# EXCAVATION DISTURBED ZONE IN THE EXPERIMENTAL FULL-SCALE DEPOSITION HOLES AND RESEARCH TUNNEL AT OLKILUOTO

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## ABSTRACT

Three experimental full-scale deposition holes (diameter 1.5 m, depth 7.5 m) were bored in the Research Tunnel at Olkiluoto on the southwest coast of Finland. The disturbance caused in the zone close to the surfaces of the full-scale experimental deposition holes has been characterised by laser profiling to assess surface roughness, and by laboratory studies of rock samples taken from the disturbed zone using scanning electron microscopy (SEM) and two novel methods: the He-gas method to measure permeability and diffusion coefficient, and the Carbon-14 Polymethylmethacrylate method ($^{14}$CPMMA-method) to study porosity and microfracturing. The Research Tunnel itself was excavated using the drill and blast technique. The results of the studies on excavation disturbance caused by blasting show that there is a fractured zone surrounding the Research Tunnel. Hydraulic studies have indicated a hydraulic skin zone. The disturbed zone close to the surface of the walls of the full-scale experimental deposition holes exhibited increased permeability, higher diffusion coefficients and higher porosity. This paper includes some preliminary results covering the studies of excavation disturbance close to the surface of the walls of the full-scale holes and the excavation disturbance caused by blasting.

## INTRODUCTION

Three holes the size of deposition holes (depth 7.5 m and diameter 1.5 m) were bored in hard rock in the Research Tunnel at Olkiluoto in Finland [1&2], see Figure 1. A novel full-face boring technique was used based on rotary crushing of rock and removal of crushed rock by vacuum flushing through the drill string, see Figure 2 & 3. Boring of the experimental full-scale deposition holes was accompanied by comprehensive pre- and post-characterization of the rock in the field close to the holes using geophysical, geological, hydraulic and rock mechanical methods.

Tests were carried out while boring in order to establish the effect of changes in the boring machine operating parameters on boring performance and on the quality of the hole. The evaluation of the quality of the holes included studies on the geometry of the holes, measurement of surface roughness using a laser profilometer and laboratory studies of excavation disturbance in the zone close to the surface of the holes by using scanning electron microscopy (SEM) and two novel methods, the He-gas method and the $^{14}$CPMMA-method.

Both the boring of the full-scale experimental deposition holes and the characterization work was commissioned as a co-operative project by the Swedish Nuclear Fuel and Waste

Management Co. (SKB) and Posiva Oy, preceded earlier by Teollisuuden Voima Oy (TVO) in Finland.

