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Estimation of the thermal structure in the oceanic upper crust using variation in crystal size of the sheeted dikes

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It is important to study pathways for hydrothermal circulation in oceanic crust in order to understand material circulation and chemical evolution between surface and interior of the earth that provide energy sources supporting subsurface biosphere. We have restored the thermal structure in the upper oceanic crust based on the variation in crystal size of the sheeted dikes from the Oman Ophiolite by means of the crystal-size thermometer which gives wall-rock temperatures at the time of dike intrusions (Spohn et al., 1988). The Oman Ophiolite provides excellent exposures of well-preserved primary structures of fast spread oceanic lithosphere, which can be regarded as an analog of fast-spreading ridge system.

There are several ways that characterize the crystal size of a volcanic rock such as the crystal size distribution (CSD: Cashman and Marsh, 1988) and characteristic crystal size by the batch method (CCS: Brugger and Hammer, 2010). In order to obtain a precise CSD, we have to trace hundreds to thousands of outlines of crystals of the mineral species in question. Batch method also requires a measurement of thousands of crystals in each sample. The average crystal size obtained by the batch method is essentially identical to the result of CSD. However, crystal shapes and textures in altered samples, which suffered from ocean-floor metamorphism such as those used in the present research, are often unidentifiable or blurred in SEM-COMPO images and chemical maps by an EPMA, but are still identifiable under an optical microscope. Alternatively, we use the average maximum crystal size (Umino, 1995). We measure the major and minor axes of the largest ten groundmass plagioclase under a microscope, which are averaged as the average maximum crystal size (major and minor axes). The average maximum crystal size thus determined gives a similar result obtained by the CSD method. This validates the utility of the average maximum crystal size as a characteristic crystal size. This method is practical because it is easy and quick to be measured than CSD or batch method and is applicable to altered volcanic rocks.

We chose 5 dikes with a thickness >1 m at Wadi ath Thuqbah which is located in the center of a second-order segment of the paleo spreading ridge. Samples were taken every 10 cm from the margin to the center of a dike. The crystal size of the groundmass plagioclase is constant in some dikes and coarsens toward the center in others. We calculated crystal growth rates, nucleation rates and wall-rock temperatures according to Spohn et al. (1988) and compared to the results for the sheeted dikes of Wadi Fizh (Umino and Miyashita, 2008). The nucleation rates of Wadi ath Thuqbah are larger than Wadi Fizh, but the growth rates and the wall-rock temperatures are similar in both locations. This might have risen from the difference in the magmatic temperature upon dike intrusions. The difference in the groundmass plagioclase crystal size inherits from the different thermal history of the dikes prior to the intrusion. If magmatic temperature is well above the liquidus, density of cluster becomes small. This lead to a small number density of crystal nuclei and a low nucleation rate upon dike intrusions, which could grow into large crystals. Furthermore, the wall-rock temperature depends on both the logarithm of crystal size and the plagioclase liquidus temperature of the dike. The lower liquidus temperatures give the lower calculated wall-rock temperatures. The nucleation rate of a dike emplaced into a cooler host becomes large because of a larger degree of undercooling.

Keywords: oceanic upper crust, thermal structure, variation in crystal size, the sheeted dikes, Oman Ophiolite