Mantle dynamics of slab breakoff constrained from the temporal change of the melting depth estimated from the Cumulate Member of the Ordovician Hayachine-Miyamori Ophiolite

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Slab breakoff, detachment of oceanic lithosphere highly expected during arc-continent collision, is one of the important mechanisms inducing passive upwelling of the asthenosphere and magma generation in arc environments [1]. In order to better understand the mantle dynamics of slab breakoff, we need to use continuous geological record with high time resolution. In this study, we have extracted a record of temporal change of the magma generation depth from cumulates in an Ordovician arc ophiolite at a time resolution of several tens of million years.
The Hayachine-Miyamori Ophiolite, northern Japan, is one of the Ordovician ophiolite formed in an arc environment [2]. The ultramafic member was built up by three main magmatic stages, which are recorded in three rock units: Tectonite Member, Cumulate Member, and ultramafic dikes, in the order of formation ages. The last two units in the entire evolution of the ophiolite is explained by decompressional melting of sub-slab mantle triggered by slab breakoff [2][3]. The melting depth of an ultramafic magma solidified as dikes in the Cumulate Member is estimated to be ~170km [3]. Our recent field study clarified a large-scale stratification characterized by alternation of wehrlite-dominant and dunite-dominant layers in the Cumulate Member. Each layer has a thickness from several meters to ~1 km and, the total thickness attains ~3km. Moreover, we succeeded in specifying the strike and plunge of the gravity field to be ~N48°E and ~20°NE during the cumulate formation from field information and westward stratigraphic younging [4].
We estimated the temporal change of generation depth of parent magmas of the Cumulate Member by garnet signature in heavy rare earth elements (HREEs) as depth proxy. The information may constrain the mantle dynamics during the slab breakoff. We examined stratigraphic variation of HREE ratio at the core of clinopyroxenes over the thickness of ~2km in the Cumulate Member. The obtained variation of the Dy/Lu increases from ~12.9 to ~16.5 with increasing the stratigraphic height. We estimated the extent of melting in the garnet stability field increasing from ~50 to ~90% of the total melting by applying an open-system fractional melting model to reproduce the Dy/Lu variation.
We also estimated the time scale of formation of the Cumulate Member by using cm –10cm scale heterogeneity recorded in contact zone of intruded magma and the host. The profile of Mg# of olivine in xenoliths of the Tectonite Member occurring at the bottom of the Cumulate Member shows that the cooling time is less than several tens of million years [5]. The dunite of the Cumulate Member contacting the ultramafic dike shows a systematic decrease of Mg# from 90 to 86.8 over the distance of 54 mm towards the contact. We calculated the time scale of subsolidus diffusional exchange between the dunite and dike and obtained several tens of million years at ~1000℃. The host was kept at a high temperature when the dikes intruded because of the absence of chilled margin. We thus estimated time scale of formation of the Cumulate Member to be < several tens of million years.
We propose the following tectonic model in the Ordovician northern Japan on the basis of the above result. The slab breakoff took place at the depth slightly deeper than the boundary of spinel and garnet stability fields (~80 km) and induced counter flow and adiabatic melting of the sub-slab mantle. The melting depth deepened down to ~170 km on the time scale of several tens of million years, which corresponds to the time scale to complete the slab breakoff. The sinking velocity of the slab is more than

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a few millimeters per year.

[1]: Davies et al., 1995. [2]: Ozawa et al., 2015. [3],[4]: Kimura et al., 2017, 2018, JpGU abstract. [5]: Ozawa, 1983.

Keywords: slab breakoff, arc ophiolite, cumulate

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