

## Diffusion of Neon in Olivine and Quartz

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Diffusion of neon has been characterized in olivine and quartz. Polished, oriented slabs of olivine (synthetic forsterite and natural Fe-bearing olivine) and synthetic quartz were implanted with <sup>22</sup>Ne at 100 keV with a dose of  $5 \times 10^{15} / \text{cm}^2$ . Experiments on the implanted olivine and quartz were run in 1-atm furnaces, with <sup>22</sup>Ne distributions in samples following diffusion anneals measured by Nuclear Reaction Analysis using the reaction  ${}^{22}\text{Ne}(p,\gamma){}^{23}\text{Na}$ .

For diffusion in synthetic forsterite, for transport parallel to the b-axis, we obtain the following Arrhenius relation over the temperature range 500-1000°C:

$$D_{\text{forst}} = 2.4 \times 10^{-12} \exp(-155 \pm 12 \text{ kJ mol}^{-1}/RT) \text{ m}^2 \text{ sec}^{-1}.$$

Diffusion parallel to the c-axis appears similar over the temperature range investigated. Data from "soaking" experiments on forsterite, in which <sup>20</sup>Ne was diffused into samples during anneals in cold-seal vessels pressurized with neon, are in generally good agreement with results from the <sup>22</sup>Ne implantation experiments. Work is currently underway on measurements of Ne diffusion in a natural Fe-bearing olivine.

The Ne diffusivities for olivine measured in this work are roughly two orders of magnitude slower than those obtained by Futagami et al. [1], who measured Ne diffusion in synthetic forsterite by outgassing <sup>20</sup>Ne implanted samples.

Activation energies for Ne diffusion are comparable to those recently measured for helium diffusion in olivine [2], but diffusion of Ne is about 5 orders of magnitude slower than He diffusion.

For quartz, we obtain the following Arrhenius relation over the temperature range 450-1000°C for Ne diffusion parallel to the c-axis:

$$D_{\text{qtz}} = 1.3 \times 10^{-14} \exp(-112 \pm 15 \text{ kJ mol}^{-1}/RT) \text{ m}^2 \text{ sec}^{-1}.$$

Ne diffusion normal to the c-axis appears similar. As with olivine, data from "soaking" experiments using pressurized <sup>20</sup>Ne are in generally good agreement with the ion implantation results. However, these diffusivities are about 10 orders of magnitude slower than the values for diffusion of <sup>21</sup>Ne in quartz from outgassing experiments reported by Shuster and Farley [3].

Our data suggest that both quartz and olivine may be moderately retentive of neon; for example, 500 micron radius grains of quartz and olivine would experience only 5% loss of Ne in 1 Myr at 320°C and 395°C, respectively, and negligible Ne losses at surface temperatures over times on order of the age of the earth.

[1] Futagami et al. (1993) *Geochim. Cosmochim. Acta* **57**, 3177-3194. [2] Cherniak & Watson (2011) 2011 AGU Fall Mtg. [3] Shuster & Farley (2005) *Geochim. Cosmochim. Acta* **69**, 2349-2359.

## The transient rheology of crystallizing magmas

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### Introduction

The viscosity of magmas is a key parameter in magma transport processes and volcanic eruptions. In nature, magmas are transient. Changes in P-T conditions force the magma to chemically and physically evolve, resolving a transient viscosity of the melt (e.g.,  $10^{-1}$  to  $10^{14}$  Pa s), overprinted by the complex rheological effects of the suspended fraction (crystals and bubbles). Such a dynamic understanding of transient rheology escapes our ability to fully assess the extent of volcanic hazards (e.g., lava flow reach out). To date, rheological studies provide a static view on individual contributions (e.g., chemical composition of the interstitial liquid [1] vs physical effects of the suspended phases [2,3]), without consideration of the feedback involved in the thermodynamic process underlying the evolution of the magmatic system. Alternatively, thermodynamic calculators (e.g., MELTS [4]) provide a static view of mineral assemblage equilibrium, disregarding kinetic information on the physical evolution of the system during crystallization. Here, we assess the adequacy of combining rheological, petrologic and thermodynamic models in a transient system (such as lava flow dynamics) by comparing their outcome to dynamic rheological experiments on crystallizing and flowing natural melts with various (andesitic to basaltic) compositions.

### Methodology and results

We optimized previous experimental methods [5,6] for the concentric cylinder apparatus to measure the dynamic apparent viscosity of a magmatic suspension undergoing cooling and crystallization. The spindle is left in situ during quenching of the experimental products, to preserve the complete developed texture of the sample. Experiments are carried out in air or under controlled oxygen fugacity in order to avoid extensive oxide crystallization. Below the liquidus we record a transient evolution of the system; when crystals nucleate and when crystals grow. Thermodynamic equilibration is then reached after some hours. With each further cooling increment equally complex rheological response (overprint by non-Newtonian behavior) is observed. Quantification of the evolving mineralogical assemblage as well as the crystal fraction and distribution reveal that the steady state flow conditions are reached upon completion of crystallization at equilibrium (under a given T increments). Comparatively, the apparent viscosity at each investigated temperature is calculated as a function of the crystallization sequences (via MELTS), the residual liquid composition (via GRD calculator [1]) and the characteristics of the solid fraction [2,3], presenting the discrepancies of employing static models in a dynamic system. Our findings suggest that dynamic models will need to be developed to improve the description of magma transport in our assessment of volcanic hazards.

[1] Giordano et al., (2008) *Earth Planet. Sci. Lett.* **271**, 123–134. [2] Mueller et al., (2010) *Philos. Trans. R. Soc. Lond. A* **466**, 1201–1228. [3] Cimarelli et al., (2011) *Geochem. Geophys. Geosyst.* **12**, Q07024, 14 PP. [4] Ghiorso et al., (1995) *Contributions to Mineralogy and Petrology*, **119**, 197–212. [5] Ishibashi and Sato, (2007) *J. Volcanol. Geoth. Res.* **160**, 223–238. [6] Vona, et al., (2011). *Geochim. Cosmochim. Acta*, **75**, 3214–3236.