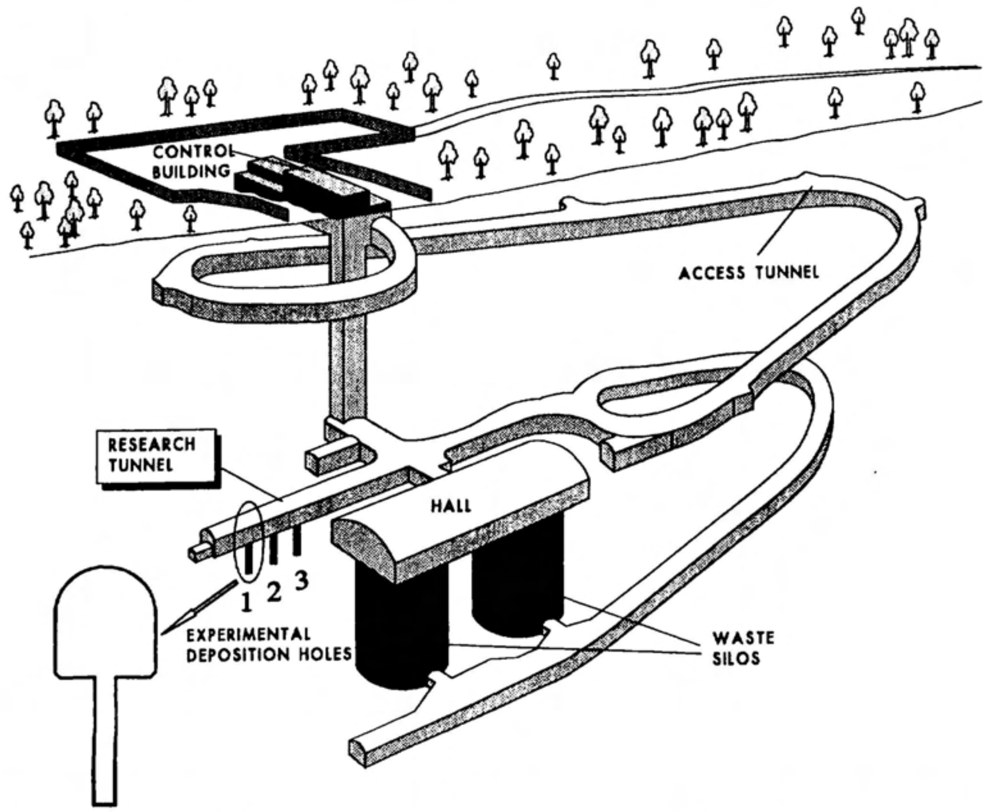


**Figure 1.** VLJ-repository, Research Tunnel and full-scale experimental deposition holes.

## THE RESEARCH TUNNEL AT OLKILUOTO

The Research Tunnel is located at a depth of 60 metres in the VLJ-repository, an underground disposal facility for the low and medium level waste generated by the Olkiluoto nuclear power plants. The repository is located approximately 1 km from the power plants on Olkiluoto island on the southwest coast of Finland. The repository was taken into operation in 1992.

The Research Tunnel was excavated using the drill and blast technique. The tunnel is located in an east-west striking gneissic tonalite formation which is surrounded by mica gneiss, see Figure 4. Rock types found in the Research Tunnel are gneissic tonalite and pegmatite. Tonalite is usually slightly foliated, medium-grained, massive and sparsely fractured. Besides gneissic tonalite, which is referred as anisotropic tonalite, a fine-grained tonalite variant is met. The pegmatite is non-foliated, coarse-grained, massive and sparsely fractured. The main minerals forming the anisotropic tonalite are quartz, plagioclase, biotite and hornblende, these represent about 94 % of the total mineral content. The mafic minerals, especially oblong grains of biotite and hornblende, are oriented. The grains are subhedral and the alteration to secondary minerals is insignificant.

The state of stress in the rock at the VLJ-repository and in the Research Tunnel area is low. The measured values of maximum in-situ stresses were on average from 5 - 6 MPa at the level of the repository [4].

