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SUMMARY

At expected radioactive waste repository depths in the ground the rock is exposed to rather high stresses caused by the large overburden of rock. When drillcores are taken up from the ground this overburden no longer exists. As a result of this there might be an increase in the porosity of the rock samples. The effective diffusivity measured in rock samples under atmospheric pressure in the laboratory would then be higher than the effective diffusivity in the rock "in situ".

To simulate the stress that may exist in the bedrock at large depths, diffusion experiments with iodide and electrical resistivity measurements in rock materials under mechanical stress have been performed. It was found that the diffusivity in rock samples at 300-350 bars stress was reduced to 20-70 % of the value in the samples under atmospheric pressure.

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INTRODUCTION

In crystalline rocks which are fissured, radionuclides released from an underground repository will be transported with the moving groundwater along fissures in the rock. A significant retardation of the nuclides can be expected if the nuclides migrate into the micropores of the rock by molecular diffusion (1).

Several investigators have studied the diffusion in micropores in rock materials (2, 3, 4). Bradbury et al (2) have determined the effective diffusivity (pore diffusivity times porosity) of iodide in United Kingdom Granites. They found the effective diffusivity to be about $3 \cdot 10^{-14}$ m^2/s in a granite with porosity of about 0.08 %, and about $2 \cdot 10^{-12}$ m^2/s in a granite with porosity of about 2 %. In a previous investigation (5) we have studied the diffusion of iodide, Uranine and Cr-EDTA in rock materials from different areas in Sweden. The experimentally found effective diffusivity of iodide was in the range $1 \cdot 10^{-14}$ m^2/s to $7 \cdot 10^{-13}$ m^2/s and the porosity was 0.07-0.3 %.

All these experiments have been performed in rock samples under atmospheric pressure in the laboratory. However, at expected repository depths in the ground the rock is exposed to rather high stresses (150-300 bars) caused by the large overburden of rock. When drillcores are taken up this overburden no longer exists. As a result of this there might be an increase in the porosity of the rock due to elastic expansion. The determined effective diffusivity can then be expected to be higher in the drillcore than in the rock "in situ".

This paper describes diffusion experiments and electrical resistivity measurements in rock materials under mechanical stress corresponding to repository depths. The diffusing component is iodide, and the rock materials are from the same areas as in the previous diffusion experiments (5). Electrical resistivity measurements may be an indirect and much faster method to determine effective diffusivities.

DESCRIPTION OF THE ROCK MATERIALS

The rock materials were taken from different areas of Sweden, and at different depths in the rock matrix. Table 1 gives the areas and depths from which the rock materials have been taken, and also a description of the materials and a notation that will be used in the presentation of the results from the experiments. The rock materials and their description have been received from the Swedish Geological Survey (SGU) in Uppsala (6).

EXPERIMENTAL

The apparatus used in the diffusion experiment is shown in Fig. 1. On each side of a water saturated rock sample (ø 42 mm, ~ 10 mm thick), a plate of stainless steel with circular channels was mounted. The channels in each plate were connected to a circulation system by stainless steel tubes. The solution in each circulation system flowed through a tube into the centre of the plate, then circulated in the channels which were in contact with the rock sample and then out to a storage bottle via the tube connected to the periphery of the plate. The rock sample with the plates were confined in a layer of polyurethane and placed in a pressure cell. The pressure in the pressure cell was raised by filling the cell with hydraulic oil. The polyurethane is deformable and can therefore transmit the pressure from the oil to the rock sample. During the diffusion experiment the pressure cell was placed in a water bath at a temperature of 25 °C.

At the high concentration side a 0.1 mol/l sodiumiodide solution, and at the low concentration side a 0.1 mol/l sodiumnitrate solution was circulated. The solution volume in each circulation system was 200 ml. At different times samples were taken out from the storage bottle at the low concentration side. The iodide concentration in the samples was measured using an ion selective electrode. Each time a sample had been taken out, the same volume (10 ml) of a 0.1 mol/l sodiumnitrate solution was added to the storage bottle to keep the volume in the circulation system constant. The rate of transport of iodide through the samples is so small that the concentration on the high concentration side changes less than 0.1 % during the experiment.

In the first experiments only the diffusivity in the samples under stress was determined. In the rest of the experiments the diffusivity in the samples was determined both under unstressed and stressed conditions.

The apparatus used in the electrical resistivity measurements was similar to the apparatus used in the diffusion experiments (Fig. 2).

Rock cores (ø 42 mm, $\ell \sim 30$ mm) were saturated with 1 mol/l NaCl solution. The concentration of the salt-water solution must not be too low because then the pore surface conductivity in the rock core might influence the results (7). On either side of the saturated rock core a stainless steel plate was placed. The plates acted as electrodes, and they could also, in small channels, take up the pore solution which would be pressed out from the core during the experiment due to compression of the sample. Between the core and the electrodes a thin compressed slab of porous foam rubber, saturated with the same NaCl-solution as the core was placed. This ensured good electrical contact between the rock core and the electrodes. The whole package with the rock core and the electrodes was then cast in polyurethane. Before doing this the rock core had to be surface dry.

The rock core with electrodes was placed in a pressure cell and the electrodes were connected to a conductivity meter (type Wheatstone bridge). The pressure in the cell was raised by pumping in hydraulic oil. At various pressures the resistance in the saturated rock core was measured at a frequency of 50 Hz.

EVALUATION OF THE DIFFUSIVITY AND THE FORMATION FACTOR

For a porous slab initially at zero concentration, with constant inlet concentration c_1 at $x = 0$, and outlet concentration c_2 ($c_2 \ll c_1$) at $x = \ell$, the total quantity of diffusing substance Q which has passed through the slab in time t is obtained by solving Fick´s first and second law. The solution is (8)

$$\frac{Q}{\ell \cdot c_1} = \frac{D_e \cdot t}{\ell^2} - \frac{\alpha}{6} - \frac{2 \cdot \alpha}{\pi^2} \sum_{n=1}^{\infty} \frac{(-1)^n}{n^2} \exp\left(- \frac{D_e \cdot n^2 \cdot \pi^2 \cdot t}{\ell^2 \cdot \alpha}\right) \qquad (1)$$

D_e = $D_p \cdot \varepsilon^+$ = effective diffusivity
D_p = pore diffusivity
ε^+ = transport porosity of the slab
α = $\varepsilon_{tot} + k_d \cdot \rho$ = rock capacity factor
ε_{tot} = total porosity of the slab
k_d = sorption coefficient
ρ = density of the slab

As $t \to \infty$ eq. 1 approaches the linear relation

$$Q = \frac{c_1 \cdot D_e}{\ell} \cdot t - \frac{c_1 \cdot \ell \cdot \alpha}{6} \qquad (2)$$

By making a linear correlation of the experimental concentration versus time data at longer times, D_e can be determined from the slope of the line.

Because of the geometry of the endplates the crossectional area available for diffusion inside the sample is somewhat larger than the contact area between the sample and the solutions at the low and high concentration side. The solutions are flowing in circular channels in the steel plates, and the contact areas between the solutions and the sample are about 50 % of the crossectional area of the sample. The use of equation 2 to determine the effective diffusivity will then give a value that is too low.

To investigate how large the error will be by using eq. 2 in estimating the effective diffusivity, Fick´s first and second law have been solved numerically for two-dimensional diffusion by a computer program (TRUMP) (9). The concentration versus time curve has been simulated for different effective diffusivities and total porosities when the crossectional area available for diffusion between solution and sample is the same as that in the diffusion experiments under stress (see figure 3). From the slope of the simulated concentration versus time curve the effective diffusivity was determined (eq. 2). The result was that eq. 2 gave a value of the effective diffusivity that was 14 % too low. Eq. 2 can then be used to determine the effective diffusivity with the knowledge that the value is 14 % too low.

