KBS TEKNISK RAPPORT

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Small-scale bentonite injection test on rock

Roland Pusch

Högskolan i Luleå 1978-03-02

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TEKNISK RAPPORT KBS 15

REPORT ON

SMALL-SCALE BENTONITE INJECTION TEST ON ROCK

Luleå 1978-03-02
Div. Soil Mechanics, University of Luleå
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HÖGSKOLAN I LULEÅ
MASKINTEKNIK · GEOTEKNOLOGI · ARBETSVETENSKAP

SMALL-SCALE BENTONITE INJECTION TEST ON ROCK

Introduction

Irrespective of the kind of radioactive waste products which are going to be deposited, a sealing of the rock in which the deposition holes are located is very valuable since it reduces the rate of water percolation and diffusion.

There are a number of possible techniques which can be used to seal the rock. Injection of bentonite gels by means of over-pressure and subsequent electrophoresis ("electro-kinetic treatment") has been suggested earlier by the author (PUSCH, 1977) and preliminary tests with glass-plates instead of rock have been fairly successful.

The present report describes a rock test series where bentonite injection was applied.

The main idea was to simulate the real conditions in a tunnel at great depth (Fig.1a). For these conditions the main steps in the injection program are:

1. A central pilot hole and a series of fairly closely located outer holes are bored. The central hole is later enlarged to form the deposition hole (cf. Fig.1b).

2. The central pilot hole (or the final hole for deposition) is filled with a Na bentonite suspension (w = 1000-2000%).

3. An over-pressure is applied in the hole with the suspension (an under-pressure can be applied as well in the surrounding bore holes) by which the dilute bentonite gel is forced into joints which extend from the central hole.

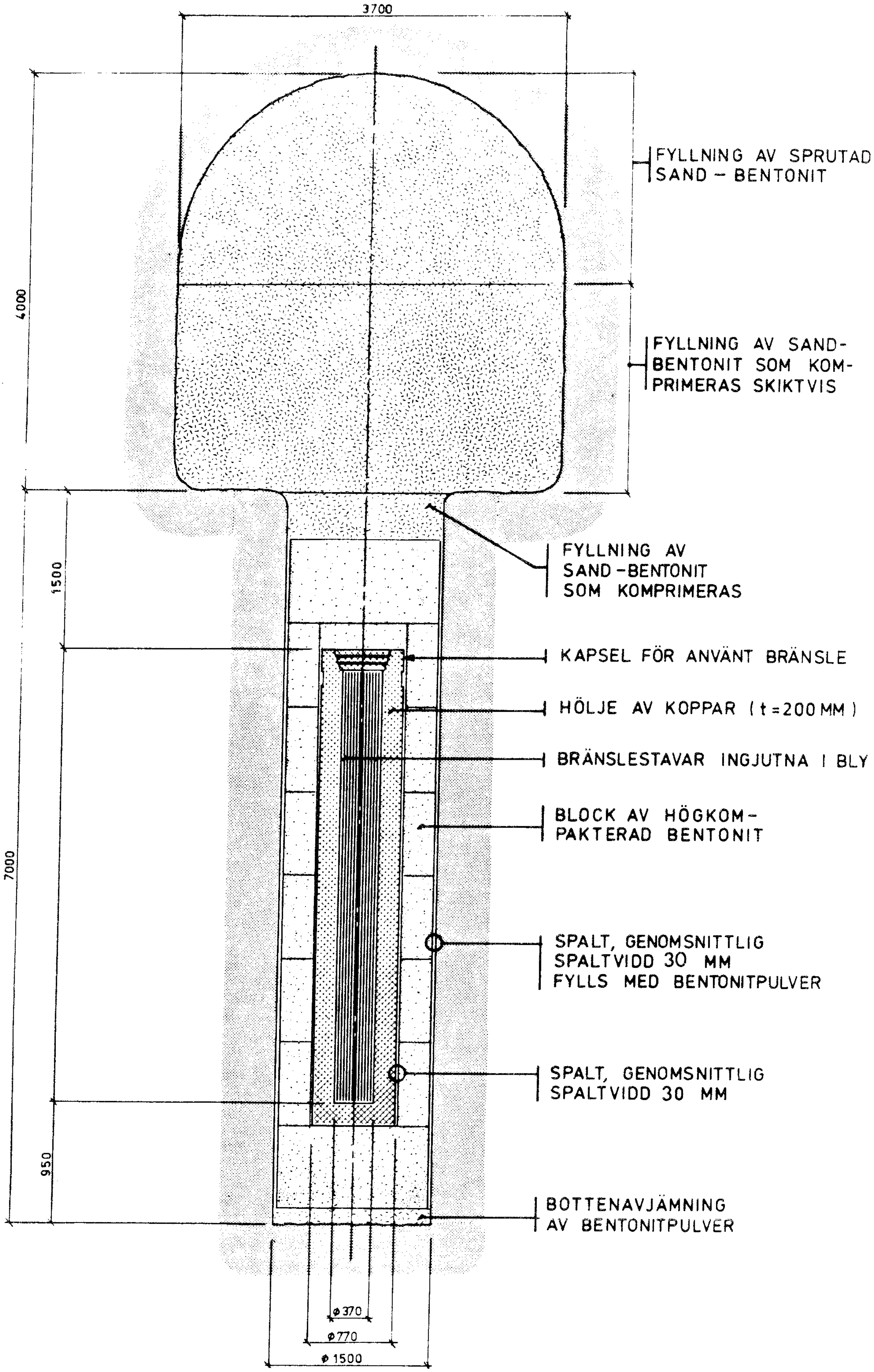
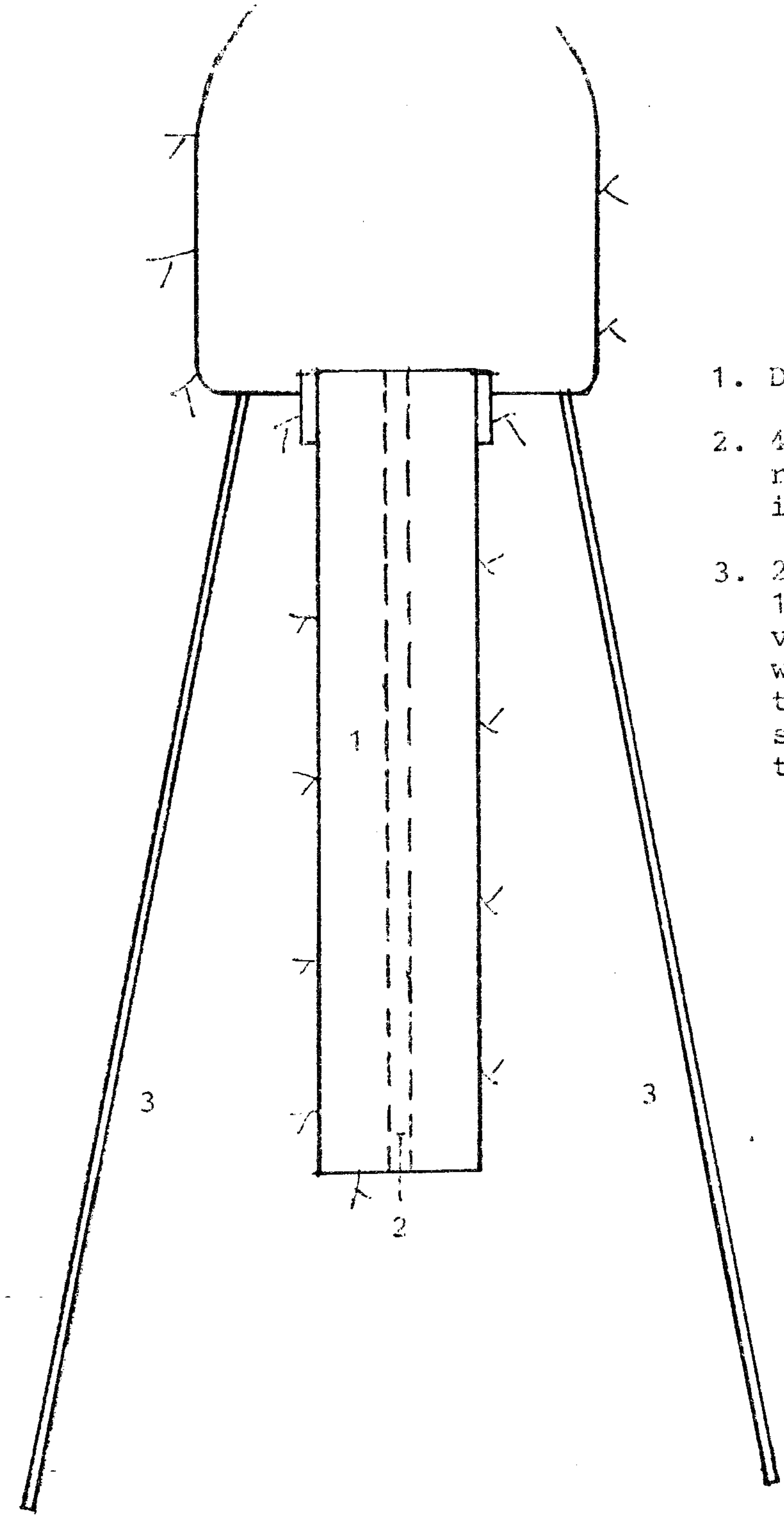


