	≈ 80 000 ppm
I^-	127	Ion selective electrode	≈ 150 000 ppm

Table 1.

After the leaching, the Cr-EDTA concentration could be analysed directly in the leaching water. Since the absorbance for Uranine is very pH-dependent in the region pH 4 - 8 (5), pH was increased to pH 8.5 - 9.5 by addition of a solid buffer (mixture of: H_3BO_3, KCl and NaOH) before Uranine was analysed.

Before the I^- concentration could be analysed. the ionic strength had to be increased by addition of a small amount 5M $NaNO_3$.

The analysis sequence was as follows:

$$\text{Cr-EDTA} \xrightarrow{\text{Solid buffer}} \text{Uranine} \xrightarrow{5M\ NaNO_3} I^-$$

The addition of the solid buffer did not 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 $c/c_0 = 0.005$ for all tracers. The accuracy was about +/- 0.1 for all tracers at the lowest concentration.

6. CORE DESCRIPTION

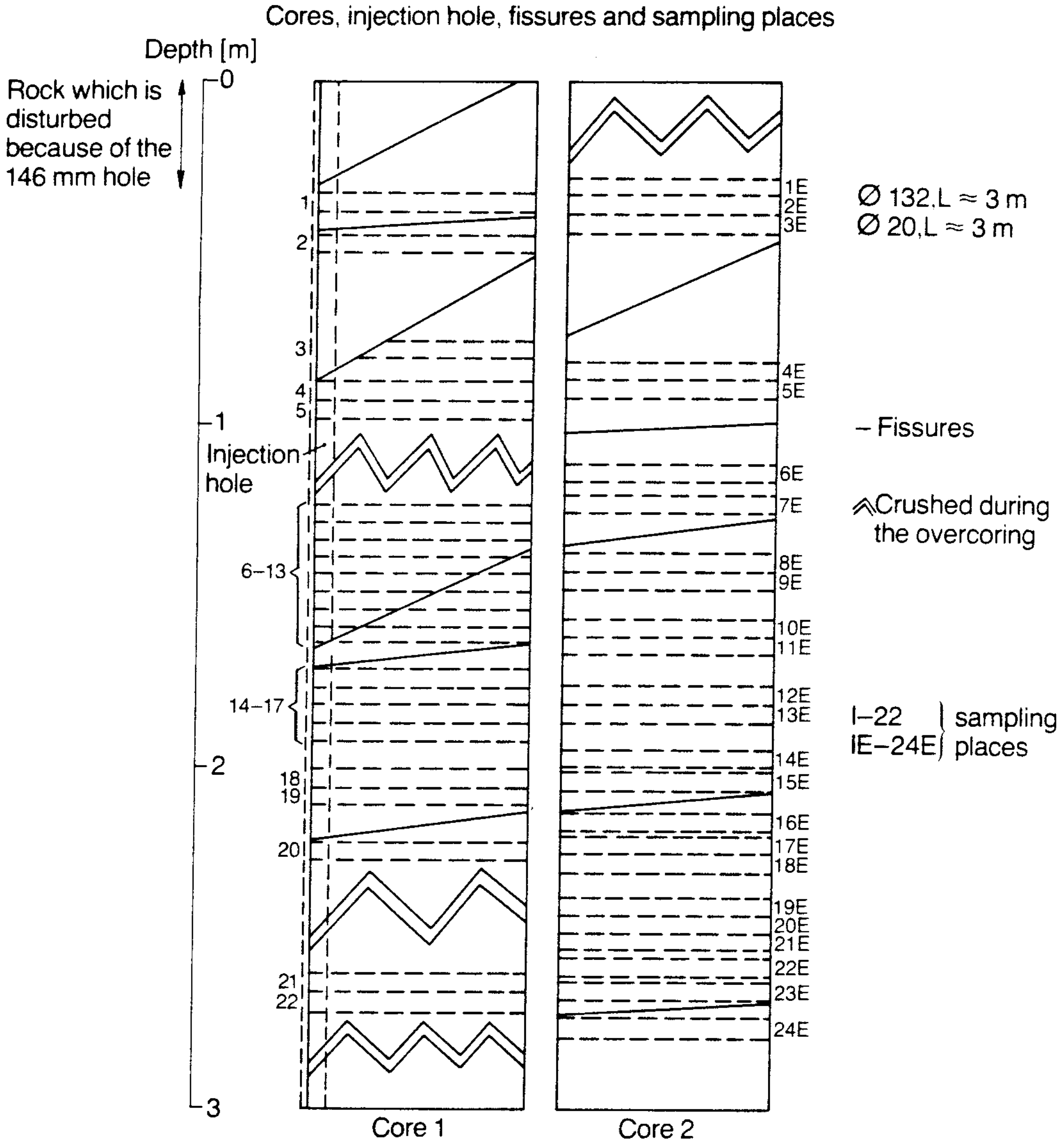


Figure 7. Core description

From core 1 samples were taken at 22 different depths. which made it possible to study the variation in migration distance in the matrix versus depth (see chapter 8).

Because of core 2, the concentration profile could in some cases be followed 25 cm outward from the injection hole at approximately the same depth (see chapter 8).

7. EXPECTED RESULTS

Part 1 of this field test, in which an injection time of 3 months and an overpressure of 0.9 MPa was used, gave some indication on the order of magnitude of the two parameters which are most important for the shape of the concentration profiles, namely the diffusivity (D_p) and the hydraulic conductivity (K_p) (for more information, see Birgersson and Neretnieks (4)). Since part 1 of this experiment was performed 11-13 m below the drift and in the same hole as the present experiment, it was assumed that the values on D_p and K_p would be of the same order of magnitude.

The equations which predict the migration distance for a non-sorbing component when radial diffusion and flow (convection) occur simultaneously are:

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

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

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

All calculations on this diffusion convection problem were done with an integrated finite difference method using the program TRUMP (6).

7.1 Results from part 1

Because the core from part 1 was intersected with a great number of fissures, the migration in the rock matrix could be followed through the whole sampling place at only 6 different depths (6 sampling places).

The concentration profiles in these 6 sampling places showed the same result, i.e. the difference in depth (< 0.5 m) did not seem to affect the shape of the concentration profile.

Diagram 2. in which all experimental points are based on a uniform porosity in the rock matrix of ε_p = 0.345 %. illustrates the concentration profile in one of these sampling places from part 1.

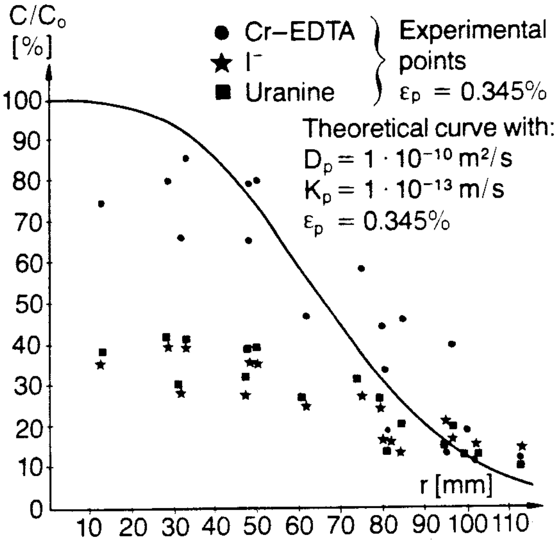


Diagram 2. Tracer concentration vs. distance from injection hole for one sampling place in part 1.

