

Existence of CO₂-rich melt in the asthenosphere evidenced by petit-spot

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Carbon dioxide (CO₂)-induced partial melting of mantle peridotite is recently expected as the cause of the seismic low-velocity and high electrical conductivity in the asthenosphere (e.g., Hirschmann 2010; Sifré et al., 2014), but not directly evidenced. To investigate the nature of the asthenosphere, petit-spot should provide important insights because of following discussions and observations. Models for the eruption of petit-spot volcanoes suggest that magma exudes from the upper-most mantle asthenosphere in response to plate flexure (Hirano et al., 2006; Valentine and Hirano, 2010; Yamamoto et al., 2014; Machida et al., 2015). The primary petit-spot magma includes 10% of CO₂ and 1% of H₂O (Okumura and Hirano, 2013). The petit-spot volcanic fields ubiquitously distribute in the region of plate deformation, such as plate subduction or glacial melting (Hirano et al., 2008; Uenzelmann-Neben et al., 2012; Hirano et al., 2013; Taneja et al., 2014). However, because these previous studies discussing about petit-spot volcanism have not constrained the processes and conditions of the generation of petit-spot magmas, we must clarify whether or not the petit-spot melt is generated in the asthenosphere. In this study, we thus conduct melting experiments to define the genesis of the CO₂-rich petit-spot primary magmas from the two youngest knolls of petit-spot in the northwestern Pacific plate.

Melting experiments were conducted using 1/2-in.-diameter piston cylinder type high-temperature and high-pressure apparatus at Kyoto university. Starting materials were prepared at Kyoto University by mixing pre-dried reagents of oxides, hydroxides, phosphate, and carbonates to represent the major elements, CO₂ and H₂O composition of the primary magma for each petit-spot volcano. As the result of our experiments, the liquidus mineralogy constrained that the petit-spot magma last equilibrated with harzburgite at 1.8–2.1 GPa (approximately 60 km deep, corresponding to the lower lithosphere) and 1280–1290 degree C (slightly lower temperature than the adiabat of the mantle potential temperature (MPT) of 1250 degree C). To explain the equilibration temperature of petit-spot primary magma, we consider that CO₂-rich silicate melt are produced in the asthenosphere because of the existence of CO₂-rich fluid or carbonate. Based on solidus for the peridotite–CO₂–H₂O system at approximately 3 GPa, the CO₂-rich silicate melt is likely stable in the asthenosphere at the MPT of 1320 degree C. Such temperature corresponds to temperature of the upper asthenosphere (1400 degree C) calculated assuming normal thermal gradient of 135 Ma lithosphere beneath the petit-spot volcanoes. Then, the following model can reasonably explain the last equilibration pressure and temperature of the primary petit-spot melt; that is (1) CO₂-rich silicate melt in the upper-most asthenosphere ascends the overlying lithosphere owing to plate flexure, (2) temperature of melt decreases during ascending and (3) melt equilibrates with ambient peridotite in the lower lithosphere before eruption. A rebuttal case is the in situ CO₂-induced melting of mantle peridotite in the lower lithosphere. However, temperature of melt (1000–1100 degree C) is significantly lower than the estimated temperature of petit-spot primary magma. Furthermore, we have no observation indicating the upwelling of hot deep mantle as the heat source to explain the temperature of petit-spot primary magma.

Based on results of our experiments, we can posit petit-spot as the definitive evidence for partial melting in the asthenosphere caused by CO₂. For future studies, geochemistry of petit-spot lavas could contribute to quantitative determination of amount of CO₂ in the asthenosphere. Furthermore, the linkage between the lithology of the seismic low-velocity layer and global carbon recycling should be investigated by petit-spot lavas.

Keywords: asthenosphere, CO₂-rich silicate melt, petit-spot, multiple saturation experiment