There are some indications that electrical conductivity and molecular diffusion may depend in the same way on the formation factor $\varepsilon^{+}\cdot\delta_D/\tau^2$ (10). This means that

$$\frac{D_e}{D_v} = \frac{\varepsilon^{+}\cdot\delta_D}{\tau^2} = \frac{R_o}{R_s} \qquad (3)$$

where R_s is the resistivity of the salt-water-saturated rock sample and R_o is that of the salt water, δ_D is the constrictivity and τ the tortuosity of the pores in the rock sample, and D_v is the bulk phase diffusivity of the diffusing component. A change in the resistivity of the salt-water-saturated rock sample with pressure will lead to a change of the formation factor and also to a change of the effective diffusivity.

RESULTS AND DISCUSSION

Figure 4 shows a plot of the concentration at the low concentration side versus time for iodide diffusion through a piece from Svartboberget SB 21. The experiment was started with the piece under atmospheric pressure. After 35 days the pressure was increased to 330 bars. A linear regression of the experimental data at atmospheric pressure and at 330 bars was made. From the slope of the lines the effective diffusivities were determined according to eq. 2. These values were then corrected by dividing them with 0.86 because of the reduced contact area between the solutions and the rock piece.

In Table II the determined effective diffusivities are presented. In about half of the experiments only the diffusivity in the rock piece under stress has been measured. In the experiments where the diffusivity has been determined both under atmospheric pressure and under stress, the relation between these two diffusivities is presented in Table II. As a comparison the effective diffusivities of iodide in the same type of rock materials from a previous investigation (5) are presented in Table II.

For Finnsjö granite (F) the diffusivities at atmospheric pressure are in agreement with the results from the previous investigation (5). The diffusivity in Finnsjö granite pieces under 320-330 bars stress is about 60 % of the value at atmospheric pressure.

In the granite from Gideå (GAA 1) both the diffusivity in a piece under atmospheric pressure and the diffusivities in pieces under stress are higher than the diffusivities from the previous investigation. However, comparing the diffusivity in a piece under 330 bars stress with the diffusivity in the same piece under atmospheric pressure shows that the diffusivity in the piece under stress is reduced to about 40 % of the value at atmospheric pressure.

In gneisses from Gideå (GAA 7) and Svartboberget (SB 1) only the diffusivity in pieces under stress has been measured. The diffusivity in the gneiss from Svartboberget (SB 1) is put within brackets. The reason is that the concentration even after long times was very low with a large scatter between the values. This made it difficult to make a linear correlation of the data. Comparing the diffusivities in the pieces under stress with the results from the previous investigation, the same rock materials but different pieces, shows that the diffusivity is lower in the pieces under stress.

In the granite (SB 7) and the biotite gneiss (SB 21) from Svartboberget the diffusivity in the pieces under atmospheric pressure lies in the range of the diffusivities determined in the previous investigation. In the granite the diffusivity in the piece at a stress of 310 bars is reduced to about 70 % of the value of atmospheric pressure and in the biotite gneiss the value at 330 bars is about 40 % of the value at atmospheric pressure.

The diffusivity in biotite gneiss pieces from Fjällveden (FJ) was found to be both higher and lower than the diffusivities determined in the previous investigation. In both pieces the diffusivity decreased when the pressure was increased. At a pressure of 200 bars the diffusivity was decreased to about 50 %, and at 330 bars to about 20 % of the value at atmospheric pressure.

An attempt was made to measure the porosity of some of the samples under stressed conditions. When the diffusion experiment under stress was finished the two circulation systems were emptied of the solutions. With the sample still under stress the circulation systems were filled with distilled water, and the water was circulated during a few hours. This was to clean the channels in the steel plates from iodide. Then the pressure was released. The sample was taken out from the pressure cell and placed in distilled water to leach out the iodide from the pores in the sample. After about 3 weeks the iodide concentration in the leach solution was constant. From this concentration the porosity of the sample under stressed conditions was determined, using the assumption that the concentration profile is linear in the sample.

After the leaching procedure the sample was taken out from the leach solution. The surfaces of the sample were dried carefully with a piece of paper. Surface dry, the sample was weighed. The sample was then kept at 90 ° C in vacuo for several days, and then weighed again. From the difference in weight of the sample water saturated and vacuum dried the porosity of the sample under unstressed conditions was determined.

In Table III the results from the porosity determination are presented. The relation between the porosity of the samples under stressed and unstressed conditions and between the diffusivity in the samples under stressed and unstressed conditions are also given.

The Table shows that the porosity of the samples under stressed conditions is lower than under unstressed conditions. The relation between the porosities and between the diffusivities are not the same. The diffusivity in the samples under unstressed conditions was measured before the samples were put under stress. The porosities of the samples under unstressed conditions was, however, measured after the samples had been stressed-unstressed. These porosities are higher than the porosities determined by the same method for the same type of rock materials in the previous investigation (5). In the previous investigation the porosity determination was made on samples that had not been exposed to mechanical stress. The porosity determinations in this investigation on samples under stressed and unstressed conditions must be looked upon as approximative values.

In the resistivity measurements the pressure was raised in steps, and the resistance was measured at each level. From the resistance the resistivity was calculated, and then the formation factor $\varepsilon^{+}\cdot\delta_{D}/\tau^{2}$, was determined by eq. 3. The resistance was also measured as the pressure was lowered from the maximum value down to atmospheric pressure.

Figure 5 shows the formation factor versus pressure for a granite sample from Finnsjön (F), where the procedure with increasing and decreasing the pressure have been made two times on the same rock sample. The formation factor decreases with increasing pressure, and then increases again when the pressure is lowered down to atmospheric pressure, however, not to the same values. The second time the procedure with increasing and decreasing the pressure was performed, about the same values as the first time was obtained for pressures higher than 100 bars. The decrease in the formation factor with pressure indicates that the crossectional area of the pores in the sample is decreased when the sample is under mechanical stress.

The gneiss from Gideå (GAA 7) and the gneiss from Svartboberget (SB 1) showed a different behavior than the rest of the samples studied. In Figure 6 the formation factor versus pressure for two gneiss samples from Gideå and one gneiss sample from Svartboberget is shown. For these samples the formation factor at 350 bars was higher than the starting value at atmospheric pressure. When the pressure was lowered down to atmospheric pressure the final value at atmospheric pressure was also higher than the starting value at atmospheric pressure. Brace and Orange (11) have presented similar results when they measured the resistivity versus pressure in rock cores that was partly saturated with a salt solution. Maybe the results for the gneisses from Gideå and Svartboberget could be explained by the fact that the samples were not fully saturated with the salt solution when the experiments were started. In the previous investigation, Skagius et al (5) it was found that these gneisses from Gideå and Svartboberget had the lowest porosity (~ 0.1 %) of the rock materials studied, and that the diffusivity of iodide was lower in these gneisses compared to the other rock materials (see Table II). If the pores in these gneisses are small the saturation method used here may not have been good enough to give a complete saturation of the samples.

In Table IV the formation factor at different pressures for all the samples studied are presented. The first value in each column is the formation factor obtained when the pressure was increased, and the second value is the formation factor obtained when the pressure was decreased. The Table shows that the formation factor decreases with increasing pressure for all the samples except for the gneisses from Gideå and Svartboberget.

Figures 7-11 show the formation factor versus pressure for granite from Finnsjön (Fig. 6), granite from Gideå (Fig. 7), granite (Fig. 8) and biotite gneiss (Fig. 9) from Svartboberget and biotite gneiss from Fjällveden (Fig. 10). The values from the resistivity experiments are the values obtained when the pressure was increased. The surface dry value is the formation factor calculated from a resistivity measurement made on the samples before the samples with the electrodes were coated with polyurethane. Before these measurements were made the outer surface of the samples had been dried so that the conduction only would be in the pores of the samples. The formation factors calculated from the diffusion experiments under stress are also marked in the Figures.

