RARE EARTH ELEMENT VARIATIONS IN RECHARGING MARTIAN MAGMA CHAMBERS: IMPACT ON SHERGOTTITE COMPOSITIONS. D. O. Peluso[1] and J. B. Balta[1], [1]Dept. of Geology & Environmental Science, University of Pittsburgh, 4107 O'Hara Street, Pittsburgh, PA 15260, danielopeluso@pitt.edu.

Introduction: The shergottite meteorites are currently the best window available into the chemistry of Mars's mantle. The rare earth element (REE) abundances in martian meteorites are an especially important characteristic as they are easy to measure and their sizes and chemical properties vary systematically. Therefore, they can give information about the composition of the mantle that generated a magma and how it was processed before it erupted. There are three groups of shergottites categorized in part by their REE abundances: depleted, intermediate, and enriched [1]. The source of this REE abundance variation remains debated as it could be either inherent in the martian mantle or a signal of crustal assimilation [1].

It has been commonly assumed that the REE abundances in a shergottite can be treated as representing the primary magma that generated the meteorite after some correction for the abundances of minerals present. However, long-lived magma chambers are chemically complex and can undergo multiple episodes of mixing and overturn during their lifetimes. There is evidence that crystals in shergottite meteorites have resided for substantial time in magma chambers before erupting [2] and recycling of crystals and melt from one magma batch to another will change the bulk composition of magma remaining in the chamber. The effect of this processes on mineral and major element abundances has been considered, but the possibility of REE variations associated with this process has not been treated systematically. In order to better understand the implications of recharging magma chambers for shergottite REE chemistry, we applied geochemical models created to simulate magma chamber processes on Earth. Using measured compositions of depleted, intermediate, and enriched shergottites, we find that REE abundance changes due to recharging magma chambers can contribute to shergottite REE chemistry in predictable ways. This process can be a source of variation in shergottite REE abundances and must be considered when using REEs to estimate martian melt fractions or mantle compositions.

Methods: The recharging, evacuating, and fractionating (REFC) model by Lee et al. [3] is designed to test how compositions vary in a long-lived and resupplied magma chamber. The algorithm requires parameters such as: the abundance of an element in a supplying magma, how many times a magma chamber has been resupplied, partition coefficients (D), and the percentage of magma crystallized at each step, all of which are generally understood for shergottites.

Applying this algorithm for shergottite REEs required use of partition coefficients appropriate for minerals in shergottites: for olivine we used measured mineral-melt Ds from Tissint [4] and for plagioclase, orthopyroxene, clinopyroxene, and merrillite we used measured Ds from ALHA 77005 [5]. We then constructed bulk partition coefficients for each REE using the formula

$$D_{bulk} = X_1D_1+X_2D_2+X_3D_3+...$$

where X is the weight fraction of the mineral crystalizing at each step. To calculate the effects of crystallization under a variety of P-T-X conditions, we calculated the abundances of minerals that would crystallize for shergottite parent magmas using the MELTS algorithm [6] and extended the trends predicted by those calculations to the limits of the plausible parameter space.

To represent the variability in shergottite melt REE abundances we used measured compositions of three shergottites: Y-980459 (depleted) [7], EETA 79001A (intermediate) [8], and LAR 06319 (enriched) [9], chosen as they can approximate martian parental liquid compositions [10] from each chemical group. With these calculated D values and shergottite compositions, we used the REFC model to simulate how the composition of the magma in a chamber varies over cycles of resupply and crystallization called overturns. A magma overturn is defined as one cycle of recharge and eruption/crystallization of a melt in magma chamber, with a portion of the melt remaining in the chamber.

Results: For all calculations using the REFC model we found that REEs concentrations in the chamber reached a steady state after ~5 to 6 overturns (Fig. 1).

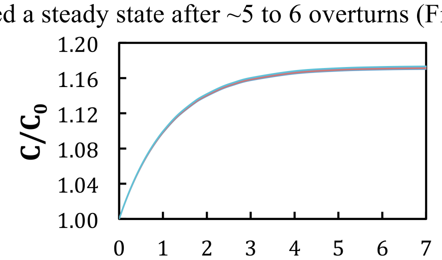

Figure 1. Number of overturns vs. concentration of element in a magma chamber normalized to the abundance in the supplying parental magma. Lines for each REE overlap (multiple colors shown).

In calculations involving crystallization of olivine abundances similar to those observed in shergottites [2], we found that at steady state, REE abundances in the magma chamber are elevated by ~17% compared to the primary magma (Fig. 2). After only a single overturn, the magma chamber is enriched by ~10% in REEs for all three shergottite groups. Olivine-only crystallization did not fractionate the REEs.

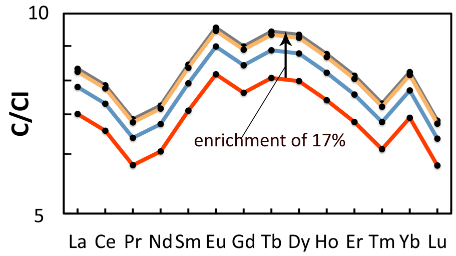

Figure 2. CI-normalized REE abundances for LAR 06319 parent magma after crystallization of 15% olivine per overturn. Colors show # of overturns: 0 (red), 1 (blue), 3 (orange), and 6 (grey).

