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Origin of chromian spinel-hosted polymineralic inclusion from oceanic lower crustal gabbros, IODP Site U1309, Mid-Atlantic Ridge

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We found polymineralic inclusions within chromian spinel grains in mafic-ultramafic rocks (olivine-rich troctolites) recovered from IODP Hole U1309D, Mid-Atlantic Ridge. Included minerals are pargasitic amphibole, Na-phlogopite (with exsolution lamellae of K-phlogopite), orthopyroxene, albite, olivine, clinopyroxene, apatite, oxide minerals and sulfide minerals.

Occurrence of such spinel-hosted polymineralic inclusions (SHPI) is very rare in mid-ocean ridge settings and only one example has been reported from Hess Deep, East Pacific Rise (Arai & Matsukage 1996). Recently, the second finding is reported from Site U1309 (Tamura et al. 2008; Suhr et al. 2008; this study). These SHPIs are characterized by high abundances of incompatible elements (Na, Ti, H2O etc.). Although Arai & Matsukage (1996) proposed that such enrichment in incompatible elements could be produced as a result of zone refining (Kushiro 1968) during mantle-melt interaction, detailed discussion on mechanism of the enrichment was not given. We discuss origin of the SHPIs based on detailed petrographic observations and trace element analyses with SIMS.

Petrographic observations indicate that the SHPI solidified from some kind of silicate melt. We calculated average bulk composition of the SHPI found in the examined samples. Estimated bulk composition is characterized by high abundances of both compatible (Mg, Cr) and incompatible (Na, K, Ti, P, REE, Zr, Hf, H2O) elements, indicating that calculated melt cannot be equilibrium with primitive MORB mineralogy. Thus a general explanation on origin of mineral-hosted inclusions due to entrapment of nearby equilibrium melt cannot be applied to these SHPIs. We tried to propose an alternative model based on experimental results by Ballhaus (1998) and Matveev & Ballhaus (2002).

Viscosity of the estimated melt calculated by the method of Giordano et al. (2008) was expected to be much lower than that of primitive melt, which crystallized host minerals in the olivine-rich troctolite. Based on the experimental results, Ballhaus (1998) and Matveev & Ballhaus (2002) proposed that melts with different polymerization (viscosity) could not mix immediately and that spinel grains concentrated in the melt with lower polymerization. From these results, it is supposed that incompatible element-rich melts incorporated as droplets in primitive melt and SHPI can be formed due to intensive nucleation and growth of spinel grains around the droplets. In our examined samples from Site U1309, trace element compositions of amphiboles included in nearby two spinel grains are completely different, which agrees with this model since SHPIs can be formed from many minute droplets within primitive melt in this model.

If the above-mentioned model is accepted, we have to mention about origin of the incompatible element-rich melt. Two candidates may be possible: extremely evolved melts due to differentiation of MORB parental magma or small-degree partial melts delivered from wall rocks by emplacement of primitive magmas. We prefer the latter because this case is much more plausible beneath mid-ocean spreading ridges. However, according to experimental results by Koepke et al. (2004), partial melting of olivine gabbros, the most dominant lithology in the oceanic crust, cannot satisfy higher Ti contents of the incompatible element-rich melts. As mentioned above, the evolved melts are characterized by higher amounts of Ti, P, and Zr, suggesting that appropriate protoliths are oxide gabbros, which contain minerals rich in such elements.

Occurrences of SPHIs have been reported from several layered gabbroic intrusions and ophiolites and these have almost the same mineral assemblage and composition. This fact indicates that a common mechanism may operate in the formation of SPHIs regardless of the localities. Our model presented here may successfully account for the origin of the SPHIs.