LU-HF ISOTOPE SYSTEMATICS OF NWA4468 and NWA2990: IMPLICATIONS FOR THE SOURCES OF SHERGOTTITES

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Introduction: Shergottites are a suite of Martian meteorites that exhibit a substantial range in mineralogy, trace element compositions, and compositions of radiogenic isotopes that reflect both the magmatic processes that produced the individual igneous rocks (e.g. evolution from a parent magma), but also the composition of the parent magma source materials. Shergottites can be classified as 'enriched', 'intermediate', and 'depleted' based on their trace element contents and initial Sr, Nd, and Hf isotope compositions [1,2]. In this contribution, we apply this terminology to define average source compositions of the shergottite parental magmas based on shergottites' Hf isotope systematics. Below we present new Lu-Hf age and initial Hf isotope data for Northwest Africa 4468 and the Hf isotope composition of Northwest Africa 2990 and place these new data in the context of existing Lu-Hf data of shergottites with the aim of identifying similarities and potential source affinities between several enriched shergottites.

Previous work:

NWA4468: Irving et al. [3] described this stone as a 675 g, "superbly fresh" olivine basaltic shergottite with 35% olivine, 30% pyroxene, 35% maskelynite with trace chromite, Ti-chromite, ilmenite, merrillite, Cl-apatite, and Fe-sulfide [3]. The REE abundances are similar to the 'enriched' suite of shergottites [3] and the enriched designation of this stone is supported by preliminary Sm-Nd analyses of two whole rock fractions that yield an age of 150 ± 29 Ma with an initial ε^{143}Nd = -6.9 ± 0.3 [4].

NWA2990: Bunch et al. [5] describe this stone as an olivine-phyric basaltic shergottite that is much more fine-grained than other olivine-phyric shergottites (Figure 1) implying a rapid cooling history for this sample. The sample consists of small olivine phenocrysts surrounded by a fine-grained groundmass containing olivine, augite, maskelynite, chromite, titanomagnetite, ilmenite, pyrrhotite, and merrillite [5].

Analytical: NWA4468 was provided to us as disaggregated and sieved material. We processed the 200-300 mesh fraction with 4.00 g/cc clerici's solution to separate the oxide grains from the other matrix minerals, the later consisting of silicate and phosphate phases. NWA2990 was provided to us as an intact chip that we broke into a 17 mg piece that was used for Lu-Hf isotope analysis. Prior to spiking and dissolution in

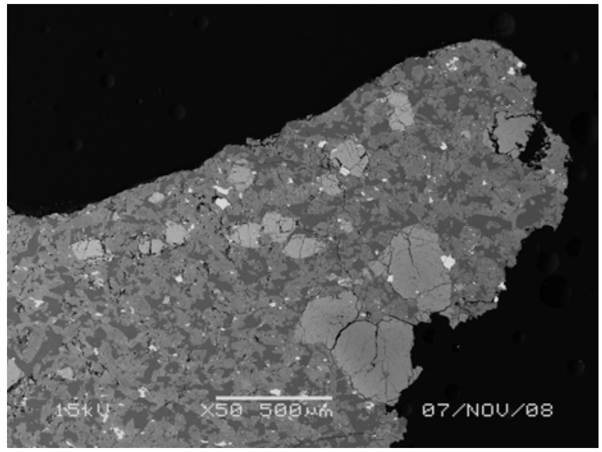

Figure 1. BSE image of NWA2990 showing the porphyritic and fine-grained nature of this sample. Large grains are olivine, groundmass consists of pyroxene, maskelynite, and a variety of oxide phases (bright).

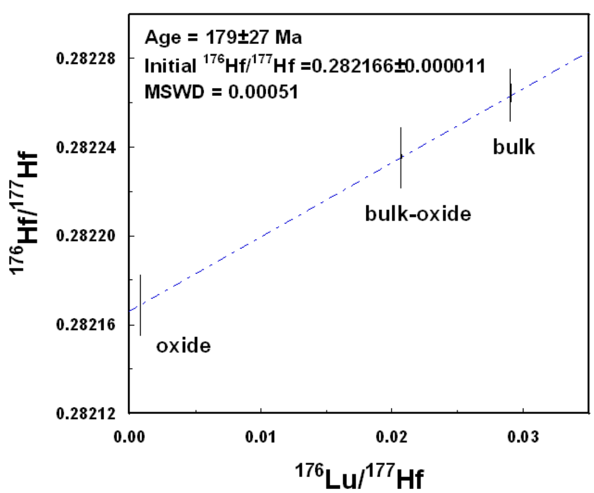

Figure 2. Lu-Hf isochron diagram of the enriched shergottite NWA4468. Data points represent the average of two duplicate analyses of the same mineral aliquots. Oxide = a bulk oxide mineral fraction; Bulk-oxide = the remaining material after oxide removal by heavy liquids; Bulk = bulk rock. All data are presented with 2σ uncertainties.

high-pressure digestion vessels, the minerals were washed with ultrapure H_2O to remove any surface contamination. All chemical separation procedures were carried out in clean lab facilities at the University of Houston and all Lu and Hf isotope analyses were carried out at the University of Wisconsin-Madison Radiogenic Isotope Laboratory using a GV Instruments *IsoProbe* MC-ICP-MS. All Hf isotope analyses were replicated at least once. Total procedural blanks are <80 pg and <15 pg for Hf and Lu, respectively and are negligible.

