

# Convection and Redistribution of Alkalis and Trace Elements during the Mingling of Basaltic and Rhyolite Melts

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**Abstract**—Numerous examples of long-lasting coexistence of basaltic and rhyolitic magmas in magma chambers indicate that it results in thermal, isotopic, and chemical exchange between the melts. This paper presents our model experiments, which demonstrate the effect of rapid potassium and sodium diffusion from the basaltic to rhyolitic melt on their density and resultant convection in each of the melts. This diffusion-induced convection leads to the rapid preferential redistribution of alkalis between the melts. Ion microprobe profiles demonstrate that rapidly diffusing trace elements are transported more quickly than bi-, tri-, and tetravalent major components, and, at the very beginning of the experiments, they were redistributed between the melt in correspondence with respective partition coefficients typical of these components when the acid and mafic melts are immiscible. Convection maintains significant chemical gradients and creates a self-sufficient mechanism for the convection, diffusion, and redistribution of trace elements and alkalis between the magmas.

## INTRODUCTION

The coefficients of chemical diffusion of network-modifying elements (CaO, MgO, and FeO) are roughly commensurate with one another and with the coefficients of network-forming elements (SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub>) (Liang *et al.*, 1996; Kress and Ghiorso, 1993). This is caused by the strong coupling between diffusing components, i.e., a dependence of the diffusion coefficient of each component not only on its own concentration gradient but also on the concentrations and concentration gradients of all other components. Contrary to them, the diffusion of isotopes (self-diffusion) is independent of the gradients of other components, and, thus, the redistribution of isotopes between magmas can proceed one–two orders of magnitude faster than chemical mixing (Lesher, 1994; Perez and Dunn, 1996). Many trace elements are characterized by high values of diffusion coefficients (Lesher, 1994; Baker, 1992; Hofmann, 1980), because, contained in low concentrations, these elements are less dependent on the gradients of major components. Alkalis (K<sub>2</sub>O and Na<sub>2</sub>O) are also able to diffuse several times faster than network modifiers and formers (Watson and Baker, 1991; Baker, 1992). This process often proceeds in the direction opposite to the gradient of alkali concentrations and is coupled with uphill diffusion (Watson and Baker, 1991; Bindeman and Perchuk, 1993).

Since the transport of trace elements and alkalis between magmas can proceed faster than the mixing of major components, this can serve as an efficient mechanism of their rapid redistribution between the melts. However, diffusion is a slow process, which cannot ensure a large-scale redistribution. Thermally or compositionally driven convection in each of the coupled

magmas (Litvinovsky and Podladchikov, 1993) can facilitate this transfer through sustaining strong diffusion gradients at the interface between the magmas.

The aim of our study is to demonstrate the results of ion microprobe examination of the products of experimentally modeled mixing between basalt and rhyolite. These results indicate that the rapid diffusion of alkalis in magmas is sufficient to stimulate and maintain compositional convection in them. This is caused by the high partial volumes of K<sub>2</sub>O and Na<sub>2</sub>O (Lange and Carmichael, 1990) and the resultant permanent instability of the system. Convection of this type leads to the rapid redistribution of many trace elements between magmas and provides a model mechanism for mixing in magmatic chambers.

## EXPERIMENTAL GOALS

We conducted a series of experiments on magma mixing using a cylinder–piston apparatus with large graphite capsules and assemblies of soft ceramics with heaters tapered in the margins to minimize the temperature gradient within the assembly. The large tallness and diameter of the assemblies (10 by 4 mm) and, hence, their large volumes and the high experimental temperatures allowed us to create conditions for modeling compositional convection in the course of the mixing of rhyolite and basalt melts. The conventional experimental procedures (with lower temperatures and, consequently, a higher viscosity of the melt, and with assemblies of smaller volume) do not allow convection to be observed (Watson and Baker, 1991; Lesher, 1994; etc.).

(a)

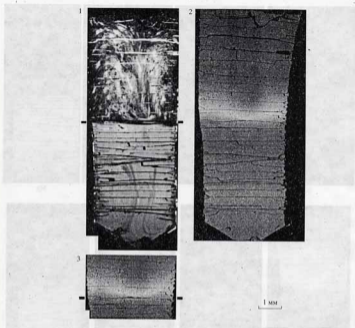


Fig. 1. Convection during the mixing of basaltic and rhyolitic melts.

