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Haruo Sato*

Abstract

The porosities and dry densities for rock samples sampled from a fractured zone (fracture type C: composed of intact granodiorite, altered granodiorite and fracture fillings) at the Kamaishi mine were obtained by a water saturation (intrusion) method as input parametaers for nuclide migration analysis in performance assessment of the geological disposal of high-level radioactive waste. Consequently, the average porosity, 8.6±0.43 %, was higher than those of fracture fillings, altered garnodiorite and intact granodiorite composing fracture type B with a single fracture taken from the Kamaishi mine so far. While, the average dry density, 2.43±0.0089 $Mg{\cdot}m^{-3}$, was lower than those of rocks composing the fracture type B. Based on this, it is predicted that radionuclides are the easiest to migrate in the fracture zone.

* Radiochemistry Group, Waste Isolation Research Division,
Waste Management and Fuel Cycle Research Center, Tokai Works,
Japan Nuclear Cycle Development Institute

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釜石鉱山における割れ目破砕帯岩石の間隙率および密度

（研 究 報 告）

佐藤治夫*

要 旨

高レベル放射性廃棄物地層処分の性能評価における天然バリア中での核種移行解析のための入力パラメータとして、釜石鉱山の割れ目破砕帯（割れ目タイプＣ：花崗閃緑岩健岩部、変質部、割れ目充填鉱物部より構成）より採取した岩石に対する間隙率および密度を水中飽和法により測定した。その結果、平均して 8.6±0.43％とこれまでに同鉱山から採取された単一割れ目を伴う岩石（割れ目タイプＢ：花崗閃緑岩健岩部 2.3%、変質部 3.2%、割れ目充填鉱物部 5.6%）と比較して大きい間隙率であった。一方、密度は平均して 2.43±0.0089Mg·m^{-3} であり、割れ目タイプ B を構成する各岩石のどの密度よりも小さい値であった。このことから、放射性核種は割れ目破砕帯で最も移行しやすいことが予想される。

*核燃料サイクル開発機構　東海事業所　環境保全・研究開発センター
処分研究部　放射化学研究グループ

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1. INTRODUCTION

In performance assessment of the geological disposal system of high-level radioactive waste (HLW), the diffusion behaviour of key radionuclides into rock matrix from fracture is important for the understanding of retardation property. Thus data acquisition and modelling studies to obtain effective diffusion coefficients (De) and apparent diffusion coefficients (Da) of such radionuclides in the rock matrix have been carried out.

In fractured crystalline rocks, radionuclide migration takes place along the connected pores into the rock matrix by diffusion from the fractures, in which advection flow occurs. The diffusion of radionuclides into the rock matrix is generally considered as one of the key retardation processes in radionuclide transport. The transport of radionuclides occurs through pores in the rock matrix and the porosity is one of the important parameters when the transport is quantitatively evaluated or predicted. In this report, porosity and density obtained focused on granodiorite sampled from a fractured zone of the Kamaishi mine are discussed.

In a previous study, fracture mapping for a total of ~ 400 fractures was carried out to develop a conceptual flow path model in the Kurihashi granodiorite at the Kamaishi In Situ Test Site, and it is already known that the fractures can mainly be classified into three types: type A with a zone of fracture fillings, type B with both a zone of fracture fillings and an altered zone, and type C consisting of several fractures with a zone of fracture fillings and an altered zone [1]. **Figure 1** shows the proposed conceptual flow path model in the Kurihashi granodiorite [1]. Since the fracture type A is included in the fracture type B, judging from the fracture structure and the mineralogy, the fracture type B after all occupies 99 % of the studied aera. The fracture type C is a mixture of the fracture types A and B, forming a fracture zone, as shown in **Figure 1**.