We also shifted bulk partition coefficients to reflect crystallization of olivine, plagioclase, orthopyroxene, and clinopyroxene in various fractions. We considered cases where as much as 50% of the initial magma crystallized to represent production and remobilization of high crystal fraction mushes. MELTS calculations indicate high crystal fractions require formation of olivine + OPX + CPX ± plagioclase, but remobilization of these magmas through multiple cycles is plausible based on magma chamber behavior on Earth. Compared to olivine-only crystallization as in Fig. 2, increasing the amount of crystallization at each step leads to much larger increases in magma chamber REE concentration (Fig. 3 & 4); at steady state REE abundances can be increased by up to a factor of 2. Crystallizing olivine, pyroxene, and plagioclase, regardless of the mineral ratio, has no significant effect on REE ratios. Similarly, we tested if plagioclase could influence the magnitude of the Eu anomaly in the melt and found no significant change in Eu/Eu*.

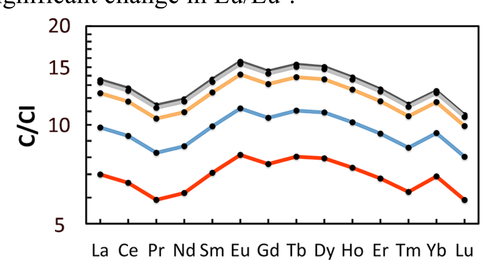

Figure 3. CI-normalized REE abundances after several overturns for LAR 06319 with 50% crystallization each overturn (20% olivine and 80% orthopyroxene mix). Colors show # of overturns: 0 (red), 1 (blue), 3 (orange), 5 (light grey), and 6 (dark grey).

We also tested crystallization of small (1-2%) amounts of merrillite; merrillite was the only phase included where the REEs were compatible. Adding merrillite caused a decrease in the magnitude of the REE increase during each overturn, but the general pattern of increasing REE during each overturn remained. For comparison, a calculation involving orthopyroxene alone (50% crystallization per overturn) showed REE enrichment of 30% relative to the starting composition, whereas with 2% merrillite the enrichment was only 15-25%. Adding merrillite to the mixes also resulted in the only noticeable REE ratio fractionation; La/Lu, Dy/Lu, and Sm/Lu displayed small but measureable decreases as merrillite preferentially incorporated the LREE and MREE.

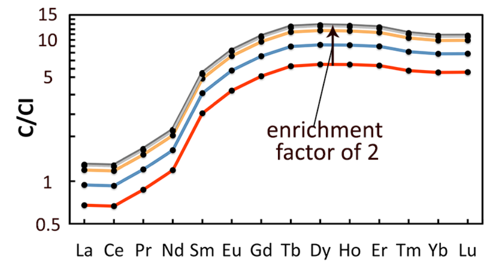

Figure 4. CI-normalized REE abundances after several overturns for Y98 with 50% crystallization during each overturn (20% olivine and 80% orthopyroxene mix). Colors as in Fig. 3.

Discussion: Meteoritic bulk compositions and melts calculated to be in equilibrium with early-crystallized pyroxenes demonstrate that shergottites from a single compositional group represent magmas that still vary in REE abundances by factors of 2-4 [4]. These variations can result from variable degrees of melting, mantle composition variation, and/or magma chamber processes. This work demonstrates that overturn and resupply in an active magma chamber will produce eruption products that are REE enriched compared to parental melts. In a typical system producing olivine antecrysts, enrichments of >10% will be common. In systems that stagnate and crystallize substantial pyroxene, the maximum possible enrichment is comparable in magnitude to the total REE variation observed within each shergottite group.

If a martian magma chamber undergoes overturn and recharge, the erupted magma will have higher REE abundances than the actual primary magma and those increased REE abundances will carry through to any estimates of melt fraction or mantle composition made based on measured REE abundances. Therefore, a factor of up to 2 variation in estimates of either melt fraction or mantle composition calculated based on shergottite compositions may be possible if this process is not taken into account.

References: [1] Symes S. J. K. et al. (2008), *GCA 72,* 1696-1710. [2] Balta J.B. et al. (2013), *MAPS 48*, 1359-1382. [3] Lee C.-T.A. et al. (2013), *GCA 143*, 8-22. [4] Balta J.B. et al. (2015), *MAPS 50,* 63-85. [5] Lundberg L.L. et al. (1990), *GCA 54,* 2535-2547. [6] Balta J.B. and McSween H.Y. (2013), *JGR 118,* 2502-2519. [7] Shirai N. and Ebihara M. (2004), *AMR 17,* 55-67. [8] Barrat J.A. et al. (2002), *GCA 66,* 3505-3518. [9] Sarbadhikari A.B. et al. (2009), *GCA 73,* 2190-2214. [10] Filiberto J. and Dasgupta R. (2011) *EPSL 304*, 527-537.