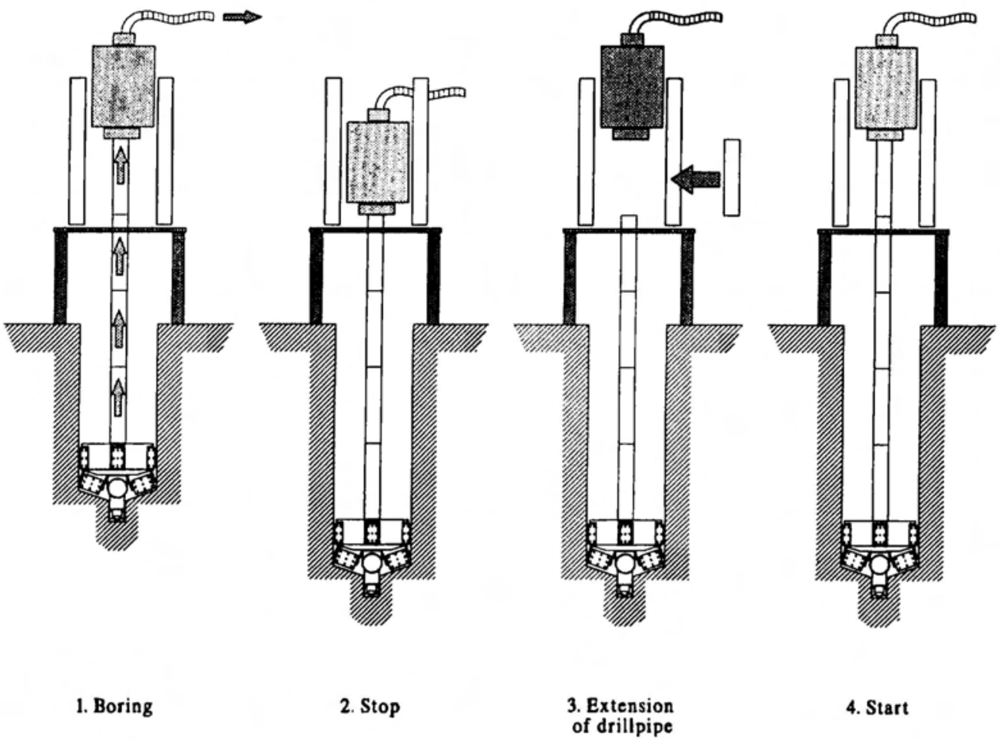


**Figure 2.** Operating principle of the boring method.

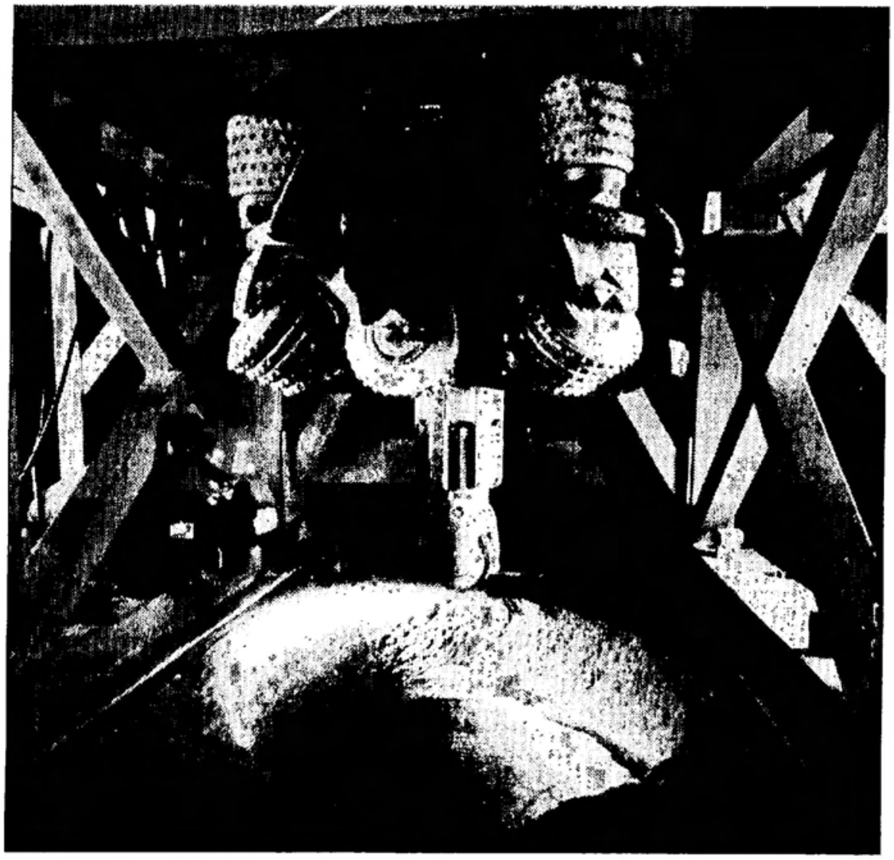

**Figure 3.** The cutter head above one of the experimental full-scale deposition holes.

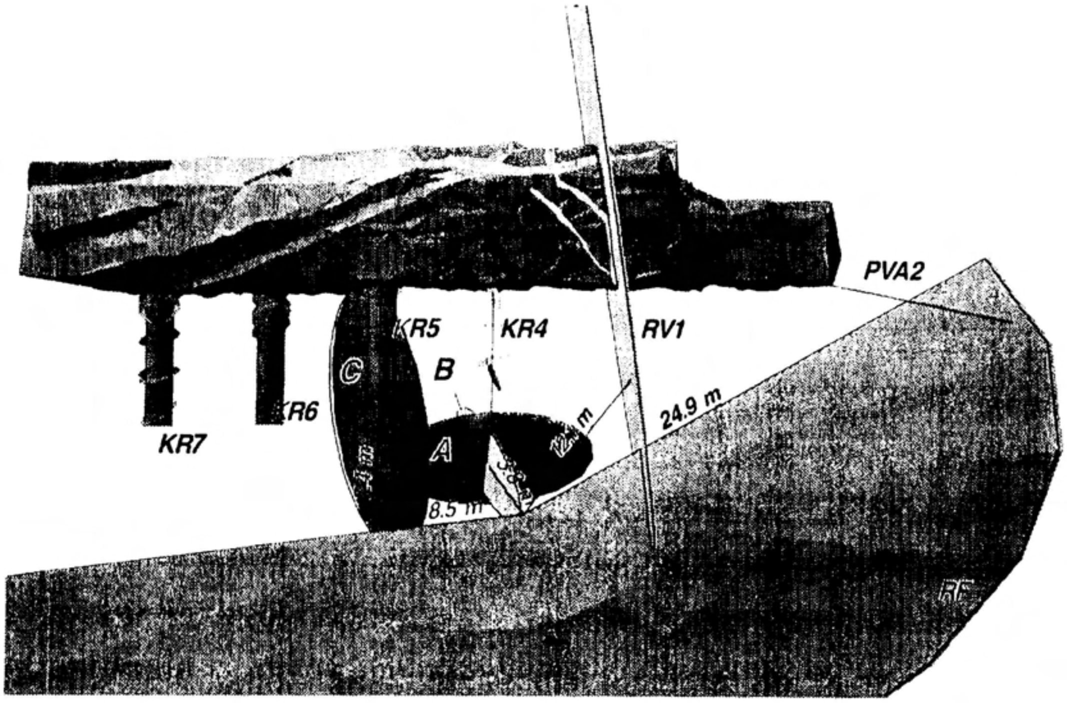


**Figure 4.** 3-D model of the Research Tunnel showing the hydraulically conductive fracture zones in the vicinity of the tunnel and the positions of the three full-scale experimental deposition holes.

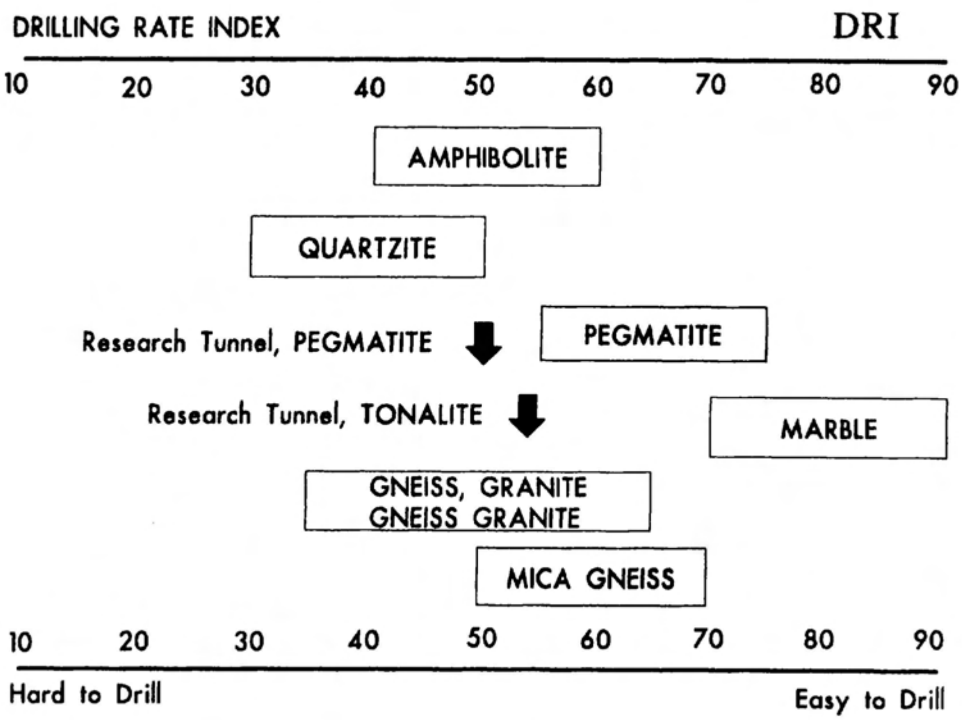


**Figure 5.** Variation of DRI in various rock types and the average DRI-values determined for the rock types in the Research Tunnel [5].

The anisotropic tonalite had a compressive strength of 80 MPa, tensile strength of 9 MPa, average DRI-value of 55 (see Figure 5), average brittleness value $S_{20}$ of 51.5, Sievers' SJ value of 32.4 and CAI-value (Cerchar Abrasitivity Index) of 3.8 [5]. The rock around the full-scale holes was sparsely fractured [6] and this description also applies to the state of fracturing in undisturbed rock not affected by blasting.

## EXCAVATION DISTURBANCE CAUSED BY BORING

The disturbance caused by boring on the rock was studied using two novel methods, the He-gas method and the $^{14}$CPMMA-method. Laboratory studies of the disturbance were made using 98 mm diameter core samples taken from different parts of the holes. The samples represented different boring parameters [7], see Figure 6.