Fig.1a. Schematic picture of tunnel and deposition hole (VBB).



1. Deposition hole
2. 4-6" pilot hole for rock investigation and injection
3. 2-4" holes (spaced 1.5-2 m) for rock investigation, ground water lowering and bentonite injection (pressure and electro-kinetic treatment)

Fig. 1b. Bore hole arrangement. Holes 3 are sealed by inserting fairly closely fitting cylindrical bodies of highly compacted bentonite.

4. Electrodes are installed in the holes (cathode in the central hole and anodes in the circumferential holes) and a 200-2000V direct current is applied for about a week. By this, additional clay particles are transported from the central hole into the joints. The clay particles belong to the montmorillonite mineral group which is the dominant constituent in bentonite.

Test arrangement

Rock type, block preparation

The limited capacity of the lifting device in the test hall (3 tons) implied a maximum block size of about 1 m^3. The block, which had an approximately cubical shape, was selected from a road construction work in Luleå on the 3rd of January. The rock type was diorite (metabasite) with a fairly high frequency of quartz lenses. The site from where the block was taken was located below the ground water level. Since the air temperature was well below $-10^{o}C$ the water in the joints froze and preserved the state of water saturation. In the warm test hall the block was flooded and covered to maintain this state (Fig. 2).

After core drilling it was transferred to a basin where it was submerged during the tests. To prevent permanent opening of joints by the pressure injection operations and to simulate the lateral support of the tunnel base, the block was confined in 15 cm reinforced concrete except for the upper side with the bore holes (Fig. 3).

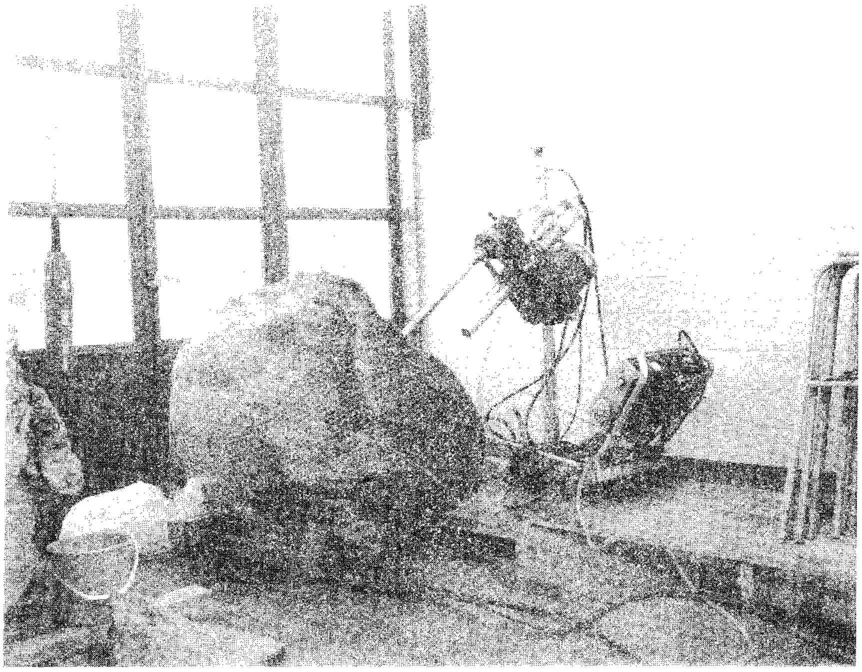


Fig. 2. Drilling device. The block was covered with plastic sheets to maintain water saturation.

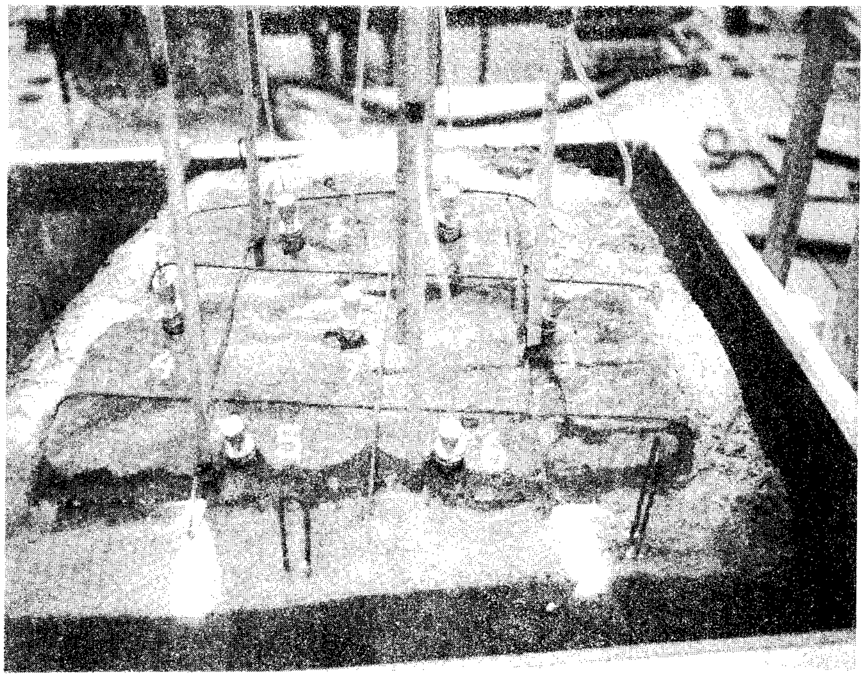


Fig. 3. Top surface of the concrete-confined block with electrodes installed. Pipe connections of glass and plastic were used for permeability measurement.

The holes, which were placed according to Fig. 4, were 4.3 cm in diameter and 48 cm deep. Holes no.1, 5 and 6 had to be inclined somewhat towards the central hole because of the irregular external shape of the block. No direct connection between the holes through joints or fissures could be seen with the naked eye. The regular joint pattern shown in Fig. 4 can be seen in the photograph in Fig. 3 also.

