

DIFFUSIVE FRACTIONATION OF REE DURING MANTLE MELTING: EXPERIMENTS AND MODELS

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ABSTRACT

Models for the chemical evolution of melts and their solid residues (including batch, fractional, and dynamic melting models) commonly assume that the solid and liquid remain in equilibrium during melting (e.g., Shaw, 1970; Langmuir et al., 1977). However, because the approach to equilibrium is limited by chemical diffusion in the solid phases, this assumption holds only when the rate of chemical diffusion is rapid compared to the melting rate (e.g., Qin, 1992; Iwamori, 1993). Here we discuss our recent experimental results on the diffusion rates of rare earth elements (REE) in high-Ca pyroxene (cpx) and pyrope-rich garnet at upper mantle pressures and temperatures. We find that diffusion rates of REE in these minerals are sufficiently slow for only partial equilibrium to be maintained under realistic melting conditions. A general model is developed for describing diffusion-controlled chemical fractionation during dynamic

partial melting of a polyphase solid, and is used to simulate the distribution of REE between solid phases and melt during decompression melting of garnet and spinel lherzolites. Under conditions relevant to melting beneath mid-ocean ridges, fractionation of the REE is significantly different than would be expected for an equilibrium dynamic melting process.

Diffusive fractionation is especially severe for cpx, in which diffusion rates of the REE depend strongly on their ionic radii. The diffusivity of La (i.r. = 0.116 nm) in cpx is a factor of ~35 slower than Yb (i.r. = 0.099 nm). This results in a strong diffusive fractionation in which the larger light REE are held within the cores of cpx grains at concentrations far above equilibrium concentrations, while the heavy REE more closely approach equilibrium with the residual melt (Fig. 1).

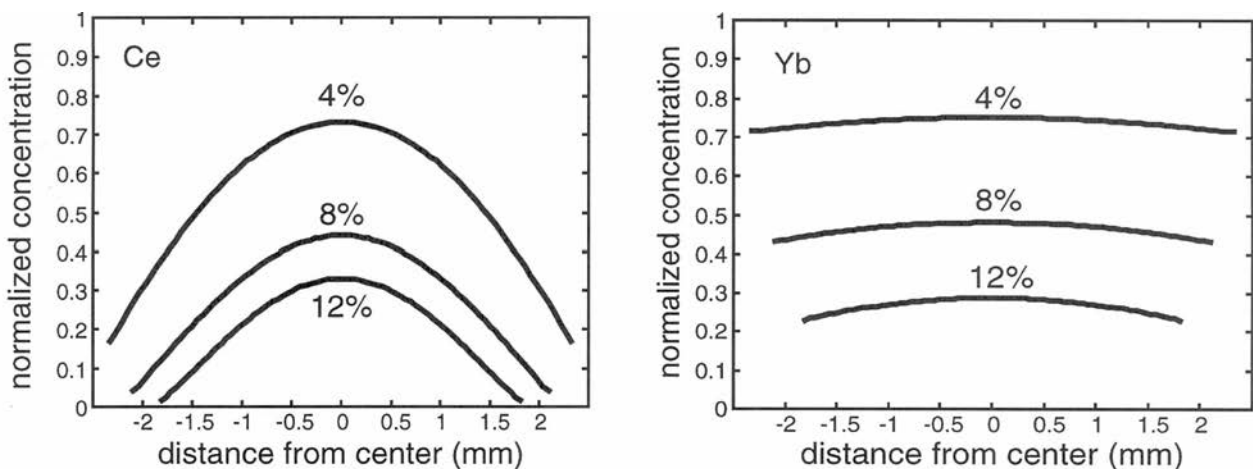


Fig. 1 - Model Ce and Yb profiles developed across a spherical 2.5 mm cpx grain during progressive melting of a spinel lherzolite. Melting begins at 2.0 GPa, 1395°C and ends at 0.4 GPa, 1240°C, with 1% melt retained with the solid throughout the melting interval. The solid upwelling rate is 3 cm/yr and the total degree of melting is 12%. The rim concentrations of Ce and Yb are the equilibrium concentrations, determined by the respective cpx/melt partition coefficients for these elements.

