LU-HF AGE AND ISOTOPE SYSTEMATICS OF THE OLIVINE-PHYRIC SHERGOTTITE RBT-04262 AND IMPLICATIONS FOR THE SOURCES OF ENRICHED SHERGOTTITES

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Introduction: Enriched Shergottites are characterized by their relatively high incompatible trace element contents and were derived from sources that had subchondritic Lu/Hf and Sm/Nd ratios [1, 2]. The enriched Shergotties include the basaltic shergottites Shergotty, Zagami, NWA856, and Los Angeles. We report new Lu-Hf age and isotope systematics of the recently discovered olivine-phyric shergottite RBT-04262 that indicate that it is also an enriched Shergottite. These new data and existing Lu-Hf isotope data, places important constraints on the composition of this enriched martian reservoir and the timing of basaltic shergotite magmatic activity.

Previous work: Whole rock Hf isotope compositions, mineral isochron ages, and isochron-derived initial isotope compositions of enriched shergottites have been determined by many groups [e.g., 2, 3, 4 and references therein, 5, 6]. In addition to the Lu-Hf age and isotope data presented here, Sm-Nd isotope analyses are under way for the same mineral aliquots analyzed for Lu-Hf. End-member source compositions for shergottites has been investigated by many workers [1, 2, 7, 8, 9] and the source region(s) for enriched basaltic shergottites can be modeled as a mixture between depleted Martian mantle and a residual trapped liquid component, similar to the KREEP layer of the Lunar Magma Ocean, that formed after >99% of the Martian magma ocean crystallized [9].

Analytical: A ~1g aliquot of RBT-04262 was gently crushed with a boron carbide mortar and pestle and sieved. Material in the size range of 200-300 mesh (~220mg) was separated by heavy liquids into maskelynite-rich, olivine-rich, clinopyroxene-rich (pigeonite+augite), and nearly pure chromite fractions. Optical inspection of all fractions indicated that the maskelynite fraction contained abundant microscopic chromite inclusions that we were unable to remove. The other fractions also contained chromite, but it was difficult to determine the relative amount optically. A 'whole rock' fraction consisted of an aliquot of the <300 mesh material. All fractions, including the whole rock were leached for 5 minutes in cold 0.5M HCl followed by 3 rinses in Milli-Q H_2O to remove any surface contamination. All leachates have been saved and will be analyzed for Lu, Hf, Sm, and Nd concentrations. 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.

Results: A Lu-Hf isochron age of 225 ± 21 Ma (2σ; MSWD = 0.71) was determined from 4 mineral fractions constituting the major minerals of the sample (Figure 1). This specimen is the oldest enriched shergottite to date. The 'whole rock' (Figure 1; faded symbol) was not included in the age regression because Lu and Hf were likely decoupled during the gentle leaching of extremely fine-grained material. The initial $^{176}Hf/^{177}Hf$ isotope ratio derived from the isochron is 0.282135 ± 0.000004 (2σ) and is similar to isochron-derived initial Hf isotope compositions of Shergotty and Zagami [5, 6].

Hafnium and Lu concentrations of the four mineral fractions and their corresponding $^{176}Hf/^{177}Hf$ isotope ratios indicate that there is no correlation between Hf

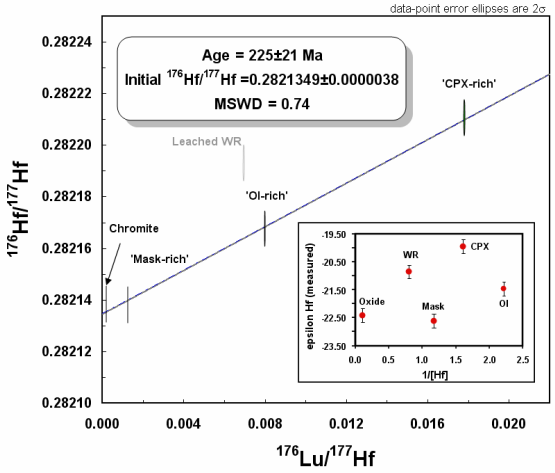

Figure 1. Lu-Hf isochron diagram of the recently discovered olivine-phyric basaltic Shergottite RBT-04262. Data points represent the average of two duplicate analyses. Inset is a plot of present-day $\varepsilon^{176}Hf_{(CHUR)}$ versus 1/[Hf]. Mask = maskelynite, Ol = olivine, CPX = augite + pigeonite (pigeonite >> augite), WR = whole rock (see text for discussion). All data are presented with 2σ uncertainties.

concentration and its isotopic composition. This relationship precludes a 2-component mixing association for these samples perhaps associated with Hf mobility during acid weathering on the Martian surface [e.g. 5].

Source Composition(s): Source $^{176}Lu/^{177}Hf$ isotope ratios are calculated assuming a differentiation age of 4.513 Ga [9], Lu-Hf CHUR parameters of Blichert-Toft et al. [10], ^{176}Lu decay constant of Scherer et al. [11], and 'preferred' shergottite crystallization ages of Nyquist et al. [4]. The Lu-Hf source data for 5 enriched shergottites is summarized in Figure 2. All $^{176}Hf/^{177}Hf$ data is normalized to JMC-475 Hf ≡ 0.282160. 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.