The diagram shows that all three tracers have passed the disturbed zone (approximately 4 cm) and migrated into the undisturbed rock.

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

The theoretical curve is calculated with the following parameter values·

K_p (hydraulic conductivity) = $1 \cdot 10^{-13}$ m/s
D_p (diffusivity in pores) = $1 \cdot 10^{-10}$ m^2/s.

7.2 Expected results in part 2

Based on the observed values on D_p and K_p from part 1 and with a contact time of 6 months. the expected result from part 2 is illustrated in diagram 3. Since no accurate value on the water pressure was found. the concentration profile has been calculated for two different overpressures (see chapter 3).

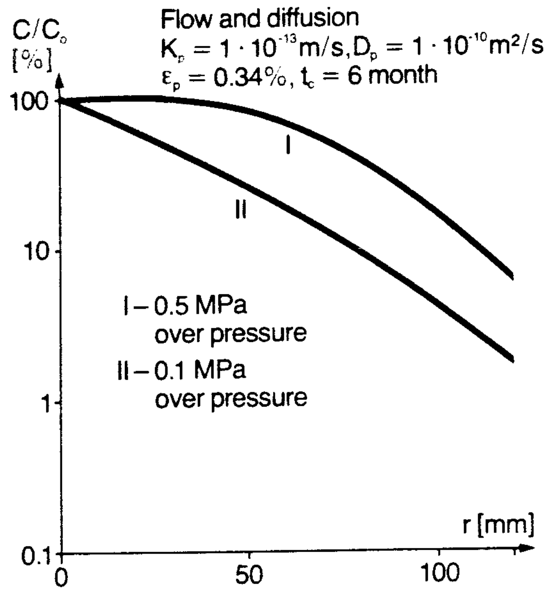


Diagram 3. FLOW AND DIFFUSION.
Expected concentration profiles in the rock matrix vs. time, for different values of the overpressure.

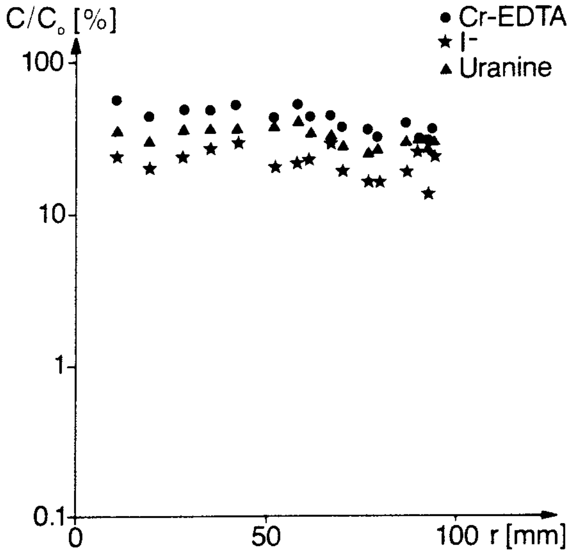
8. CONCENTRATION PROFILES IN THE CORES

8.1 Concentration profiles in core 1

The results of the experiments in part 2 show a considerable variation in migration distance with depth compared to part 1. The penetration depth could in some cases vary with a factor 3 or more in sampling places that were separated by just a few tens of centimeters in depth.

The pervading trend is that all three tracers have migrated a long distance into the rock matrix at the top and the bottom of the injection hole, while the migration distance is rather short in the middle section of the hole.

The variation in migration distance with depth is illustrated in the following diagrams·



There is almost no decline in concentration with distance in this sampling place for at least the first 100 mm that could be studied from core 1. Sampling place 1 (depth 0.36 m) has the same tendency.

Diagram 4. Tracer concentration vs. distance from injection hole for sampling place 2. Depth 0.48 m.

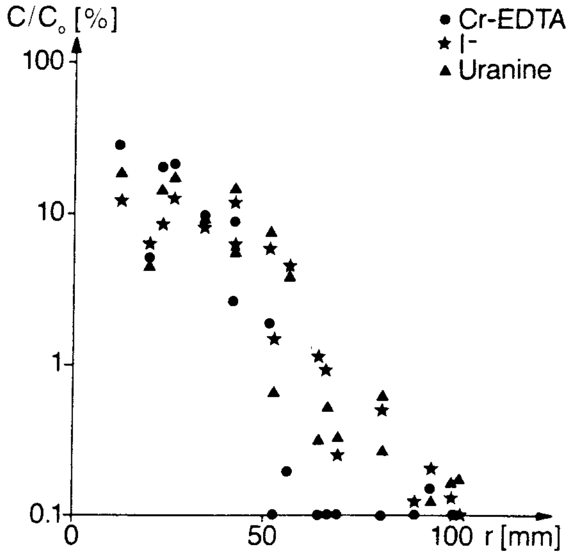


Diagram 5. Tracer concentration vs. distance from injection hole for sampling place 6. Depth 1.27 m.

The concentration profiles in sampling places 3 to 9 were rather similar. It can be seen from diagram 5 that the concentration decreases rapidly between 40 and 70 mm outward from the injection hole and that the penetration depth (i.e. concentrations higher than the detection limit) is at least 80 mm.

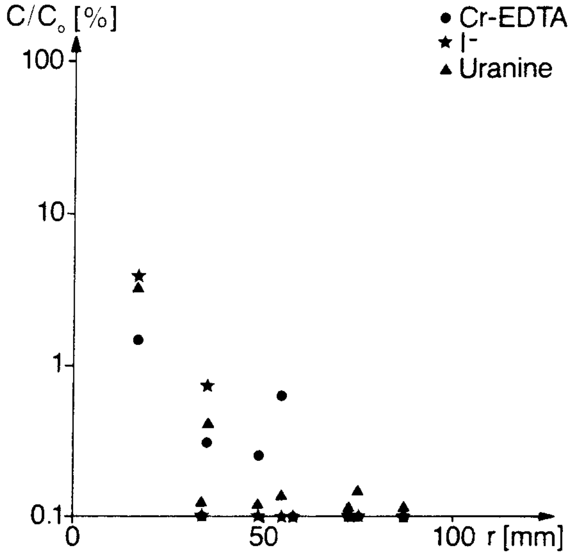
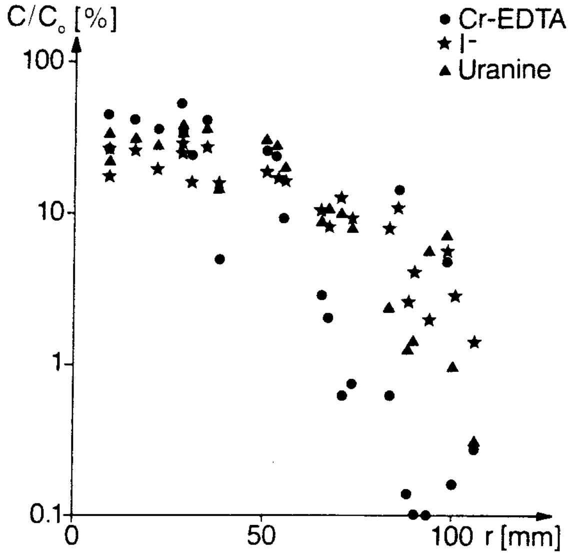