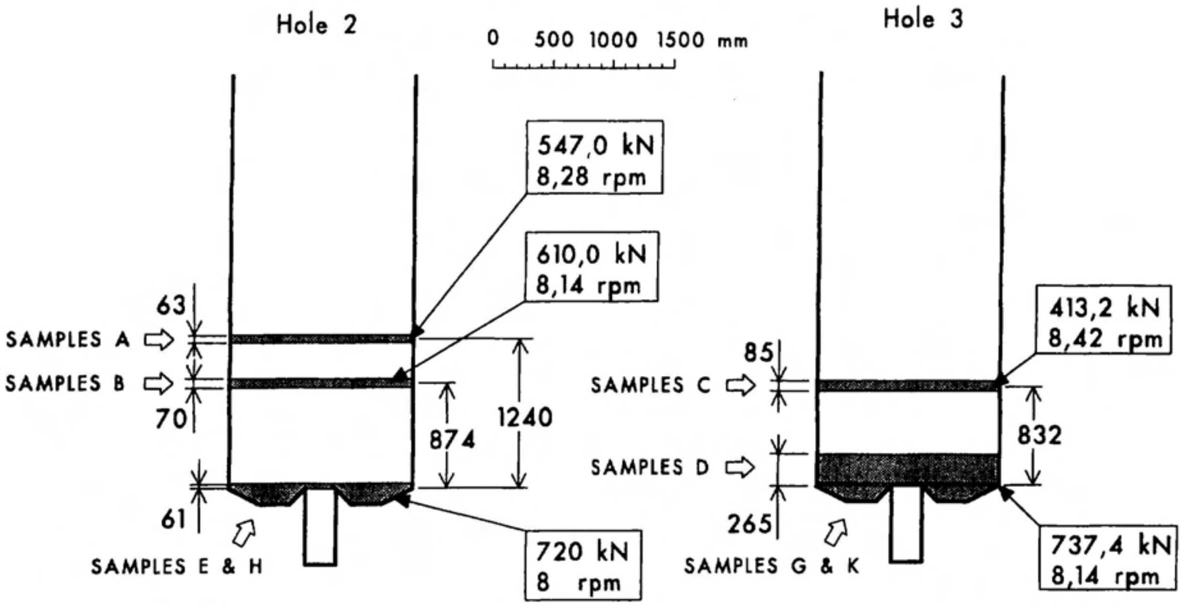


**Figure 6.** Location of some sampling sections in the experimental full-scale deposition holes together with the corresponding boring parameters [7].

## $^{14}$CPMMA-METHOD

The degree of mechanical disturbance of the rock in the side walls was determined in terms of geometry of microfracturing and porosity profiles measured using the $^{14}$CPMMA-method [8].

This method involved impregnation of the rocks with $^{14}$C methylmethacrylate, irradiation polymerization, sample partitioning (see Figure 7), autoradiography (see Figure 8) and optical densitometry using digital image processing techniques. Scanning electron microscopy (SEM) and energy dispersive X-ray analysis (EDX) were used in addition to the $^{14}$CPMMA-method to investigate pore apertures and minerals in some porous regions in greater detail. SEM/EDX studies were conducted on impregnated samples.

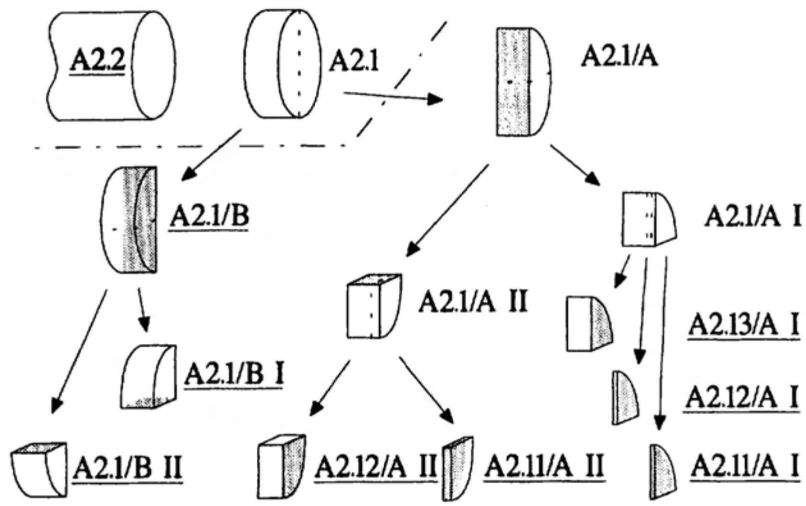


**Figure 7.** Partition diagram for 98 mm diameter core sample A3 from full-scale experimental deposition hole 2 as used for $^{14}$CPMMA study. The exposed surfaces were assessed.