The Figures show that in the resistivity experiments the surface dry formation factor for a sample is always lower than the formation factor obtained when the experiment was started. Obviously something happens when the samples are coated with polyurethane. A higher formation factor means a higher conductivity, but no conduction could be measured in the polyurethane. One explanation could be that the samples are more porous near the outer surface, because of introduced micro fissures and cracks during the drilling out of the cores. When the measurement was made on the sample surface dry, the pores that are connected with the outer surface were dried out and therefore did not contribute to the conduction in the sample. When the sample was coated with polyurethane, salt solution may have been sucked out from the sample and the surface connected pores were filled. This would lead to a higher conductivity and therefore to a higher formation factor. There is also a possibility that some of the conduction in the polyurethane coated samples at atmospheric pressure could be due to a thin salt solution film at the outer surface of the samples. At higher pressures, however, the conduction is probably only due to the solution filled pores in the samples as the surface film is squeezed into the interior.

The formation factor calculated from the diffusion experiments under stress are in fair agreement with the formation factors from the resistivity measurements at higher pressures (Fig. 7-11). At atmospheric pressure, however, the formation factor from the diffusion experiments is always lower than the formation factor for the polyurethane coated samples in the resistivity experiments.

In Figures 12-16 a relative formation factor have been plotted versus pressure. For the resistivity experiments two curves are given for each sample. One curve gives the formation factor at each pressure level relative to the formation factor at atmospheric pressure in the polyurethane coated sample (starting value). The other curve is the formation factor at each pressure level relative to the formation factor in the sample surface dry. For the diffusion experiments the formation factor calculated from the diffusivity in the stressed sample is given relative to the formation factor calculated from the diffusivity in the sample at atmospheric pressure.

Fig. 12 shows that the formation factor from the resistivity measurements at 300-350 bars for Finnsjö granite, F, is reduced to 40-60 % of the value for the unstressed sample, depending on whether the starting value or whether the surface dry value is the true value for the unstressed sample. According to eq. 3 this means that the diffusivity at 300-350 bars is reduced to 40-60 % of the diffusivity in the unstressed sample. From the diffusion measurements it was found that the diffusivity at 320-330 bars was reduced to 60-65 % of the diffusivity in the unstressed samples.

From the resistivity measurements in granites from Gideå, GAA 1, (Fig. 13) it was found that the formation factor and therefore the diffusivity of 300-350 bars was reduced to 20-50 % of the value in the unstressed samples. The diffusion measurement gave as result that the diffusivity at 330 bars was about 40 % of the diffusivity in the unstressed sample.

For granites from Svartboberget, SB 7, (Fig. 14) the results from the resistivity measurements was that the formation factor and therefore the diffusivity at 300-350 bars was about 25-50 % of the value in the unstressed samples. The diffusion experiment showed that the diffusivity at 310 bars was about 70 % of the diffusivity in the unstressed sample.

In the biotite gneiss from Svartboberget, SB 21, (Fig. 15) the formation factor at 300-350 bars, from the resistivity measurements, was about 20-40 % of the value in the unstressed sample. The diffusivity measured at 330 bars was about 40 % of the diffusivity in the unstressed sample.

Fig. 16 shows the result for biotite gneiss from Fjällveden (FJ). The formation factor at 300-350 bars, from the resistivity measurements, was found to be 30-70 % of the value in the unstressed sample. The diffusivity in a sample at 330 bars was about 20 % of the diffusivity in the sample at atmospheric pressure. The diffusivity in another sample at 200 bars was about 50 % of the diffusivity in the sample under atmospheric pressure.

In figures 17 and 18 the results from this investigation and the previous investigation (5) are put together. Figure 17 shows the diffusivities of iodide determined in granites and Figure 18 the diffusivities of iodide determined in gneisses. The open bars represents the diffusivities in samples under stressed conditions and the filled bars the diffusivity in samples under atmospheric pressure. The diffusivity of iodide from the electrical resistivity measurements have been calculated by eq. 3 using the surface dry formation factor for the unstressed samples and the formation factor at maximum stress for the stressed samples.

CONCLUSIONS

The diffusion experiments and the electrical resistivity measurements showed that the diffusivity and thus the formation factor decreased when the samples were put under mechanical stress. This is probably a combined effect of a decrease in the crossectional area of the pores in the material and increases in tortuosity and constrictivity.

The formation factor in samples at 300-350 bars stress relative to the formation factor in the samples at atmospheric pressure obtained in the diffusion experiments are in fair agreement with those determined from the electrical resistivity measurements for the same rock materials (Fig. 11-15). The diffusivity or the formation factor in samples at 300-350 bars were in no case lower than about 20 % of the value in unstressed samples.

The formation factor in samples at atmospheric pressure determined from the electrical resistivity measurements seems in general to be higher than those determined from the diffusivity experiment for the same rock materials. In an earlier investigation (5) it was also found that the formation factor was different for the same rock material depending on which diffusing component used in the diffusion experiment. This indicates that the formation factor is not only dependent on the properties of the rock material but also to some extent on the diffusing component. Electrical resistivity measurements can, however, be used to give approximate values of the diffusivity. The advantage with electrical resistivity measurements is that the experimental time is much shorter than in the diffusion experiments.

NOTATION

c	concentration in fluid	mol/l
c_1	concentration at the high concentration side	mol/l
c_2	concentration at the low concentration side	mol/l
D_e	effective diffusion coefficient	m^2/s
D_p	pore diffusion coefficient	m^2/s
D_v	diffusion coefficient in bulk phase	m^2/s
k_d	sorption coefficient	m^3/kg
ℓ	thickness or length of a rock sample	m
Q	total amount of diffusing component which has passed through the piece at time t	mol/m^2
R_0	resistivity in salt solution	Ωm
R_s	resistivity in salt-water saturated rock sample	Ωm
t	time	seconds, days
x	length coordinate	m
α	rock capacity factor	
δ_D	constrictivity for diffusion	
ε_{tot}	total porosity	
ε^+	"transport" porosity	
ρ	density of the solid material	kg/m^3
τ	tortuosity	
$\frac{\varepsilon^+ \cdot \delta_D}{\tau^2}$	formation factor	

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TABLE 1

Area	Depth (m)	Decription of the material	Notation
Finnsjön Fi 4	~ 100	granite, quartz-granodiorite; quartz, feldspar, microcline, dark mica, hornblende	F
Gideå	495-496	granite, finegrained, light grey; quartz, feldspar, light and dark mica	GAA 1
Gideå	500-501	gneiss, medium-to coarsegrained, dark grey; quartz, feldspar, biotite	GAA 7
Svartboberget	503-504	gneiss, fine-to medium grained; plagioclase, garnet, epidote, mica, accessoric silicate mineral	SB 1
Svartboberget	514-504.5	migmatite granite, fine-to medium grained, grey; remains of garnet holding gneiss, newly formed coarse grained quartz feldspar	SB 7
Svartboberget	508.7-509.2	garnetholding biotite gneiss; stripes of coarsegrained quartz-feldspar	SB 21
Fjällveden	508-509	biotite gneiss; dark stripes of quartz and biotite, light stripes of quartz and feldspar	FJ

Table II

TABLE II

Notation	D_e, m^2/s $p = 1$ bar	p_{max}, bar	D_e, m^2/s $p = p_{max}$	$\frac{D_e(P_{max})}{D_e\ (1\ bar)}$	Results from Skagius et al (5) Notation		D_e, m^2/s $p = 1$ bar
F 5	-	250	$3.6 \cdot 10^{-14}$	-	F	1	$8.4 \cdot 10^{-14}$
11	$6.2 \cdot 10^{-14}$	330	$3.8 \cdot 10^{-14}$	0.62		2	$7.0 \cdot 10^{-14}$
12	$5.0 \cdot 10^{-14}$	320	$3.2 \cdot 10^{-14}$	0.64		5	$7.1 \cdot 10^{-14}$
						6	$4.1 \cdot 10^{-14}$
GAA 1 19	-	285	$11.3 \cdot 10^{-14}$	-	GAA 1	1	$10.0 \cdot 10^{-14}$
20	-	320	$14.9 \cdot 10^{-14}$	-		2	$9.0 \cdot 10^{-14}$
21	$31.2 \cdot 10^{-14}$	330	$12.1 \cdot 10^{-14}$	0.39			
GAA 7 16	-	330	$0.54 \cdot 10^{-14}$	-	GAA 7	2	$1.8 \cdot 10^{-14}$
SB 1 35	-	250	$(0.23 \cdot 10^{-14})$	-	SB 1	1	$1.9 \cdot 10^{-14}$
						2	$3.5 \cdot 10^{-14}$
SB 7 16	-	330	$9.4 \cdot 10^{-14}$	-	SB 7	1	$66.0 \cdot 10^{-14}$
48	$36.3 \cdot 10^{-14}$	310	$24.9 \cdot 10^{-14}$	0.68		4	$34.0 \cdot 10^{-14}$
						7	$26.0 \cdot 10^{-14}$
SB 21 28	$28.7 \cdot 10^{-14}$	330	$12.1 \cdot 10^{-14}$	0.42	SB 21	2	$15.0 \cdot 10^{-14}$
						5	$36.0 \cdot 10^{-14}$
FJ 15	$17.0 \cdot 10^{-14}$	330	$3.7 \cdot 10^{-14}$	0.22	FJ	1	$7.2 \cdot 10^{-14}$
18	$3.3 \cdot 10^{-14}$	200	$1.6 \cdot 10^{-14}$	0.48		2	$7.4 \cdot 10^{-14}$