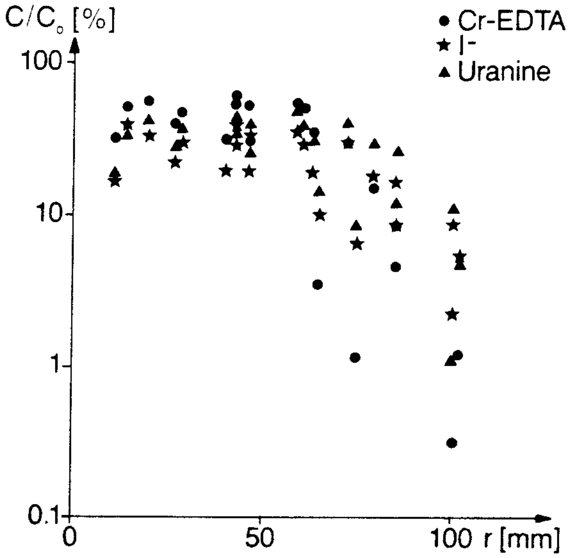
Diagram 6. Tracer concentration vs. distance from injection hole for sampling place 12. Depth 1.55 m.

Sampling places 10 to 13 (depth 1.46 m - 1.59 m) showed the shortest penetration depth. The concentration in these sampling places was low even close to the injection hole and the penetration depth was only about 50 mm (see diagram 6).



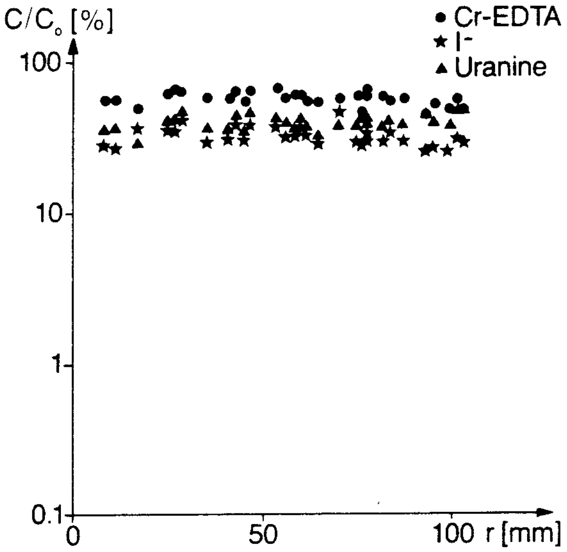
In sampling places 14-19 (depth 1.74 m - 2.08 m) somewhat higher concentrations were found. Diagram 7 shows that Uranine and I^- have migrated at least 110 mm, while the Cr-EDTA con- concentration becomes very low approximately 90 mm from the injection hole.

Diagram 7. Tracer concentration vs. distance from injection hole from sampling place 19. Depth 2.08 m.



In sampling place 20. the concentration had increased a little further. For Uranine and I^- the concentration tends to decrease approximately 90 mm from the injection hole. while the decrease comes ≈ 20 mm earlier for Cr-EDTA.

Diagram 8. Tracer concentration vs. distance from injection hole for sampling place 20. Depth 2.24 m.



For sampling places 21 and 22 (depth 2.62 m - 2.67 m). none of the three tracers showed any drop in concentration for at least 110 mm.

Diagram 9. Tracer concentration vs. distance from injection hole for sampling place 21. Depth 2.62 m.

From diagrams 4. 5. 7-9, which show a high concentration of all three tracers, it can be seen that close to the injection hole Cr-EDTA has the highest concentration while Uranine in most cases has a somewhat higher concentration than I$^-$.

In diagrams 5-8, which show a decrease in concentration with distance from the injection hole. it is obvious that Cr-EDTA has the lowest concentration at distances 50-100 mm from the injection hole, while the concentration for Uranine and I$^-$ is nearly equal.

8.2 Concentration profiles in core 2

The distance between the injection hole and the sampling cores from core 2 was between 150 mm and 250 mm.

Tracers were found in 8 of the 24 sampling places from core 2. These 8 sampling places are: E1-E3 (depth 0.31 m - 0.42 m) and E19-E23 (depth 2.41 m - 2.64 m) (see figure 7). The fact that tracers were found only in the top and the bottom of core 2 agrees well with the concentration profiles from core 1.

Since some of the sampling places from core 1 and core 2 were situated at approximately the same depth, it was in some cases possible to study the concentration profile all the way from the injection hole and ≈ 250 mm outward.

