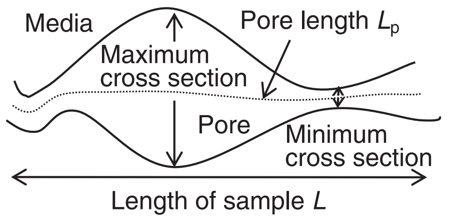
# 2-4 Revealing the Pore Structure and Diffusion Mechanism in Rock

## — Analysis of Pore Structure of Siliceous Mudstone Using Nano X-ray Computed Tomography —




$$\tau^2=(L_p/L)^2$$

$$\delta=\frac{(\text{maximum}\times\text{minimum cross section})^{1/2}}{\text{mean cross section}}$$

**Fig.2-9 Definitions of tortuosity ( $\tau^2$) and constrictivity ( $\delta$ )**
The image obtained is analyzed on the basis of the definitions.

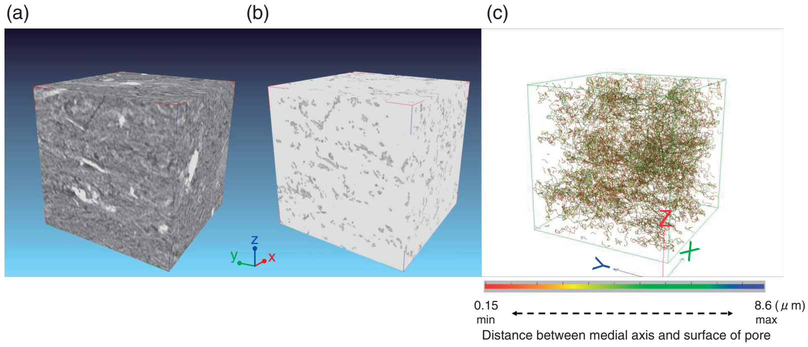



**Fig.2-10 The porous network of the rock matrix with sub-micron-sized features is imaged and analyzed**
(a) Three-dimensional image ($512^3$ with a voxel size of 270 nm) of siliceous mudstone of the Wakkanai formation, (b) after segmentation (dark gray areas denote pore spaces), and (c) medial axes with color indicating the distance between each axis and the pore surface.

**Table 2-1 Results of image analyses and tritiated water (HTO) diffusion tests**
A comparison of the pore structure and diffusion tests suggests that the pore connectivity collates with the diffusion-accessible porosity, and that the dominant parameters in an HTO diffusion system are the tortuosity and diffusion-accessible porosity.

| Image analysis | | | | | | Diffusion experiments | | |
|---|---|---|---|---|---|---|---|---|
| Direction to the ground | Direction | Starting face voxels connected to end face | Average of tortuosity | 1/tortuosity | Average of constrictivity | Accessible porosity | Effective diffusion coefficient/$m^2s^{-1}$ | Geometry factor |
| Vertical | Z | 20 | 6.97 | 0.14 | 0.47 | 0.19 | $8.80\times10^{-11}$ | 0.19 |
| Horizontal | Y | 152 | 4.75 | 0.21 | | 0.22 | $1.02\times10^{-10}$ | 0.19 |
| Horizontal | X | 55 | 8.64 | 0.11 | | | | |

Diffusion in a rock matrix is one of the key processes for the migration of radionuclides from high-level radioactive waste. The diffusion coefficient is an important factor in the safety assessment for deep geological disposal of high-level radioactive waste. Diffusion in a rock matrix is affected by the rock porosity and pore geometry. A typical diffusion model represents the geometry factor as follows: effective diffusion coefficient/(accessible porosity × diffusion coefficient in bulk water) = constrictivity/tortuosity (Fig.2-9). Empirically, the geometry factor is equal to 1/tortuosity in the case when the pore diameter is much larger than the solute diameter; however, there is no verification of the pore geometry by direct measurement. In this study, these measurements were performed by using nano X-ray computed tomography (CT) to identify the actual tortuosity and constrictivity values of siliceous mudstone samples of the Wakkanai formation at a depth of 500 m in a borehole of the Horonobe underground research center. In addition, a comparison of the results with the pore-space properties obtained from a set of tritiated water (HTO) through-diffusion tests was performed on the rock samples.

The pore structure of the rock was revealed as shown in Fig.2-10. Table 2-1 shows the results of the image analyses and HTO diffusion tests. The value of 1/tortuosity is close to the geometry factor obtained from the diffusion test. These results support the empirical law in the case when the pore diameter is much larger than the solute diameter.

The values of the effective diffusion coefficient and accessible porosity obtained from HTO diffusion tests in the vertical direction are lower than those obtained in the horizontal direction. What is the origin of this result? The tortuosities obtained by image analyses are similar in both directions. This corresponds with the fact that the geometry factors evaluated from the HTO diffusion tests are similar in both directions. On the other hand, the number of start-face voxels connected to the end face in the *Z*-direction is lower than in other directions. This result is consistent with the results from the HTO diffusion tests, which show that the accessible porosity in the vertical direction is smaller than in the horizontal direction. This indicates that the number of connective pores and the diffusion-accessible porosity are the origins of the diffusion anisotropy. Thus, we performed a quantitative evaluation of the pore structure of the rock matrix. This method is a useful tool for the clarification of diffusion mechanisms.

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**Reference**

Takahashi, H. et al., 3D X-ray CT and Diffusion Measurements to Assess Tortuosity and Constrictivity in a Sedimentary Rock, diffusion-fundamentals.org, vol.11, issue 89, 2009, p.1-11.