TABLE III

Notation	p_{max} bars	Porosity, ε_{tot} %		$\frac{\varepsilon_{tot}(p_{max})}{\varepsilon_{tot}(1\ bar)}$	$\frac{D_e(p_{max})}{D_e(1\ bar)}$
		$p = 1$ bar	$p = p_{max}$		
F 11	330	0.37	0.10	0.28	0.62
GAA 1 21	330	0.26	0.19	0.73	0.39
SB 7 48	310	0.51	0.20	0.39	0.68
FJ 15	330	0.56	0.12	0.21	0.22
18	200	0.34	0.08	0.24	0.48

Table IV

TABLE IV

Formation factor x 10^5

Notation	1 bar	50 bars	100 bars	150 bars	200 bars	250 bars	300 bars	350 bars
F 9	7.4, -	6.1, -	5.3, -	4.7				
10	6.5,5.7	5.3,5.1	4.6,3.9	4.0,3.4	3.5,-	3.2, -	2.9, -	2.5
33	10.1,7.9	7.4,6.2	6.2,5.2	5.2,4.5	4.3,4.1	3.9^{240}		
35	6.9,4.9	5.9,4.0	4.9,3.4	4.2,2.9	3.2,2.6	2.6^{230}		
GAA 1 17	23.8,20.7	16.0,12.1	12.3,9.0	9.6,7.4	7.8,5.8	6.2,5.1	5.3, -	4.6
18	25.1, -	16.8, -	13.0, -	10.3, -	8.4, -	7.4, -	6.5	
GAA 7 13	0.80,2.10	0.82,1.44	0.97,1.35	0.99,1.24	0.97, -	0.92,0.91	0.88,0.88	0.85
14	0.49,0.98	0.52, -	0.54, -	0.55,0.96	0.55, -	0.78, -	0.85, -	0.89
SB 1 38	0.08,0.61	0.12, -	0.39,0.34	0.39, -	0.40, -	0.38,0.35	0.33,0.33	0.32
SB 7 18	38.2,19.1	24.4,14.9	17.8,10.6	11.5,8.9	9.3,8.4	8.0^{240}		
20	63.5,57.6	40.9,32.8	34.1,25.3	28.6,21.7	25.0,19.3	21.5,17.7	18.1, -	16.6
SB 21 29	30.7,13.2	15.6,8.4	9.5,7.3	7.4,5.8	6.0,5.1	4.8^{240}		
30	18.3,10.0	10.4,7.5	8.2,6.0	6.9,5.1	6.0,4.6	4.8,4.2	4.3,4.0	3.8
46	26.6, -	18.6, -	14.6, -	10.2, -	8.1			
FJ 8	21.1,14.5	12.4,9.2	10.6,7.7	8.6,6.7	7.9,6.0	6.6,5.7	5.7,5.6	5.3
9	26.1,16.4	15.9,12.5	14.0,9.9	11.0,9.2	10.0,8.0	8.8, -	7.8,7.3	7.3
SV 7	15.7,11.0		8.2,5.9		5.4, -		4.5,4.4	4.2

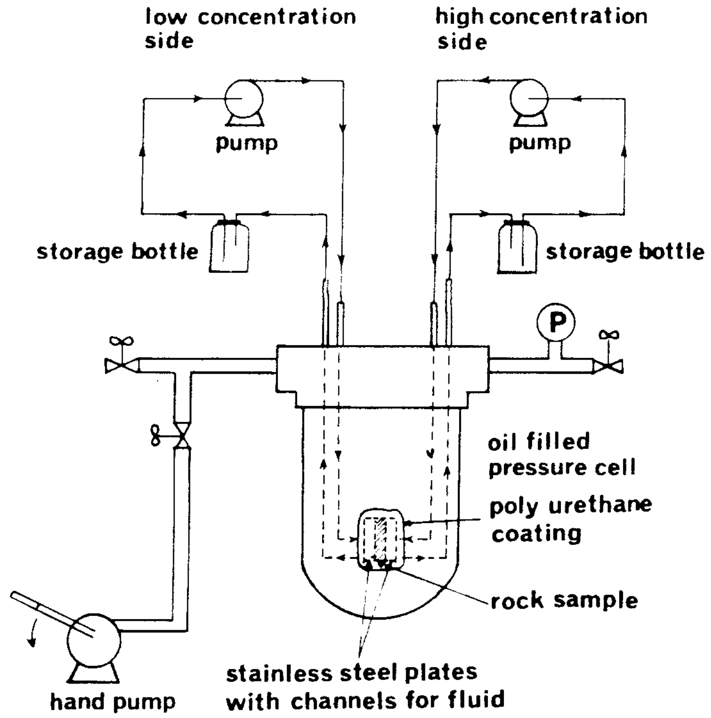

Figure 1: The apparatus used in the diffusion experiments with rock materials under mechanical stress.

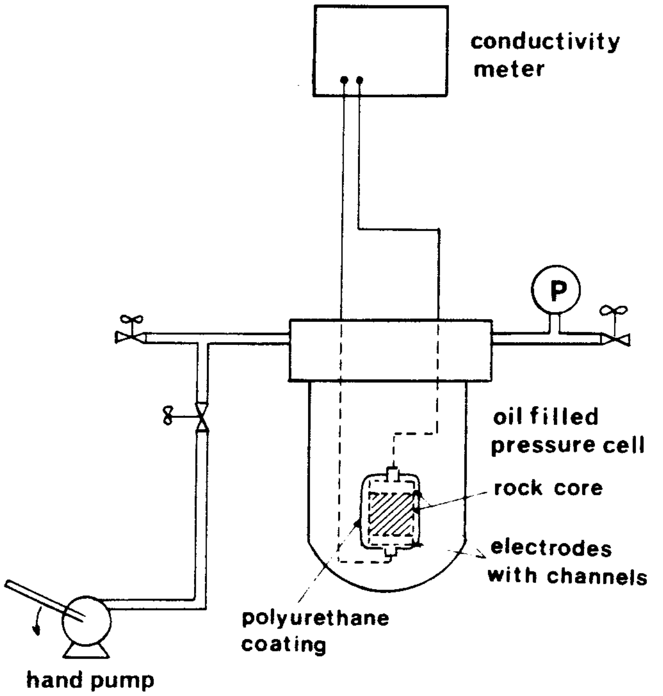

Figure 2: The apparatus used in the electrical resistivity measurements.