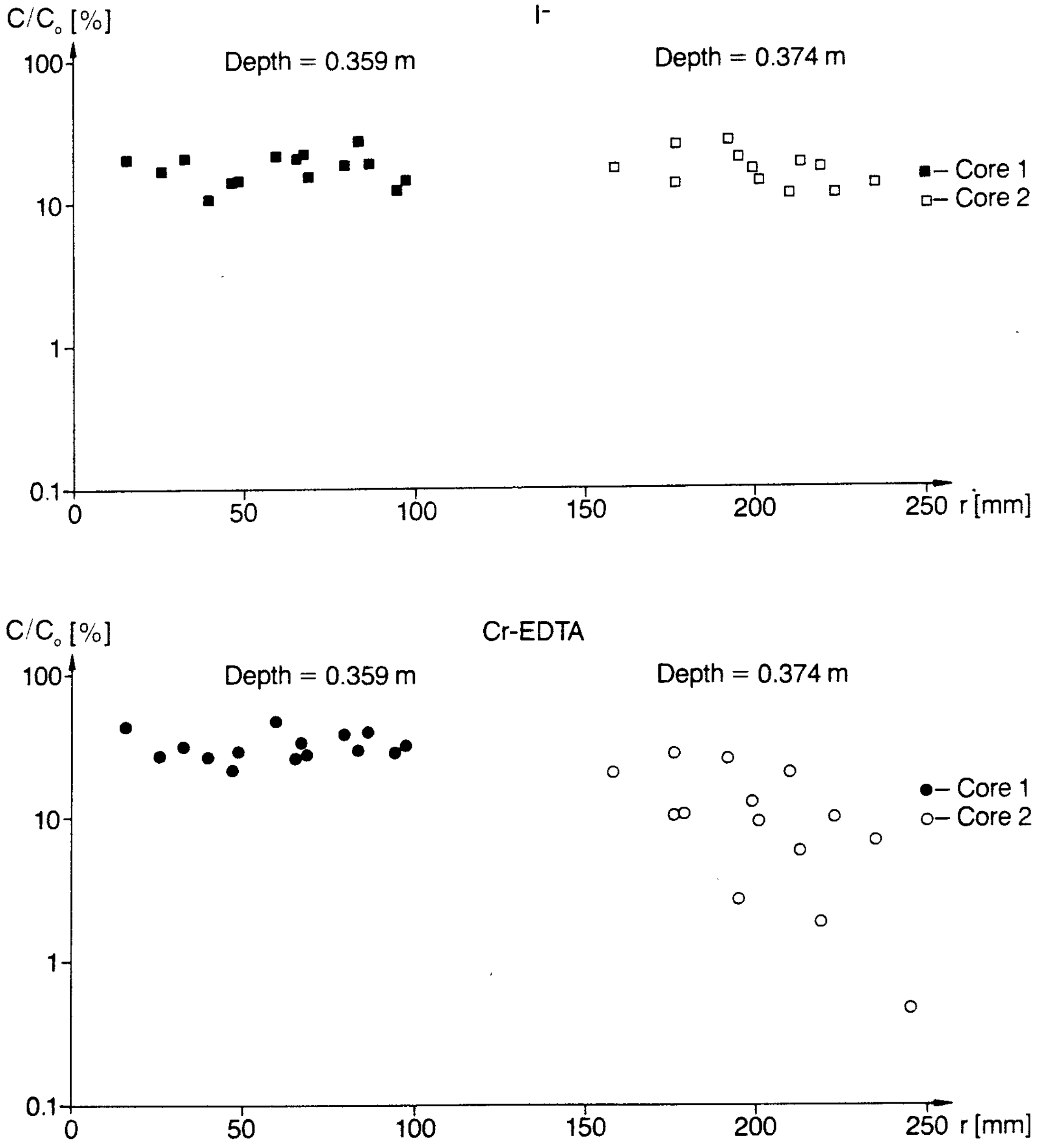


Diagram 10. Tracer concentration vs. distance from injection hole for sampling place 1 and 2E.
Difference in depth = 15 mm.

Diagram 10 indicates that the I^- concentration does not decrease with distance from injection hole for at least 250 mm. Furthermore, the Cr-EDTA concentration shows a significant decrease 200-250 mm from the injection hole.

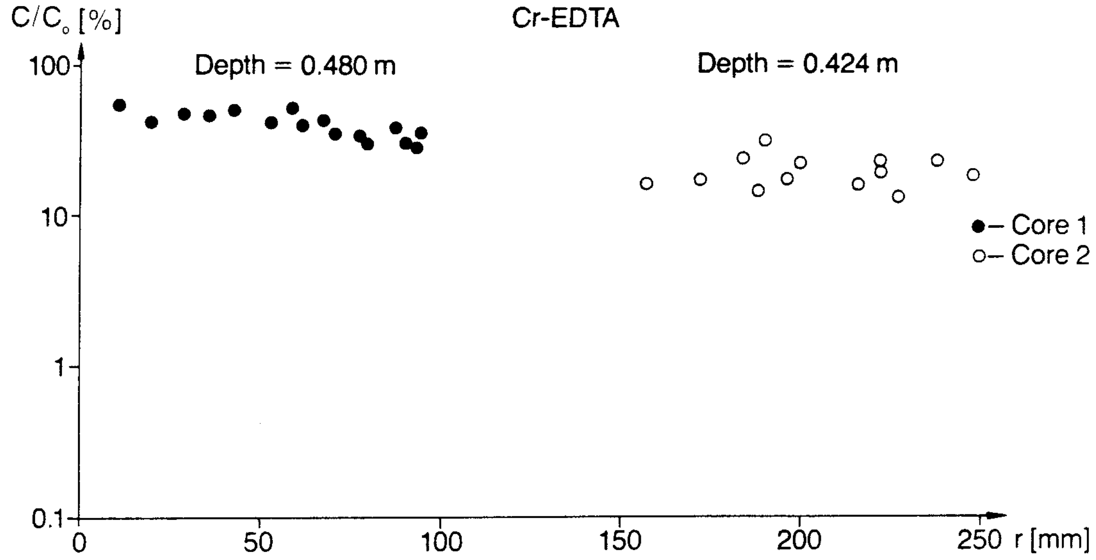


Diagram 11. Cr-EDTA concentration vs. distance from injection hole for sampling place 2 and 3E.
Difference in depth = 56 mm.

Diagram 11 illustrates the depth in core 2 that has the highest Cr-EDTA concentration. There is no significant decrease in concentration for Cr-EDTA (or the other tracers) for at least 250 mm.

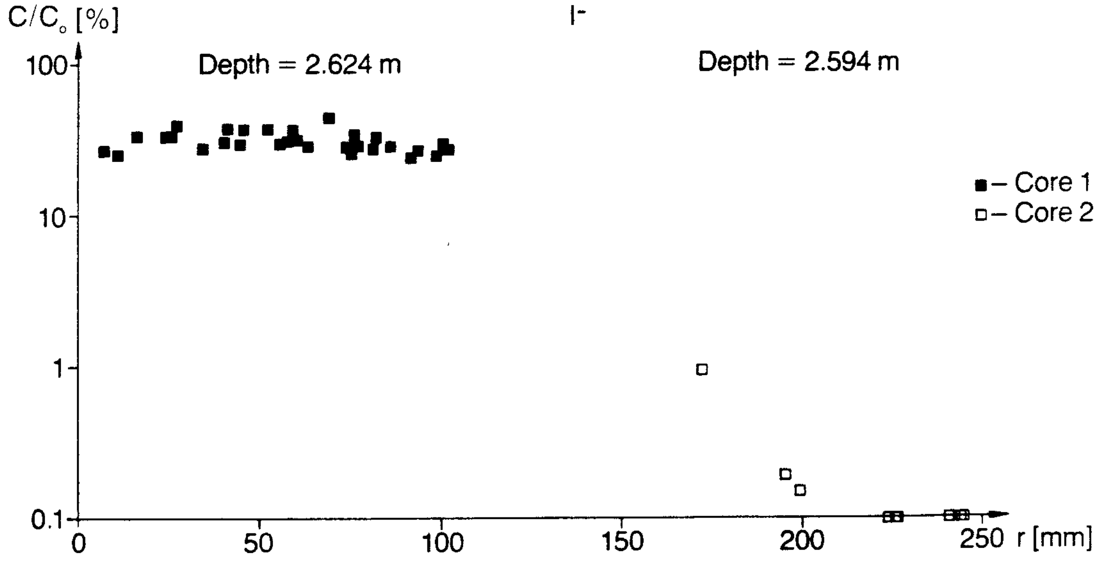


Diagram 12. I$^-$ concentration vs. distance from injection hole for sampling places 21 and 22E.
Difference in depth = 30 mm.

Neither Cr-EDTA nor Uranine was found in sampling place 22E, but diagram 12 shows that I^- has penetrated this sampling place. It can also be seen that there is a drastic drop in concentration between core 1 and core 2 (i.e. between 110-170 mm from the injection hole).

