Connectivity of volatile-rich melts in mantle source-regions: Constraints from Fe-transport experiments

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Introduction

Low-degree, volatile-rich melts may play an important role in mobilising H_2O, CO_2 and highly incompatible trace elements and thus constitute effective agents of chemical modification in the lithospheric upper mantle. Knowledge of the grain-scale distribution of such melts in mantle rocks is key to defining the processes by which such small melt fractions may become mobile. Past laboratory studies of this problem have focused on characterizing the textural properties of melts in olivine-rich matrices (i.e., wetting angle measurements), but the combination of crystal faceting and multiple mineral phases suggests that inferences of melt connectivity, based solely on these data, may be ambiguous (Wolf and Wyllie, 1991; Waff and Faul, 1992). Recent studies have shown that monitoring the bulk transport of melt soluble elements provides a more accurate measure of melt connectivity, particularly at low melt fractions (Daines and Richter, 1988; Watson, 1991; Minarik and Watson, submitted). We present new data, derived from Fe-transport experiments, to assess the connectivity, and hence potential mobility, of carbonate- and water-rich melts in olivine-rich lithologies.

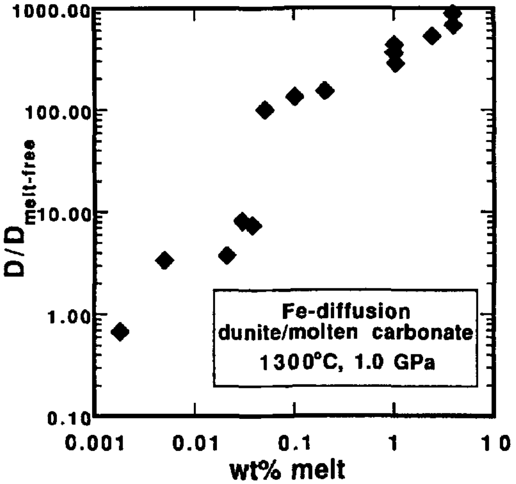

FIG. 1. Enchancement of bulk iron diffusion relative to dry polycrystalline olivine due to the presence of molten carbonate

Materials and Method

Melt connectivity was assessed by monitoring the enhancement of diffusive Fe-loss from the constituent ferromagnesium silicates of partially molten vs melt-free dunite and lherzolite. Lherzolites and dunites were synthesised from cleaned and sieved (< 38 μm) San Carlos xenolith mineral separates. Experiments were initiated by loading mixtures of dunite or lherzolite with H_2O (1–3 wt% total) + pre-dried MORB powder or Na-carbonate in noble metal or graphite capsules, respectively, and melt fractions varied from 0 to 8 wt%. Pt was used as a sink for Fe in these experiments and was introduced as a tight-fitting plug at the end of the sample. Capsules were packed in graphite and run in a 3/4" piston-cylinder apparatus in the P-T range of 1050 to 1300°C and 1.0 to 2.5 GPa for 1 to 5 days. Run-products were mounted in epoxy, sectioned and vacuum impregnated several times prior to polishing for electron microprobe analyses. Fe concentration profiles in the lherzolite/dunite were measured as a function of distance from the rock/platinum interface by EDS analysis using a rastered (500 × 10 μm) beam with the long dimension parallel to the platinum interface. Bulk Fe diffusivities were calculated from concentration *vs* distance data using an appropriate solution to Fick's 2^{nd} Law. X-ray maps of the samples were used to assess abundance of melt and porosity.

Results and discussion

Consistent with previous results, textural observations of run-products indicate mineral/melt dihedral angles for both hydrous and carbonate-rich melts are low (i.e. < 50°) and faceted crystal/melt contacts are common. Experiments involving hydrous melts are vapour saturated and vapor is typically isolated from mineral contact by the preferential wetting of grains by melt. This implies that at low vapor and melt abundance, the pathways for iron transport are controlled by the topology of intergranular melt. We observe enhancement in bulk Fe diffusion of 10 to 10^3 times relative to melt and fluid-free samples over the entire range of melt fractions studied (1–8 wt% hydrous melt, 0.01–5 wt% carbonate melt) indicating the presence of interconnected melts in all cases except at the lowest abundances of carbonate melt. In the experiments involving carbonate melt, a series of runs to assess Fe-diffusivity as a function of melt fraction indicates that the functional form of this relation is discontinuous and a rapid drop in the Fe diffusivity at melt fractions < 0.05 wt% is indicated (see Figure 1). We interpret this effect as resulting from the partial closure of interconnected porosity (i.e., an increase in tortuosity) perhaps arising from the stabilization of dry grain edges in response to surface energy anisotropy. The melt fraction marking the onset of partial interconnectivity may be lower still in a mantle assemblage with a typical grain size on the order of 1 mm. This occurs because a larger grain size results in the presence of volumetrically fewer grain-grain contacts. The presence of pyroxenes and other minor phases may, however, serve to offset this effect.

Our results indicate that small degree, volatile-rich melts may be interconnected in mantle rocks at melt fractions much less than 0.01 for carbonate-rich and hydrous compositions. Owing to the extreme efficiency with which highly incompatible trace elements and C-O-H fluids may dissolve in such materials, these results supply the physical basis for the process of chemical transfer and metasomatism inferred by geochemical models and petrologic observation.

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References

Daines, M. J. and Richter, F. M. (1988) *J. Geophys. Res.*, **15**, 1459–62.

Minarik, W. G. and Watson, E. B. (1994) Submitted.

Waff, H. S. and Faul, U. H. (1992) *J. Geophys. Res.*, **97**, 9003–14.

Watson, E. B. (1991) *Contrib. Mineral. Petrol.*, **107**, 417–34.

Wolf, M. B. and Wyllie, P. J. (1991) *Mineral. Petrol.*, **44**, 151–79.