

Fluid infiltration and change in mass transfer during the exhumation of Sanbagawa metamorphic belt, Japan

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Introduction: Individual parcel of regional metamorphic rock records physico-chemical conditions such as P-T path, mass transfer and deformation with the Lagrangian specification. On the other hand, a metamorphic belt as an ensemble of such parcels may provide a large-scale flow field of energy (e.g., temperature, entropy) and mass (including both solid and fluid phases with elements and isotopes) with the Eulerian specification. However, there are so far few models that integrate all the variables stated above. Phase petrology provides mostly the intensive variables (e.g., P-T path), whereas geochemistry provides mostly the extensive variables (time-integrated mass transfer), and these two have been treated separately. Here we combine phase petrology and geochemistry from a scale of mineral grain, and solve them under a simultaneous and consistent set of thermodynamic and mass balance equation. The results revealed the changes in mass transfer with changing P-T paths.

Method: The Sanbagawa metamorphic belt in Japan, the subduction-origin high-P type metamorphic belt, has been surveyed. To understand the nature of fluid during rehydration, we analyzed basic rocks that record retrograde reactions. Major and trace element compositions of each mineral, and bulk rock chemistry have been analyzed with EPMA, LA-ICP-MS, XRF and ICP-MS, respectively. Retrograde P-T path have been obtained by applying the Gibbs' method (e.g. Spear, 1993; Okamoto&Toriumi, 2001) to amphiboles and garnets.

Trace element budget along a specific P-T path were calculated by equating differential mass balance equation for major and trace elements as follows;

$$X_{fluid} dM_{fluid} = \text{Sum}(M_{solid} X_{solid}) + \text{Sum}(X_{solid} dM_{solid})$$

where X and M denote compositions and modes of minerals and dX and dM represent their changes along a specific P-T change. X_{solid} , M_{solid} , dM_{solid} for zoned minerals (amphibole and/or garnet) and X_{fluid} were derived from the results of Gibbs' method, X-ray map and fluid/mineral partition coefficients, respectively. Thus, the unknowns are dM s, and the equations are solved for them. As a result, the mass transfer during a specific P-T change ($X_{fluid} dM_{fluid}$) can be specified.

Furthermore, trace element budget during rehydration reactions were also constrained based on proportionality of bulk fluid-mobile element composition with H₂O (LOI (loss on ignition)). Based on a simple model that accounts for heterogeneity of protolith composition and devolatilization by dehydration reaction, the fluid composition during rehydration was estimated.

Results and Discussion: The P-T path obtained from the least rehydrated sample records the P-T path from 15kbar, 550°C to 11kbar 600°C, which corresponds to the exhumation just after the peak pressure condition. The mass balance analysis revealed that it was a dehydration reaction and Y and Cs increased whereas Ba decreased during this P-T path. No significant change was observed for Rb, Pb and Sr.

It is revealed that fluid mobile elements such as LIL elements, Sr and Pb are mostly proportional to LOI (loss on ignition). LOI and extent of rehydration are proportional in the Sanbagawa belt (Okamoto&Toriumi, 2005), thus the observed enrichment of LILE and Pb are interpreted to be associated with rehydration (from 11kbar 600°C to 3kbar 400°C). The Sr isotope ratios of the basic shists also increase with LOI, implying that the differences in bulk rock chemistry are due to an addition and/or reaction with external source of fluids with high ⁸⁷Sr/⁸⁶Sr. The estimated fluid composition is similar to calculated compositions of slab-derived fluids (Nakamura et al., 2008).

Comparing the results of (1) the mass balance analysis with early part of exhumation P-T path and (2) bulk composition analysis reveals that the mode of mass transfer changed from Y and Cs enrichment with Ba depletion, to LILE (Li, K, Rb, Cs, Sr, Ba) and Pb enrichment, associated with the change in P-T path.

Keywords: fluid, mass transfer, metamorphism, subduction zone, Sanbagawa metamorphic belt, trace element