

RE-OS ISOTOPE SYSTEMATICS OF THE SHERGOTTITE ‘DEPLETED’ END-MEMBER. A.D. Brandon¹, R.J. Walker², I.S. Puchtel², and A.J. Irving³. ¹NASA-JSC, Houston, TX 77058, alan.d.brandon@nasa.gov, ²Department of Geology, University of Maryland, College Park, MD 20742, ³University of Washington, Seattle, WA 98195.

Introduction: The $^{187}\text{Os}/^{188}\text{Os}$ ratios of planetary materials provide powerful information on early differentiation and evolution of their parent bodies. Previously determined initial $^{187}\text{Os}/^{188}\text{Os}$ for martian meteorites indicates that their mantle sources evolved with largely chondritic Re/Os from the time of earliest differentiation of Mars to at least the time of the latest shergottite crystallization from 180 to 150 Ma [1,2]. Nevertheless, the existing data base indicates that different petrologic-lithophile element isotopic end-members constrained from martian meteorites may have distinct $^{187}\text{Os}/^{188}\text{Os}$ as well, indicative of differences in their long-term Re/Os in their mantle sources [1,2]. Shergottites with long-term chondritic to enriched incompatible trace element (ITE) signatures, such as the lherzolites and Zagami, cluster at $\gamma\text{Os} = +4 \pm 2$ (% deviation from average chondrites with present-day $^{187}\text{Os}/^{188}\text{Os} = 0.1270$ and $^{187}\text{Re}/^{188}\text{Os} = 0.4186$), whereas the intermediate shergottite EETA 79001 and the ITE-depleted shergottite DaG 476 have values of -0.9 and +0.8, respectively [1]. Depending on the initial Re/Os and consequent evolution of $^{187}\text{Os}/^{188}\text{Os}$ and the γOs of bulk Mars, each of these Os isotopic compositions require a different set of conditions for early differentiation of their mantle sources, possible contamination of the lavas by martian crust, and whether their highly siderophile element (HSE) budgets were set solely by core separation from silicate Mars, or if a late veneer is needed to reseed HSE in the martian mantle following core extraction.

A crucial shergottite compositional end-member Os isotope composition that needs to be better constrained is that represented by the ITE-depleted shergottites such as Dhofar-019, SaU-005,008,094, DaG-476, NWA-1195 and Y-980459. Collectively, these meteorites require a mantle source with long-term depletion in Sm/Nd, manifested by $\epsilon^{143}\text{Nd} = +35$ to $+40$ at their times of crystallization (350-575 Ma, [3] and references therein; [4-6]). This early depletion also led to $\epsilon^{142}\text{Nd} = +0.57$ to $+0.65$ [3]. The coupled $\epsilon^{143}\text{Nd}$ - $\epsilon^{142}\text{Nd}$ systematics of these meteorites can be explained by formation of their mantle source at ~ 4.535 Ga, likely as a mixture of early-formed cumulates and quenched melts from a global-scale magma ocean [3]. The ITE-enriched shergottites likely formed from later cumulates and quenched melts. If the resultant source regions are reseeded in HSE by further planetary accretion after core formation, and if all of the end-member mantle source regions have remained unaffected by magmatic processes since crystallization of the magma

ocean and subsequent late additions, these rocks should have nearly-identical and largely chondritic Os-isotope compositions, and they do. However, the fact that neither EETA-79001 nor DaG-476 have initial γOs identical to the lherzolites and Zagami, suggests that additional processes may be needed to explain the HSE budgets of the shergottites.

Hence, to further evaluate the relationships between Os isotopic compositions of shergottites in the context of their end-member compositions, we have initiated a comprehensive analytical program to examine their HSE systematics. In this contribution, new data for Dhofar-019, SaU-008,094 (both paired with SaU-005), DaG-476, NWA-1195 and Y-980459 are presented for the purpose of constraining the Os isotopic composition of the ITE-depleted end-member. All of the meteorites within this group are desert finds with the exception of the Antarctic meteorite Y-980459. Hence, it is important to evaluate the affect of desert alteration to the Re and Os budgets for these meteorites. New data for EETA-79001 are also presented to provide a direct comparison to the previous data reported for shergottites and to further test whether this meteorite has a distinct initial γOs as previously reported [1].

