Fluid pressure gradients and permeability evolution in the crust: insights from metamorphic fluid-rock reaction zones and hydrothermal experiments

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Fluid pressure and permeability in the crust is one of the most important parameters that govern the fluid activities in the crust. High pore fluid pressures and associated permeability changes in the crust and mantle have been recognized by geophysical observations, and are generally considered as triggers of earthquakes and slow–earthquakes (e.g., Audet and Bürgmann, 2014; Nakajima and Uchida, 2018). Although such high pore fluid pressures are evidenced as mineral filled fractures in geologic observations, the actual fluid pressure gradients and permeability in the crust have not been evaluated quantitatively and remain largely unknown. In this talk we show constraints on the crustal permeability evolution from (a) natural metamorphic reaction zones showing high fluid pressure gradients and permeability changes in the crust, (b) hydrothermal experiments showing the evolution of transport properties (permeability and diffusion) and mechanical responses (stress) during hydration reactions.

(a) Fluid pressure and permeability evolution constrained from natural metamorphic fluid-rock reaction zones
Here we show (1) various geologic evidences of fracturing and permeability enhancement in the supercritical, deep crustal conditions where plastic deformation is dominant (upper-greenschist to lower-granulite facies conditions of 200–500 MPa, 450–700°C; Tsuchiya et al., 2016; Uno et al., 2017; Nohara et al., 2019; Mindaleva, et al., under revision). (2) A new, quantitative estimates of crustal fluid pressure gradients and permeability recorded in metamorphic fluid-rock reaction zones, associated with crustal fracturing (Uno et al., 2017; Mindaleva et al., under revision).
These results show that the permeability of intact crust is ~10^{-20-22} m^2 for the granulite– and amphibolite–hosted reaction zones, and are several orders smaller than the widely accepted crustal permeability model (~10^{-18} m^2; e.g., Ingebritsen and Manning, 2010). On the other hand, permeability along the fractures are estimated as high as >10^{-14-15} m^2 for the granulite and amphibolite-hosted fractures, which is analogous to the permeability estimated for the hypocenter migrations in the crust (~10^{-14-15} m^2; e.g., Okada et al., 2014; Nakajima and Uchida, 2018). These results show the importance of low permeability of intact amphibolite/granulite-facies metamorphic rocks in conjunction with episodic high permeability of brittle fractures even at high temperature conditions of 450–700°C, both of which affect the regional scale permeability in the deep crust.

(b) Reaction-enhanced permeability, diffusivity and stress during fluid-rock reactions revealed by hydrothermal experiments
We further show the recent advances in reaction-enhanced transport properties of rocks revealed by hydrothermal experiments including (3) more than 2-orders of permeability enhancement by reaction-induced fracturing during hydration reactions (Uno et al., in prep.), (4) reaction-enhanced diffusion that are ~10 times faster than the static diffusion rate during replacement reactions and (5) role of reaction-induced stress or swelling of clays on the weakening of fault (Kameda et al., 2019).

These experimental results show the importance of fluid-rock reactions controlling the hydro-mechanical properties of the crust. We discuss non-dimensional parameters that controls the permeable/impermeable nature of crust during hydration reactions.

[References]

Audet, P., Bürgmann, R., 2014. *Nature* **509**, 389–92.
Ingebritsen, S.E., Manning, C.E., 2010. *Geofluids* **10**, 193–205.
Nakajima, J., Uchida, N., 2018. *Nature Geoscience*, **11**, 315–356.
Okada, T., Matsuzawa, T., Umino, N. et al., 2015. *Geofluids* **15**, 293–309.
Uno, M., Okamoto, A., Tsuchiya, N., 2017. *Lithos* **284–285**, 625–641.
Tsuchiya, N., Yamada, R., Uno, M., 2016. *Geothermics* **63**, 182–194.
Nohara, T., Uno, M., Tsuchiya, N., 2019. *Geofluids* **2019**, 6053815.
Kameda, J., Uno, M., Conin, M., Ujiie, K., Hamada, Y., Kimura, G., 2019. *Earth, Planets and Space* **71**, 131.

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