Results:

NWA4468**:** A preliminary Lu-Hf isochron age of 179 ± 27 Ma (2σ; MSWD = 0.0005; Figure 2) was determined from 3 fractions consisting of oxide phases, bulk rock, and bulk minus oxide (the leftovers from the oxide removal step). The initial $^{176}Hf/^{177}Hf$ isotope ratio derived from the isochron is 0.282166 ± 0.000011 (2σ) and is similar to isochron-derived initial Hf isotope compositions of Shergotty, Zagami, RBT04262, Los Angeles, and LAR06319 [6,7,8,9].

NWA2990: Lu-Hf analysis of NWA2990 whole rock yielded a present-day $\varepsilon^{176}Hf$ = 21.28 ± 0.37 (2σ) and a measured $^{176}Lu/^{177}Hf$ = 0.0194. At present, there is no information on the age of crystallization of this sample.

Source Composition(s): Source $^{176}Lu/^{177}Hf$ isotope ratios of NWA4468 as well as other enriched shergottites where isochron initial Hf isotope compositions are determined are calculated assuming a differentiation age of 4.513 Ga [10], Lu-Hf CHUR parameters of Blichert-Toft et al. [11], and ^{176}Lu decay constant of Scherer et al. [12] (Table 1). Included in Table 1 is the source data of the 4.086 Ga ALH84001 which is derived from a source with a similar $^{176}Lu/^{177}Hf$ ratio as the enriched shergottites [13]. All $^{176}Hf/^{177}Hf$ data used to calculate source compositions are normalized to JMC-475 Hf ≡ 0.282160. The Lu-Hf source data for the 6 enriched shergottites in Table 1 are nearly identical. Although uncertainties in CHUR parameters and absolute age of shergottite source differentiation exist, the relative source compositions do not dramatically change with reasonable variations of these parameters.

Table 1. Source data calculated from [6,7,8,9,13].

Sample	*Source* $^{176}Lu/^{177}Hf$
Zagami	**0.0274**
Shergotty	**0.0275**
Los Angeles	**0.0284**
RBT04262	**0.0275**
NWA4468	**0.0276**
LAR06319	**0.0274**
ALH84001	**0.0236**

Mineral isochron ages and isochron-derived initial isotope compositions of enriched shergottites listed in Table 1, perhaps with the exception of Los Angeles, indicate that their source compositions are nearly identical. Because the crystallization ages range from 165 to 225 Ma for these samples [8,14], it is remarkable that these are derived from a source with similar Lu/Hf ratios. However, because there is evidence that the enriched, intermediate, and depleted shergottites represent rocks derived from variable mixtures of at least two distinct sources, one that is very depleted and one that is quite enriched [2], it seems unlikely that separate sources for these rocks would impart a constant aggregate Lu/Hf ratio. We propose two explanations. 1) The enriched shergottites listed in Table 1 may be related to the same igneous center that was active over roughly 70Ma. 2) If these samples are not part of the same igneous center and are separated geographically, a source reservoir in Mars for these rocks would have to be large, homogenous, enriched, and old. Based on the recent work by our group on ALH84001 [13], the enriched reservoir in Mars is at least 4.086 Ga and probably 4.46 Ga in age [15].

Although we do not as yet have age information on NWA2990, its present-day $\varepsilon^{176}Hf$ is unlike any other shergottite measured to date. Since the sample is very fine grained [5] (Figure 1), we argue that the analyzed aliquot is a good approximation of the true 'whole rock' value because at the sampled scale, there is a relatively homogenous distribution of constituent phases. Based on the available data for this sample and others in the literature, it has a measured $^{176}Lu/^{177}Hf$ ratio that is similar to that of the enriched shergottites, but it is about 40 $\varepsilon^{176}Hf$ units more radiogenic. The $^{176}Lu/^{177}Hf$ ratio of NWA2990 is also similar to that measured in ALHA77005, EETA79001, and QUE94201 [16], but the present-day $\varepsilon^{176}Hf$ is about 10 units lower. With age information of this stone (under way by our group), we can better place it in the context of possible variable source end-member mixtures that result in the array of shergottite compositions observed in the samples available to us on Earth.

References: [1] Borg et al. (2003) GCA, 67, 3519-3536. [2] Debaille et al. (2008) EPSL. [3] Irving et al. (2007) LPSC XXXVIII. [4] Borg et al. (2008) LPSC XXXIX. [5] Bunch et al. (this meeting). [6] Bouvier et al. (2005) EPSL, 240, 221-233. [7] Bouvier et al. (2008) EPSL. [8] Lapen et al. (2008) LPSC XXXIX. [9] Shafer et al. (this meeting). [10] Borg and Draper (2003) MAPS, 38, 1713-1731. [11] Blichert-Toft et al. (1997) EPSL, 148, 243-258. [12] Scherer et al. (2002) Science, 293, 683-686. [13] Righter et al. (this meeting). [14] Nyquist et al. (2001) Space Sci. Rev., 96, 105-164. [15] Debaille et al. (2007) Nature, 22, 525-528. [16] Blichert-Toft et al. (1999) EPSL, 173, 25-39.