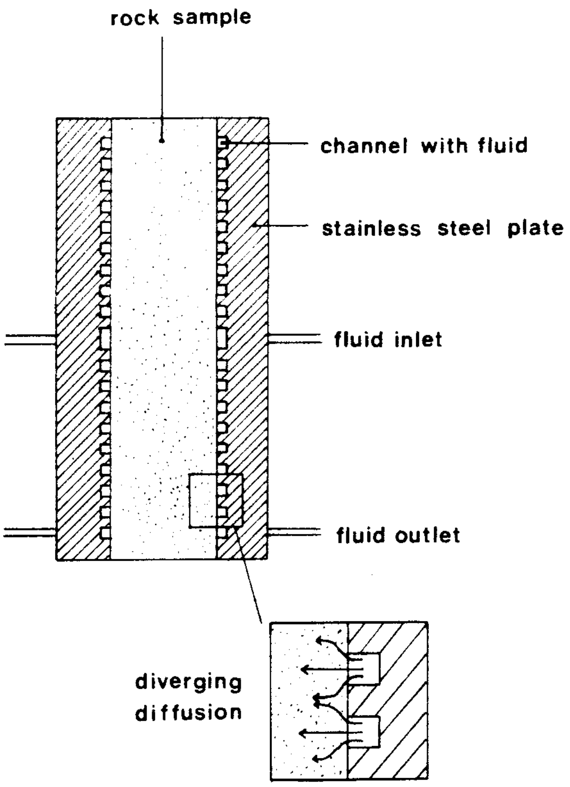

Figure 3: Illustrates the effect of reduced contact surface between the sample and the end plates. The species introduced in the small channels will first have to diffuse into the rock not directly in contact with the fluid before the whole crossection of the sample becomes effective for diffusion.

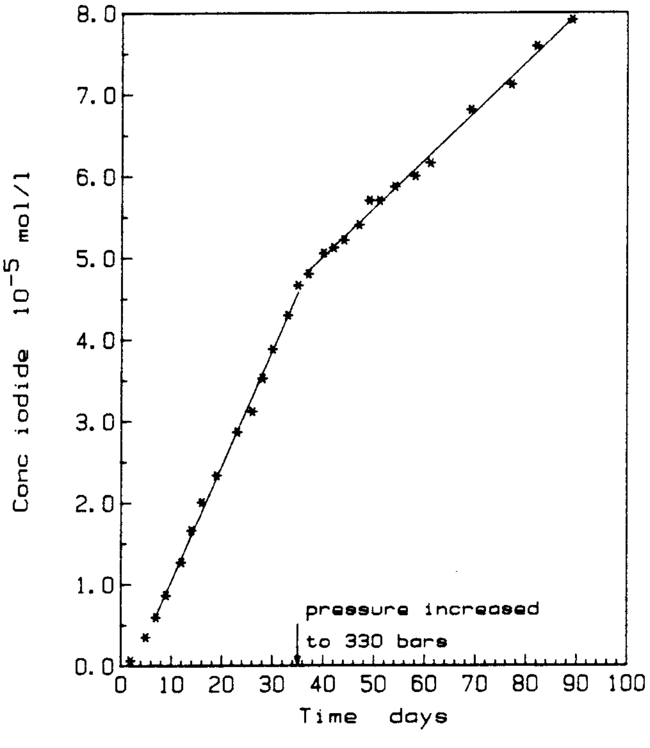

Figure 4: Concentration of iodide versus time, diffusion through biotite gneiss from Svartboberget.

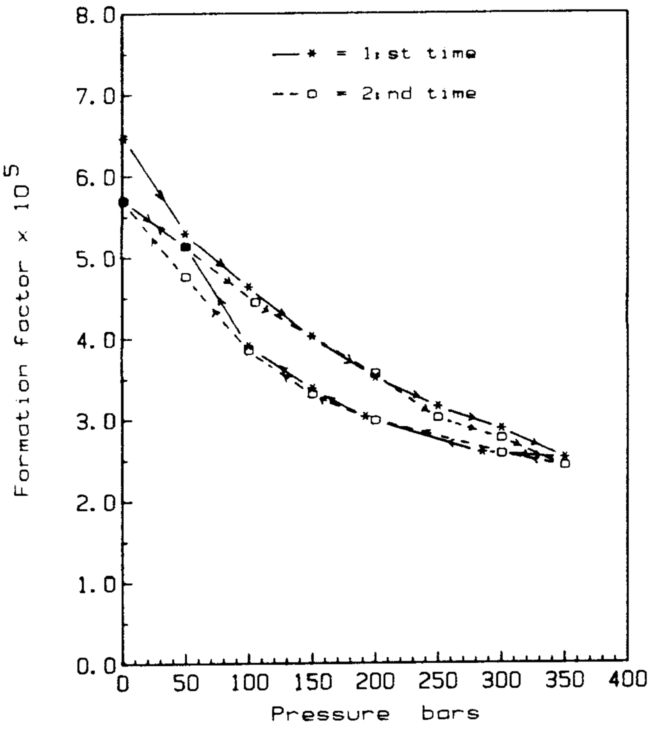

Figure 5: Formation factor versus pressure for a granite sample from Finnsjön.

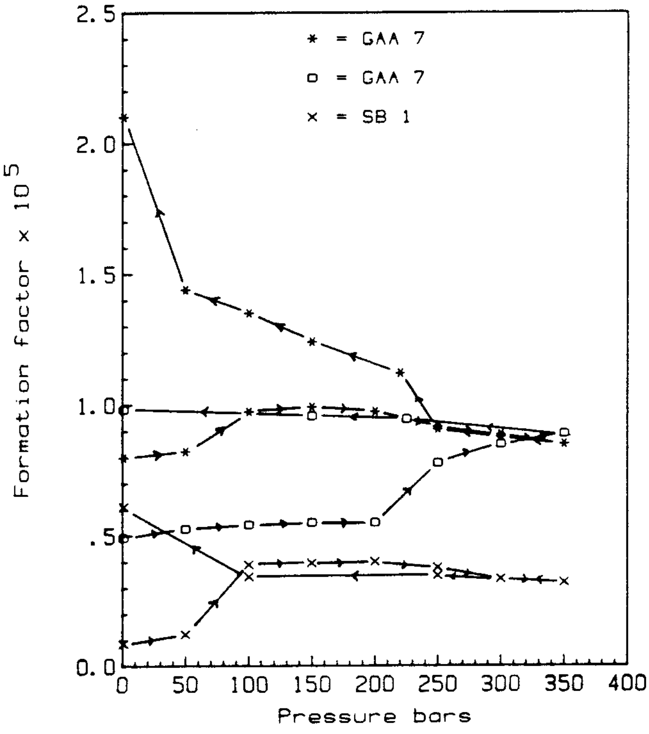

Figure 6: Formation factor versus pressure for gneiss samples from Gideå and Svartboberget.

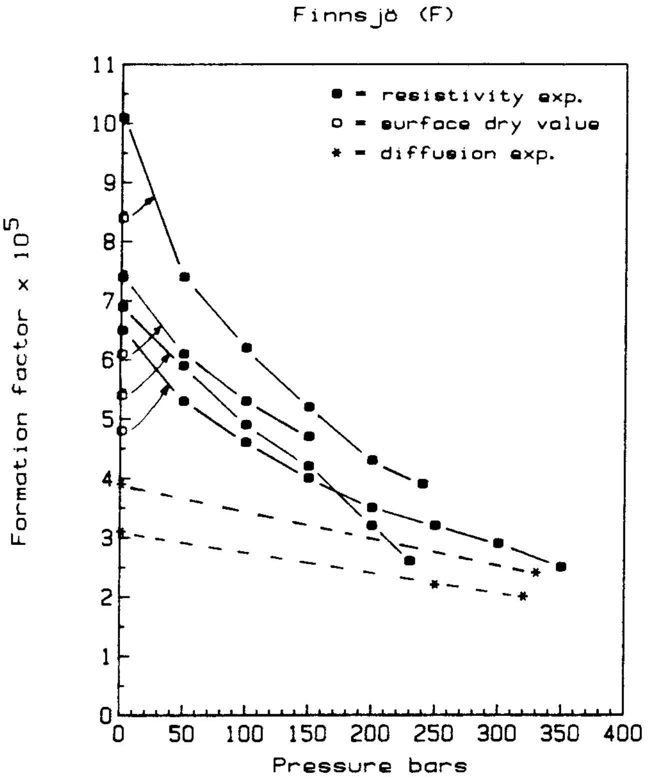

Figure 7: Formation factor versus pressure for granite samples from Finnsjön.