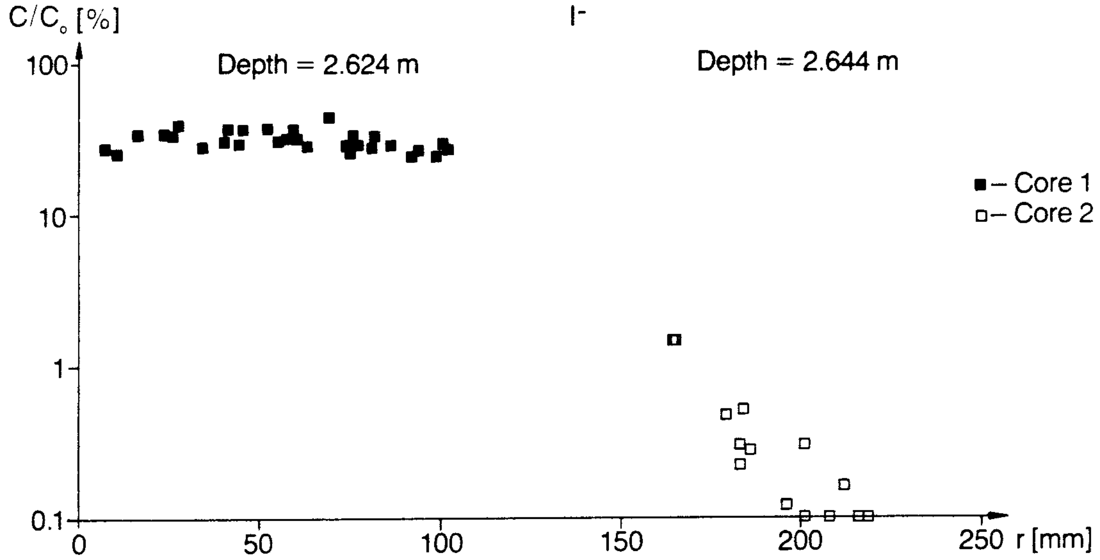


Diagram 13. I^- concentration vs. distance from injection hole for sampling places 21 and 23E.
Difference in depth = 20 mm.

The results from sampling place 22E and 23E (diagrams 12 and 13) both show that only I^- has penetrated core 2 at these depths and that there is a drastic decrease in concentration between core 1 and core 2.

The concentration profile for sampling places E19-E21 (depth 2.41 m - 2.51 m) could not be followed all the way from the injection hole, since core 1 was crushed at the corresponding depth.

However, sampling places 19E and 20E showed high concentrations of all three tracers and even if the values from these sampling places are scattered, there is no significant indication of any major decrease in concentration for at least Uranine and I^-.

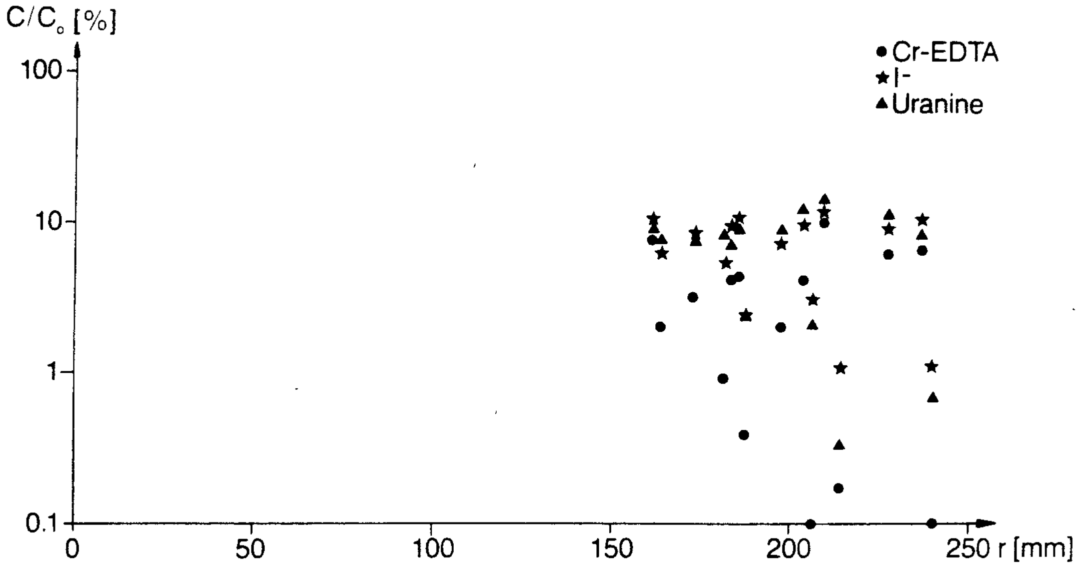


Diagram 14. Tracer concentration vs. distance from injection hole for sampling place 20E.
Depth 2.46 m.

Compared with the previous diagram, sampling place 21E had lower concentration and all three tracers (particularly Cr-EDTA) show a significant decrease in concentration at large distances from the injection hole (see diagram 15).

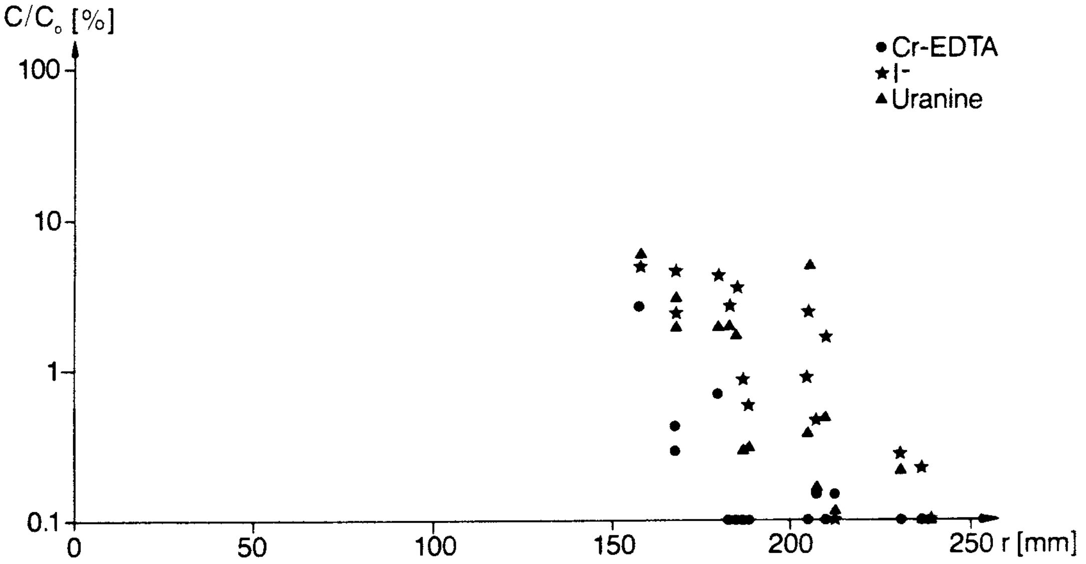


Diagram 15. Tracer concentration vs. distance from injection hole for sampling place 21E.
Depth 2.51 m.

8.3 Penetration depth for a fixed concentration

The difference in migration distance with depth, can be illustrated very clearly if the penetration depth for a fixed concentration is plotted versus the depth in core.

