

## A heat and mass transfer model for coupled assimilation and fractional crystallization in high-silica magma bodies

# Koshi Nishimura[1]

[1] Inst. for Geothermal Sciences, Kyoto Univ.

### 1. Introduction

One of the most popular petrogenetic concepts is that of coupled assimilation and fractional crystallization (AFC) in magma bodies. DePaolo (1981) developed equations describing isotope and trace element behavior during AFC process. These equations have been very useful in reproducing trends commonly seen on plots of isotope data. In the DePaolo (1981) model, relative rates of assimilation versus fractional crystallization ( $r$ ) and the bulk solid/liquid partition coefficient for a trace element ( $D$ ) must be constant because the model is only based on a mass balance differential equation. In the case of high-silica magma and country rock (76-78 wt % SiO<sub>2</sub>),  $D$  can be regarded as constant (e.g., Anderson et al., 2000). However,  $r$  may vary greatly with time. DePaolo model implicitly assumes 0 % crystal fraction within the magma body. This assumption is also unrealistic and crystal fraction can vary with time. In order to investigate more realistic isotope and trace element behavior, this study incorporates temporal variations of  $r$  and crystal fraction into the AFC model, from the viewpoint of heat and mass transfer.

### 2. Modification of DePaolo (1981) mass balance equation

The mass balance differential equation of DePaolo (1981) implicitly neglects the fraction of crystals suspended in the magma body. This assumption can be applicable to the low viscosity magma such as basaltic magma because its crystals settle out quickly. However, the assumption would be unsuitable for crystal-rich silicic magmas. This study proposes new mass balance differential equation that incorporates effects of crystal fraction in suspension. In the following section, a numerical model is developed using this new mass balance differential equation, energy balance equation in a convecting magma body (Huppert and Sparks, 1988), and chemical equilibration equation (Nishimura, 2006). However, if we assume constant  $r$  and constant crystal fraction in suspension, the mass balance differential equation can be solved solely. From the analytical solution, we can roughly investigate effects of crystal fraction in suspension on the compositional evolution of a magma body during AFC processes. For example, in the case of 20% crystals in suspension, an incompatible element ( $D=0.1$ ) concentration is almost same as DePaolo (1981) model, and a compatible element ( $D=10$ ) concentration can however be greater than DePaolo (1981) model by two orders of magnitude.

### 3. Heat and mass transfer model for AFC processes

In this model, magma is convecting vigorously and melts the country rock at the roof of the body (Huppert and Sparks, 1988). The assimilated crystals are perfectly reequilibrated within the body and crystal settling occurs at the floor of the body with Stokes velocity (Martin and Nokes, 1988). The relative rates of assimilation versus fractional crystallization  $r$ , crystal fraction, isotope and trace element concentration in a magma are determined so as to satisfy the mass balance equation described above, the energy balance equation (Huppert and Sparks, 1988), and the chemical equilibration equation (Nishimura, 2006). Melt viscosity is assumed to be  $10^5$  Pa s. At an early stage of solidification, magma composition evolves along a mixing line on the trace element versus isotope ratio diagram, because assimilation rate is greater than crystallization rate. Because assimilation rate decreases with time, the effect of crystal fractionation becomes relatively larger and the magma composition is directed away from the mixing line. After the magma temperature reaches the effective fusion temperature of country rock, assimilation no longer occurs and isotope ratio is fixed. However, crystal settling can proceed and trace element concentration continues to change.