Results and Discussion: The new data for EETA-79001 give $^{187}\text{Os}/^{188}\text{Os} = 0.12633 \pm 0.00012$ ($\pm 2\sigma$) and $^{187}\text{Re}/^{188}\text{Os} = 0.4134$. Previous work on two separate fractions of this meteorite [1] give $^{187}\text{Os}/^{188}\text{Os} = 0.12768 \pm 0.00018$ and 0.13087 ± 0.00019 , and $^{187}\text{Re}/^{188}\text{Os} = 0.991$ and 1.987 , respectively. Despite the narrow range in compositions, the combined fractions produce a 3-point isochron at 165.7 ± 14 Ma, with initial $^{187}\text{Os}/^{188}\text{Os} = 0.12514 \pm 0.00019$, $\text{MSWD} = 5.1$. This equates to an initial $\gamma\text{Os} = -0.61 \pm 0.16$. These results show internal consistency between the prior analytical campaign and the present one, and indicate that EETA-79001 is distinct in its Os isotopic composition relative to published results for Zagami and the lherzolites. The age obtained for the Re-Os isochron overlaps previously reported ages from lithophile isotope chronometers [7].

Desert martian meteorites have undergone terrestrial alteration, including up to several percent addition of calcite [6,8]. To test the effect of potential terrestrial alteration on the Re and Os isotopic systematics, two fractions of DaG476 were measured previously [1]. These have Re/Os and $^{187}\text{Os}/^{188}\text{Os}$ that are the same within uncertainty, despite having different Re and Os concentrations by 20% and 23%, respectively. The calculated initial γOs for the two fractions at the crys-

tallization age of 474 Ma are +0.66 and 0.+98, respectively (Fig. 1) [1]. Terrestrial crustal materials typically have $^{187}\text{Os}/^{188}\text{Os}$ of ≥ 1 , and widely varying, very high Re/Os [9]. Small but variable amounts of these materials could result in different $^{187}\text{Os}/^{188}\text{Os}$ and Re/Os in the different bulk fractions if the Re and Os concentrations of the terrestrial alteration products are sufficiently large. Because the $^{187}\text{Os}/^{188}\text{Os}$ and Re/Os for the two different bulk fractions of DaG-476 were reproducible within analytical uncertainties, Brandon et al. [1] concluded that terrestrial alteration had no discernable effect on the Re and Os isotopic systematics of this meteorite. This was not unexpected, because of the relatively high concentrations of Re and Os in the sample of 0.5-0.6 ppb and 1.5-2 ppb, respectively, combined with the low concentrations of Os in crustal rocks and minerals (< 0.05 ppb, [9]).