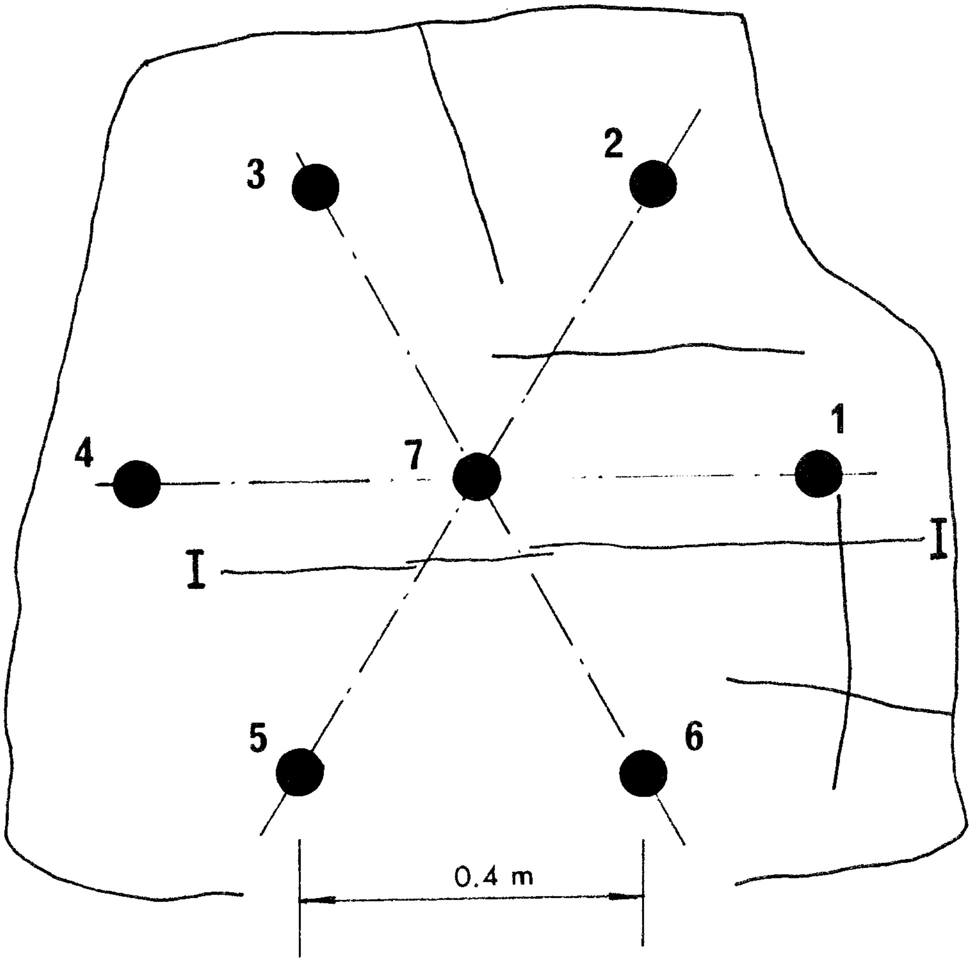


Fig. 4. Schematical top view of the block.

The cores (Fig. 5) were inspected with reference to joints and fissures, the observations being listed in Table 1.

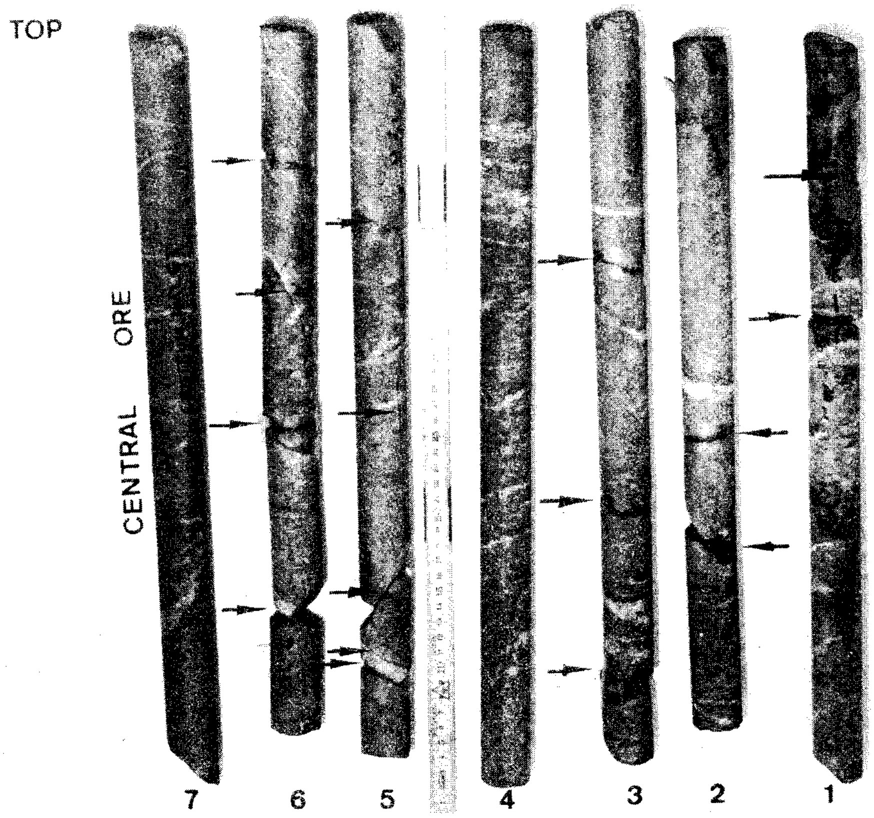
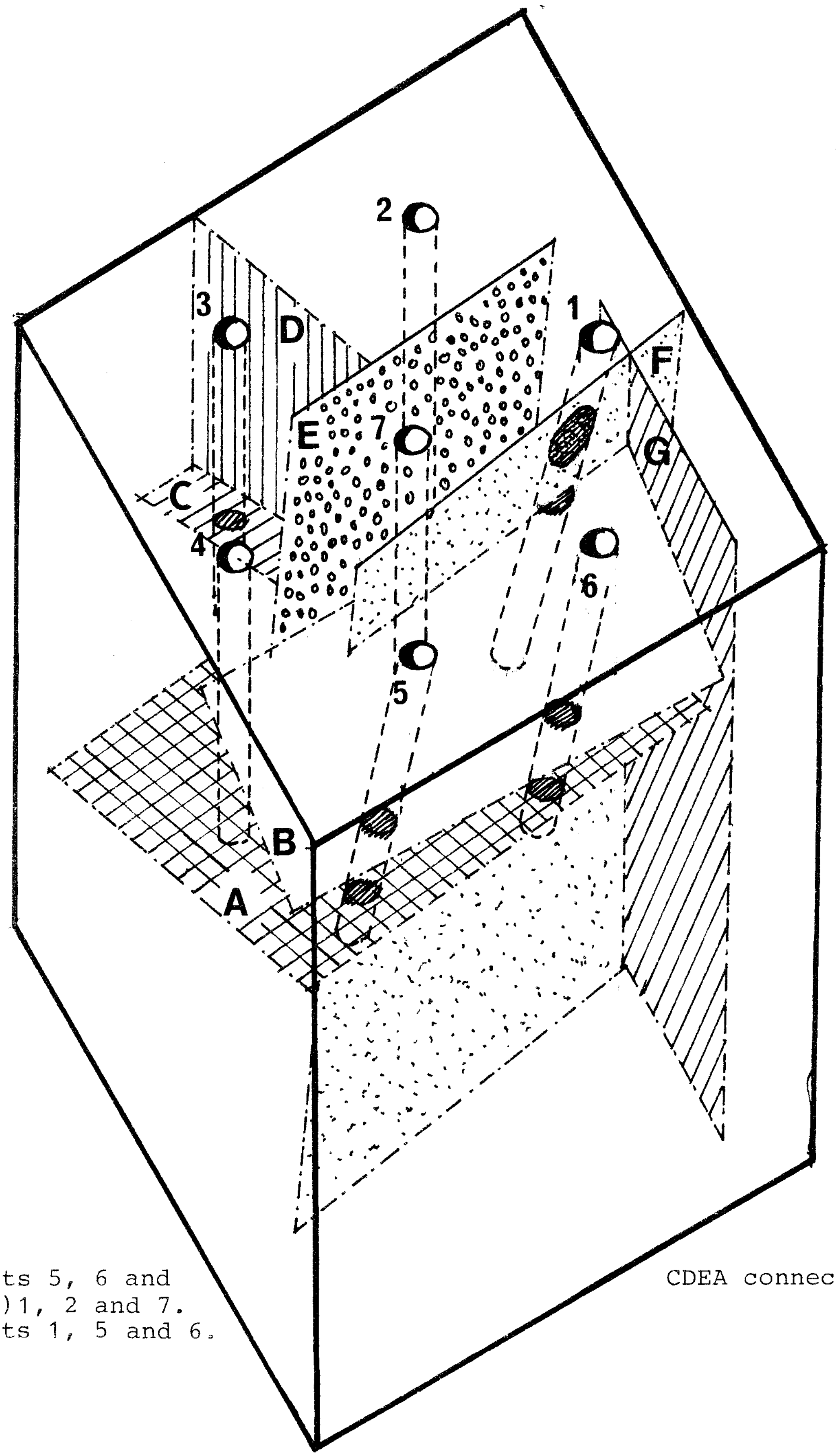


Fig. 5. Cores with joints indicated by arrows. Note that cores from hole 4 and 7 show no joints or fissures. The rather fine-grained rock matrix is rich in biotite and hornblende. As seen in the picture quartz lenses and laminae are frequent.

