HIGHLY SIDEROPHILE ELEMENT EVIDENCE IN SHERGOTTITES FOR PERVASIVE LATE ACCRETION IN THE INNER SOLAR SYSTEM.

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Introduction: For nearly half a century there has been vigorous ongoing debate to explain the observed highly siderophile element abundances (HSE: including Os, Ir, Ru, Pt, Pd, Re) in the mantles of terrestrial bodies. Two models are presently favored. In the first, HSE are extracted into iron-rich cores, leaving the silicate mantles strongly depleted in these elements. In this model, the mantle abundances are controlled by the partitioning behavior of HSE between metal and silicate at variable pressures and temperatures within the terrestrial bodies during core extraction [1,2]. In general this should leave their silicate mantles with non-chondritic HSE ratios and severely depleted in at least some HSE [1,2]. In the second model, after core extraction removes more than 99% of the HSE, their silicate mantles are then reseeded with HSE via late accretion of up to 1% by mass of chonditic material [1-3]. This latter model has been questioned because the timing of late accretion and the mechanisms that could homogenize the late accreted HSE within the mantle are not well understood [2].

The determination of which of these mechanisms predominated in the different terrestrial bodies has been hampered by a lack of HSE abundance data for mantle and/or mantle-derived materials. A growing body of high quality and accurate HSE data from angrites [3,4], ureilites [5], aubrites [6], HED's [3,7], the Moon [8,9], martian meteorites [3,10,11], and a wide range of mantle and mantle derived Earth materials [e.g. 12-23] have been recently obtained. These expansive datasets now allow for a more comprehensive assessment of this issue because of the wide range of predicted outcomes for HSE ratios and abundances in residual silicate mantles by core extraction in different sized terrestrial bodies [1-3,24].

In this contribution, the primary focus is on contraints obtained from recent data on shergottite meteorites [11]. A suite of 23 Mars shergottite meteorites, spanning their known range in bulk composition, and Rb-Sr, Sm-Nd, and Lu-Hf isotopes were measured for ^{187}Re-^{187}Os systematics and HSE abundances [11]. The advantage of examining Mars for this issue is two-fold. First, Mars is 10.7% of the relative mass of Earth. Because HSE metal/silicate partitioning strongly changes with pressure [2,24] the lower pressures in the martian mantle, relative to the Earth's mantle during core extraction, predict distinct HSE abundances in their respective mantles. Direct comparison of the estimates of the HSE budget for each is a test for the core extraction model. Second, the martian mantle did not completely remix and homogenize after early differentation (e.g. [25]). Thus, a record of the timing of when the HSE budget was set in Mars is likely preserved.

Results and Discussion: There is a strong correlation between the initial ε^{143}Nd and γ^{187}Os in shergottites from approximately +40 to -7, and 0 to +15, respectively [11]. These relationships can be assessed in models for mixing depleted mantle-derived melts with ancient crust, and with assimilation-fractional crystallization. These models show that the correlation is unlikely to be the result of the participation of martian crust. More likely, the Os-Nd isotope correlation relates to mixing between depleted and enriched reservoirs that formed from a martian magma ocean at *ca*. 4.5 Ga [25,26]. These models indicate that the shergottite endmember sources were generated by mixing between residual melts and cumulates that formed at variable stages during solidification of a magma ocean [11,26]. If so, then the HSE budget for the martian mantle was set between the time of Mars formation by ≤10 Ma after the onset of solar system condensation, and the solidification of a global magma ocean during the first 100 Ma of planet history [11].

The expanded database for the HSE abundances in shergottites suggests that their martian mantle sources have indistinguishable HSE abundances to Earth's mantle, consistent with other studies [10,11,27]. For example, when plotting an HSE, such as Os, versus an index of differentiation, such as MgO (Figure 1), the mantle-derived samples from Mars and Earth plot as overlapping fields that converge upon the Earth's purported Primitive Upper Mantle (PUM) value. Plots for other HSE versus MgO also show the similarity between mantle-derived samples from Mars and Earth. The relatively high HSE abundances in both planetary mantles likely cannot be accounted for by high pressure-temperature metal-silicate partitioning at the bases of their magma oceans, as has been suggested for Earth. This is because of the strong differences in metal/silicate parition coefficients as a function of pressure for the various HSE, as well as the fact that Earth and Mars must have undergone integrated core extractions at strongly different pressures given their differences in size. This relationship would instead predict very dif-