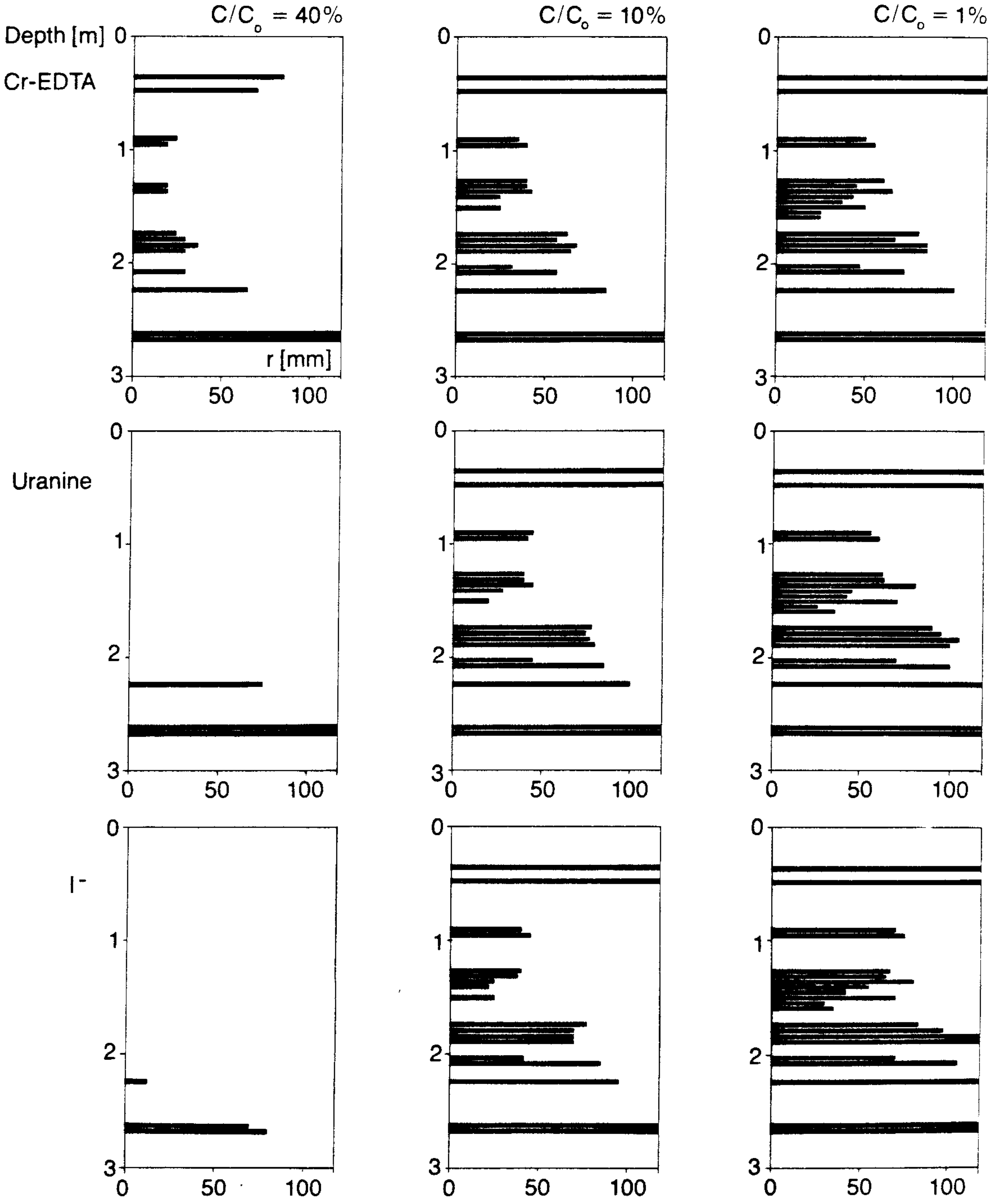


Figure 8. Core 1. Penetration depth for different concentrations for Cr-EDTA. Uranine and I$^-$ vs. depth in core.

It can be seen from figure 8 that just 3 of the 22 sampling places from core 1 had Uranine and I^- concentrations of c/c_0 = 40 % or higher. while this concentration was found in 14 sampling places for Cr-EDTA.

The diagrams for c/c_0 = 10 % indicates that the penetration distance for this concentration is approximately the same for all three tracers. The variation in penetration distance is illustrated for all three tracers.

The diagrams for c/c_0 = 1 % clearly show that I^- has the longest and Cr-EDTA the shortest penetration distance for this concentration.

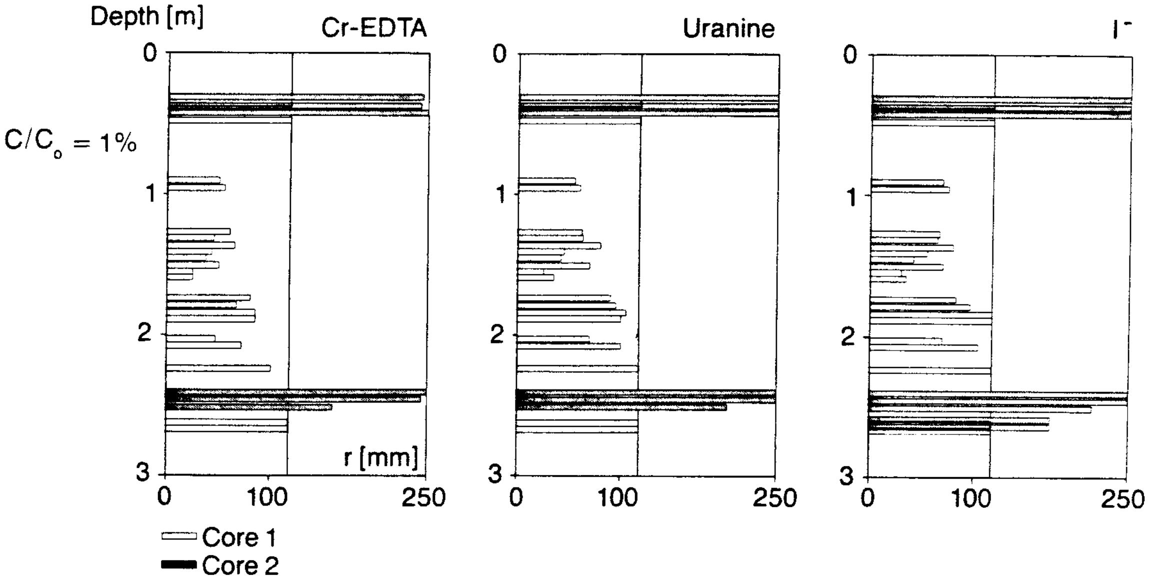


Figure 9. Core 1 and core 2. Penetration distance for c/c_0 = 1 % for Cr-EDTA, Uranine and I^- vs. depth in the cores.

Figure 9 shows that the concentration profiles for all three tracers could be followed at the same depth in core 1 and core 2 in the top of the cores. This was also possible in the bottom of the cores for I^-.

9. CAUSES OF THE DIFFERENCES IN PENETRATION DEPTHS

The fact that the migration distance is different at different depths. can be caused by·

- o Differences in porosity (ε_p)
- o Differences in the migration parameters (K_p and D_p).

9.1 Porosity

The porosity has been measured for every individual sampling core by comparing the weight difference between wet and dry core. Figure 10 illustrates the mean value of the porosity (+/- the standard deviation) for each sampling place from core 1 and core 2.