Table 1. Observed openings in cores. (Cores 4 and 7 dense).

Depth below top surface, cm	1	2	3	5	6
0					
5	Steep joint				
10				Slightly incl. joint	Slightly incl. joint
15	Horiz. joint		Incl. joint in quartz		Steep joint
20					
25		Horiz. joint		Axial joint	Horiz. joint
30					
35		Joint system	Joint system		
40				Joint system	Joint system
45					
50					

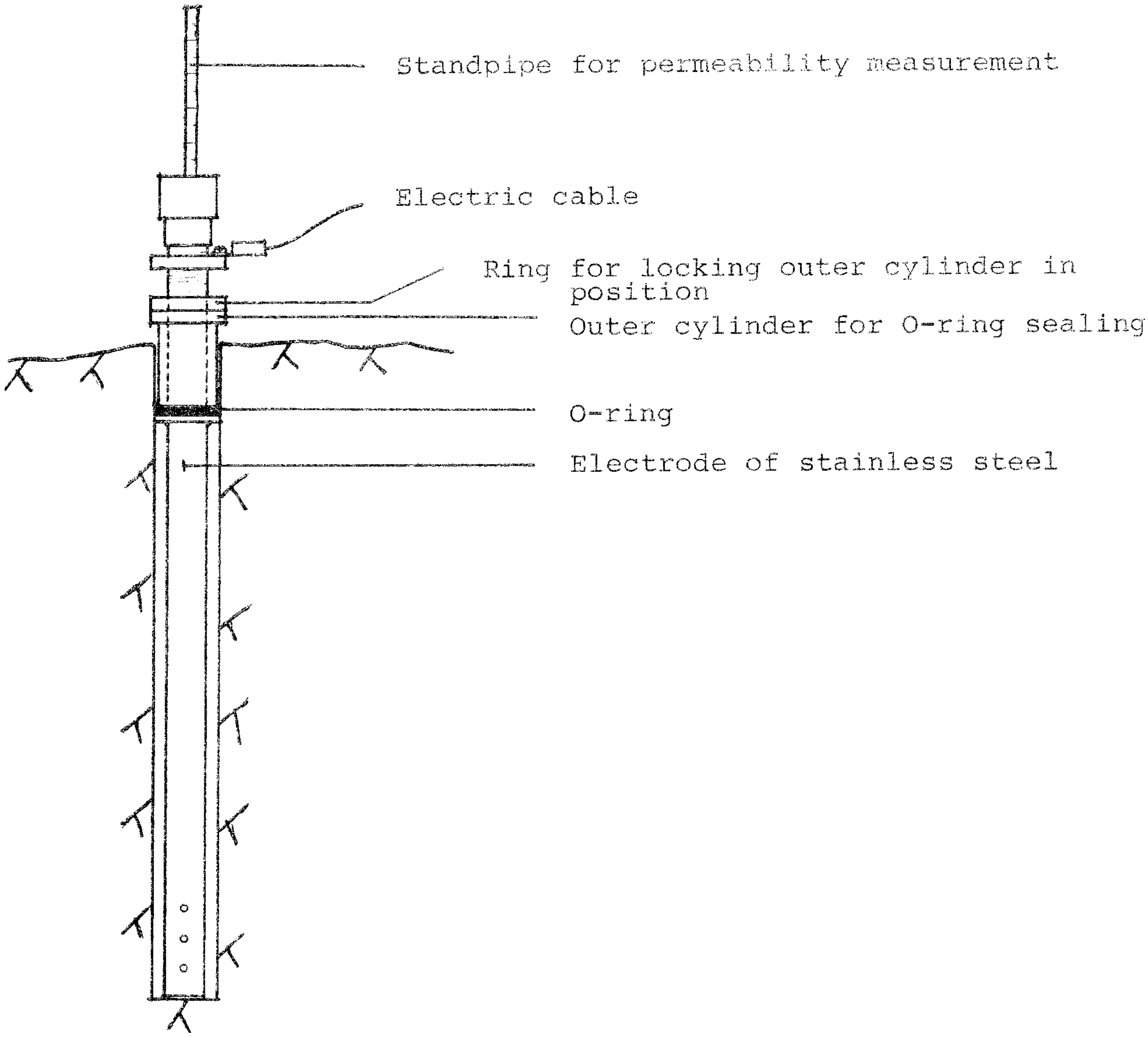
It should be noticed that the cores from the "deposition hole" (no. 7) and hole no. 4 had no joints or fissures. They gave the impression of being perfectly free from any kind of openings. It was not possible to draw any conclusions from the core inspection as concerns possible connections between the various holes. However, the permeability tests and the disintegration of the block after the test gave the information collected in Fig. 6. It is concluded that there is a connection through horizontal or slightly inclined joints between holes 1, 2, 5, 6 and (the base of) hole 7. The width of one joint was about 0.4 mm but most of them were probably less than 0.1 mm wide. The pore volume of the block estimated from the detailed determina-



A connects 5, 6 and (base of) 1, 2 and 7.
B connects 1, 5 and 6.

CDEA connects 3 and 7.

Fig. 6. Main joints.



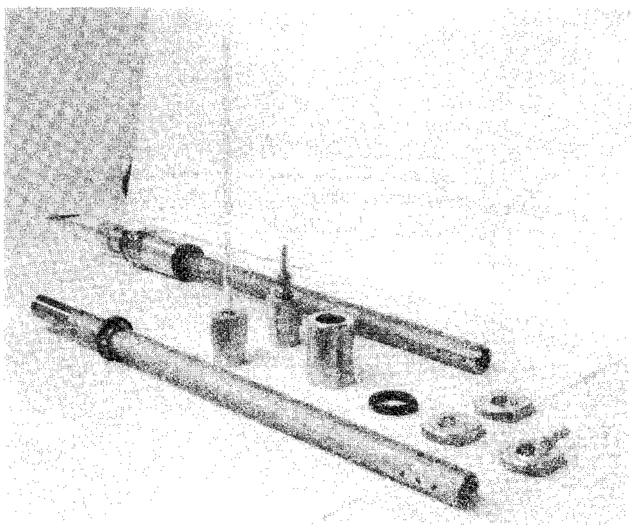


Fig. 7. Electrode. Upper picture: Schematical drawing. Lower picture: Dismantled and mounted electrodes.

tion of the width and extension of the joints and from the injection work was about 500 ml. This means that the average porosity was about $5 \cdot 10^{-4}$.

In order to make possible both the over-pressure and the "electro-kinetic" injection as well as the permeability tests, electrodes of the type shown in Fig. 7 were mounted in the holes. Greased rubber O-rings were used for sealing purposes.

Some preliminary short-term pilot tests were used to find out the most suitable percolation technique and to test whether compressed air could be used for injection purposes. In order to restore the block after these pilot tests the holes and joints had to be washed by water under 500 kPa pressure before the main test started. This may have created some permanent joint opening.