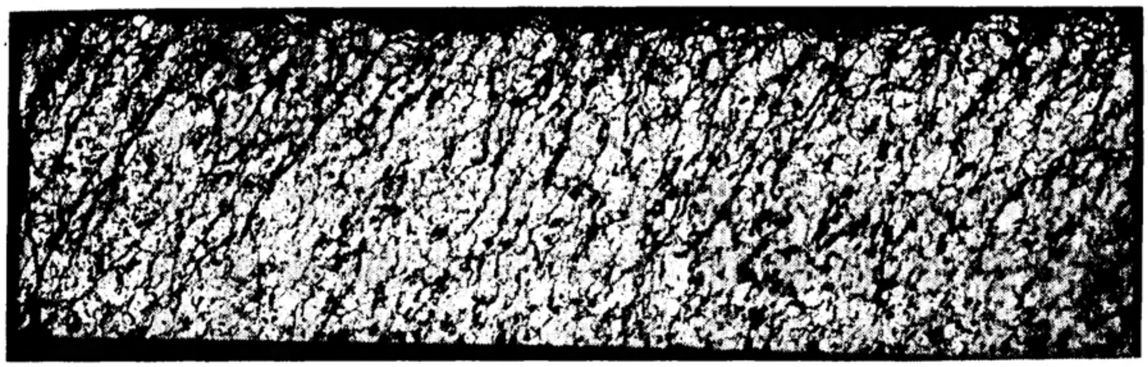

**Figure 8.** Example of a autoradiograph, sample C2 [8]. The upper surface of the sample is a 98 mm long section of the surface of deposition hole 3. The plane of the section is perpendicular to the surface. Different shades of gray represent different levels of porosity.

HELIUM-GAS METHOD

Disturbance in the rock of the side walls was determined using samples taken from six positions in the walls of the holes. The disturbance was assessed by measuring effective diffusion coefficients and permeability coefficients using a novel He- gas method [9]. The method employs two techniques, one based on the pure diffusion of helium gas (see Figure 9) and the other on flow of helium through the sample caused by a pressure gradient.

Both techniques allow easy and effective determination of diffusion and permeability coefficients. For example the time required to measure the diffusion coefficient of sample B3.1 was 23 hours. The length of the sample was 55.6 mm and the diameter 98 mm.

The diffusion and permeability coefficients of 30 samples of both undisturbed and disturbed rock were measured measured to a direction perpendicular to the disturbed surface of the holes. The measurements were used to calculate the thickness of disturbed zone and to estimate the maximum extent of microcracking.

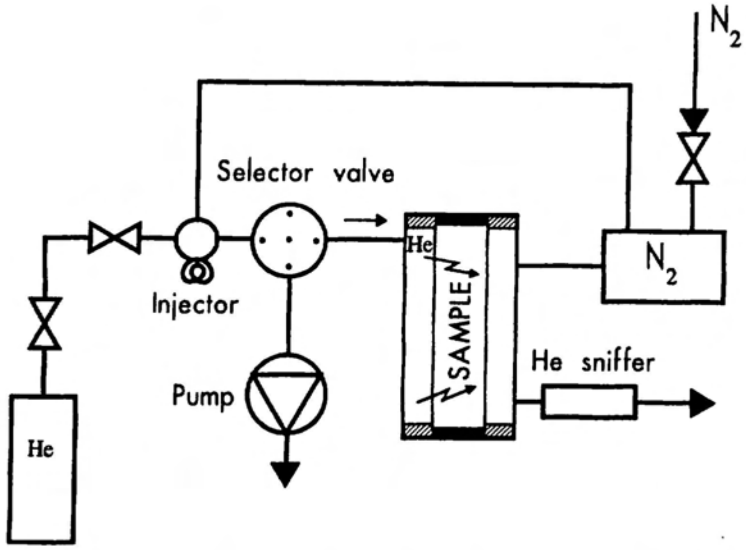


**Figure 9.** The experimental set up for the through diffusion measurement [9].

## THE EXCAVATION DISTURBANCE CAUSED BY BLASTING

During the excavation of the Research Tunnel the density of charge used varied over the range 0.063-1.13 kg-dyn/m (equivalent to the charge density of dynamite). The extent of excavation disturbance has been studied by surface mapping of the walls of the tunnels [10], by mapping half barrels on the walls with the aid of colour penetrant [11] and by surface mapping of the full-scale deposition holes [6], Figure 10 & 11. Samples were also taken from the walls of the tunnels to study the geometry of microfracturing and porosity in regions close to blast holes where different charge densities were used. The length of the radial fractures starting from the half barrels are being studied with the aid of colour penetrant and the porosity profiles adjacent to the half barrels with the $^{14}$CPMMA-method.