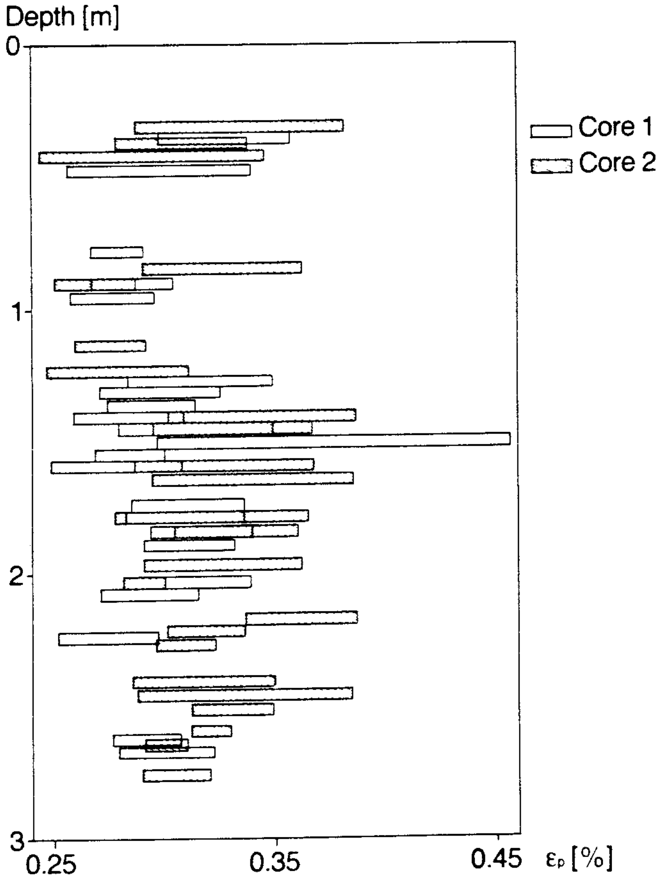


Figure 10. Core 1 and core 2. The porosity (+/- the standard deviation) vs. depth.

Since the porosity is almost the same for all sampling places, the difference in migration distance with depth cannot be explained by the porosity.

9.2 Hydraulic conductivity and diffusivity

Variation in the migration parameters (K_p and D_p) with location due to inhomogeneities, seem to be the reason for the considerable differences in migration distance for sampling places that were separated by just a few tens of centimeters.

The values of the hydraulic conductivity that are given in the discussion below are based on an overpressure of 0.5 MPa (see chapter 3). If the overpressure is lower, the hydraulic conductivity will increase correspondingly (overpressure x K_p = const.). All calculated curves are based on an uniform porosity in the rock matrix of $\varepsilon_p = 0.34$ %.

In diagram 16 a comparison is made of computed and experimental values for one of the sampling places from the part of the core which had the shortest migration distance.

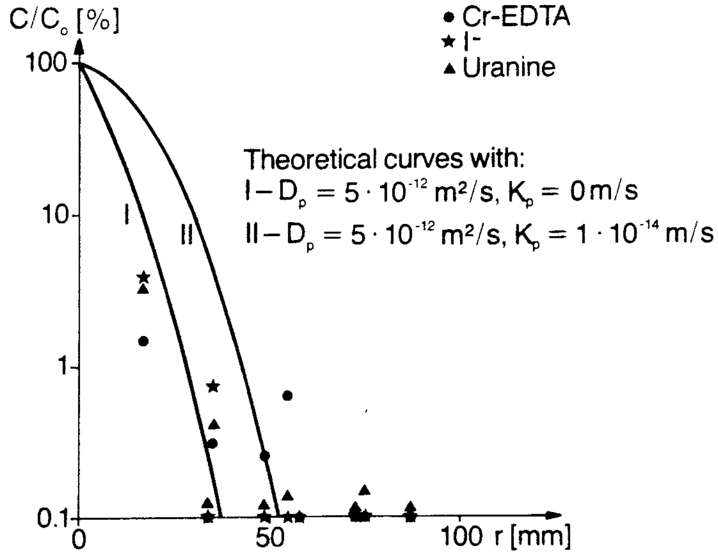


Diagram 16. Sampling place 12. Comparison of computed and experimental values.

If the concentration profiles for sampling place 12 should be explained by diffusion only (curve I), a diffusivity of $D_p \approx 5 \cdot 10^{-12}$ m^2/s is obtained. This diffusivity should be compared with $D_p = 1 \cdot 10^{-10}$ m^2/s, which is the expected value of the diffusivity based on the results from part 1 of the field test (see chapter 7).

Part 1 of the field test also indicated that the hydraulic conductivity was approximately $K_p \approx 1 \cdot 10^{-13}$ m/s (see chapter 7). If the concentration profile for this sampling place should be explained by diffusion and convection, it can be seen from diagram 16 that the hydraulic conductivity can not be higher than $K_p \approx 1 \cdot 10^{-14}$ m/s.

o The results from sampling places 10 to 13, here illustrated with sampling place 12, which was taken from that part of the core which showed the shortest migration distance can be explained by diffusion and convection, but the values of D_p and K_p will then be at least one order of magnitude lower than previously obtained.

The concentration profiles from sampling places 3 to 9, which showed somewhat higher concentrations than sampling places 10 to 13, can also be explained by diffusion and convection.

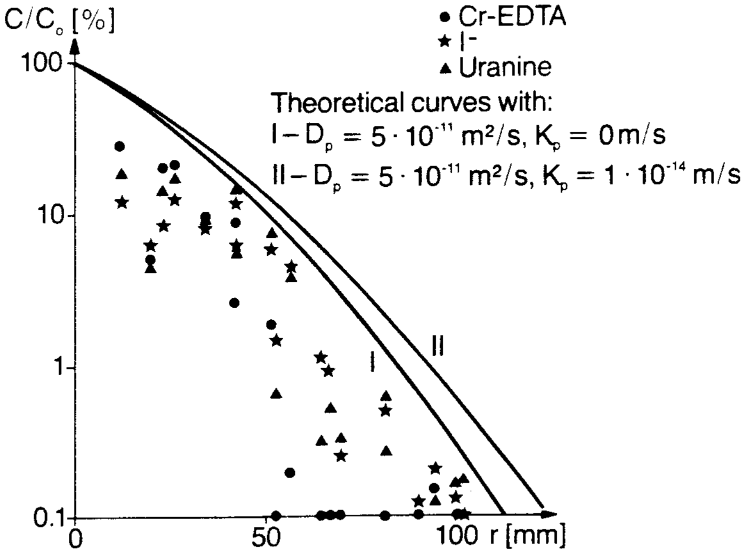


Diagram 17. Sampling place 6. Comparison of computed and experimental values.

If caused by just diffusion, the diffusivity becomes $D_p \approx 5 \cdot 10^{-11}$ m^2/s for sampling place 6. This diffusivity is rather close to the expected diffusivity ($D_p = 1 \cdot 10^{-10}$ m^2/s). In order to explain the concentration profiles with diffusion and convection, the hydraulic conductivity has to be approximately one order of magnitude lower than "expected", i.e. $K_p \approx 1 \cdot 10^{-14}$ m/s.

o The concentration profiles for sampling places 3 to 9, which showed rather short migration distances, can be explained by a diffusivity that is only somewhat lower than "expected" and a hydraulic conductivity that is approximately one order of magnitude lower than "expected".

The concentration profiles for sampling places 14 to 20 agree rather well with the "expected" values of D_p and K_p.