Test program

The following program was chosen:

1. Percolation test of each individual hole (only one test at the time) using the falling head principle and starting with 1 m head (10 kPa water pressure at the upper end of each hole).[1)]

2. Injection of a bentonite slurry with 1000% water content (2‰ NaCl solution) by means of a specially designed, easily operated injection pump (Fig. 8). The pump house was filled with the slurry which was injected

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[1)] Here, the preliminary tests came in by which some increase of the joint width may have been caused.

under a constant pressure of 1 MPa. After the injection of 350 ml, which took about 2 hours, the operation was stopped. A minor extrusion of water and bentonite suspension was observed along line I-I in Fig. 4 which indicates the presence of an irregular joint with connection to hole no. 7.

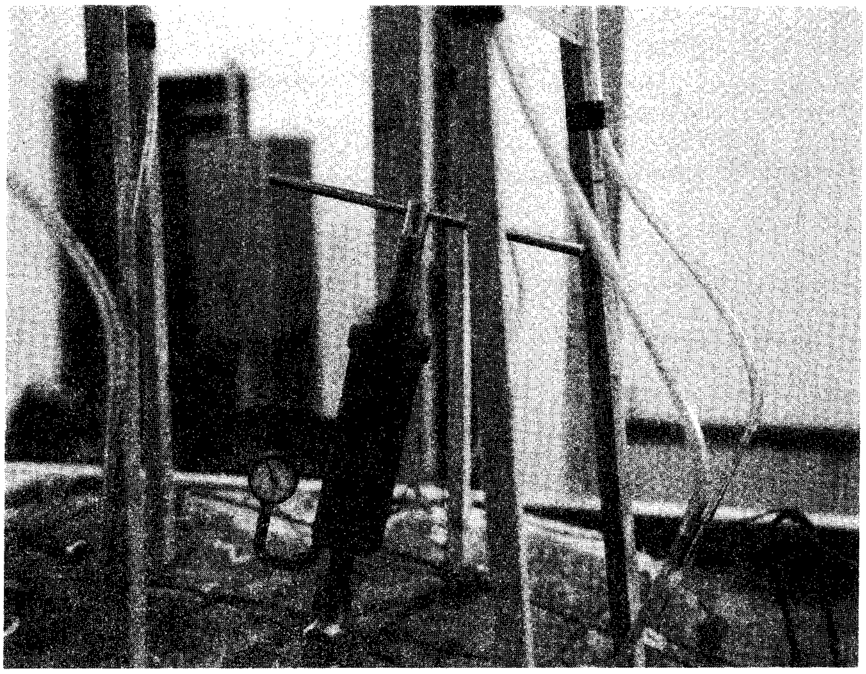


Fig. 8. Injection pump in operation.

3. Percolation test as in Paragraph 1 after thorough cleaning of the "deposition hole" no. 7. Samples of the water in holes no. 1-6 were first taken to find out whether montmorillonite had been transferred from hole no. 7.

4. Electro-kinetic treatment. The central, deposition hole was again filled with a 1000% water content (2‰ NaCl solution) bentonite slurry to which a small amount of a

gold sol was added. This substance formed positively charged particles of colloidal size which were thus adsorbed on negatively charged basal planes of montmorillonite particles. The intention was to mark the montmorillonite so that particles transferred by the electrical field from the central hole to the peripheral holes and transported out into joints could be identified by applying electron microscopy.

A 240 volt potential was then applied for 4 days, the electrode in the deposition hole (no.7) being cathode and all the other electrodes being anodes. The current decreased from 16-40 mA to 3-10 mA at the end of the treatment. It was initially about 35-40 mA for holes no. 1, 2, 5 and 6 while it was only about 16 mA for holes no. 3 and 4. This indicates a different degree of connection between the circumferential holes and the central hole. Thus, holes no. 3 and 4 seem to have little or no connection with hole no.7.

5. Percolation test as in Paragraph 1 after thorough cleaning of the deposition hole.

6. The block was split to expose the joints and to investigate them with reference to width and orientation and to their content of montmorillonite.

Test results

Permeability

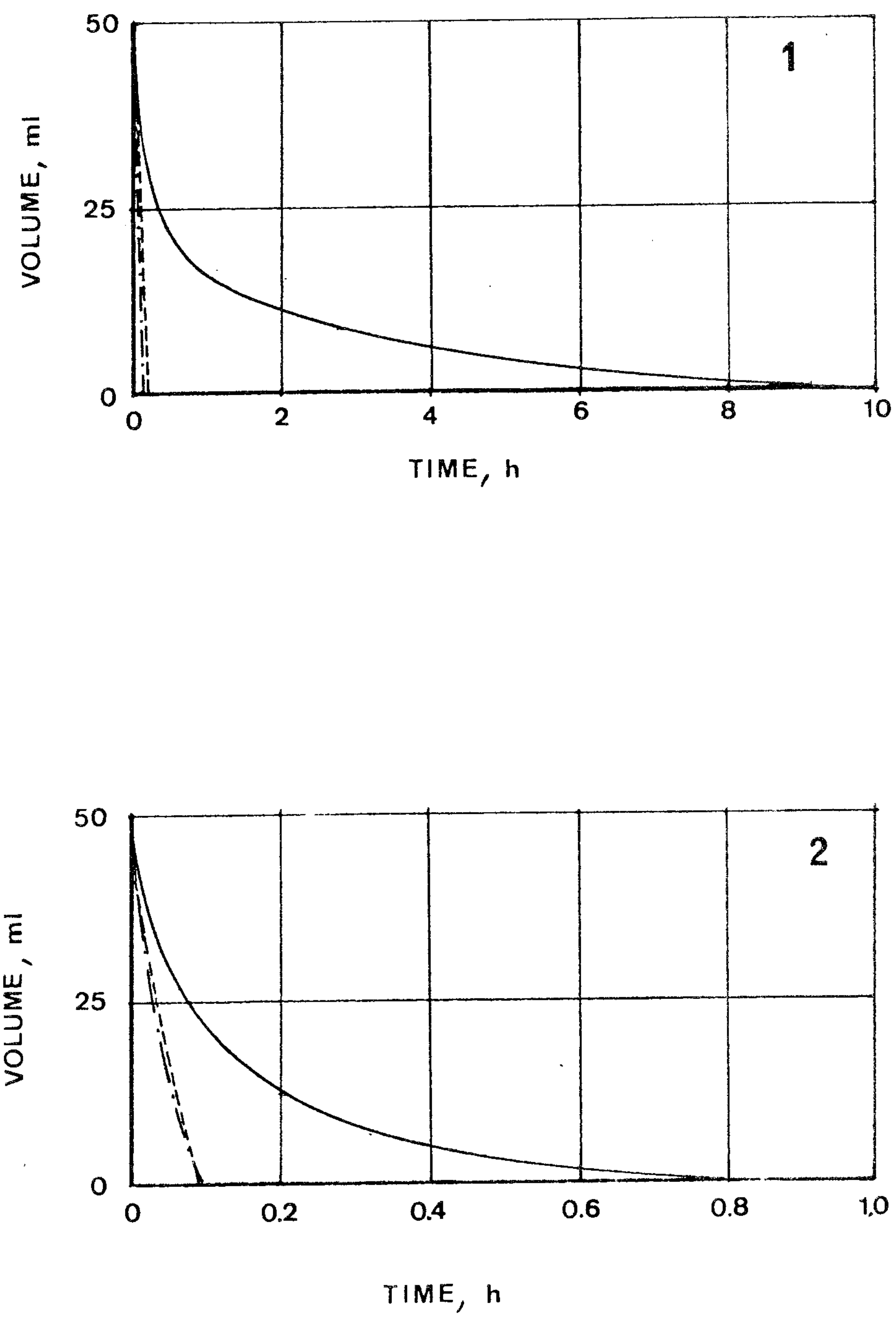
Ground water flow in rock takes place in continuous joints (rapid flow) and in continuous pore systems (mainly incomplete grain contacts; slow flow) as shown by PUSCH, 1977. The large majority of the water flow takes place in one or two joints per unit volume and it is therefore hardly relevant to describe the circulation pattern by using flow nets for an assumed isotropic medium or by applying the term (average) permeability.

