Effect of melt structure on trace-element partitioning between clinopyroxene and silicic, alkaline, aluminous melts

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ABSTRACT

We have investigated trace-element partitioning between clinopyroxene and silicic melts ranging from 62 to 69 wt% SiO2 in piston-cylinder experiments at 1.1 GPa and 1145–1155 °C. Run products consist of diopsidic clinopyroxene (with 3–5 wt% Al2O3 and ~1 wt% Na2O) coexisting with silicic, aluminous, and alkaline melts. Clinopyroxene-melt partition coefficients for rare earth elements (REE) are significantly higher (e.g., $D_{Sm} = 0.76$ to 3.1) than previous studies of clinopyroxene-basaltic melt partitioning. The maximum $D_{REE}$ is also shifted toward middle REE (e.g., Tb). Although the partition coefficients of Sr and Ti ($D_{Sr} = 0.23$–0.39, $D_{Ti} = 0.28$–1.0) are also elevated relative to clinopyroxene-basaltic melt, partition coefficients for Zr and Li (0.14–0.23 and 0.16–0.25, respectively) are within the range of literature values.

The high partition coefficients for REE, Sr, and Ti in this study do not reflect crystal-compositional effects. For instance, no relationship is observed between $^{10}$Al and these partition coefficients. REE and Ti partition coefficients correlate poorly with jadeite component of the clinopyroxene; however, the elevated Na2O contents of both the melt and clinopyroxene make it difficult to discriminate fully the effect of jadeite component from the effect of changes in melt structure. The non-bridging oxygen to tetrahedral cation ratio (NBO/T; Mysen et al. 1985) varies from 0.08 to 0.17 and roughly correlates with $^{\text{max}}D_{REE}$, consistent with a recent study (Gaetani 2004) that concluded that melt structure significantly affects partitioning when NBO/T < 0.49. Notably, we find a strong correlation between the molar Ca2+/(M+ + M2+) of the melt and the optimum $D$ ($D_{0}$) for the REE, indicating that melt structure, and not jadeite content, is the dominant control on clinopyroxene-melt partitioning in these experiments.

The partition coefficients for the REE, Ti, Zr, and Sr are in good agreement with observed clinopyroxene-silicic glass partitioning within mantle xenoliths (Chazot et al. 1996; Vannucci et al. 1998), indicating these results may apply to lithospheric melting. Furthermore, the origin of hump-shaped REE patterns observed in residual clinopyroxene from abyssal peridotites could be explained if shallow depleted melts of peridotite are silica-rich. A two-stage fractional melting model assuming clinopyroxene-silicic melt partitioning at shallow mantle depths from 10 to 30 km beneath a mid-ocean ridge can reproduce the observed hump-shaped REE patterns. If so, hump-shaped REE patterns may provide evidence for the existence and extraction of silica-rich melt created in the shallow mantle.

Keywords: Melt structure, partition coefficient, trace element, clinopyroxene

INTRODUCTION

There is increasing awareness of the range in melt compositions created during mantle melting and a corresponding acceptance that erupted magmas reflect integration and mixing of these diverse melts. Although their role in ultimately contributing to erupted lavas is unclear, glasses enriched in silica, alumina, and alkalis are often observed in mantle xenoliths, with several studies suggesting these melts may contribute to aggregate ocean island basalts (Wulff-Pedersen et al. 1996, 1999; Vannucci et al. 1998; Lundstrom et al. 2003). Consistent with this, phase-equilibria experiments show that some silica-rich glasses observed in xenoliths are in equilibrium with harzburgitic and lherzolitic mineral assemblages at 1.0–1.5 GPa and ~1150 °C (Draper and Green 1997, 1999), indicating that they represent a plausible melt component contributing to mantle-derived magmas.

Clinopyroxene (cpx) is generally considered the most important mineral controlling the partitioning of trace elements between melt and residual solid during mantle melting (e.g., McKenzie and O’Nions 1991). The partitioning of trace elements between silicate melts and minerals depends on both crystal chemistry and melt structure. Several recent studies have demonstrated the importance of crystal-chemical control on trace-element partitioning between cpx and basaltic melt, with a particular emphasis on the site size energetics of an element substitution (e.g., Blundy and Wood 1994). Notably, the effect