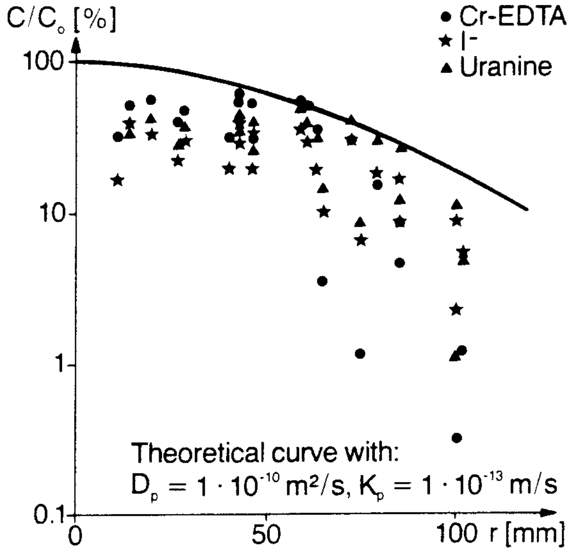


Diagram 18. Sampling place 20. Comparison of computed and experimental values.

- o The concentration profiles for sampling places 14-20 can be explained with the "expected" values for both the diffusivity and the hydraulic conductivity, i.e. $D_p \approx 1 \cdot 10^{-10}$ m^2/s and $K_p \approx 1 \cdot 10^{-13}$ m/s.

The concentration profiles for the sampling places which have not been discussed so far (i.e. sampling places 1, 2, 21. 22). in which the concentration was very high and did not decrease for at least the first 120 mm from the injection hole. can be explained by a hydraulic conductivity that is $K_p > 2\text{-}5 \cdot 10^{-13}$ m/s, with data from core 1 only, the diffusivities for these sampling places cannot be estimated since there was no decrease in concentration with distance. A matrix which has a high hydraulic conductivity, will probably also have a high diffusivity.

- o The concentration profiles for sampling places 1, 2, 21, and 22 can be explained with a hydraulic conductivity that is somewhat higher than the "expected " conductivity (i.e. $K_p > 2\text{-}5 \cdot 10^{-13}$ m/s). Because of the high value on the hydraulic conductivity, the diffusivity is also expected to be high, i.e. $D_p > 1 \cdot 10^{-10}$ m^2/s.

These approximative values of D_p and K_p are summarized in table 2, to indicate what the difference in migration distance with depth means in terms of diffusivity and hydraulic conductivity.

Sampling place	Depth (m)	D_p (m^2/s)	K_p (m/s)
1-2	0.36-0.48	$> 1 \cdot 10^{-10}$	$> 2\text{-}5 \cdot 10^{-13}$
3-9	0.78-1.41	$\approx 0.5 \cdot 10^{-10}$	$\approx 0.1 \cdot 10^{-13}$
10-13	1.46-1.59	$\approx 0.05 \cdot 10^{-10}$	$< 0.1 \cdot 10^{-13}$
14-20	1.74-2.24	$\approx 1 \cdot 10^{-10}$	$\approx 1 \cdot 10^{-13}$
21-22	2.62-2.67	$> 1 \cdot 10^{-10}$	$> 2\text{-}5 \cdot 10^{-13}$

Table 2. Approximative values on D_p and K_p for different depths in core 1.

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 removed. The release of pressure allows the tracers to migrate to the injection hole from the surrounding rock by flow and diffusion. The time between pressure release and overcoring was approminately 1 week for core 1 and ≈ 2 weeks for core 2.
II - Overcoring	During the overcoring, the cores were flushed with water (drilling liquid) and the tracers could migrate out from the core by diffusion. It took ≈ 3 hours to overcore 3 m.
III - Sampling	During the sampling (cutting into pieces and drilling of sampling cores) the cores were flushed with water. This means diffusion out from the core during ≈ 5 minutes (cutting) respective ≈ 2 minutes (drilling).
IV - Analysis	The accuracy of the analysis was about +/- 0.1 for $c/c_0 = 0.005$ and < +/- 0.1 for higher concentrations.

Points I, II, and III will decrease the concentration in the sampling cores. Therefore, the concentration in the cores may have been higher than indicated in the foregoing diagrams.

The fact that the concentration relative to the injection concentration does not become higher than c/c_0 = 40-60 % even close to the injection hole was also observed in part 1 of the field test. A part of this concentration difference between the experimental points and theoretical calculated points can naturally be explained by points I, II, and III above, but at present we have no satisfactory explanation for the remaining difference in concentration.

10.2 Impact on radionuclide migration

The calculations of migration rates for different radionuclides includes diffusion into the rock matrix. The diffusivity is assumed to be $D_p\varepsilon_p = 5 \cdot 10^{-14}$ m^2/s in some calculated examples (KBS III).

From figure 10, which illustrates the porosity vs. depth, it can be seen that the porosity in this experiment is close to $\varepsilon_p = 0.3$ % and that there is no significant change in porosity with depth. The value $D_p\varepsilon_p = 5 \cdot 10^{-14}$ m^2/s corresponds to a diffusivity of $D_p \approx 0.2 \cdot 10^{-10}$ m^2/s, with a porosity of $\varepsilon_p \approx 0.3$ %. How relevant this diffusivity is for diffusion in the rock matrix can be seen from table 2, where the approximate values for the diffusivities from this experiment is presented.

Sampling place	Number of sampling places	Comment
10-13	4	Lower diffusivity than $5 \cdot 10^{-14}$ m^2/s
3-9	7	Somewhat higher diffusivity than $5 \cdot 10^{-14}$ m^2/s
1-2, 14-22	11	Higher diffusivity than $5 \cdot 10^{-14}$ m^2/s

Table 3. Comparison between the diffusivities that have been obtained in this experiment and the diffusivity that is used in some sample calculations.

The discussion above indicates that the diffusivity that is used in the sample calculations should be regarded as somewhat conservative, compared with the diffusivity that was obtained from this experiment.

11. CONCLUSION

The conclusions from this experiment are:

- Tracers have migrated through the disturbed zone and a distance into "undisturbed" rock.
- The diffusivities found in in-situ experiments compare well with those found in laboratory measurements (7).

The results indicate that it is possible for tracers (and therefore radionuclides) to migrate a distance into a rock matrix under natural stress conditions.

12. FUTURE WORK

An experiment similar to that described here is now carried out in another hole in the Stripa mine. The injection of tracers (same tracers as in the presented experiment) started at the same time in both experiments, and will continue approximately 2.5 years for the experiment underway.

The drilling arrangements are similar in both holes, with the exception that the hole underway is somewhat shorter (15 m Ø 146 mm + 3 m with Ø 20 mm).

REFERENCES

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

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

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

4. Birgersson, L., Neretnieks, I., Diffusion in the matrix of granitic rock. Field test in the Stripa mine. Part 1. SKBF/KBS Technical Report 82-08, July 1982.

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

6. 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.

7. Skagius, K., Neretnieks, I., Diffusion measurements in crystalline rocks. SKBF/KBS Technical Report, 1983.

NOTATION

c	concentration in liquid	mol/m^3
c_o	injection concentration	mol/m^3
d	diameter	m
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
r	radial distance	m
t	time	s
t_c	contact time	s
v_r	radial velocity	m/s

Δ	difference	
ε_p	porosity in unfractured rock, matrix porosity	m^3/m^3
σ_r	radial tension	Pa
σ_t	tangential tension	Pa
Ø	diameter	m

LIST OF KBS's TECHNICAL REPORTS

1977-78

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

1979

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

1980

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

1981

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

1983

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The Royal Institute of Technology
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I Puigdomènech
J Bruno
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Royal Institute of Technology
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State University of New York at Buffalo
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