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Estimation of water content in the arc upper mantle: application to the Izu arc

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Melt generation in subduction zone is controlled mainly by the water distribution and thermal structures in the mantle wedge. They are principally governed by subduction parameters, such as age of subducting slab, convergent rate, angle of subduction, and thickness of arc crust. They are expected to appear as chemical composition of volcanic rocks characteristic for each arc. To understand the magma generation and its tectonic control from erupted volcanic rocks, water content in the mantle must be determined. Although water content in magmas has been estimated by various methods, that in the mantle has not been well constrained. This is because pressure, temperature, and degree of partial melting as well as the extent of fractional crystallization must be consistently specified in order to accurately estimate the water content on the basis of primary melt compositions.

Primary melt compositions of island arcs magmas were estimated from differentiated magmas by Tatsumi et al. (1983) by adding olivine in equilibrium with the melt until it reaches an assumed mantle olivine with Fo#89 (olivine maximum fractionation model). However, this procedure is apparently inappropriate, firstly because magmatic fractionation could involve several phases in addition to olivine, of which assemblage and compositions are controlled by many factors, such as the initial magma composition, water contents, depth of differentiation, and differentiation mechanisms (Kuritani, 1999). Secondary, fixing mantle olivine composition implies specification of the degree of melting from the beginning, and the method does not provide information on extent of partial melting. In order to remedy from this drawback, Takahashi (1986) proposed an improved method by using NiO content in the mantle olivine as an additional constraint, but olivine is still assumed to be the sole fractionated phase.

In this study, primary melt compositions and melting conditions including water content are estimated by more rigorous method to give better constraints on magma generation beneath island arcs under the assumption of the common source mantle composition (KLB-1) and batch melting. On the basis of experimental results of Hirose and Kushiro (1993), the partial melt compositions can be described as functions of degree of partial melting (F) and melting pressure (P). At low to moderate water contents, the partial melt compositions are not so deviated from that of dry condition, and the water content only affects melting degree (Hirose and Kawamoto, 1995; Ulmer, 2001). Olivine, plagioclase, and clinopyroxene are assumed as fractionated phases. Least squares approach was taken to optimize degree of partial melting, melting pressure, proportions of fractionated phases, and compositions of olivine and plagioclase all at once by minimizing the differences between observed melt composition and that of modeled differentiated magma.

This method was applied to the most primitive groundmass composition from Aogashima Volcano. The result shows that, not only olivine (~20wt%) but also plagioclase (~15wt%) and clinopyroxene (~15wt%) are important fractionated phases from a primary melt generated at ~2GPa and ~20% degree of melting. It is shown that low water content (0.2~0.3wt%) is required to generate the most primitive melt of Aogashima Volcano by fractional crystallization of the estimated primary melt. Moreover, this water content is consistent with the water contents required to explain the differentiation trend of Aogashima Volcano. These considerations strongly support the inference that in the mantle beneath the Izu Arc, melt with very low in water content was generated by high degree (~20%) of partial melting of the mantle with water content of 0.04-0.06wt%. This condition is attributable to subduction of cold slab beneath the relatively thinner crust above high temperature mantle wedge