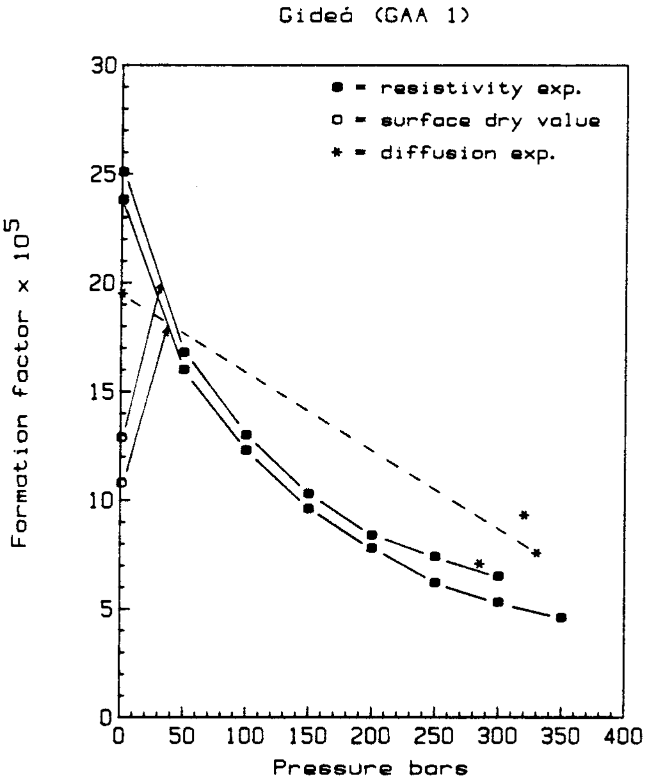

Figure 8: Formation factor versus pressure for granite samples from Gideå.

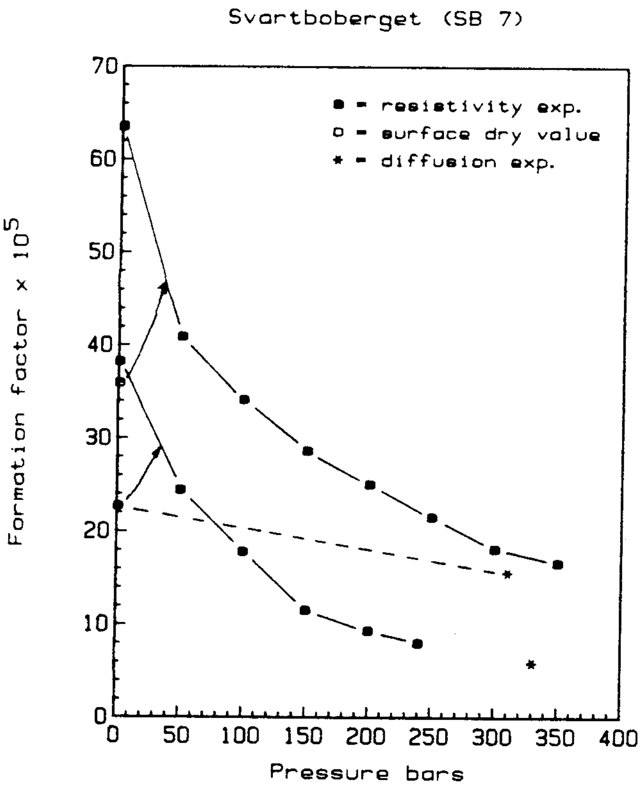

Figure 9: Formation factor versus pressure for granite samples from Svartboberget.

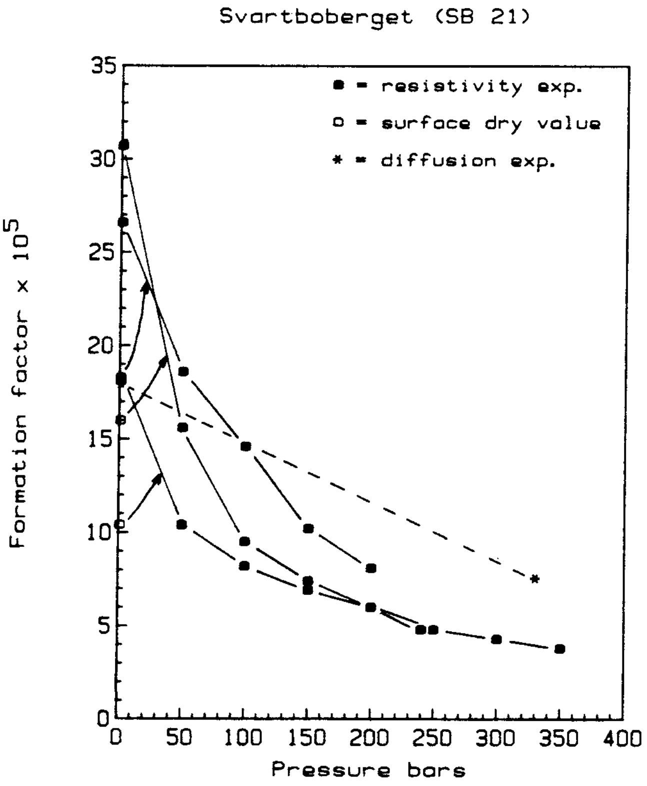

Figure 10: Formation factor versus pressure for biotite gneiss samples from Svartboberget.

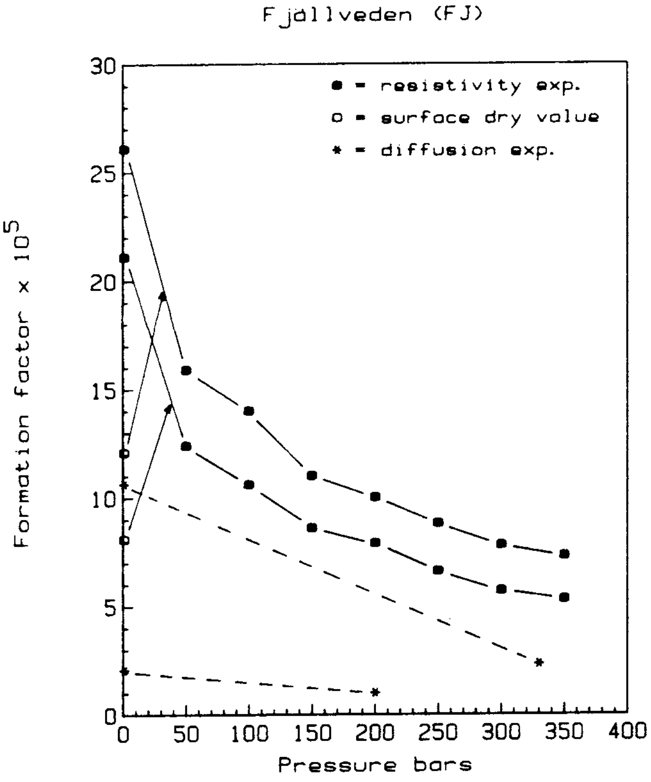

Figure 11: Formation factor versus pressure for biotite gneiss samples from Fjällveden.

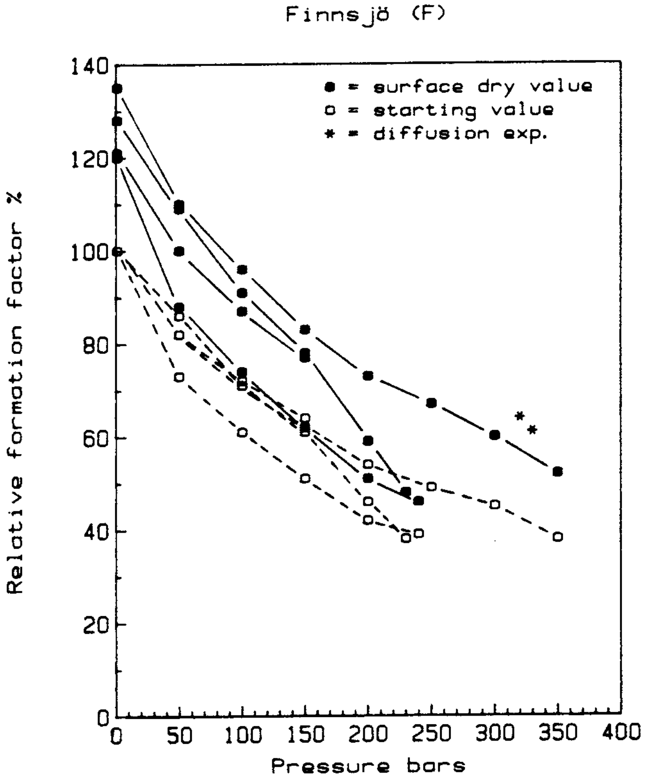

Figure 12: Relative formation factor versus pressure for granite samples from Finnsjön.

