EVIDENCE FOR A DISTINCTIVE RARE EARTH ELEMENT-ENRICHED MANTLE RESERVOIR ON MARS Scott M. McLennan, Department of Geosciences, State University of New York at Stony Brook, Stony Brook, NY, 11794-2100, USA (Scott.McLennan@sunysb.edu)

Introduction: At least three major geochemical reservoirs have been identified in the crust-mantle system of Mars, including the primitive mantle, an ancient highly depleted mantle, best sampled by the most LREE-depleted basaltic shergottites, and an ancient enriched crust [e.g., Refs. 1-4]. Some workers, evaluating both isotopic and geochemical data, have suggested additional reservoirs, for example, representing the sources of Nakhlites and Chassigny [e.g., 5-7]. In light of the recent dramatic increase in the number of basaltic through ultramafic meteorites derived from Mars, and better understanding of the composition and size of the Martian crust, from Pathfinder chemical data, GRS measurements, the chemistry of shergottites, and geophysical data from Pathfinder and Mars Global Surveyor, there is a need for re-evaluating the character of major geochemical reservoirs in the crust-mantle system on Mars.

Primitive Mantle of Mars: The chemical composition of SNC meteorites has long been used to estimate the composition of the Martian primitive mantle. However, it is increasingly clear that the magmatically young shergottites represent a mixture between an ancient, LIL-depleted mantle and an ancient LIL-enriched crust [e.g., 2,3]. McLennan [8] suggested that certain key element ratios used to estimate the moderately volatile element content of the Martian primitive mantle, notably K/Th, K/U and K/La, are strongly fractionated between depleted mantle and enriched crust. Accordingly, while the composition of the Martian primitive mantle is probably known to a first order, it is likely not well constrained for the critical moderately volatile lithophile elements, such as K, Rb and Cs.

On the other hand, essentially all workers agree that refractory lithophile elements should be present in chondritic proportions in the primitive mantles of all the terrestrial planets, including Mars. For example, apart from a few samples affected by U-adddition during terrestrial weathering processes [e.g., 9], SNC meteorites all have Th/U ratios close to the chondritic value of about 3.5 [8]. Both Th and U have similar degrees of incompatibility during most partial melting processes. In other cases, significant differences in solid-liquid partition coefficients can result in major changes in ratios among the refractory lithophile elements during magmatic processes (e.g., La/Sm, Th/Sc, Ba/Y, etc.), but "enriched" and "depleted" reservoirs should be complementary and the average composition of all of the major geochemical reservoirs will result in chondritic ratios among the refractory lithophile elements.

La/Th Ratios in SNC Meteorites. Figure 1 plots La/Th ratios against La content for SNC meteorites and these are compared to the terrestrial crust and depleted mantle (as sampled by mid-ocean ridge basalts). Although La and Th typically are both highly incompatible elements, there is enough difference to result in significant fractionation of the La/Th ratio during igneous differentiation processes leading to relatively low La/Th in most felsic rocks and high La/Th in most mafic rocks [12]. This is clearly seen on Earth, where there is a four-fold difference in the average La/Th ratio of continental crust and depleted mantle as sampled by MORB. Nevertheless, terrestrial MORB and continental crust have complementary La/Th ratios relative to the CI value of 8.6 and reasonable mixtures can lead to a chondritic La/Th ratio.

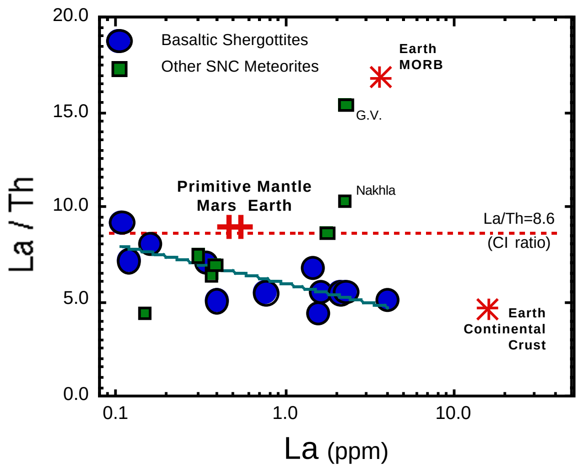

Figure 1. Plot of La/Th versus La for SNC meteorites and selected geochemical reservoirs for Earth and Mars. SNC data compiled from numerous sources; Mars primitive mantle from Ref. [1]; Earth geochemical reservoirs from Ref. [11]. On Earth, the continental crust and depleted mantle (as sampled by MORB) have complementary La/Th ratios relative to the CI value. On Mars, shergottites are characterized by subchondritic La/Th ratios and display a trend consistent with mixing between "enriched" and "depleted" end-members. Any reasonable mixture of these end-members results in a subchondritic La/Th ratio, suggesting that there must be an additional high La/Th reservoir, likely within the mantle.

