diffusion-fundamentals

The Open-Access Journal for the Basic Principles of Diffusion Theory, Experiment and Application

Diffusion of Water in Thermally Fractured Granite Rock Cores Studied by PFG NMR and MRI

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Abstracts

Diffusion of water in thermally fractured granite was studied by using pulsed field gradient NMR (PFGNMR) and MRI methods. Two different approaches gave consistent results, indicating that these methods can be applied for materials of low porosity with fracture networks.

Keywords: granite, fracture, self-diffusion coefficient, tortuosity, PFGNMR, MRI

1. Introduction

Migration of solutes in natural rocks has been extensively studied in relation to deep geological disposal of radioactive wastes. Rocks with low permeability have been expected to function as a natural barrier to retard migration and granite is one of such rocks with low permeability that has been most extensively studied as it is commonly found and its physical properties are well understood. Large fractures become pathways of migration but matrix diffusion from fracture walls becomes important when flow rate becomes smaller and depth of migration becomes critical in simulation of solute transport. Observations of thin slices with optical microscope and X-ray CT scans have already been applied to visualize fractures in granites and deposition of elements. However, it is difficult to detect fractures and pores below resolution with these methods.

In contrast, signal from water can be detectable by NMR measurement even in the case it is inside pores smaller than resolution. While NMR has been successfully applied to sedimentary rocks, few studies have been reported on igneous rocks due to their low porosity and effect of magnetic susceptibility. We reported that single point imaging and measurement at lower B_0 gave MR images of water distribution in thermally and mechanically fractured granite [1]. In this study we report our preliminary measurement on diffusion of water in granite by pulsed field gradient (PFG)-NMR and MRI.

2. Experimental

Coarse-grained Inada and fine-grained Okazaki granites were used as they contain relatively small amount of dark mineral grains. Cylindrical rock cores were fabricated from blocks and they were heated to induce fractures. Rock cores were immersed in water and evacuated to saturate fractures and pores.

Relaxation time and self-diffusion coefficients were measured with MARAN Ultra (Resonance Instruments, U.K.) at 0.55 and 0.05T. MR images of 50mmϕ cores were measured with Tecmag Libra console at 1.9T. Hydraulic and electrical conductivities were also measured.

3. Self diffusion measurement by PFGNMR

Apparent self-diffusion coefficients (D_{app}) of water in granite were measured at 0.55T by using 15mmϕ cores. A stimulated echo sequence with gaussian-shaped bipolar gradients was applied and D_{app} were derived from echo intensities by changing gradient strength (G). D_{app} were dependent on diffusion time (Δ) and they decrease as Δ becomes longer. Samples heated to higher temperature showed higher D_{app} values due to networks of thermally induced fractures, while little difference were found between Inada and Okazaki granites. Tortuosities estimated from long time limits were consistent with those calculated from electrical conductivity measurement.

4. Macroscopic diffusion measurement by MRI

Macroscopic diffusion of D_2O into a rock core saturated with H_2O was measured with MRI. An Inada granite rock core (50mmϕ, 50mmH) was heated to 923K and then saturated with H_2O, coated except one face, and this face was contacted with D_2O reservoir. The sample was placed in the MRI system and changes of H_2O spatial distribution were imaged by 3D spin echo sequence. MR images showed density driven flow of D_2O into bottom of the rock core, which is similar to the case of saltwater intrusion in coastal aquifers. This intrusion process was simulated by using SUTRA code [2] which can treat variable density flow solute transport. 2D simulation was successful by assuming homogeneous distribution of measured porosity, hydraulic conductivity and long time limit of self-diffusion coefficient.

5. Conclusion

Diffusion of water in thermally fractured granite has been studied by PFGNMR and MRI measurements. Both methods gave consistent results on diffusion of water. Further study can be performed on macroscopic diffusion process by using spatial distribution of pores and fractures by MRI measurement to clarify effect of heterogeneity on rock core scale to diffusion of water and solutes.

Acknowledgment

Hydraulic and electrical conductivities were measured by OYO corporation (Saitama, Japan). This study is a part of research project entrusted by Ministry of Economy, Trade and Industry, Japan.

References

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