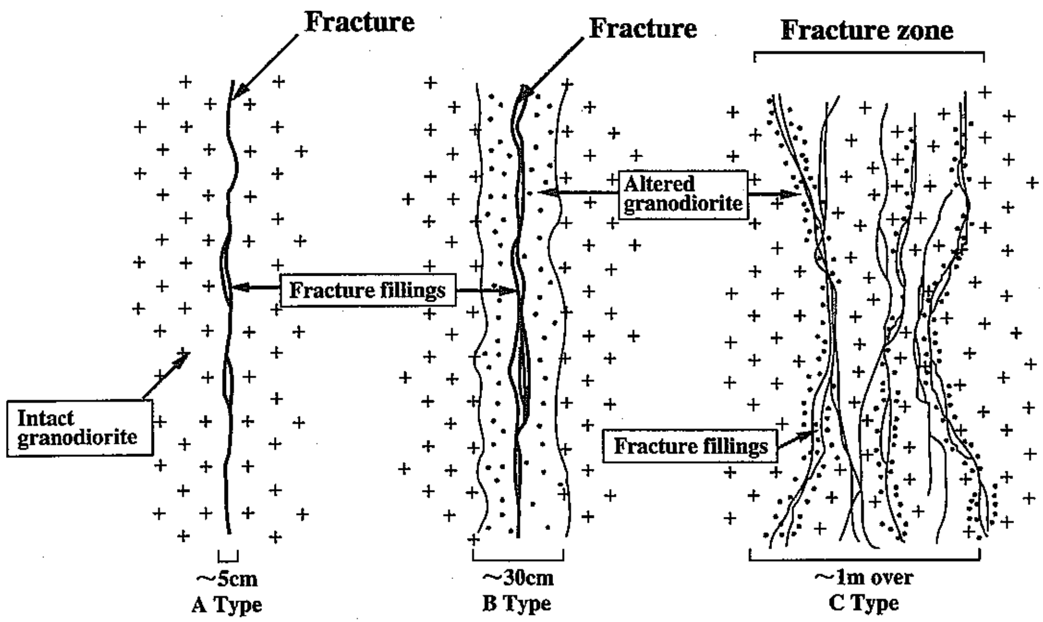

Figure 1 Illustration of fracture types identified in the Kurihashi granodiorite at the Kamaishi In Situ Test Site
Fracture types A, B and C occupy ~ 35, 64 and 1 %, respectively, from fracture mapping for a total of ~ 400 fractures in the studied area.

For physical properties of granodiorite sampled from the Kamaishi mine, the author has reported porosity, dry density, pore-size distribution and specific surface area of the pores obtained by water saturation (intrusion) method and mercury porosimetry so far [2, 3]. However, the data obtained to date have been focused on the fracture type B which has a single fracture, and no study has been carried out for the fracture type C which forms fractured zone, because rock sample is friable and it is difficult to take sampling.

In this study, porosity and dry density measurements focused on the fracture type C which is considered to affect mass transport were carried out by a water saturation (intrusion) method.

2. EXPERIMENTAL

2.1 Location of the Kamaishi In Situ Test Site and the Geological Map

Figure 2 shows location of the Kamishi In Situ Test Site and the geological map around the Kamaishi In Situ Test Site. The Kamaishi In Situ Test Site, ~ 20 km west of Kamaishi city, is located ~ 600 km north of Tokyo and is in a coastal area facing the Pacific Ocean.

The geology of the area studied consists of Paleozoic sedimentary rock, Cretaceous sedimentary rock, the Ganidake granodiorite, and Kurihashi granodiorite. This study was carried out using rock samples taken from the "KRC-003" borehole, which is in a drift 550 m above sea level (~ 300 m deep from the ground surface) and is about 4000 m distant from the drift entrance of 550 m.