The SNC meteorites display very different La/Th relationships than those seen for the Earth. Most notable is the negative trend defined by the basaltic shergottites (lherzolitic shergottites also fall on this trend) where La/Th ratios vary between about 4 and 9, and decrease with increasing La content. Similar trends are seen on plots of K/Th and K/U ratios versus K content [8] and are likely due to mixing between depleted mantle and enriched crustal end-members, such as that suggested by Norman [2] to explain the REE and Nd-isotopic relationships of shergottites. The "enriched" crustal end-member is characterized by high La content (>4 ppm) and, compared to CI, low La/Th ratio (<4), reminiscent of the Earth's continental crust. The "depleted" end-member, likely representative of partial melts from the Martian depleted mantle, has very low La content (<0.1ppm) and a La/Th ratio of around 8 to 9.

The other ultramafic SNC meteorites have much greater variation in La/Th ratio, with no apparent relationship with La content (if anything, there is a positive correlation between La/Th ratio and La content). Of these, the Nakhlites have the highest La/Th ratios, but only Governador Valadares is significantly higher than the CI ratio.

Discussion: Any reasonable mixture of the depleted and enriched components in the shergottites results in subchondritic La/Th ratios. Assuming that the primitive mantle of Mars indeed does have a chondritic La/Th ratio, this relationship provides strong evidence that an additional major geochemical reservoir, characterized by high La/Th (>8.6), must be present on Mars to provide the complementary La/Th ratio to the shergottites.

Of the currently available SNC meteorites, only the Nakhlites appear to have the La/Th characteristics that could provide the complementary reservoir. However, the average La/Th ratio of Nakhlites cannot be well established because their number is small, they have a substantial range in La/Th ratio, and these meteorites are cumulate clinopyroxenites and so the relationship between their trace element composition and that of the parent magma may not be straight forward.

Relationships between Th and other refractory lithophile elements (notably U) in SNC meteorites appear generally consistent with a CI composition for the primitive mantle. Accordingly, it is most likely that this additional, high La/Th reservoir is characterized more by enriched La, relative to the other refractory lithophile elements, rather than depleted Th. The size of the reservoir is difficult to constrain and depends on both the La content and the La/Th ratio. Assuming the reservoir has very high La/Th (i.e., negligible Th), a simple mass balance calculation indicates that it would involve approximately 20-30% of the primitive mantle La budget. The physical size of the reservoir, of course, could be much smaller. Mars is characterized by high phosphorus content [1] and trace phosphatic phases typically dominate, or at least strongly influence, the REE budget of SNC meteorites [13]. Accordingly, a physically small reservoir, characterized by one or more REE-enriched trace phases might also meet the constraints.

References: [1] Halliday, A. N., et al. (2001) *Space Si. Rev.*, 96, 197-230. [2] Norman, M. D. (1999) *Meteor. Planet. Sci.,* 34, 439-449. [3] Blichert-Toft, J., et al. (1999) *Earth Planet. Sci. Lett.*, 173, 25-39. [4] McLennan, S. M. (2001) *Geophys. Res. Lett.,* 28, 4019-4022. [5] Jagoutz, E. (1991) *Space Sci. Rev.,* 56, 13-22. [6] Brandon, A. D. et al., (2000) *Geochim. Cosmochim. Acta,* 64, 4083-4095. [7] McSween, H. Y., Jr. (2002) *Meteor. Planet. Sci.*, 37, 7-25. [8] McLennan, S. M. (2002) *LPSC XXXIII,* Abst. # 1280. [9] Dreibus, G., et al. (2002) *Meteor. Planer. Sci.,* 37, A43. [10] Surkov, Yu. A., et al. (1994) *Geochem. Int.*, 31, 50-58. [11] Taylor, S. R. and McLennan, S. M. (1985) *The Continental Crust: Its Composition and Evolution.* Blackwell, 312pp. [12] McLennan, S. M., et al. (1980) *Geochim. Cosmochim. Acta,* 44, 1833-1839. [13] McSween, H. Y., Jr. and Treiman, A. H. (1998) *Rev. Mineral.,* 36, 6-1 – 6-53.