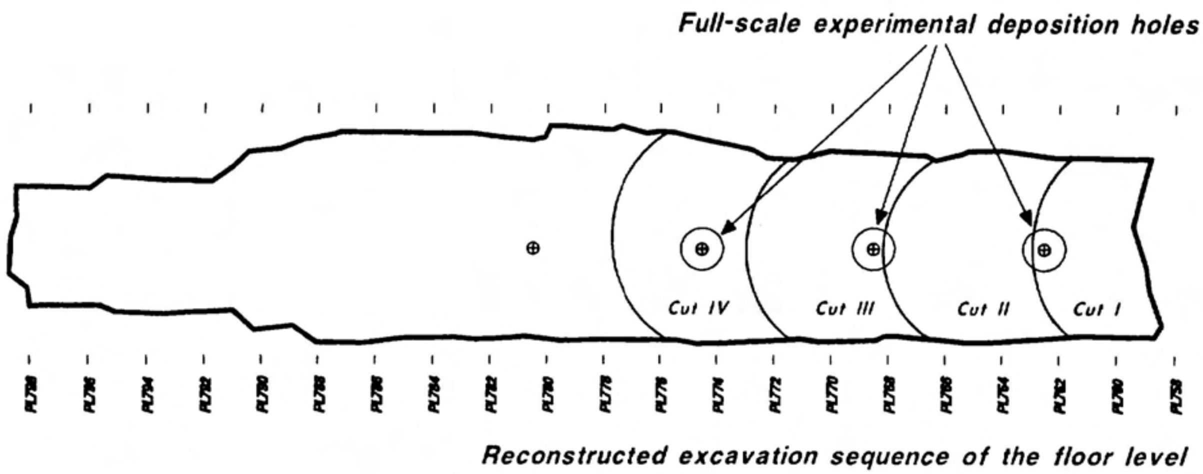


**Figure 10**. A plane section through the floor of the Research Tunnel. The geometry of the blasting cuts and the position of the experimental full-scale deposition holes is shown.

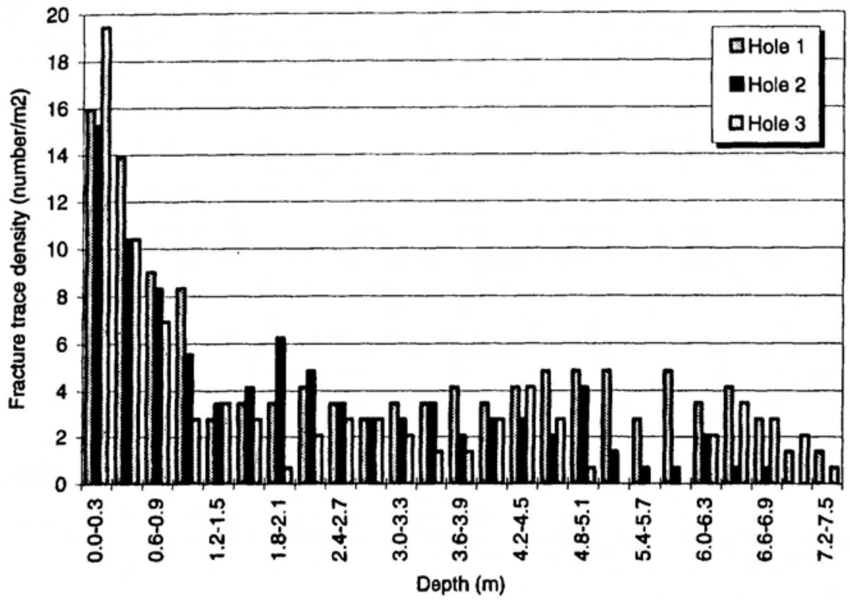


**Figure 11.** Fracture density (expressed as the number of fractures per square metre of surface) in experimental full-scale deposition holes 1,2 and 3 plotted in relation to depth [6].

RESULTS

There is clear evidence of a disturbed zone close to the full-scale experimental deposition holes. A summary report of the related studies made will be published in 1996 [12]. Total porosities measured with the $^{14}$CPMMA-method indicated a zone of increased porosity extending to a depth of about 10 mm from the wall surface, this zone is labelled 'h' in Figure 12. Porous tracelines extended to depths of 29-31 mm at most from the surface, these are labelled 'H' in Figure 12.

The results obtained using the He-gas method showed that there is a zone of higher permeability and diffusivity close to the surface of the holes in a direction perpendicular to the disturbed surface [9]. The estimated thickness of the zone was about 19 mm (labelled '$h_{He}$' in Figure 12). The average permeability of the disturbed zone of thickness about 19 mm was estimated to be $2.6*10^{-19}$ $m^2$, which was 56 times higher than in the undisturbed rock. The average diffusion coefficient of Helium in Nitrogen was estimated to be 3.6*10-9 $m^2/s$, which was 13 times higher than in the undisturbed rock.