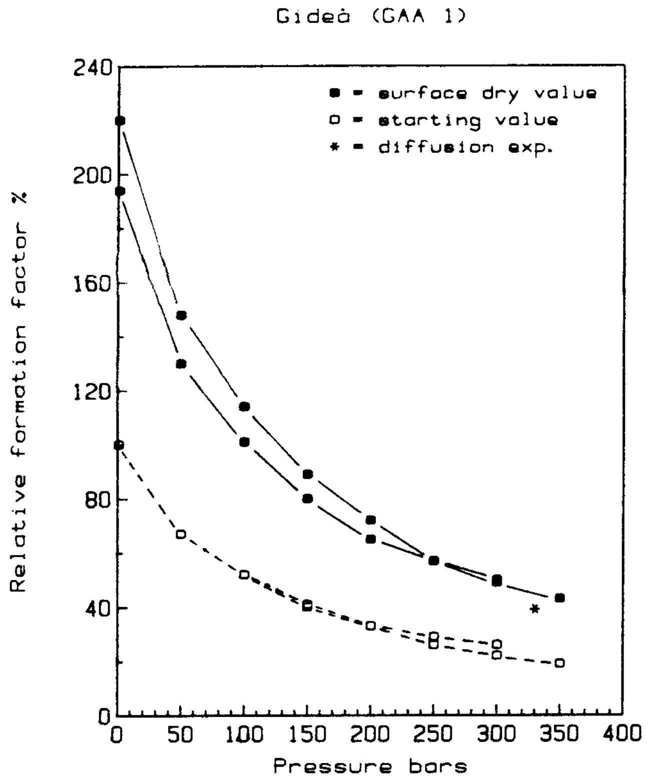

Figure 13: Relative formation factor versus pressure for granite samples from Gideå.

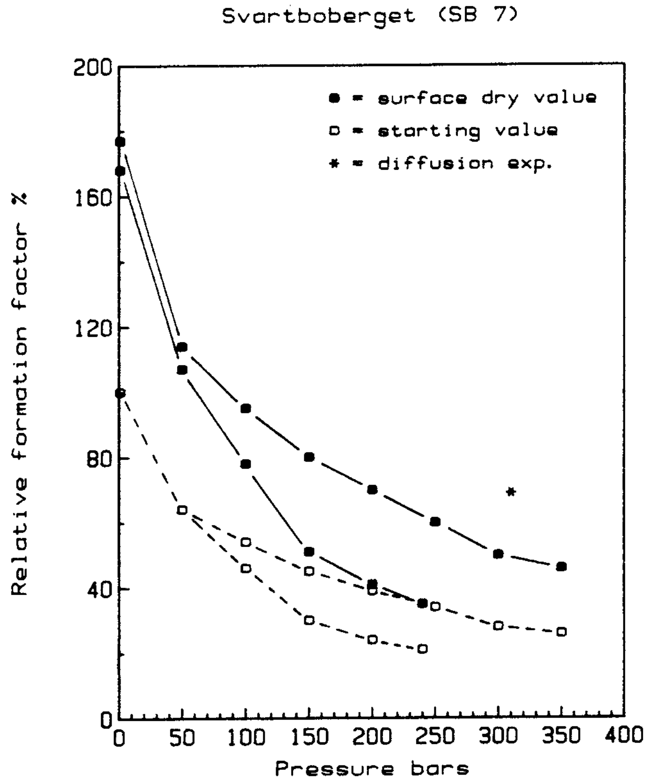

Figure 14: Relative formation factor versus pressure for granite samples from Svartboberget.

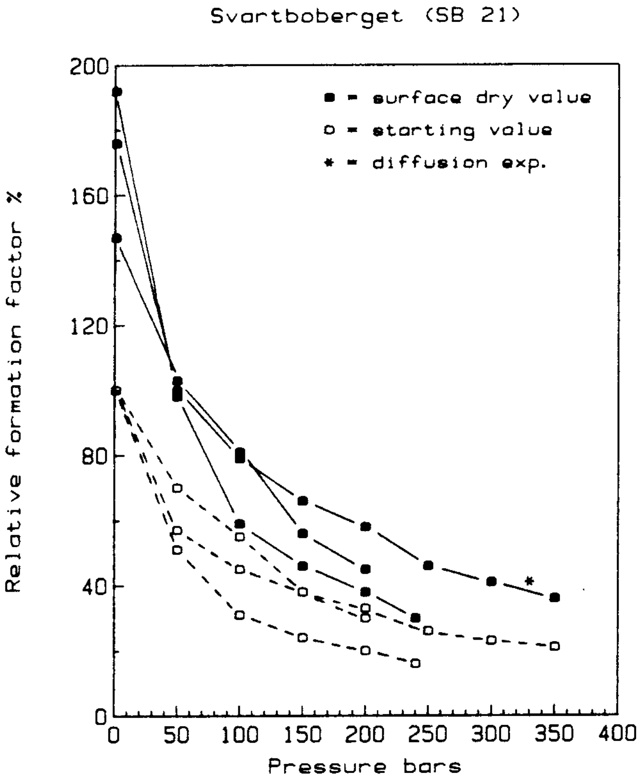

Figure 15: Relative formation factor versus pressure for biotite gneiss samples from Svartboberget.

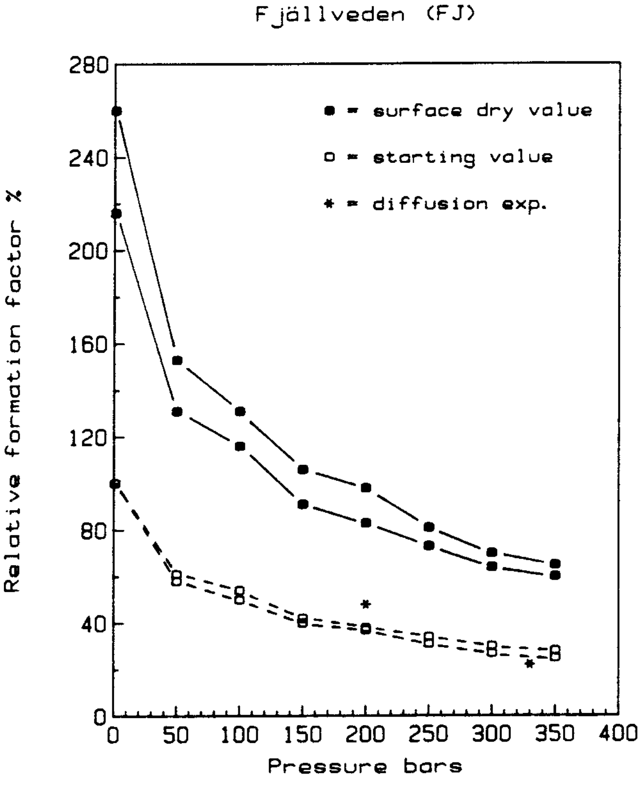

Figure 16: Relative formation factor versus pressure for biotite gneiss samples from Fjällveden.

