

論文内容の要旨

論文題目 Origin of arc magmas in the Sengan region, Northeastern Japan and Thermodynamic modeling of mantle melting
(東北日本仙岩地域の島弧火山岩の成因とマントル溶融の熱力学モデリング)

氏名 上木 賢太

Part I: Origin of arc magmas in the Sengan region, Northeastern Japan

Subduction zone is considered to be a major site of material flux into the mantle and also a major site of material fractionation of the Earth. Understanding chemical and physical processes in subduction zone is a key to investigate dynamics and material/thermal evolution of the Earth. Recently, in addition to subducting slab depth related across-arc two-dimensional structure, along-arc periodical melting structure in the mantle wedge and crust with wavelength of 50 km have been suggested based on geological and geophysical studies, in the northeastern Japan arc.

In this study, three-dimensional thermal and compositional structure of mantle wedge and crust beneath the volcanic front of northeastern Japan is investigated with analysis of arc magmas at spatial scale equivalent to that of observed periodical structure. Detailed analyses of volcanic rocks have been carried out in a volcanic cluster called Sengan region, in the northeastern Japan. The Sengan region is a volcanic region of 30 km-30 km in area and consists of 45 Quaternary volcanoes, including those aligned on the volcanic front. Basaltic and andesitic volcanic activities have continued in the last 2 m.y. after the eruption of voluminous Tamagawa welded tuff (dacite to rhyolite) at 2 m.y.

Characteristics of whole rock compositional variations are investigated in each volcano, based on equilibrium analysis between core composition of phenocryst and its host rock, texture and zoning profile of phenocryst minerals, mass-balance calculations and phase relation analysis. In many volcanoes in Sengan region, it is shown that whole rock compositional trend approximates liquid line of descent from mantle derived magma and groundmass composition/observed phenocryst assemblages represent shallower H₂O saturated crystallization during ascent. Fractionation conditions of these volcanoes are estimated with mass-balance calculation and thermodynamic calculation simulating fractional crystallization (Ghiorso and Sack, 1995). On the other hand, in some volcanoes, evidences for magma-mixing between mantle derived basaltic magma and crustal derived felsic magma are observed. Primary melt compositions of each volcanoes are estimated from analyzed rock compositions by correcting fractionation or minimizing effect of magma-mixing in each volcano.

To investigate mantle condition, temperature, pressure and H₂O content of mantle melting are estimated from observed major element composition of volcanic rocks utilizing thermodynamic model pMELTS (Ghiorso et al., 2002). Melting conditions are searched to minimize the difference between the compositions of partial melt calculated at a given temperature, pressure, H₂O-content and the primary magma estimated from the observed volcanic rocks. Beneath the Sengan region, melting temperatures are estimated to be 1268 to 1388 degree and melting depth is estimated to be 1 to 2 GPa. Temperature and pressure of melting show no clear systematics in the mantle beneath the region when estimation error is considered. H₂O contents show systematics in the volcanic region. H₂O content are estimated to be higher beneath the central part with up to 0.7 wt. % and lower beneath the outer rim with 0.3 to 0.1 wt. %. Trace element compositions also suggest degree of addition of slab derived fluid is higher beneath the central part than the outer rim.

Beneath the central part, the voluminous magma underplated to the crust may induce middle to lower crustal melting. So, primary magma undergo magma mixing beneath the central part. On the other hand, beneath the outer rim, Mantle derived low-degree of melting magma ascended to the surface in relatively cool and rigid crust and underwent olivine dominant fractionation without inducing crustal melting. Based on inferred temperature, pressure and H₂O content and previously reported phase diagram of mantle peridotite, temperature and H₂O content in a mantle wedge beneath the Sengan region is discussed. Gradient of H₂O concentration with range of 0.1 to 0.7 wt. % is necessary for observed along-arc three-dimensional melting structure in the mantle wedge. The H₂O content is about 0.7 wt. % beneath the volcanic zone and lowers toward the surrounding non-volcanic zone.

Part II: Thermodynamic modeling of mantle melting

Partial melting of mantle peridotite is an important process for both material fractionation and cooling of the Earth, yet there remain a number of fundamental questions for the actual processes. Thermodynamic modeling is a useful approach to describe the phase relation, mass balance and energy balance of mantle melting. However, there exists number of problems to handle phase relation, mass balance and energy balance of mantle melting with previously constructed thermodynamic models. In this study, newly calibrated thermodynamic parameters of silicate liquid with revised equations for apparent molar Gibbs energy and new energy minimization calculation algorism are provided to make better descriptions of energy balance between silicate liquid and minerals during mantle melting.

In this study, compositional space of $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-FeO-Fe}_3\text{O}_4\text{-MgO-CaO}$ with mineral assemblage of spinel lherzolite (olivine, clino-pyroxene, ortho-pyroxene and spinel) is employed to describe mantle melting. The equations of silicate liquid have been established with a revised formulation to improve the reproducibility of apparent molar Gibbs energies of pure liquid at a given temperature and pressure. In revised equation, apparent molar Gibbs free energies of silicate liquid end-components are anchored to the experimentally well-defined Gibbs free energies of solid components. Values of apparent molar Gibbs free energies of silicate liquid end-components are described as difference between Gibbs free energies of corresponding solid components. With the equation, specific heat and compressibility of silicate liquid are newly calibrated in this study. Melting temperature and enthalpy of melting is also calibrated if melting temperature of the component has not been determined. Parameters are calibrated with previously reported high pressure melting experiment of peridotite and previously reported thermodynamic properties of rock forming minerals. New energy minimization algorism is also developed to make better prediction of phase relation and energy balance for melt-absent and melt-present system. Stable phase assemblage and composition to minimize Gibbs free energy of the system at given temperature, pressure and whole rock composition are calculated with the new algorism.

Thermodynamic calculation model of mantle melting is established with the revised equation, calibrated parameter and new algorism. Mass-proportion of silicate liquid and residual solid phase and composition of anhydrous mantle peridotite at given temperature, pressure and whole rock composition are computed with the newly establishes model. The model predicts relationship between composition of the system, temperature and phase relation, including melting degree well.