This was also obvious from some preliminary permeability tests which indicated a very complex joint pattern. They showed that the best way of describing the time-dependent clearance of the holes was to measure the time for clearance of each individual hole when the water level outside the block and within all the holes (except the one being tested) and all joints was the same (cf. Test program). It is true that this does not give any information as to where the water flows which means that the length of the water passage and, thus, the hydraulic gradient are not known. The coefficient of permeability can therefore not be used. For the present purpose the main thing was to find out the percolation rate before and after the various treatments. In the report, therefore, this rate is simply given in terms of the time required to dissipate 50 ml of water from each hole in a "falling head" test with 1 m head at the start of each test. A very rough estimate gives the value 2.0 for the hydraulic gradient at the test start.

The results of the percolation tests are given in Fig. 9, 10 and 11. They are commented as follows:

Hole no 1

The time for clearance of this hole before the treatments was about 12 minutes. The pressure-injected bentonite doubled this time. The most effective sealing was obviously produced by the electro-kinetic treatment by which the time was increased to 9 hours.

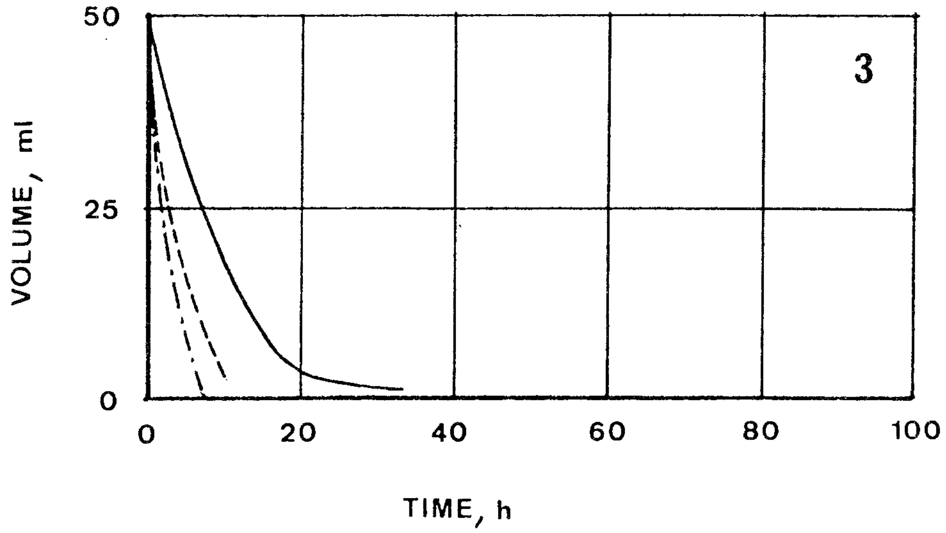


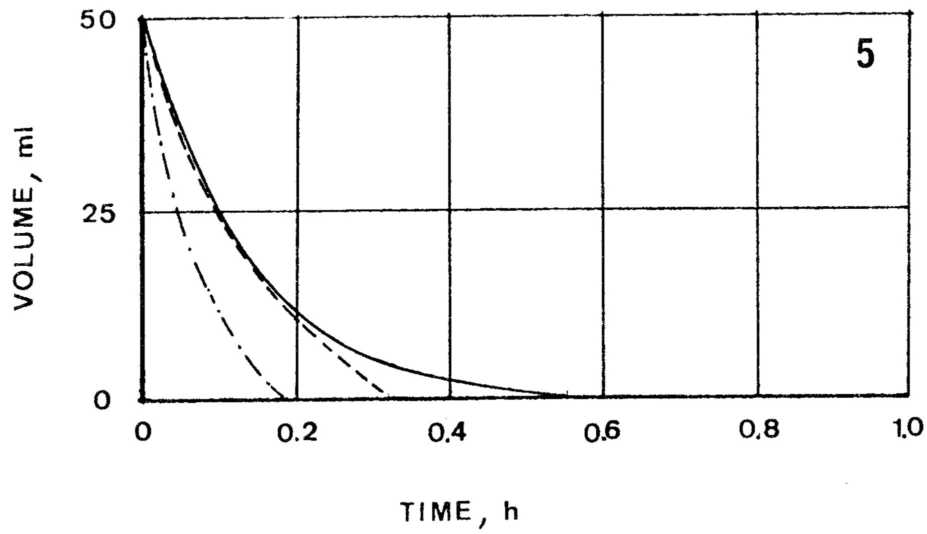
—·—·— Before treatment

– – – – After pressure-injection

——— After electro-kinetic treatment

Fig. 9. Percolation tests. Upper picture: Hole no 1. Lower picture: Hole no 2.





—·—·— Before treatment

------ After pressure-injection

——— After electro-kinetic treatment

Fig. 10. Percolation tests. Upper picture: Hole no 3. Lower picture: Hole no 5.

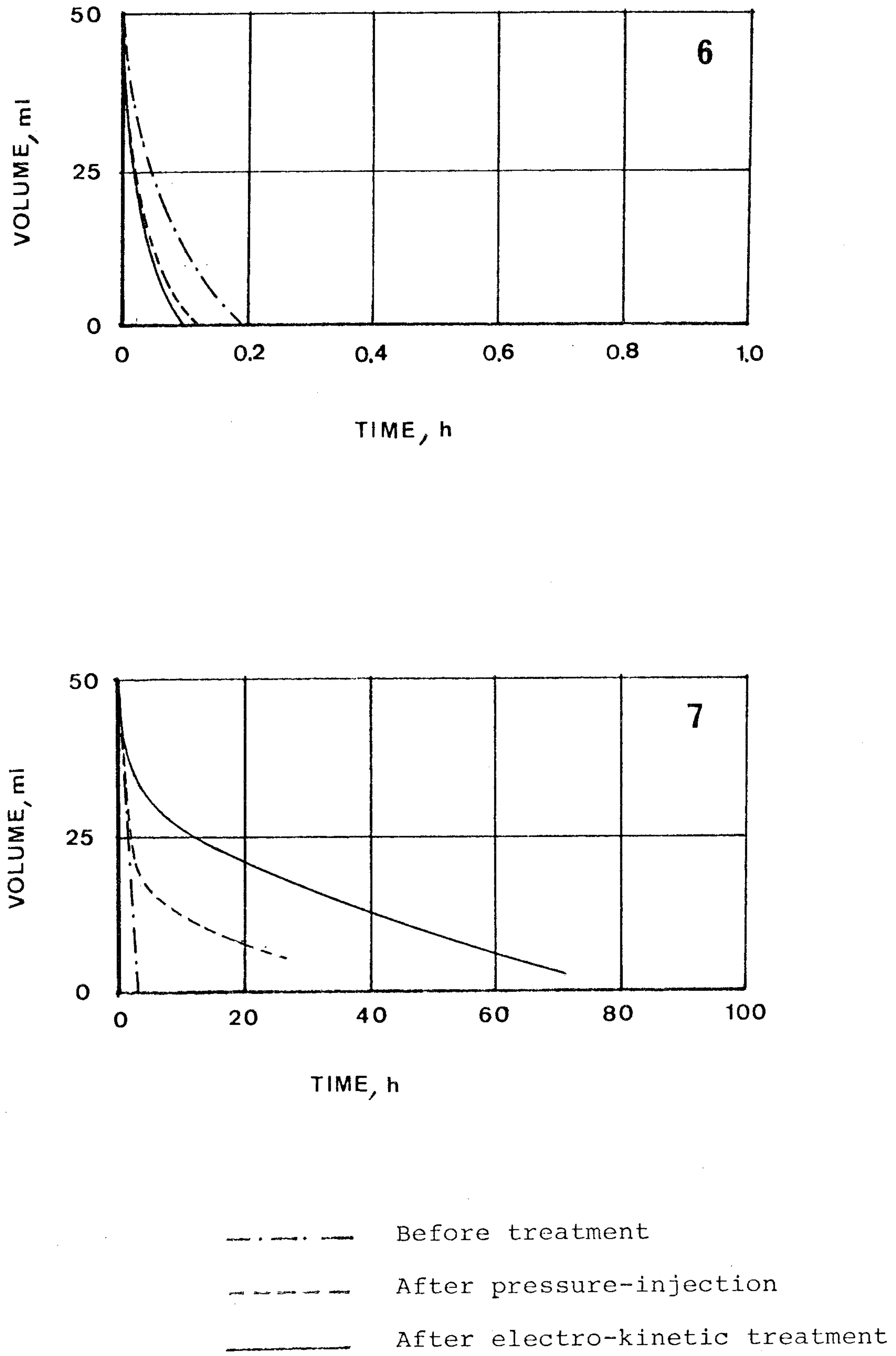


Fig. 11. Percolation tests. Upper picture: Hole no 6.
Lower picture: Hole no 7.