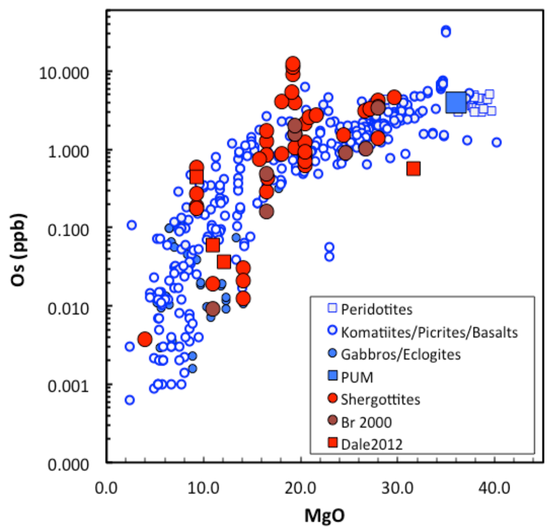

Figure 1. Os versus MgO for martian meteorites, Earth peridotites and mantle-derived igneous rocks [10-23]. The primitive upper mantle (PUM) estimate is from Becker et al. [12]. Diagram modified from Brandon et al. [11].

ferent HSE abundances for their two respective mantles, which is not observed.

Another point of comparison comes from plotting inter-element ratios such as Pt/Os, versus one HSE, such as Os (Figure 2). Where the differentiation trends intersect the CI chondrite Pt/Os value, relative HSE proportions of mantle sources for individual sample suites can be estimated [3]. In this case, the martian meteorite data again show overlap with mante-derived samples from Earth. Of note, individual suites of terrestrial samples plot with a factor of 10 variance for Os abundance at the CI Pt/Os ratio. This is consistent with the Earth's mantle having inhomogenous distribution with respect to HSE, or with complications in estimating initial mantle abundances from this form of plot.

Conclusions: The new and comprehensive HSE data for shergottites do not support core extraction as an explanation for estimated abundances in the martian mantle. The alternative is that HSE were instead supplied by late accretion. Late accretion must have occurred prior to crystallization of the last martian magma ocean and thus within the first 100 Ma of solar system history in order to be sampled within the shergotite mantle source [11]. The broadly chondritic CI-normalized patterns for the majority of igneous achondrite suites is also consistent with late accretion rather than core extraction, as a sole mechanism on their parent bodies [3-9]. Hence, the collective results from these rocks, Mars, and Earth indicate a pervasive late accretion in the inner solar system.

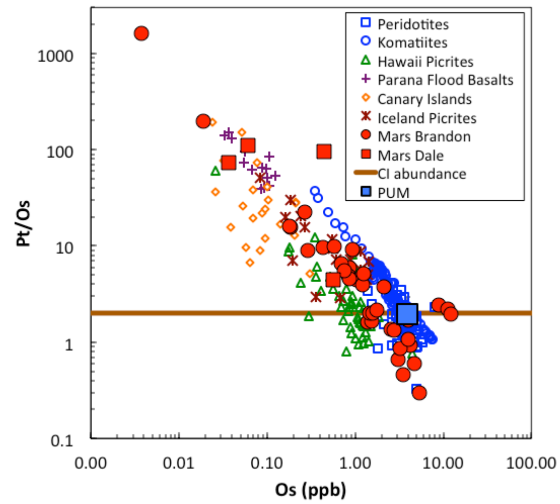

Figure 2. Pt/Os versus Os for martian meteorites, Earth peridotites, and different suites of mantle-derived terrestrial igneous rocks. The CI Pt/Os ratio is plotted as a horizontal line. References as in Fig. 1.

The question of how late accretion materials are thoroughly mixed into a large body such as Earth as a barrier to the late accretion hypothesis is also removed with the new data. These data show that the Earth's mantle has an inhomogenous distribution of HSE consistent with inefficient mixing of late accretion materials (Figure 2). Inefficient mixing is also proposed to explain the range of HSE abundances for the angrite and HED parent bodies as well [4,7].

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