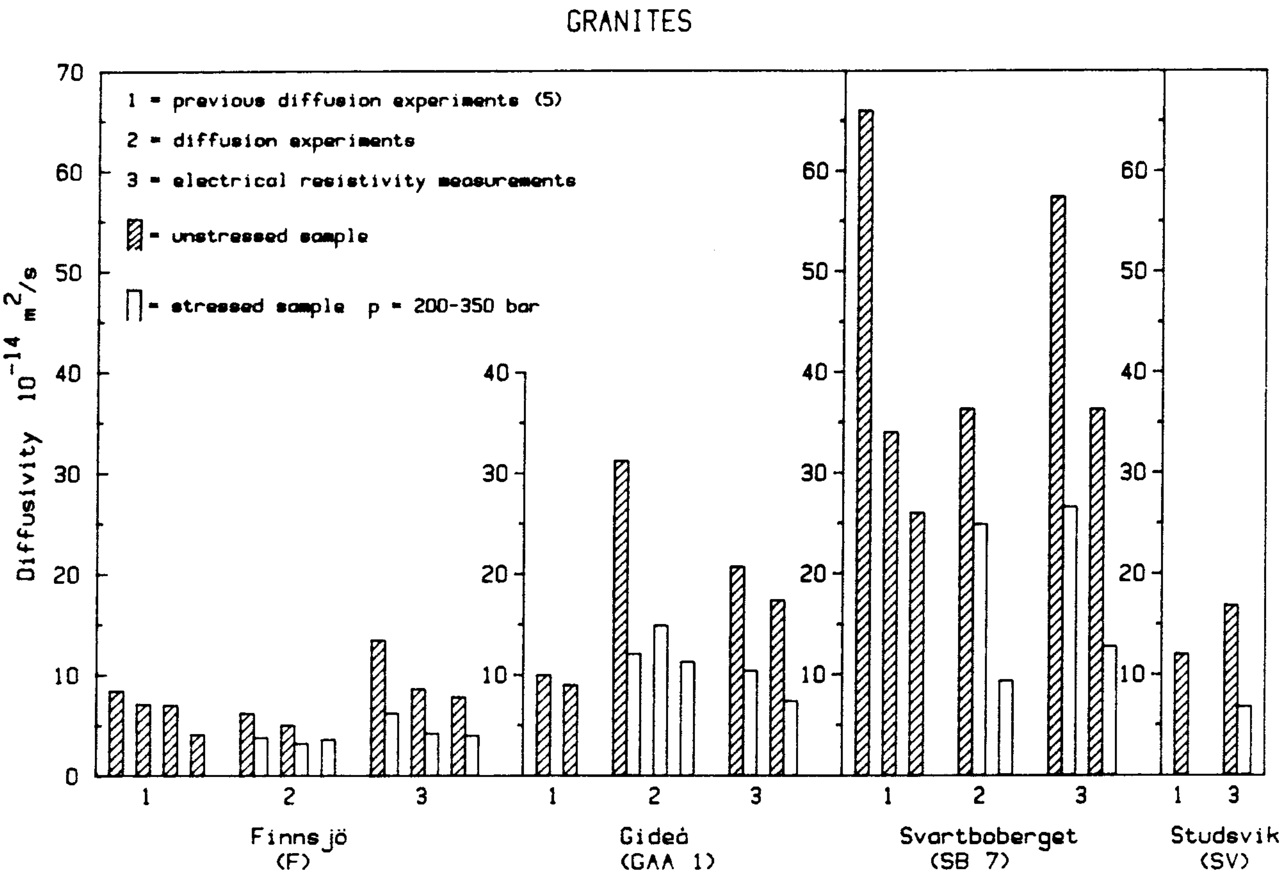

Figure 17: Effective diffusivities in granites. Results from this investigation and a previous investigation (5).

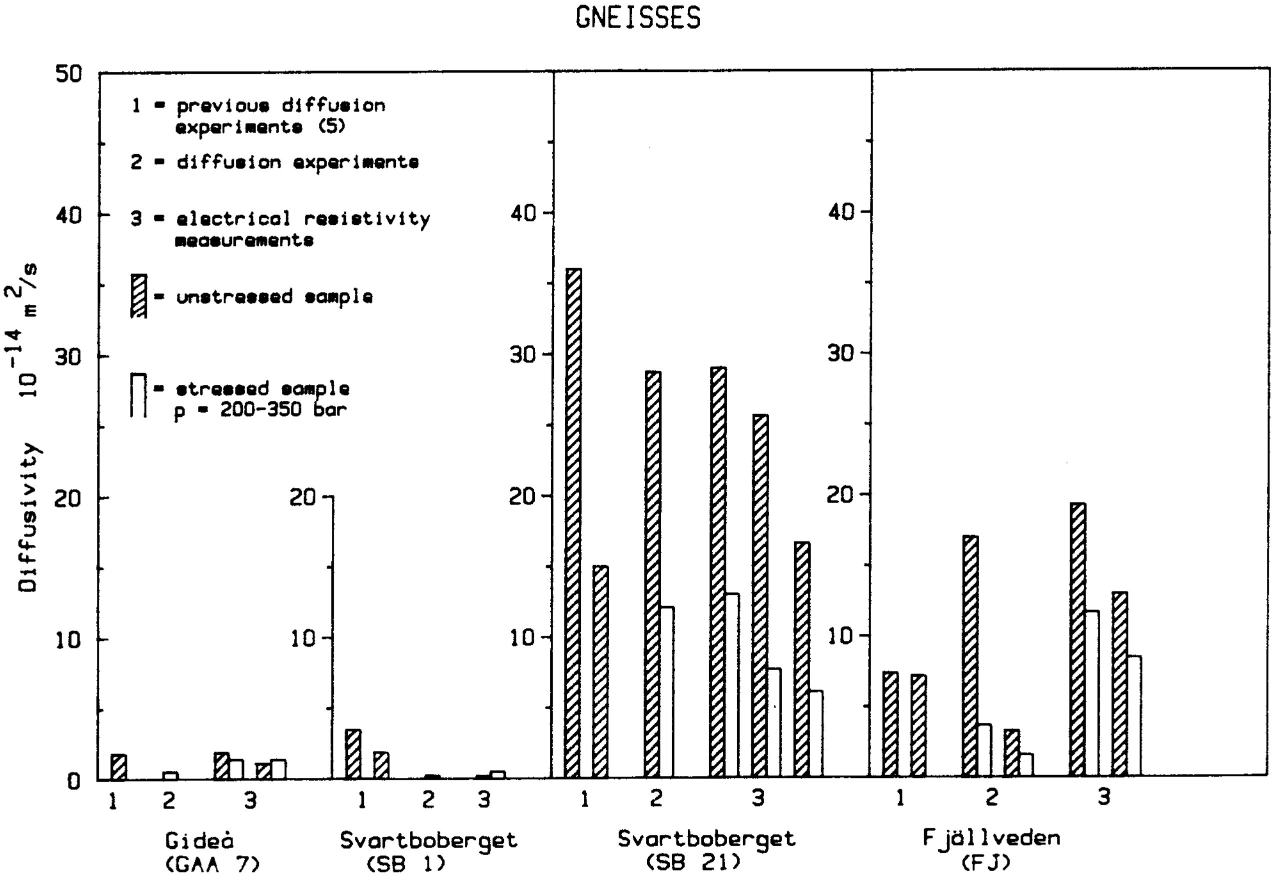

Figure 18: Effective diffusivities in gneisses. Results from this investigation and a previous investigation (5).

List of Technical Reports

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Including Summaries of Technical Reports Issued during 1984.
Stockholm June 1985.

TR 85–02
The Taavinunnanen gabbro massif. A compilation of results from geological, geophysical and hydrogeological investigations.
Bengt Gentzschein
Eva-Lena Tullborg
Swedish Geological Company
Uppsala, January 1985

TR 85–03
Porosities and diffusivities of some nonsorbing species in crystalline rocks.
Kristina Skagius
Ivars Neretnieks
The Royal Institute of Technology Department of Chemical Engineering
Stockholm, 1985-02-07

TR 85–04
The chemical coherence of natural spent fuel at the Oklo nuclear reactors.
David B. Curtis
New Mexico, USA, March 1985