Hole no 2

As in hole no 1 only the electro-kinetic treatment was really effective. It is obvious, however, that also after this treatment fairly large water passages extend from the hole. This is explained by Fig. 5 which shows a very open joint system at the lower third of the core. A largely prolonged electrical treatment should have improved the sealing.

Hole no 3

Same comment as for hole no. 2. The rather small effect is also due to the tortuous passage-way from hole no. 7.

Hole no 4

No water loss before or after the treatments could be observed.

Hole no 5

The bentonite injections were not especially successful. Again this is probably due to fairly large openings (cf. Fig. 5).

Hole no 6

We get the impression that the injections reduce the time for clearance in this test. As mentioned previously the preliminary tests with compressed air etc probably opened the frequent joints (cf. Fig. 5). Also, the injection of the bentonite gel by means of the injection pump may have caused an additional widening. This hole was situated close to the block surface so the pressure-injection may in fact have produced a local splitting of the rock and concrete.

Hole 7

This hole is the most interesting since it represents the deposition hole where the injections were performed. We see that the pressure-injection contributed considerably to the sealing of the rock (the test had to be finished after 27 hours) but that the electro-kinetic treatment was the most effective one.

We can conclude from these measurements that a pressure-injection in a bore hole from a tunnel floor should be much more effective than our test since the confining rock is pre-stressed and gives a very effective lateral support with less risk of joint opening. This requires, however, that no tensile stresses exist in the confining rock.

We also find that the electro-kinetic treatment works and that it gives a valuable contribution to the sealing. Very probably a more efficient technique can be developed, for instance by applying other potentials and by making a series of prolonged electrical treatments with pressure-injections in between.

It is interesting to see that while the pressure-injection transferred 350 ml bentonite suspension out into the joints (that is about 35 g of solid clay), the electrical treatment brought an additional amount of 15 g of solid clay out into these joints. The effect of the electrical treatment was of course also that of transporting pressure-injected clay further out into the joints. This is probably the major effect of this treatment.

It should be mentioned that the physical process which transfers minute negatively charged clay particles towards the positive anodes is accompanied by an electro-osmotic water transport towards the cathode in the central hole. This was manifested by a slow rise of water in the standpipe of the cathode. The water column had rosen to about 25 cm above the external water level when the test was stopped.

The transfer of clay

The splitting of the block (cf. Fig. 12) showed that the main joints in Fig. 6 contained a thin film of fairly stiff montmorillonite gel.

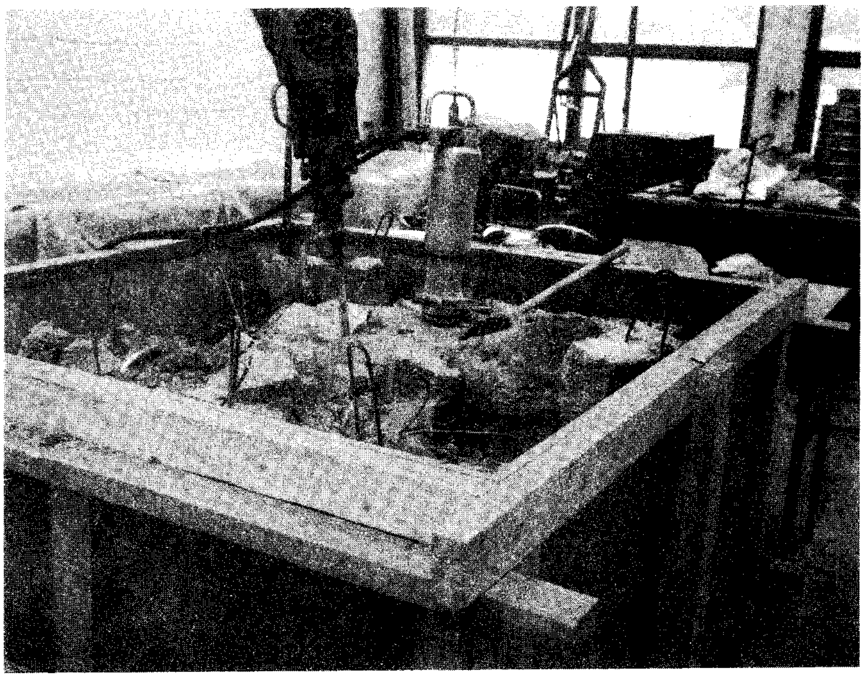


Fig. 12. Block splitting operation

The stiffness of the clay was much higher than that of gelated bentonite suspensions with a water content of 1000%. This means that consolidation occurred in course of the pressure-injection and/or that electro-phoresis increased the concentration of the gel. The latter process was observed in the previous glass-plate tests (PUSCH, 1977) and must have contributed to the increased density.

Four representative samples were taken from various joints for mineral identification. The positions were (cf. Fig. 6): 1) Joint A between bore holes no.1 and 2, 2) Joint B between bore holes no. 1 and 7 (passage way from base of hole no. 7 via joint A through hole no. 1 into joint B), 3) Joint B close to hole 5 (passage way from base of hole no. 7 via joint A through hole no. 5 into joint B, 4) Crossing of joints F and G 8 cm from top surface (passage way from base of hole no. 7 via joint A through joints F and G.

All the samples showed the presence of biotite and montmorillonite. The biotite origins from the rock while the montmorillonite is an evidence of the succesful injection operations. This is because the rock is completely free from the natural wheathering products. Fig. 13 is an example of the X-ray diffraction pattern for the sample from location 4. The conclusion of this study is that montmorillonite has been able to move a considerable distance despite the very tortuous passage-ways. This is most certainly an effect of the electro-kinetical treatment.

The water samples taken in the outer bore holes before and after the pressure-injection were investigated by means of electron microscopy. Due to the large amount of cations (the electrodes are dissolved as a result of the electrical treatment) and the low pH the montmorillonite flocculated immediately and settled to the base of the bore holes where it was mixed with rock flour. The electron micrographs are therefore difficult to interpret. Very probably, however, the frequently occurring extremely small and thin flakes represent this mineral (Fig. 14).

