Slab breakoff tectonics: constraints from temporal changes of melting conditions recorded in geochemical stratigraphy of the Cumulate Member and ultramafic dikes of the Hayachine-Miyamori ophiolite, northeast Japan

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Slab breakoff models have been applied to explain thermal perturbations in asthenosphere inducing various geological events, such as, extensive alkali basaltic magmatism ([1]), bimodal basaltic and rhyolitic magmatism ([2]), and rapid exhumations of high-pressure metamorphic belts ([3]). These records, however, do not necessarily require the slab breakoff tectonics as a casual mechanism. [4] and [5] warned that the slab breakoff models are invoked mostly for a pure convenience without any compelling factual evidence in the literatures.

When a slab detachment and sinking occur as a terminal event of a steady-state subduction during continent/arc collision events, passive upwellings of the wedge and/or sub-slab asthenosphere are inevitably take place owing to the counter flow (e.g., [4], [6]). A numerical modeling suggests that the asthenosphere upwells from various depths ranging 100 - 600 km ([6]), which are distinctively deeper than those in other spreading tectonics. Such upwelling could cause decompressional melting if appropriate conditions for melting, such as thermal state and chemical compositions of the supra- or sub-slab mantle, are satisfied. [7] succeeded to show magma generation by passive upwelling of the sub-slab asthenosphere from at least ˜160 km depth triggered by the slab breakoff in the Cambrian-Ordovician northeast Japan. In this study, we show an evolution of the slab breakoff tectonics estimated from the temporal change of the melting depth and fluid influx rate recorded as geochemical stratigraphic of the Cumulate Member and ultramafic dikes in the Hayachine-Miyamori ophiolite, northeast Japan.

The Cumulate Member has ˜2 km in thickness and consists of dunite-dominant lower and upper horizons and a wehrlite-dominant middle horizon. We examined stratigraphic variation of rare earth element (REE) ratios of cumulus clinopyroxene to estimate those of parental magmas for the Cumulate Member by carefully evaluating effects of trapped melt crystallization and subsolidus elemental exchange. The mean values of (Ce/Sm)n of the parental magma in a layer for the lower, middle, and upper horizon range 0.65 –1.03, 1.02 –1.23 and 1.29 –1.59, respectively, and (Sm/Gd)n, 0.48 –1.10, 1.03 –1.17, and 1.28 –1.50, respectively, and (Dy/Yb)n, 0.63 –0.79, 1.10 –1.18, and 1.43 –1.55, respectively. Extensive examination of REE behavior in a fractional melting with material influx ([8]) shows that these elemental ratios provide useful proxies for melting conditions during open-system melting: degree of melting in the mantle ((Sm/Gd)n), percentage of melting in the garnet-stability field in total melting (PMGF; (Dy/Yb)n), and influx rate of fluid in the melting (β; (Ce/Sm)n). The degree of melting for the lower, middle, and upper horizon of the cumulates and the dikes range 6.4 –15.0, 7.8 –14.2, 8.6 -.12.4, and 16.6 in %, respectively, the PMGF, 76 –92, 76 –93, 85 –93, and 88.4 in %, respectively, the β, 0.00 –0.26, 0.00 –0.38, 0.01 –0.11, and 0.03, respectively.

The degree of melting with limited material influx ($\beta < 0.1$) is positively correlated with the PMGF, while that with significant influx ($\beta > 0.1$) is high with low PMGF. This indicates that the melting took place through two mechanisms: (1) decompressional melting of a depleted mantle with limited material influx at the depth > ˜75 km and (2) fluxed melting at the depth < ˜75 km. The PMGF and β for the lower horizons show wide variations from 76 to 93 % and 0.00 to 0.38, respectively. By contrast, those for the upper horizons tend to converge to 85 –93 % and 0.00 –0.11, which is the values for the ultramafic dikes occurring in the Cumulate Member. This temporal change in the conditions suggests decompressional melting of supra- and sub-slab mantle took place at various depths from ˜75 km to ˜160 km involving various amounts of fluid influx, which was followed by decompressional melting of sub-slab mantle under suppressed material influx with convergence of the depth of the melting to ˜160 km. From this sequence of the melting, we propose that a slab breakoff in young oceanic lithosphere (< 30 Ma, [9]) was initiated at a depth shallower than ˜75 km and its sinking continued up to the depth of ˜160 km.

[1] Dal Piaz et al., 2003; [2] Sui et al., 2013; [3] Ernst et al., 1997 [4] Niu et al., 2017; [5] Garzanti et al., 2018; [6] Gerya et al, 2004 [7] Kimura et al., 2020 (under review for American Mineralogist); [8] Ozawa, 2001; [9] Duretz et al., 2011

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