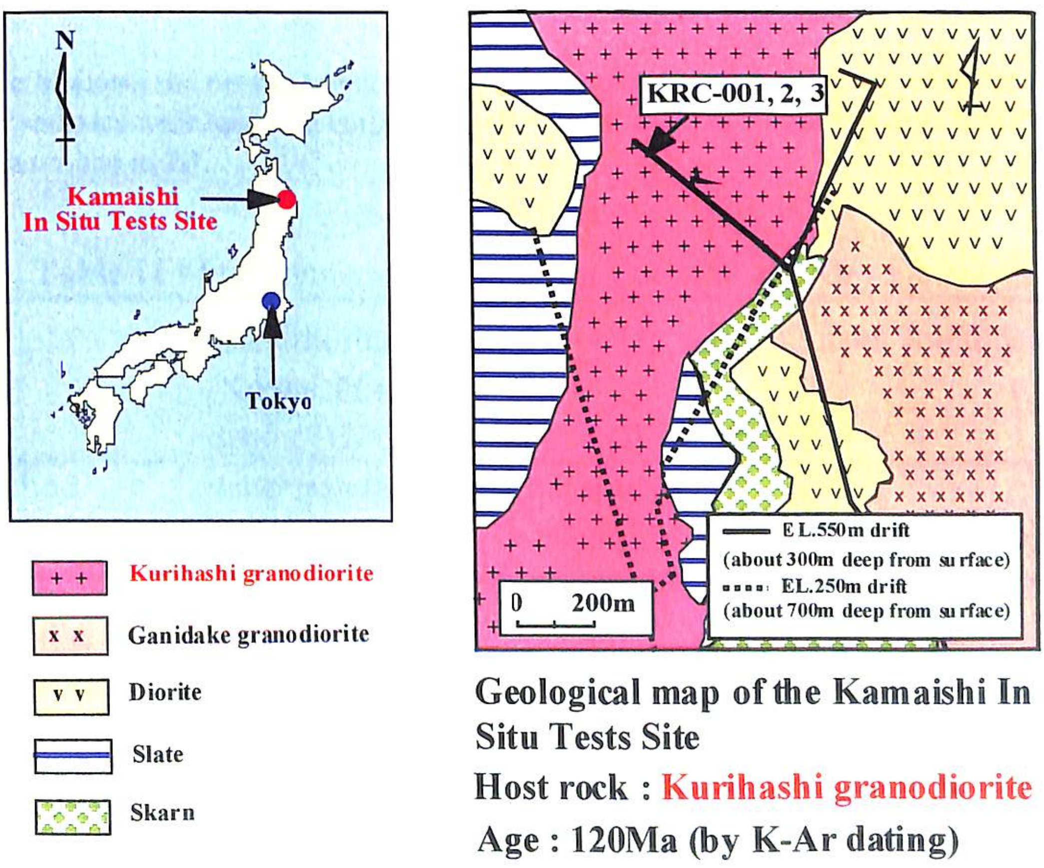

Figure 2 Location of the Kamaishi In Situ Test Site and the geological map around the Kamaishi In Situ Test Site

The major constituent minerals of the fracture fillings are calcite and stilbite, and those of the altered and intact granodiorite are quartz and plagioclase. In the altered granodiorite, the content of constituent chlorite is a little higher than that in the intact granodiorite. Biotite is contained in the intact granodiorite instead of chlorite. The mineralogy is described in more detail by Osawa et al. [1] and Ota et al. [4]. **Table I** shows the summary of mineralogy for fracture fillings, altered granodiorite and intact granodiorite.

Table I Mineral Composition for Fracture Fillings, Altered Granodiorite, and Intact Granodiorite

Rock	Quartz	Plagioclase	Calcite	Stilbite	Biotite	Chlorite	Laumontite	K-feldspar	Hornblende	Sericite	Epidote
Intact granodiorite	◎	◎			○	△		△	△		
Altered granodiorite	◎	◎				○		△	△	△	
Fracture fillings	○	△	◎	◎		○	○				△

Content: ◎>○>△[1]

2.2 Material

Table II shows the measurement condition for porosity and dry density of the rock samples. The rock samples were taken by coring from the "KRC-003" borehole in a drift 550 m above sea level as described in **2.1**.

