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The mantle conditions for magma generation beneath island arcs constrained by major element concentrations in volcanic rocks

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Subduction zone is one of the most important tectonic environments where active volcanisms are taking place. Subduction zone volcanisms are more complicated and diverse as compared to those of mid-ocean ridges and hot spots mostly because of the following two factors. One is contribution of H_2O-rich fluid which is thought to be expelled from the subducting slab (e.g., Schilling et al., 1978; Gill, 1981; Ito et al., 1983), and the other is complexity of thermal and flow structure of the wedge mantle (e.g., Furukawa, 1993; Kincaid and Sack, 1997). The H_2O distribution and thermal structures in the mantle wedge may be governed principally by subduction parameters, such as age of subducting slab, converged rate, angle of subduction, and thickness of arc crust. They are expected to affect chemical composition of volcanic rocks, giving rocks to specific characteristics for each arc featuring different combination of subduction parameters. Absolute abundance of H_2O-rich fluid added to the wedge mantle and temperature where melting occurs are the most critical condition for arc volcanisms, and their tectonic controls must be resolved.

Major element compositions of magma are expected to be useful information related to the magma generating conditions. In order to obtain such information from the major compositions of volcanic rocks, the first step to be made is estimation of a melt composition that is generated in the upper mantle and that path to the crust through evaluating fractionation processed to produce the observed volcanic rocks. However, the primary melt composition depends on pressure, temperature, H_2O content, and mechanism of segregation for a given source composition. Therefore, melting conditions as well as conditions of fractional crystallization must be determined consistently.

Primary melt compositions and melting conditions including degree of partial melting, melting pressures, melting temperatures, and water contents in the mantle are estimated by the following three procedures. First, under the assumption of the common source mantle composition (KLB-1) and batch melting, primary melt compositions, which depend on the degree of partial melting, and melting pressure in the wedge mantle, and fractionated phase proportions, are estimated from the composition of volcanic rocks on the basis of experimental results of Hirose and Kushiro (1993). Second, the H_2O contents in primary melt were estimated by differentiating estimated primary melt to observed volcanic rock compositions using MELTS program (Ghiorso and Sack, 1995; adiabat_1ph: Smith and Asimow, 2005) to optimize differentiation conditions. Third, H_2O contents and temperature in the wedge mantle under island arc were estimated using estimated degree of partial melting, melting pressure, and water content of the primary melt.

The magma generating conditions for four arcs volcanoes, Izu Arc, Northeastern Japan Arc, Aleutian Arc, and Cascades Arc, are estimated by this method. Generally, magma generating conditions of volcanoes which belong to the same arc show similar tendency. The estimated degree of partial melting is highest at Izu Arc volcanoes, and decreases in the following order, NE Japan Arc, Aleutian Arc, and Cascades Arc. The H_2O contents in wedge mantle increase in the following order Cascades Arc, Izu Arc, NE Japan Arc, and Aleutian Arc. The estimated temperatures decrease in the following order, Izu Arc, NE Japan Arc, Aleutian Arc, and Cascades Arc. The relationship between the H_2O contents and temperatures in wedge mantle for each arcs, and tectonic parameters was examined. The temperatures of wedge mantle and subducting slab age show linear correlation. H_2O contents in the wedge mantle are inversely correlated with the subducting slab age except for Cascades Arc.