(a) (1) Optical microphotograph of a thin section of Run BR-7 products showing "quenched" convective textures in coupled basaltic (bottom) and rhyolitic (top) melts. Tiny graphite particles accentuate the convective texture. (2) Back-scattered electron image showing the distribution of K. (3) Enlarged fragment of the previous figure (two horizontal marks at the figure sides indicate the boundary between the melts).

(b) Topochemical maps showing the distribution of major elements that accentuate convective textures and convection-controlled redistribution (see text for discussion).

ion microprobe are given in (MacPherson and Davis, 1993; Bindeman *et al.*, 1998). The contents of  $\text{CO}_2$  and  $\text{H}_2\text{O}$  were analyzed on a Nicolet NMR IR spectrometer in a doubly polished platelet that was prepared of the products of experiment BR-7.

## RESULTS

Three thin sections made of the products of 3-h-long experiments contain quench textures, which can be

interpreted as convection flows "quenched" in the basaltic and rhyolitic glasses.

X-ray mapping of the whole thin-section area (accomplished on a microprobe) provides evidence of the apparent uphill diffusion of both alkalis from the basalt toward rhyolite, as can be inferred from the enrichment of these elements in the lower portion of the rhyolitic glass layer and their depletion in the upper basaltic glass layer (Figs. 1a–1b). The uphill diffusion

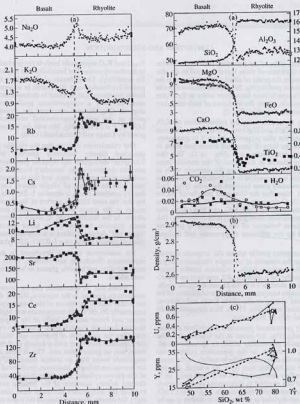
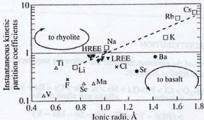


Fig. 2. Behavior of major (wt) and trace (ppm) elements during the mixing of basaltic and rhyolitic melts.

(a) Electron and ion microprobe profiles through the glasses of Run BR-7. The thicknesses of the major-element and Zr mixing zones are similar. Note the uphill-diffusion profile for K<sub>2</sub>O, Na<sub>2</sub>O, Cs, Rb, Li, Sr, Ce, TiO<sub>2</sub>. The Z-shaped configuration of the profile for Ce is valid; similar configurations are typical of the profiles for other REEs and Y.

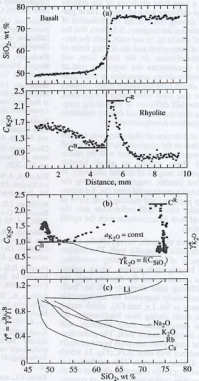
(b) "Quenched" density profile through the capsule, calculated at run conditions (Large and Carmichael, 1990). Note that a transient negative density gradient is preserved in the rhyolitic glass.

(c) Binary Y-SiO<sub>2</sub> and U-SiO<sub>2</sub> plots showing that the diffusion of Y is faster than that of Si, and the diffusion mobility of U and SiO<sub>2</sub> is similar.



**Fig. 3.** Instantaneous kinetic partition coefficients (IKPC) for fast-diffusing trace elements (see text).

Note that larger ions within each valence group have larger partition coefficients.



**Fig. 4.** Graphic representation illustrating the hypothesis of the constant activity of fast-diffusing  $K_2O$  between the peaks of its concentration ( $C_{K_2O}$ ) at a coupled change in  $SiO_2$  concentration ( $C_{SiO_2}$ ).

(a) Variations in  $C_{K_2O}$  and  $C_{SiO_2}$  along the diffusion profile across the coupled melts.

(b) Variations in  $C_{K_2O}$  as a function of  $C_{SiO_2}$  (in compliance with the condition of constant activities between the peaks, the activity coefficient should be a function of the form  $1/C_{K_2O}$ ).

(c) Activity coefficients (determined in a similar manner) of other alkaline trace elements between their concentration peaks (see Fig. 2) as functions of  $SiO_2$ . Note the more vigorous dependences of alkalis with larger ionic radii.