Table II Measurement Condition for Porosity and Dry Density

Sample	granodiorite (fracture type C), sampled from fracture zone (Kamaishi mine) depth: GL–300 m (KRC-003 borehole)
Method	water saturation (intrusion) method
Producibility	n=6 (6 samples were taken from the "KRC-003" core)

2.3 Procedure

The porosity and dry density of the rock were determined by a water saturation method. The water saturation method is the method to determine porosity and dry density from the water saturated and dried sample weight by making the rock pores saturate with water.

Fist-sized samples were soaked in distilled water under ~ 60-Torr pressure conditions. The sample weight was periodically measured in distilled water. This operation was repeated until the sample weight reached a constant level. The water temperature was also simultaneously measured in order to correct the distilled water density when dry density is calculated.

After the saturation, the water-saturated samples were wiped off to remove their surface water, and then they were weighed. Next, the samples were dried at 110 °C in an oven until the weight reached a constant level.

3. CALCULATIONS OF POROSITY AND DRY DENSITY

The porosity is defined by the following equation [5].

$$\phi = \frac{V_P}{V_T} = 1 - \frac{\rho_d}{\rho_t} \qquad (1)$$

Where ϕ is the porosity (–), V_p is the pore volume of the sample (m^3), V_T is the total rock sample volume (m^3), ρ_d is the dry density of the sample ($Mg{\cdot}m^{-3}$) and ρ_t is the theoretical (pure) density of the sample ($Mg{\cdot}m^{-3}$).

When the sample is soaked in water, buoyancy acts to the sample. Therefore, the weight of the sample in water becomes light compared with that under air. The balance of the force in water for a water-saturated sample and the buoyancy is expressed by the following equation.

$$W_s + P = M_d \qquad (2)$$

and

$$P = \frac{V_T - V_P}{\rho_w} \qquad (3)$$

Where Ws is the weight of the water-saturated sample in distilled water (Mg), P is the buoyancy (Mg), Md is the weight of the dried sample (Mg) and ρ_w is the density of the distilled water ($Mg{\cdot}m^{-3}$).

Substituting equation (3) into equation (2), the following equation is derived.

$$W_s + (V_T - V_p) \cdot \rho_w = W_s + \rho_w \cdot V_T \cdot (1 - \phi) = M_d \qquad (4)$$

The weight of the water-saturated sample under air-dry condition is derived from the following equation.

$$M_s = \rho_w \cdot V_T \cdot \phi + \rho_w \cdot V_T \cdot (1 - \phi) + W_s \qquad (5)$$

Where Ms is the weight of the water-saturated sample under air-dry condition (Mg).

While, from $\phi{\cdot}V_T{\cdot}\rho_w$ = Ms – Md, the following equation is derived.

$$\phi = \frac{M_s - M_d}{V_T \cdot \rho_w} \tag{6}$$

From equation (4),

$$\rho_w \cdot V_T = \frac{M_d - W_s}{1 - \phi} \tag{7}$$

is derived, and substituting equation (7) into equation (6), the porosity is calculated by the following equation.

$$\phi = \frac{M_s - M_d}{M_s - W_s} \tag{8}$$

The total sample volume is also calculated by the following equation from equation (6).

$$V_T = \frac{M_s - W_s}{\rho_w} \tag{9}$$

Therefore, the dry density of the sample is calculated by the following equation.

$$\rho_d = \frac{M_d}{V_T} = \frac{M_d \cdot \rho_w}{M_s - W_s} \tag{10}$$

In this study, since the average temperature of distilled water was 18.8±0.6 °C, the density of water at 19.0 °C (0.998405 $Mg{\bullet}m^{-3}$) [6] was used for the calculation of dry density. As described above, ϕ, V_T and ρ_d were calculated based on equations (8), (9) and (10), respectively.

