

Differentiation process of arc magmas revealed by principal component analysis on trace element composition

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Chemical composition of magma can be used to address state of the magmatic system and the processes during magma generation, ascent and eruption. Various processes from the mantle to the crust in various pressure, temperature and chemical composition modify magma composition. Consequently, bulk chemical composition of erupted magma represents a sum of these processes.

Differentiation in terms of major element composition is controlled by non-linear thermodynamic relation. Major element composition of magma is modified by temperature, pressure and H₂O content dependent saturation states of mineral phases, and partition between melt phase and mineral phases. In this sense, major element composition can be a proxy of physical state during magma generation and ascent. However, the non-linearity of major element processes and a small degree of freedom in compositional space prevent us from decomposition of processes that have derived compositional variation in terms of major element.

On the other hand, partition of trace elements between melt and mineral phase can be modeled with relatively simple equation, and can be considered as a linear process. Consequently, trace element composition of erupted magma represents a simple sum of a melting and differentiation processes. Trace element can be a tracer of the specific phase or reaction, because partition coefficients between various minerals melt show wide range of variation. Therefore, trace element can be used as a proxy of a specific chemical mass reaction process during magma generation and ascent. In addition, trace element composition shows a large degree of freedom. Therefore, it is expected that nature and the number of processes during magma generation and ascent can be decomposed by analyzing trace element composition of volcanic rock using multivariate statistics.

In this study, principal component analysis is used to analyze compositional variation of volcanic rocks in Northeastern Japan Arc.

Analysis based on a series of volcanic rocks from single volcanic activity has shown that the differentiation process and/or mantle melting process beneath each volcano (crystal fractionation and magma mixing) can be decomposed by using principal component analysis on trace element compositions. Consistent relationship between the trace element principal components, major element composition, and petrological information such as mineral composition is derived from the analysis.

In order to illustrate the differentiation process in terms of large scale spatial and compositional range, 262 samples from 17 different volcanoes in the Sengan region, northeastern Japan are analyzed with principal component analysis. Result of the analysis clearly demonstrates that differentiation processes in the arc crust, are the primary controlling factor to derive compositional variation of arc magmas. Only three principal components account for the compositional variation of 262 samples. It is estimated the three principal components represent magma mixing, relatively high pressure olivine fractionation, and relatively shallower pressure plagioclase differentiation, respectively. No strong mantle signature is identified by the analysis. This result shows intermediate-felsic magmas (SiO₂>60 wt. %) can only be derived through magma mixing, not by crystal fractionation.

Keywords: volcanic rock, arc magma, crystal fractionation, magma mixing, trace element