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Principal Component Analysis based determination of chemical differentiation processes of volcanic rocks

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Bulk chemical compositions of igneous rocks represent sums of a series of chemical processes during generation and migration of magmas. Various processes from the mantle to the crust in various pressures, temperature and chemical composition modify magma composition (e.g., Annen et al., 2006). Multivariable analysis can be used to investigate such reactions involving multi-element and multi process.

Differentiation in terms of major element composition is controlled by non-linear thermodynamic relation (e.g., Ueki and Iwamori, 2014). As such, major element composition can be a proxy for the pressure and temperature of the source region of magma. However, major element composition is often overwritten by shallower processes because it exhibits a relatively restricted degree of freedom in terms of composition. On the other hand, trace element shows a large degree of freedom. In addition, the concentration of a specific trace element can be a tracer of a reaction in which a specific phase is involved, because the partition coefficient of a specific element in phases show wide range of variation. Moreover, partition of trace elements between phases exhibits a weak non-ideality, and can be modeled with a simple equation. Consequently, trace element concentrations can be used as a proxy of a specific phase and chemical mass reaction process during the formation of the rock (e.g., Depaolo, 1981; Pearce et al., 2005).

In this study, principal component analysis is used to analyze compositional variations of volcanic rocks in Northeastern Japan Arc. 14 trace elements of 262 samples including basalt to rhyolite, sampled from 17 different volcanoes in a volcanic cluster of northeastern Japan, called the Sengan region, are processed with principal component analysis.

The result of the principal component analysis shows that the only 3 processes are enough to cover the $\sim$90% of the geochemical variation of the magmas of the Sengan region. It is estimated that the three principal components represent magma mixing, crystallization-fractionation of mafic minerals at deep crustal depth and crystallization-fractionation of plagioclase at shallower crustal depth, respectively. This result shows that intermediate-felsic magmas (SiO_2>60 wt. %) can only be derived through magma mixing, not by crystal fractionation. No mantle signature is observed; indicating that differentiation processes in the arc crust, are the primary controlling factor to derive compositional variation in terms of trace element. The first principal component (magma mixing) shows good correlations with petrological observation (core composition of plagioclase phenocryst), and geophysical observations (distribution of seismic low velocity zone in the crust; Nakajima et al., 2001 and geothermal gradient; Tamanyu, 1994), indicating consistent description between the trace element principal components, major element composition, and petrological information such as mineral composition can be derived from the analysis.

Keywords: volcanic rock, multivariable analysis, magma, arc, Northeastern Japan