MAGMATISM ON MARS: MANTLE DEPLETION AND POSSIBLY LONG-TERM MIXING

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Introduction: The ejection ages of martian meteorites, the sum of the cosmic ray exposure (CRE) and terrestrial residence ages, have been used to link groups of meteorites to common pre-launch locations on Mars [1-4]. At least 11 shergottites, whose geochemical signatures indicate a mantle source depleted in incompatible trace elements (ITE), share a Mars ejection age of 1.1 ± 0.2 Ma [4]. The crystallization ages and mantle source compositions of some of these 11 launch-paired shergottites have been measured and indicate that the ejection site hosts igneous rocks with ages of 347 to 2403 Ma and a range of mantle source compositions (Fig. 1). This spatial relationship provides insights into the timing and compositions of magmas produced from a particular magmatic center.

Observations: The geochemical imprint of mantle sources, as expressed in the shergottite record, attest to a poorly-mixed mantle (Fig. 1 [5]) which produces compositional variations that are likely spatially restricted [4]. A plot of age versus source composition of depleted shergottites (Fig. 1) shows, with the exception of Tissint and NWA 7635 (not shown), an overall trend of increasing mantle depletion (higher Sm/Nd ratios) with decreasing age.

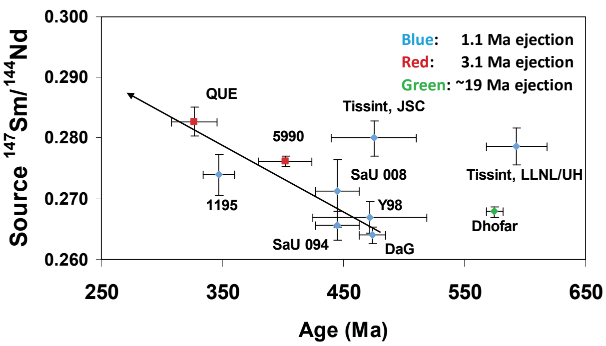

Figure 1. Mantle source versus age for depleted shergottites [3-5 and references therein]. Tissint samples analyzed at UH and LLNL differ in age from that measured at JSC. The arrow illustrates a trend of some depleted shergottites with the exception of Tissint.

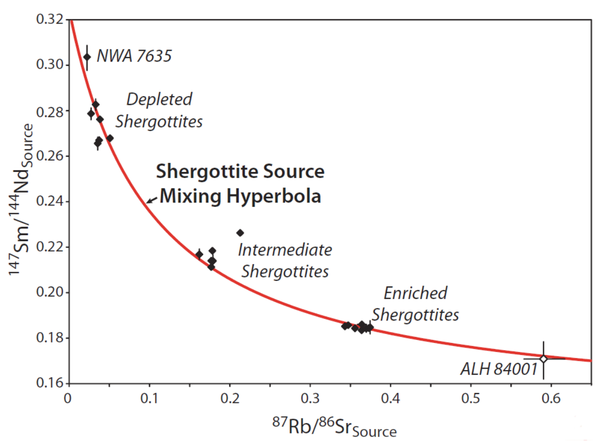

Figure 2. Rb/Sr-Sm/Nd source mixing array modified from [4]. Red line represents the best fit mixing hyperbola; ALH was not used in the curve fitting.

The mantle sources of shergottites, including those that are 'enriched,' 'intermediate,' and ALH 84001 (ALH; Fig. 2), show a wide range in mantle source compositions. Figure 2 shows a cluster of enriched shergottites, whose ages are 150-220 Ma, and intermediate shergottites, whose ages are between 340 and 166 Ma. The most extreme depleted and enriched compositions are those reflected by the 2.03 Ga shergottite NWA 7635 and the 4.1 Ga orthopyroxenite ALH, respectively.

Discussion: Partial melting of poorly-mixed mantle reservoirs that persisted for much of Mars' history have produced some of the largest and longest-lived volcanic centers in the Solar System [6]. Measured mantle source compositions from a progressively melted mantle plume [7] could produce more depleted magma compositions with time, which may be observed in the depleted shergottite data (Fig. 1). All shergottites do, in fact, show evidence for progressive, short-term (on the order of a few m.y.) melt depletions of their mantle sources because the melt Sm/Nd ratio is higher than the modeled source Sm/Nd ratio. Long-term melt depletions (10s-100s of m.y.) could produce the trends in Fig. 1.

With respect to all shergottites and ALH (Fig. 2), the oldest materials show the greatest difference in source compositions. Whether the younger enriched, intermediate, and depleted shergottite Sm/Nd and Rb/Sr source compositions reflect mantle components that have been somewhat mixed by mantle convection for the last 4.5 Ga or that they represent a hybridized mantle is, as yet, highly speculative.

References: [1] Nyquist L. E. et al. 2001. *In Chronology and Evolution of Mars. Springer*. [2] Nishiizumi K. et al. 2011. *Lunar and Planet. Sci. Conf.* Abstract #4371. [3] Wieler R. et al. 2016. Meteorit. Planet. Sci. 51, 407-428. [4] Lapen T. J. et al. 2017. *Science Advances*, 3:e1600922. [5] Borg L. E. 2016. *Geochim Cosmochim. Acta*. 175, 150-167. [6] Robbins S. J. et al. 2011. *Icarus* 211, 1197-1203. [7] Kiefer W. S. 2003. *Meteor. Planet. Sci*. 38, 1815-1832.