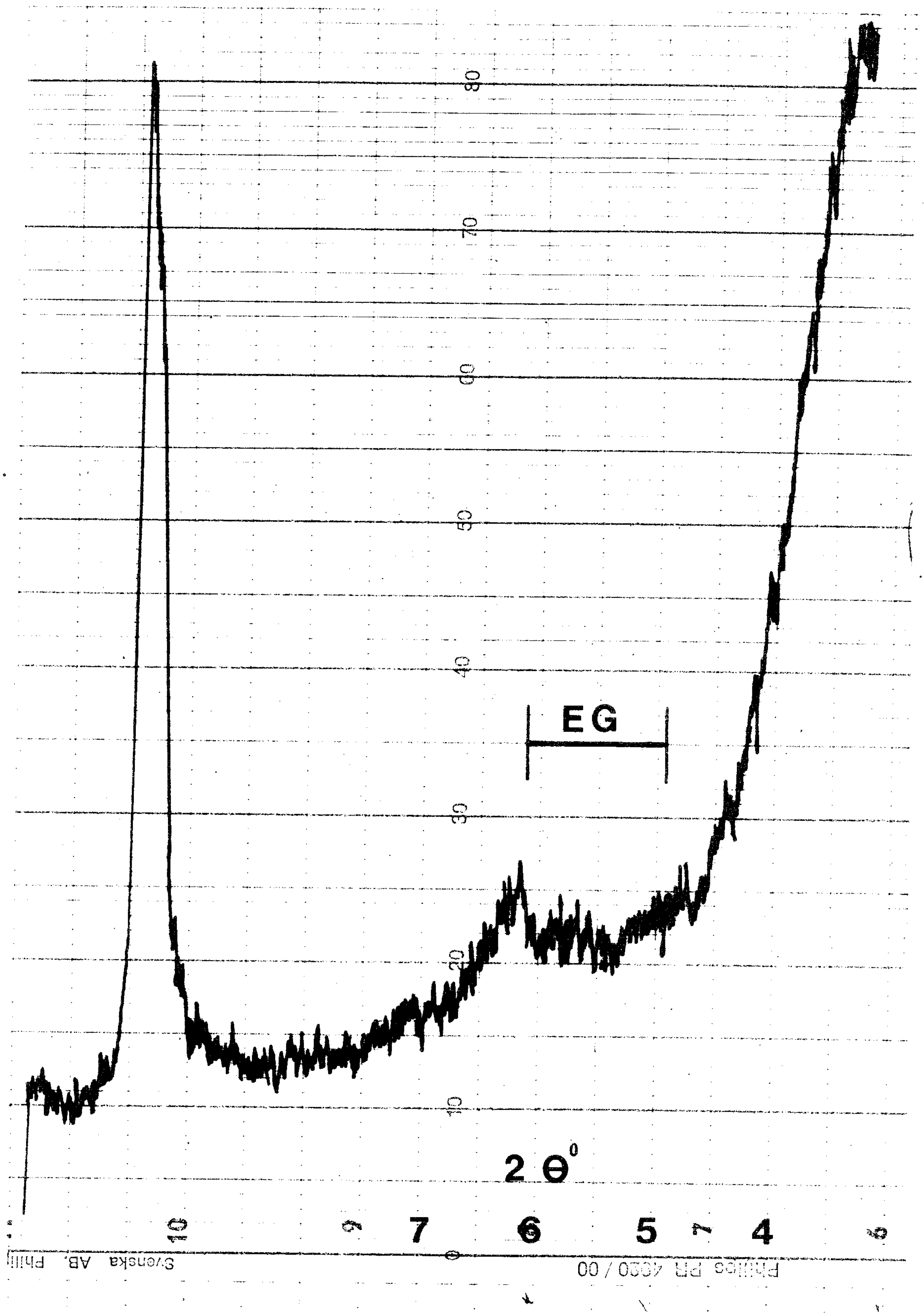


Fig. 13. X-ray diffraction pattern for sample from joint (no. 4). EG indicated the position to which the montmorillonite peak shifts after ethylene glycol treatment.

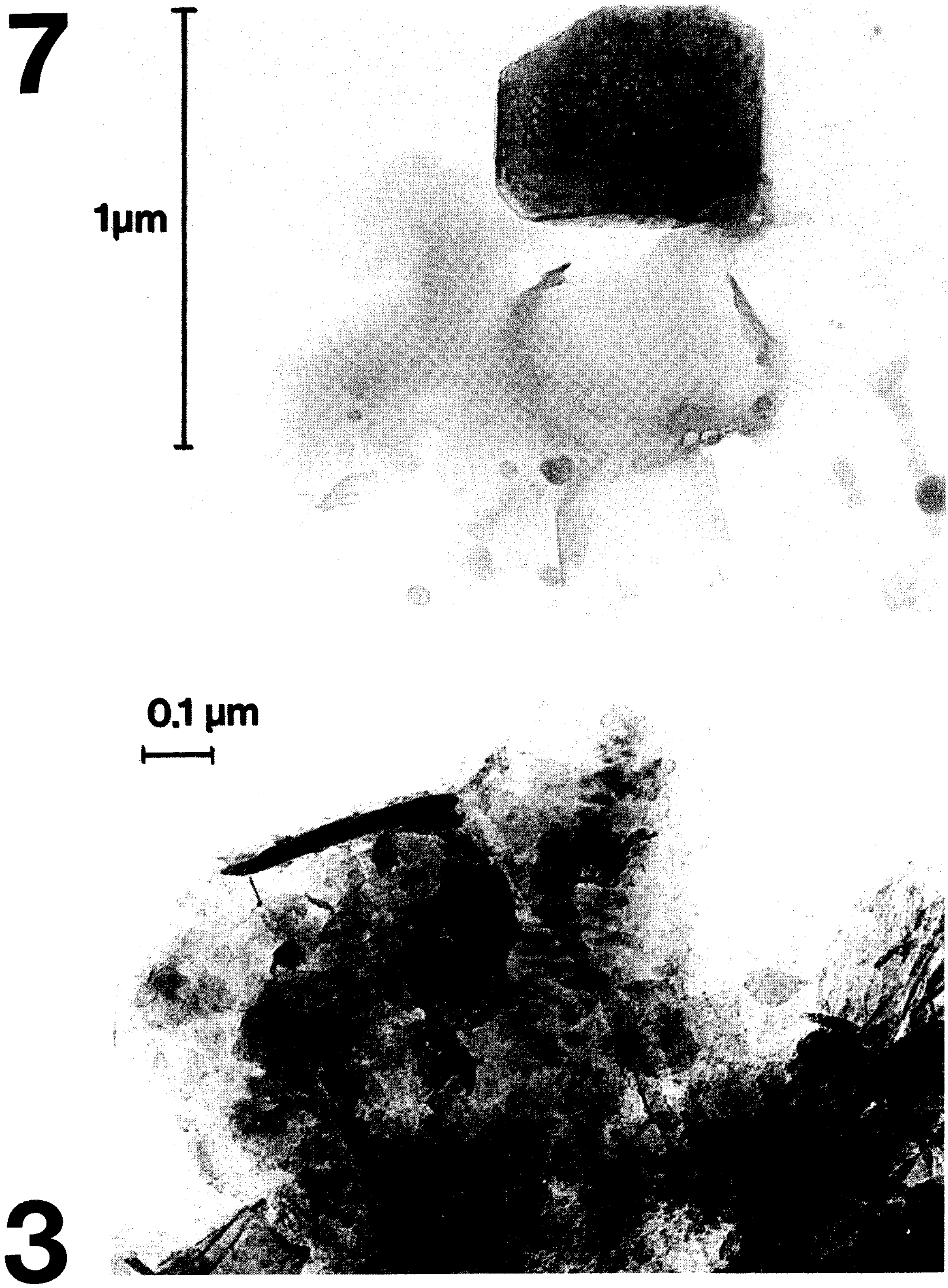


Fig. 14. Electron micrographs of samples from the bentonite slurry in bore hole 7 (for comparison) and from bore hole 3. The mineral assembly in the lower picture contains a number of small and very thin flakes.

Unfortunately, the colloidal gold particles could not be identified with certainty (cf. PUSCH, 1962 for technique description). It should be added that the montmorillonite in bore hole no. 3 had passed through such a tortuous joint system that the electrical field must have been the driving force.

Conclusions

The main conclusions from this investigation are:

* Pressure-injection of dilute bentonite suspensions ($w \sim 1000$) has a sealing effect but the depth of extrusion of the suspension into rock joints is probably not large because of gelation of the strongly thixotropic substance.

* Electro-kinetic injection of montmorillonite particles from a Na bentonite gel is a promising technique for rock tightening. It was found to be more effective than the pressure-injection. This was probably due to the electro-phoretic particle transport far out into the joints, directly from the central hole through the pressure-injected bentonite, and from the outer part of this bentonite.

* Since the clay particles have a net negative electrical charge they are transported towards the anodes, which should therefore be arranged around the central hole with the cathode. In practice, the joint system of the rock mass is not known in detail when the location of the bore holes with anodes is to be decided. This is of no importance since the electrical field is con-

tinuous and transports clay particles towards the anodes in any kind of passages, provided that they begin at the deposition hole or are connected with joints which start there. A further testing of the technique on a larger scale should now be made.

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