The modeled source $^{176}Lu/^{177}Hf$ isotope ratio for RBT-04262 is 0.02735 ± 0.00013 based on the isochron initial $^{176}Hf/^{177}Hf$ isotope ratio. The uncertainty in the source largely reflects the age error (Figure 2). Figure 2 illustrates the very poor reproducibility of whole rock analyses from the same lab as well as

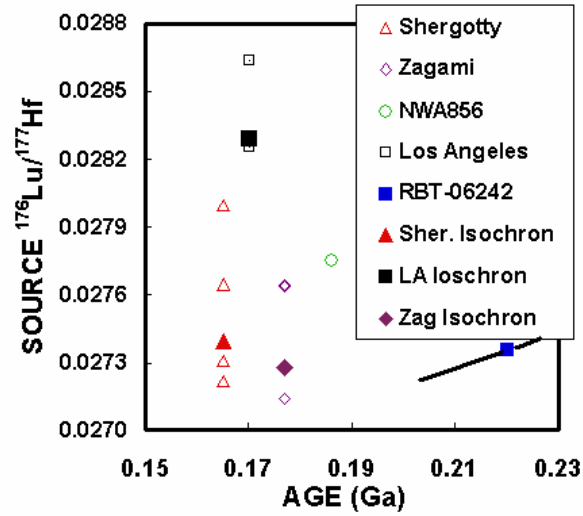

Figure 2. Long-term $^{176}Lu/^{177}Hf$ isotope ratio of lava source versus crystallization age for 5 enriched Shergottites. Solid symbols represent source compositions calculated form $^{176}Hf/^{177}Hf$ isotope ratios derived from isochron initials and open symbols represent source compositions calculated from age-corrected whole rock data. All data are normalized to $^{176}Hf/^{177}Hf$ = 0.282160 for JMC-475. Crystallization ages are those of [4]. Sources of Lu-Hf data: [2, 3, 5, 6]. Correlated error in age and source (black line) is large for RBT-04262 due to the large uncertainty in age relative to the other samples.

different labs. Furthermore, many of the whole rocks are negatively or not correlated on $^{176}Lu/^{177}Hf$ versus $^{176}Hf/^{177}Hf$ diagrams. We do not offer an explanation for this but suspect that the whole rocks may retain some contamination from recent Martian weathering that cannot be identified microscopically and the conundrum with this explanation is that this contamination cannot be removed by leaching without risking fractionating Lu from Hf during the process. Regardless of the cause for poor reproducibility of $^{176}Lu/^{177}Hf$ and $^{176}Hf/^{177}Hf$ in whole rock samples, it is advantageous to, if possible, use the initial $^{176}Hf/^{177}Hf$ isotope ratio derived from an isochron or a durable phase with a very low $^{176}Lu/^{177}Hf$ such as chromite to calculate source parameters. Comparing the source $^{176}Lu/^{177}Hf$ isotope ratios determined from isochron initials (solid symbols, Figure 2) shows much less scatter than the whole rocks would indicate and suggest possible source affinities even within the so-called enriched source.

Concluding Remarks: Given the very poor reproducibility of $^{176}Lu/^{177}Hf$ and $^{176}Hf/^{177}Hf$ of whole rocks (Figure 2), an approach that estimates source Lu/Hf ratios derived from mineral isochron initial isotope compositions or a robust near-liquidus phase with a low Lu/Hf ratio such as chromite, yields tighter constraints on source compositions. Based on source Lu-Hf compositions derived from isochron initials (Figure 2), Shergotty, Zagami, and RBT-04262 are derived from a source with the lowest Lu/Hf ratio (greatest KREEP basalt-like component?) whereas NWA856 and Los Angeles were derived from sources that had higher Lu/Hf ratios. Furthermore, RBT-04262, Shergotty, and Zagami appear to be derived from a source with near identical $^{176}Lu/^{177}Hf$ ratios. Although there is strong sampling bias and the collection of Martian meteorites offers but a small sampling of crustal material, these new Lu-Hf data expand the duration of magmatism derived from the most enriched source recognized on Mars by ~ 30 m.y.

References: [1] Borg et al. (2003) GCA, 67, 3519-3536. [2] Debaille et al. (in revision) EPSL. [3] Blichert-Toft et al. (1999) EPSL, 173, 25-39. [4] Nyquist et al. (2001) Space Sci. Rev., 96, 105-164. [5] Bouvier et al. (2005) EPSL, 240, 221-233. [6] Bouvier et al. (in press) EPSL. [7] Borg et al. (1997) GCA, 61, 4915-4931. [8] Beard et al. (2002) LPS XXIII, Abstract #1933. [9] Borg and Draper (2003) MAPS, 38, 1713-1731. [10] Blichert-Toft et al. (1997) EPSL, 148, 243-258. [11] Scherer et al. (2002) Science, 293, 683-686.