Magma mixing in nature and experiments: a review

I.N.Bindeman (1)1 & L L.Perchuk (2)

(1) Department of Geological Sciences, University of Oregon, Eugene, OR 97403-1272, USA

(2) Institute of Experimental Mineralogy, Russian Academy of Sciences, Chernogolovka, Moscow District, 142432 Russia

Magma mixing is a common process related to both the mantle plume – continental crust interactions and the basalt – rhyolite mingling in the magmatic chambers beneath island arcs [1, 2, 7-9]. Numerous examples of long-lasting coexistence of basaltic and rhyolitic melts in magma chambers indicate that it results in thermal, isotopic, and chemical exchange between the melts. Natural evidence inspired many experimental studies on mixing of natural melts in the systems by convection and interdiffusion. We report results of superliquidus mixing experiments involving komatiite-dacite, and basalt-rhyolite of different compositions at T up to 1850˚ C and P= 1-12 kbar [3-6, 10, 11] run in of piston-cylinder. Three types of experimental results are discussed: (1) gravity-driven convective mixing, (2) purely diffusive mixing , and (3) double-diffusive convecton induced by the to uphill diffusion of alkalies. The results demonstrate efficiency of the contrasting magmas mixing in the course of relative motion. In the case of *convective* mixing [2, 3, 14], low-viscousity ultramafic melt impregnates highly viscous dacitic melt and easily transforms into a boninite composition. Similarly, basaltic melt transforms into andesitic magma much more easily than viscous rhyolitic melt. The latter tends to "dissolve" any silicic into the mafic melt. Thus, mixing of two contrasling muiticomponcnt melts by convection is very effective due to natural buoyancy or as a result of forced convection. It is connected with sharpening gradients of diffusion, increasing the interface area of interaction and mechanical separation of the intermingling melts. *Diffusive* runs reveal selective behavior of alkalies and to a lesser extent other components due to diffusion, similar to experiments described by [10]. Uphill diffusion of alkalies may cause double-diffusive convection

in intercoupled melts. Diffusive interaction of two contrasting melts is explained as a multistage chemical reaction. In less complex experiments in multicomponent systems [4, 14,15] activity-composition relations can strictly determine diffusion coefficients in any diffusion direction within compositional space, affecting diffusion coefficients within one order of magnitude. In our experiments, due to much faster diffusion of alkalies or only Na_2O, they are distributed in accordance with the ratio of their activity coefficients, affecting other components and changing properties of adjacent melts. Activity coefficients of other basic components of MgO, CaO, FeO, and trace metals [2] increase, while network-forming acid components SiO_2 and Al_2O_3 decrease they activity in accordance with Korzhinskii's principle of base-acid interaction of components in silicate melts. These changes may accelerate or decelerate diffusion through their effect on the gradients of activities. Unlike simple synthetic experiments, experiments involving natural composition are strongly dependent on the relatively small variations of alkalinity of intercoupled melts. Further mixing proceeds as an additive diffusion of all components. We describe extreme examples when an uphill diffusion of alkalies, which have large partial molar volumes, can even cause double-diffusive convection in intercoupled alkali basalt under a layer of rhyolite.

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 in magma chambers maintains significant chemical gradients and creates a self-sufficient mechanism for the convection, diffusion, and redistribution of trace elements and alkalis between the magmas.

Results of experimental studies support strongly support many recent observations of mixing in the island arcs magma chambers, diffusive dissolution of crustal rocks in deep-seated mafic and ultramafic magmas. The results also allow correct interpretation of the formation of an inverse sequence of volcanism in marginal sea floors resulted from melting and mixing magmas at the front of ascending mantle plumes [7, 8], as follows from the 3D seismic data treatment [12, 13].

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