4. RESULTS AND DISCUSSION

Figures 3 and **4** show the changes in the weights of the rock samples in distilled water as a function of time and those in the weights of the samples under air-dry condition as a function of drying time, respectively. And **Table III** shows Ms, Md, Ws, ρ_w and the calculated results of porosity (ϕ), dry density (ρ_d) and of total sample volume (V_T). The value of 0.998405 $Mg{\bullet}m^{-3}$ (19.0 °C) was used for the calculations as the density of water [6].

The measured porosities, in a range of 7.63 to 11.3 % (average 8.6±0.43 %) excepting one sample, were the highest of the porosities for fracture fillings, altered granodiorite and intact granodiorite composing fracture type B with a single fracture taken from the Kamaishi In Situ Test Site reported so far. Although low porosity, which is 3.0 %, was also obtained only for one sample (C-1), this may be because intact granodiorite, which is massive was included in rock samples taken from the fractured zone. However, porosities quite higher than those of common granodiorite were measured. While, the average dry density, 2.43±0.0089 $Mg{\bullet}m^{-3}$, was lower than those of fracture fillings, altered granodiorite and intact granodiorite composing the fracture type B with a single fracture.

The porosities for each rock composing the fracture type B have been already reported to be on the average 2.3 % for intact granodiorite, 3.2 % for altered granodiorite and 5.6 % for fracture fillings [2, 3]. **Figure 5** shows the porosities for each rock composing the fracture type B and for fractured zone sampled from the Kamaishi In Situ Test Site. Although some variations in the porosity are found, the average porosities are approximately in the following order: fracture fillings > altered granodiorite > intact granodiorite > fractured zone, showing a tendency to decrease into the rock matrix from fracture. The porosities obtained in this study are large compared with those and it is predicted that radionuclides are the easiest to migrate in the fractured zone if distribution coefficient (Kd) is constant.

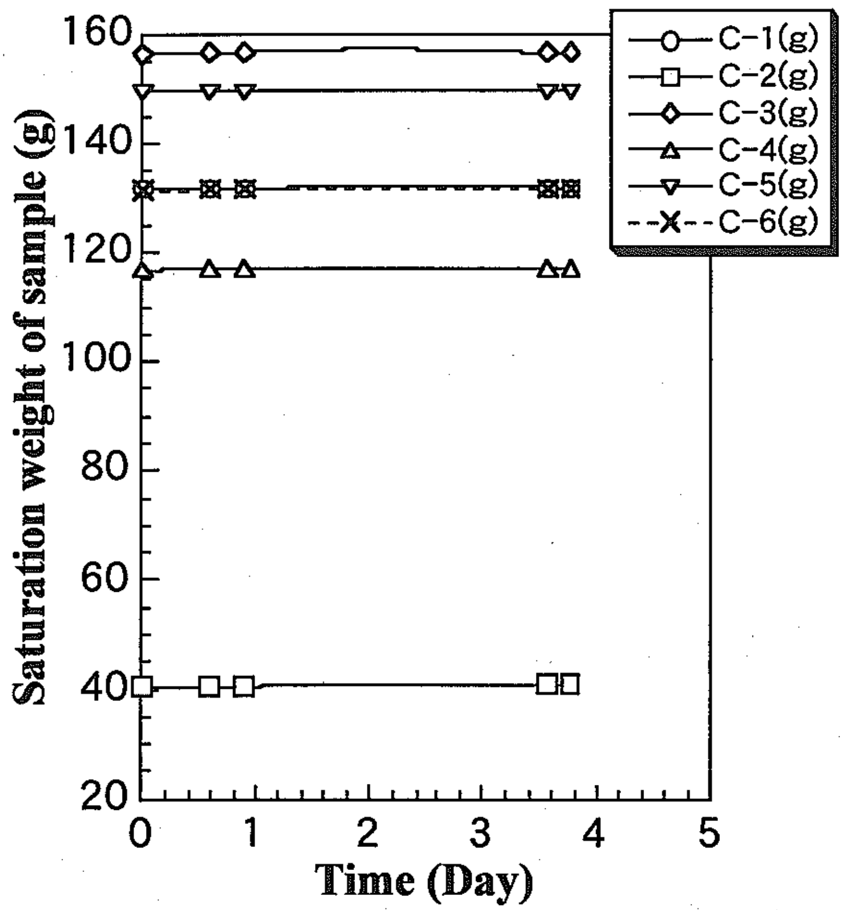

Figure 3 Changes in the weights of the samples in distilled water as a function of time

