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Evolution of permeability and fluid pathway in the oceanic crust inferred from experimental studies on basalt cores

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Ocean crust is formed at mid-ocean ridge and transported to the trench, which takes about hundred million years. At the trench, ocean crust is subducted under continental crust or other ocean crust. The ocean crust is suffered various chemical and physical alternation at seafloor. Hydrothermal system is very active owing to volcanic activity near ridge axis. Low-temperature hydrothermal system is continued to several hundred km far from the ridge axis have been investigated from the gap between observation and simulation of heat flow. Hydrothermal systems are closely related to the permeability in the ocean crust. Bore-hole measurement indicate that permeability are different with depth and age, which probably reflect the rock type and structure.

The uppermost ocean crust is composed of pillow basalt and hyaloclastite. Such basalt layer has a large fracture, so the permeability is relatively high, and the range is 10^{-10} m^2 to 10^{-12} m^2. Below this layer, massive basalt, sheeted dyke and gabbro is located, which layer has a low permeability, of less than 10^{-16} m^2. After the ocean crust is formed, pelagic sediment is gradually increased at the top of the ocean crust. It permeability is significantly low ranging 10^{-14} m^2 to 10^{-18} m^2. Consequently, the uppermost basalt layer is the most permeable layer in the ocean crust. Thus the hydrothermal systems far from the ridge axis is occurred beneath the seafloor.

In-situ measurements of permeability of the uppermost basalt layer reveal a systematic decrease with increasing crustal age, in which permeability reduces by four orders of magnitude from crustal ages of 1 to 7 Ma. In this study, We measured the permeability of basalt core sample from Ocean Drilling Program. The confining pressure at the uppermost basalt layer is increase with crustal age. So, in the laboratory measurement of permeability, we focused on the effect of confining pressure to test whether mechanical compaction is able to explain the age evolution of permeability of the uppermost basalt layer of oceanic crust. However, the pressure effects found in the laboratory experiment are insufficient to fully explain the result of in-situ measurement of permeability through the oceanic crust. This result indicate that mechanical compaction alone cannot explain the observed evolution of permeability in the uppermost oceanic crust.

Based on these experiments, factors in addition to mechanical compaction are required to explain the decrease in permeability with age in young oceanic crust within the uppermost basaltic layer. Carbonate veins are ubiquitous in oceanic crust accreted in ophiolite sections and are precipitated within a few million years of formation of the crust. This carbonate precipitation likely result in the reduction in porosity, consequently permeability also decreased with crustal age. I calculated the potential inorganic precipitation of $CaCO_3$, in which the total amount of $CaCO_3$ in the oceanic crust is represented by the fluid flux (m/s) and the concentration of $CaCO_3$ (mM) in aqueous fluid. Even though these carbonates are fully precipitated in the oceanic basement, the calculated volume of precipitation is insufficient to fill the available porosity in the basalt layers. Staudigel and Furnes (2004) reported that about 50% of alternation in the upper oceanic crust is caused by the biotic activity. These data implies that $CaCO_3$ precipitation might be associated with biotic activity.

Futhermore, I discuss the effect of these fluid flow structure on the accreted oceanic crust as a green rocks or green schist. To investigate such rocks, we need to investigate the structure of ocean crust in terms of fluid flow properties.

Keywords: Oceanic crust, Hydrothermal system, Permeability, Porosity, Carbonate precipitation