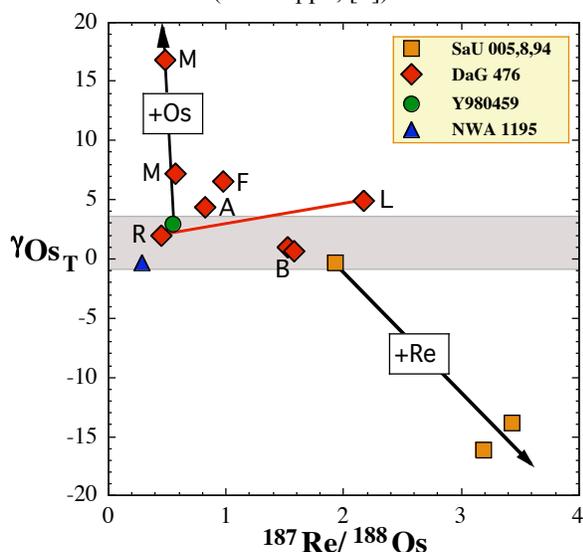


Fig. 1. The $^{187}\text{Re}/^{188}\text{Os}$ versus initial γOs_T at the time of crystallization (T) for depleted shergottites. Data for DaG-476 include M - magnetic separates, F - visibly fresh, A - visibly altered, R and L, residue and leachate of acetic acid leaching with tie line connecting, and B - from Brandon et al. [1]. Two possible mixing curves with radiogenic terrestrial Os (+Os) and terrestrial Re (+Re) are shown. The shaded region represents the range in γOs_T that best represents the least-altered depleted-shergottite compositions.

The new data for DaG-476 and the other ITE-depleted shergottites indicate that the picture is not as simple as concluded earlier [1]. The calculated initial γOs for NWA-1195, SaU-005 [2], Y-980459, and a residue for an acetic acid leach on one fraction of DaG-476, cluster within a narrow range from -0.4 to +2.93, despite a range in $^{187}\text{Re}/^{188}\text{Os}$ of 0.28 to 1.93 (Fig. 1). Visibly 'fresh', 'altered', magnetic separates, and the leachate from acetic acid leaching of DaG-476 have initial γOs that are higher, likely indicating a

small amount of added terrestrial crustal Os. Samples SaU-008 and -094 have lower initial γOs coupled with elevated $^{187}\text{Re}/^{188}\text{Os}$ relative to the paired SaU-005 fraction, that likely results in an over correction to initial $^{187}\text{Os}/^{188}\text{Os}$ because of terrestrial Re addition. Two fractions measured for Dhofar-019, which was heavily altered in the terrestrial desert [10], have impossible initial γOs of -389 and -480, respectively, and exemplify the extreme case of Re addition. Hence, these data show that great care must be employed when considering the implications from Re-Os isotopes on the mantle sources of desert shergottites.

Implications and Summary: New Re-Os isotope data, coupled with previous data show that different purported end-member martian mantle source compositions have largely chondritic Re/Os, as exemplified by the initial γOs of shergottites. These systematics are most easily explained by late accretion of chondritic material to the martian mantle following core formation, that reseeded Mars with HSE. If efficient mixing of late accreted material is difficult into a solid mantle, then these systematics may instead imply that late accretion occurred during the time of a global scale magma ocean in Mars. Late accreting materials may be oxidized enough such that no metal is transferred into the core but instead HSE remain in the silicate mantle [11]. The hypothesized duration for a magma ocean in Mars is 60 to 100 million years, starting at ~ 4.535 Ga [3], and likely coincided with the last significant stages of accretion. This hypothesis must be tested for the thermal and physical conditions necessary to sustain magma oceans during 'heavy' bombardment. If so, then this mechanism of explaining the chondritic HSE budget for Earth and Mars may be viable.

The small resolved differences in the initial γOs of shergottites that are derived from different mantle sources may result from modest variations in the materials accreting during the late veneer stage, small amounts of Re/Os fractionation during magma ocean processes, or by later magmatic processes. These possible scenarios require additional examination.

References: [1] Brandon A. et al. (2000), *GCA*, 64, 4083. [2] Walker R. et al. (2002), *LPS XXXIII*, 1042. [3] Debaille V. et al. (2007), *Science* 450, 525. [4] Shih C. et al. (2005), *Ant. Meteor. Res.* 18, 46. [5] Symes S. et al. (2005), *LPS XXXVI*, 1435. [6] Borg L. et al. (2003), *GCA* 67, 3519. [7] Meyer. C. Chapter IX, *Mars Meteor. Compendium*, NASA. [8] Zipfel J. (2000), *MAPS* 35, 95. [9] Pueker Ehrinbrink B. and Blum J. (1998) *GCA* 62, 3193. [10] Borg L. et al. (2001) *LPS XXXII*, 1144. [11] Wood B. and Halliday A. (2005), *Nature* 437, 1345.