Diffusive fractionation by cpx results in REE patterns in the residual solid that are far less steep than patterns produced by equilibrium dynamic melting (Fig. 2).

In contrast to cpx, REE diffusivities in pyrope-rich garnet are nearly independent of ionic radius and are very similar to each other. Thus diffusive fractionation of the REE by garnet is very weak, and REE patterns produced by disequilibrium dynamic melting are similar in form to those produced by an equilibrium process. The rate of diffusion of REE in garnet is similar to Yb in cpx, so that strong diffusion zoning (such as that seen in Fig. 1 for Ce) is only expected if melting rates are very high or the grain size is very large.

REFERENCES

- Iwamori H., 1993. Dynamic disequilibrium melting model with porous flow and diffusion-controlled chemical equilibration. *Earth Planet. Sci. Lett.*, 114: 301-313.
- Langmuir C.H., Bender J.F., Bener A.E., Hanson G.N., and Taylor S.R., 1977. Petrogenesis of basalts from the FAMOUS area: Mid-Atlantic Ridge. *Earth Planet. Sci. Lett.*, 36: 133-156.
- Qin Z., 1992. Disequilibrium partial melting model and its implications for trace element fractionations during mantle melting. *Earth Planet. Sci. Lett.*, 112: 75-90.
- Shaw D.M., 1970. Trace element fractionation during anatexis. *Geochim. Cosmochim. Acta*, 34: 237-243.

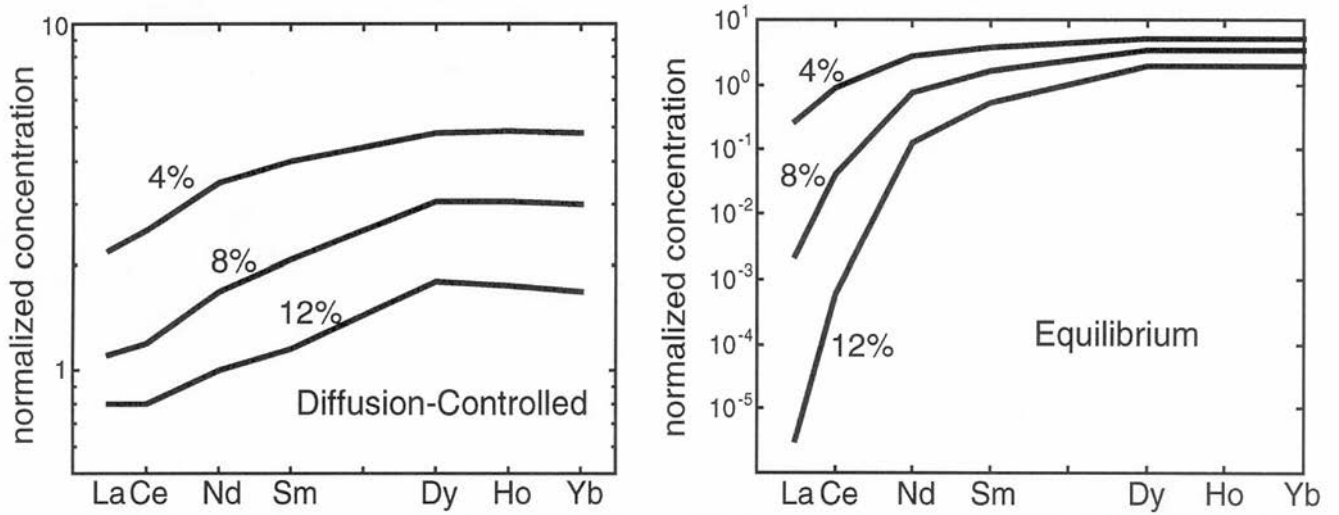


Fig. 2 - REE patterns in residual cpx with progressive melting. Parameters are the same as those described in the caption of Fig. 1. On the left are patterns produced by a melting model with diffusion-controlled equilibration between solid and melt, where concentrations are integrated over the entire volume of the zoned cpx crystals. On the right are patterns produced by an equilibrium dynamic melting model.