微小地震から探る岩石き裂浸透率ダイナミクス
Dynamics of rock fracture permeability explored through MEQs

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For the success of unconventional geothermal reservoirs (i.e. EGS), maintaining conduits with high-fluid-throughput is desirable. Hydraulic stimulation for such reservoirs is recognized as one of the most general ways to improve or maintain their crustal permeability, which is known as the key parameter controlling crustal fluid flow [*Ingebristen and Manning*, 2010]. During the hydraulic stimulation, in-situ microearthquakes (MEQs) data are basically recorded to capture the underlying active processes and the permeability evolution within the reservoir [*Majer et al.*, 2007], and these MEQs are in general regarded as signals that somehow represent permeability change in a fractured reservoir. If we have an insight into quantitative linkage between the permeability change and MEQ, such an insight is definitely useful for mapping in-situ permeability evolution in a reservoir. However, it remains ambiguous how much the fracture permeability is enhanced by a MEQ.

In the present study, we explore a linkage between fracture permeability change and MEQs. For this purpose, we first prepared heterogeneous aperture distributions for rock fractures with various combination of fracture length (m), l, and shear displacement (m), d, according to the method of *Ishibashi et al* [2015]. Through the analyses of these aperture distributions, scale dependencies of fluid flows through joints, i.e. fractures without shear displacement, and faults, i.e. fractures with shear displacement of d (m), are predicted as followings. Both joint and fault aperture distributions are characterized by a scale-dependent geometric mean and a scale-independent geometric standard deviation of aperture. Changes in the geometric means of joint and fault apertures (mm), $e_{m,\ joint}$ and $e_{m,\ fault}$, with fracture length (m), l, are approximated by $e_{m,\ joint} = 1.3\times 10^{-1} l^{0.10}$ and $e_{m,\ fault} = 1.3\times 10(d/l)^{0.59} l^{0.71}$, whereas the geometric standard deviations of both joint and fault apertures are approximately 3. Fluid flows through both joints and faults are characterized by formations of preferential flow paths (i.e., channeling flows) with scale-independent flow areas of approximately 10%, whereas the joint and fault permeabilities (m^2), k_{joint} and k_{fault}, are scale dependent and are approximated as $k_{joint} = 9.8\times 10^{-13} l^{0.16}$ and $k_{fault} = 2.3\times 10^{-6}(d/l)^{1.18} l^{1.08}$. By coupling these scaling laws with the concept of moment magnitude [*Hanks and Kanamori*, 1979], quantitative change in mean aperture ($e_{m,\ fault}/e_{m,\ joint}$) and fracture permeability (k_{fault}/k_{joint}) are successfully linked with moment magnitude of MEQs (M_w) during hydraulic stimulation for a reservoir as $e_{m,\ fault}/e_{m,\ joint} = 1.0\times 10^{0.35Mw}$ and $k_{fault}/k_{joint} = 116.4\times 10^{0.46Mw}$. Validity of the equation will be discussed through comparisons with some data of real field development/experiments (e.g., EGS system in Basel and Soultz-sous-Fôret).

In summary, such linkages may enable rough inverse-mapping of evolving fracture permeabilities using in-situ MEQ data. This mapping will facilitate new insights into transport phenomenon within the Earth’s crust and it relevant to engineering and scientific applications such as the development of geothermal or hydrocarbon reservoirs and clarification of earthquake mechanisms.

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