A mass balance model for compositional convection between the bottom mush and the central melt layer and its application to a sill

Rayko Simura[1]

[1] Earth. & Plan., Sci., Univ. of Tokyo

The major factors governing the chemical evolution of a magma chamber is thought to be position of crystallization and mechanism of relative motion between crystals and melt. The crystallization in the peripheral region in a magma chamber causes compositional convection between the peripheral mush and the central crystal-free region. In this presentation, I propose a mass balance model for compositional convection between a bottom crystallizing boundary zone within a bottom crystal-pile of preexisting phenocryst and the overlying crystal-free zone. The model is applied to the Nosappumisaki intrusion to constrain the fractionation mechanism.

In a small sheet like intrusion solidified from the roof and floor contacts without vigorous convection, transportation of fractionated melt formed in the roof and floor boundary zones into the central crystal-free zone is thought to be the major factor to fractionate melt composition of the main magma body, because there are almost no observation of deposition of crystals formed in situ in smaller intrusions (Mangan and Marsh 1992). Chemical aspects of this process are discussed by Langmuir (1989), Nielsen & DeLong (1992), and Kurintani (1999) (boundary layer fractionation). The authors show that compositional trends produced by the boundary layer fractionation is different from those of homogeneous fractionation by crystal settling. However, actual mechanism of melt transportation is not constrained by their model, because of poor examination of spatial variations. The boundary layer fractionation is caused by compositional exchange between the peripheral mush and the central melt either by compaction or compositional convection. Studies on the mechanism of compositional convection have done extensively (e.g., Kerr & Tait, 1985; Tait & Jaupart, 1988; and Kaneko & Koyaguchi, 2000. Their analogue experiments imply that compositional convection occurs with upwelling flow through chimney structure in the crystal-mush zone and compositional plume in the crystal-free zone and downwelling into mush with permeable flow.

In the Nosappumisaki intrusion, there was compositional convection between the bottom crystal pile and the overlying crystal-free zone (Simura, 2003: this meeting), and there are observations showing melt transportation with upwelling flow through focused paths such as pipe-like structure, and with downwelling permeable flow inferred by partial dissolution or overgrowth of crystals grown in deeper levels and deposited on the bottom of the sill. This is fairly consistent with results of analogue experiments.

Key concepts of the mass balance model developed here are as follows. The sill can be divided into two zones, phenocryst-pile (PP) and crystal-free (CF) zones. Solidification proceeded from both the top of the CF zone and bottom of the PP zone toward the contact of the two zones at certain rates. The CF zone is divided into the upper CF zone, where fractionated melt transported from the PP zone through melt conduits and mixing with the interstitial melt, and as compositional plume in the lower CF zone mixing with the residing melt to various extent. The PP zone is also divided into two: one without no in-situ crystallization and the bottom boundary zone where fractionated melt was produced by crystallization, which is responsible for the fractionation of the CF zone.

Constructed mass balance model is adapted for the vertical compositional trend for the interstitial part extracted from the Nosappumisaki intrusion. Optimized parameters suggest that there is incomplete mixing in the CF zone to maintain the layered structures with upper more fractionated zone. This suggests that model with homogeneous mixing in the central part considered by Langmuir (1989) and others may be insufficient to reproduce magma chamber evolution. Spatial heterogeneity should be taken into account when the effect of the boundary layer fractionation is considered.