The intensity of fracturing on the surfaces in the Research Tunnel is clearly higher than in the undisturbed rock. Increased fracturing is visible to a maximum depth of about 2 m below the floor of the tunnel which has been blasted using relatively high charge densities. The maximum extent of radial fractures starting from the floor appears to be from 1 m in the area of full-scale deposition hole 1 (charge density of 0.9 kg-dyn/m) to about 2 m in the area of full-scale deposition holes 2 and 3 (charge density of 1.1 kg-dyn/m).

The rock surface in the upper part of the full-scale experimental deposition holes, from the tunnel floor down to a depth of about 1 m is clearly more fractured than the remainder of the hole, as seen in the fracture density diagram in Figure 11.

In wall sections where the charge density 0.063 kg-dyn/m was used 87-100 % of the half barrels in the walls were visible. In sections where the charge density was 0.22 kg-dyn/m, 67-75 % of the half barrels were visible. The length of radial fractures on the surface of the half barrels was 6-25 % of the total length of the holes in sections where the charge density was about 0.063 kg-dyn/m and 24-26 % in sections where the charge density was 0.22 kg-dyn/m.

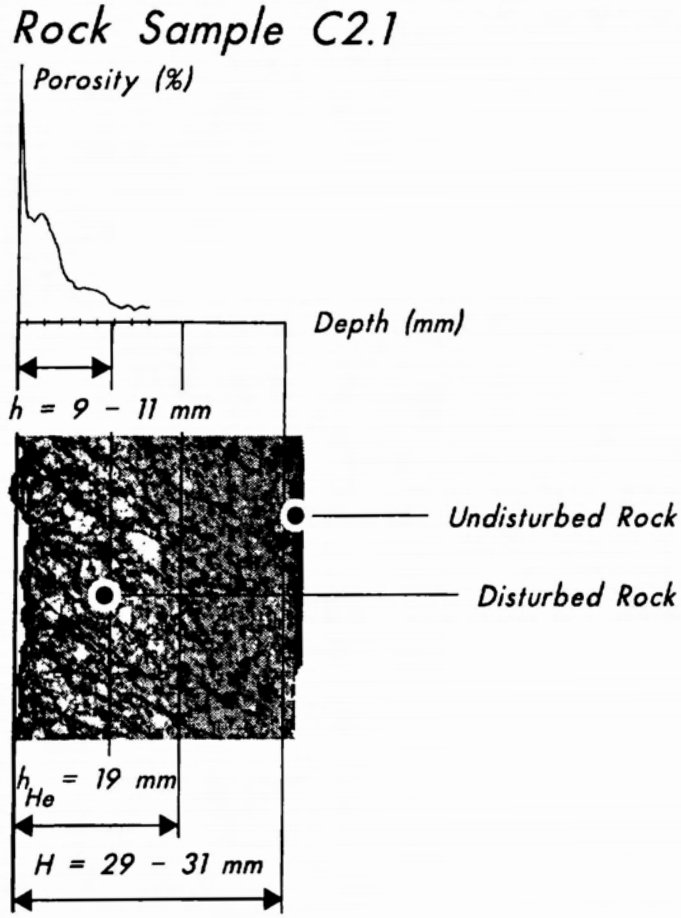


**Figure 12.** A section of rock sample, the corresponding porosity profile and the different disturbed zones (see text for symbols). The disturbed surface is on the left of the diagram [12].

According to preliminary results the depth extent of primary radial fractures in the tunnel walls caused by blasting of the perimeter row ranges from less than 10 cm in smooth blasted sections (charge density of 0.063 kg-dyn/m) to about 30 cm (charge density of 0.22 kg-dyn/m). The depth extent quoted here describes the extent of single primary fractures caused by blasting and is therefore assumed to represent the maximum thickness of the zone of clearly increased fracturing.

In addition to the zone which is mechanically disturbed, comprehensive hydraulic studies [3] have indicated the existence of a hydraulic skin zone around the Research Tunnel which hinders the inflow of water in the tunnel and flow and transport through sparse and narrow channels [3]. Clear evidence of that was provided by the fact that the amount of water that flowed into the pilot holes drilled on the axis of the full-scale experimental deposition holes and subsequently into the full-scale holes, was almost as high as the total flow of water into other parts of the Research Tunnel.

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