Rare Earth Elements in Recharging Martian Magma Chambers: Impact on Shergottite Compositions

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INTRODUCTION

The shergottite meteorites are the best window available into the chemistry of Mars's mantle. Rare earth element (REE) abundances are an important characteristic as they are easy to measure and divide the shergottites into 3 groups: depleted, intermediate, and enriched, with each group varying in its total REE abundances by a factor of ~2 [1]. Typically, shergottite REE abundances are considered to represent the primary magma after correction for the minerals present. However, magma chambers can undergo cycles of mixing, overturn, and recharge, complicating this scenario. In this project we consider two questions:

- **How do magma chamber processes impact REE abundances?**
- **How do these changes compare to variability observed in the shergottites?**

METHODS

We used the recharging, evacuating, and fractionating (REFC) model of Lee et al. [2].

- Calculates magma composition over cycles of resupply and crystallization in a magma chamber.
- Applied to shergottites from each REE group.
  - o Y-980459 (depleted) [3], EETA 79001A (intermediate) [4], and LAR 06319 (enriched) [5].
- Used mineral/melt partition coefficients (D) appropriate for martian minerals [1, 6].

RESULTS

- For all calculations, REE concentrations in a magma chamber increase each cycle and reach steady state after ~5 to 6 overturns (Fig. 1).

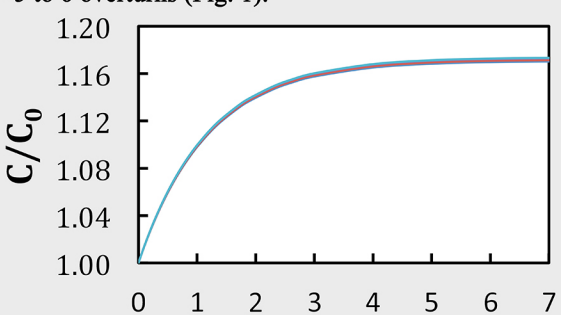

Figure 1. Number of overturns vs. concentration of element in a magma chamber normalized to the abundance in the supplying parental magma. Lines for each REE overlap (multiple colors shown).

Crystallizing Olivine Only

- Reasonable olivine abundances for shergottites [7]
  - o REEs are elevated in magma chambers by ~17% over the primary magma at steady state (Fig. 2).
  - o ~10% REE enrichment after only 1 overturn
  - o Olivine-only crystallization did not fractionate REEs.

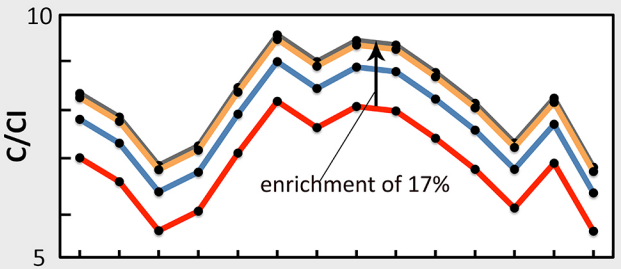

Figure 2. CI-normalized REE abundances for LAR 06319 parent magma after crystallization of 15% olivine per overturn. Colors show # of overturns: 0 (red), 1 (blue), 3 (orange), and 6 (grey).

Co-Crystallizing Multiple Minerals

- Included olivine, orthopyroxene, clinopyroxene, and plagioclase.
- Considered up to 50% crystallization.
  - o Overturn of crystal-rich mushes
- Much larger increases in magma chamber REE concentration (Fig. 3 & 4).
- At steady state REE abundances increased by ~2x.
- Regardless of minerals used, no REE fractionation and no change of Eu/Eu* due to plagioclase.

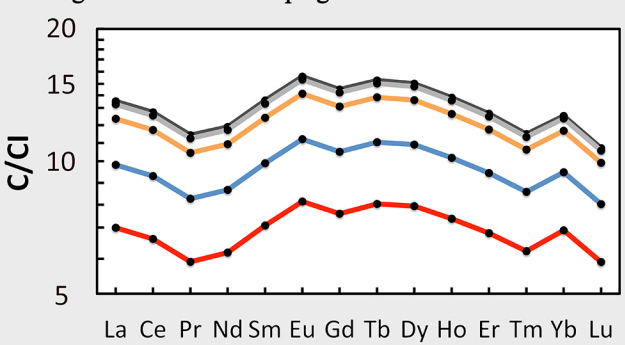

Figure 3. CI-normalized REE abundances after several overturns for LAR 06319 with 50% crystallization each overturn (20% olivine and 80% orthopyroxene mix). Colors show # of overturns: 0 (red), 1 (blue), 3 (orange), 5 (light grey), and 6 (dark grey).

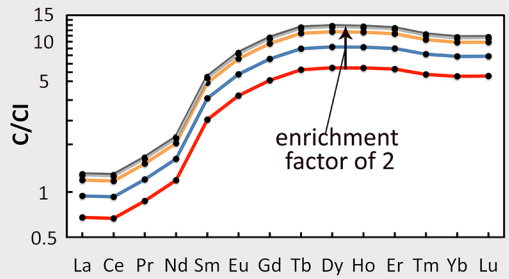

Figure 4. CI-normalized REE abundances after several overturns for Y98 with 50% crystallization each overturn (20% olivine and 80% orthopyroxene mix). Colors as in Fig. 3.

If Merrillite Crystallizes

- Only phase with compatible REEs (D>1).
- 1-2% merrillite decreased magnitude of REE increase (Fig. 5).
- Produced only significant REE ratio fractionation

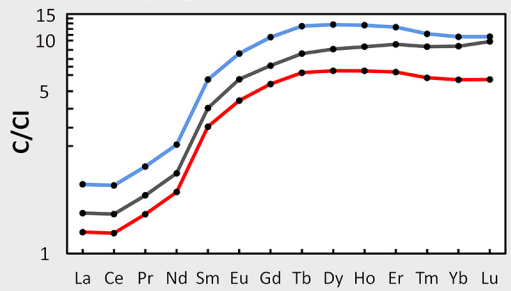

Figure 5. CI-normalized REE abundances after several overturns for Y98 with 50% crystallization during each overturn. Red (0 overturns) and dark grey (8 overturns) lines: 20% olivine and 78% orthopyroxene, 2% merrillite mix. Blue line (8 overturns): 20% olivine and 80% orthopyroxene. Note that the grey and blue lines are both at 8 overturns.

SUMMARY

- Olivine only crystallization as seen in shergottites increases magma chamber REE abundance by ~17% over primary melts
- Higher crystal fractions/crystal mushes enrich melts by up to a factor of 2
  - o Phosphate formation could limit REE enrichment, fractionate LREE/HREE
- Observed shergottite REE variation in each group of similar magnitude to that calculated here [1]
  - o **This process could be a major contributor to REE variability observed in shergottites**
- Resupplied magma chambers must be taken into account if using REE abundances to infer mantle chemistry or melt fractions.

[1] Balta J.B. et al. (2015), MAPS 50, 63-85. [2] Lee C.-T.A. et al. (2013), GCA 143, 8-22. [3] Shirai N. and Ebihara M. (2004), AMR 17, 55-67. [4] Barrat J.A. et al. (2002), GCA 66, 3505-3518. [5] Sarbadhikari A.B. et al. (2009), GCA 73, 2190-2214. [6] Lundberg L.L. et al. (1990), GCA 54, 2535-2547. [7] Balta J.B. et al. (2013), MAPS 48, 1359-1382.