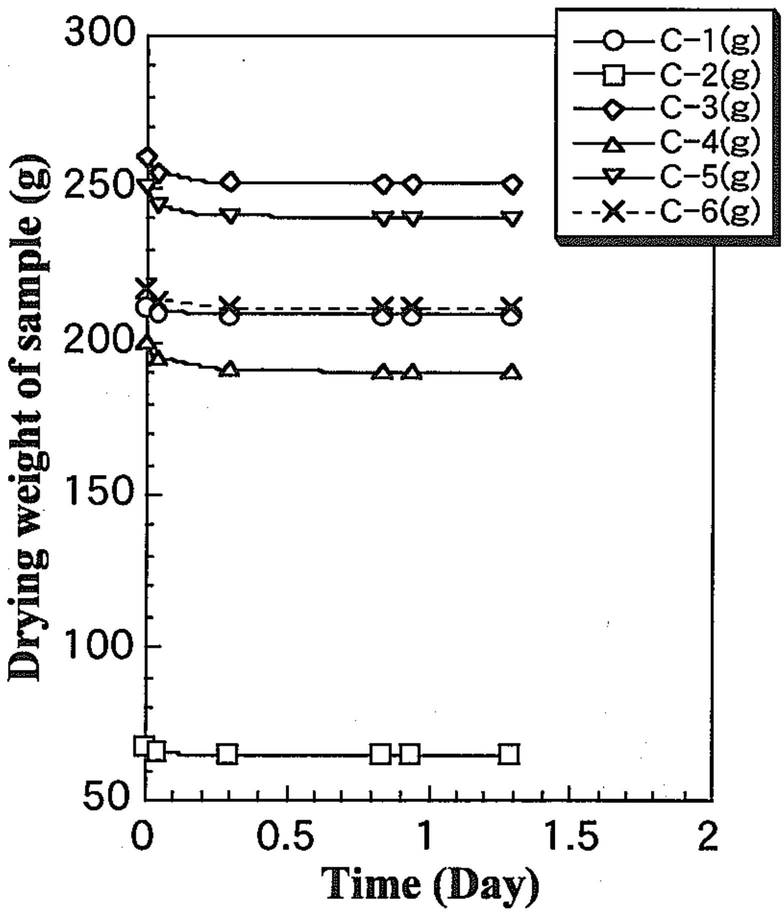

Figure 4 Changes in the weights of the samples under air-dry condition as a function of drying time

Table III Porosity and Dry Density of the Rock Obtained

Sample No.	Ms [g]	Md [g]	Ws [g]	ρ_w* [Mg•m^{-3}]	ϕ [%]	ρ_d [Mg•m^{-3}]	V_T [cm^{-3}]
C–1	211.28	208.88	131.84	0.998405	3.0	2.63	79.57
C–2	67.85	35.0	40.69	0.998405	10.5	2.39	27.20
C–3	260.43	251.50	156.55	0.998405	8.6	2.42	104.0
C–4	199.82	190.52	117.28	0.998405	11.3	2.30	82.67
C–5	250.67	240.37	149.56	0.998405	10.2	2.38	101.3
C–6	217.49	210.94	131.65	0.998405	7.63	2.45	85.98
Average					8.6±0.43	2.43±0.0089	

* Density of water at 19.0 °C

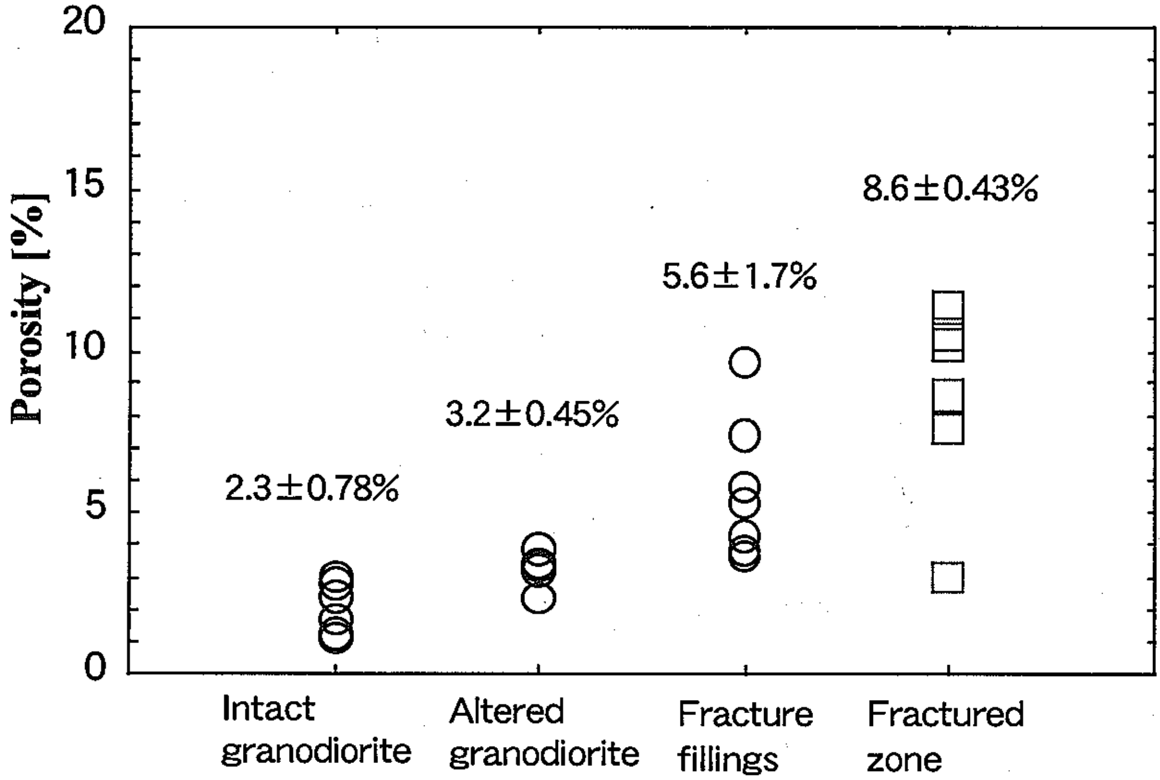

Figure 5 Porosities for each kind of rock composing fracture type B and for fractured zone sampled from the Kamaishi In Situ Test Site
○: rocks composing fracture type B [2, 3]
□: this work

5. CONCLUSIONS

(1) The porosities and dry densities for rocks taken from a fractured zone (fracture type C: composed of intact granodiorite, altered granodiorite and fracture fillings) at the Kamaishi mine were obtained by a water saturation (intrusion) method as input parameters for nuclide migration analysis in performance assessment of the geological disposal of high-level radioactive waste. Consequently, the average porosity and dry density, 8.6±0.43 % and 2.43±0.0089 $Mg{\bullet}m^{-3}$, respectively, were obtained.

(2) The average porosity was higher than those of fracture fillings, altered granodiorite and intact granodiorite composing fracture type B with a single fracture. While, the average dry density was lower than that of each rock composing the fracture type B. Based on this, it is predicted that radionuclides are the easiest to migrate in the fractured zone.

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