LU-HF AGE AND ISOTOPE SYSTEMATICS OF INTERMEDIATE PERMAFIC OLIVINE-PHYRIC SHERGOTTITE NWA 2990: IMPLICATIONS FOR THE DIVERSITY OF SHERGOTTITE SOURCES.

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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]. Here we present the first Lu-Hf age, initial Hf isotope data, and representative major element composition data for Northwest Africa 2990. We also present new whole rock Hf isotope compositions of intermediate shergottites Northwest Africa 6234, 6342 and 7042, with implications for the diversity of source compositions that define the 'intermediate' shergottite group.

Samples: NWA 2990 is paired with NWA 5960, 6234, and 6710 [3-4], and all are permafic. They are olivine-phyric shergottites that are much more fine-grained than other such shergottites (Figure 1), implying a rapid cooling history. NWA 2990 consists of olivine phenocrysts (up to about 0.6 mm in diameter) surrounded by a fine-grained groundmass containing olivine, augite, maskelynite, chromite, titanomagnetite, ilmenite, pyrrhotite, and merrillite [5]. Bunch et al. [5] reported Mg# of olivine phenocrysts ranging from 71 in cores to 52 in rims, but new analyses indicate that some phenocryst cores have Mg# up to 77.

Analytical Methods: We divided an intact chip of NWA 2990 into two portions. A 17 mg piece was used for bulk rock isotope analysis. The remaining material was gently crushed in a mortar and pestle and sieved. Mineral aliquots were separated with heavy liquids and hand picking under a binocular microscope. Prior to spiking and dissolution in high-pressure digestion vessels, the minerals were washed with ultrapure H_2O three times to remove any surface contamination. All chemical separation procedures were carried out in ultraclean facilities, and all isotope analyses were carried out on a Nu Plasma II MC-ICP-MS at the University of Houston following methods outlined in [6]. All $^{176}Hf/^{177}Hf$ and $^{143}Nd/^{144}Nd$ isotope data are normalized to JMC-475 ≡ 0.28216 and JNdi ≡ 0.512115, respectively. Total procedural blanks are <80 pg and <15 pg for Hf and Lu, respectively and are negligible.

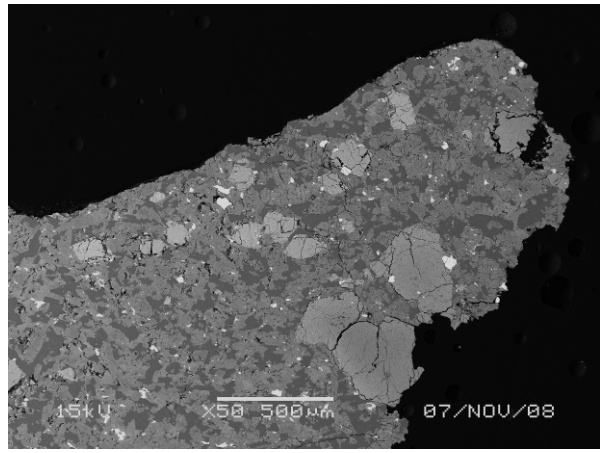

Figure 1. BSE image of NWA 2990 showing the porphyritic and fine-grained nature of this sample. Large grains are olivine, groundmass consists of pyroxene (gray), maskelynite (dark gray), and accessory phases including chromite, Fe oxides and pyrrhotite (bright).

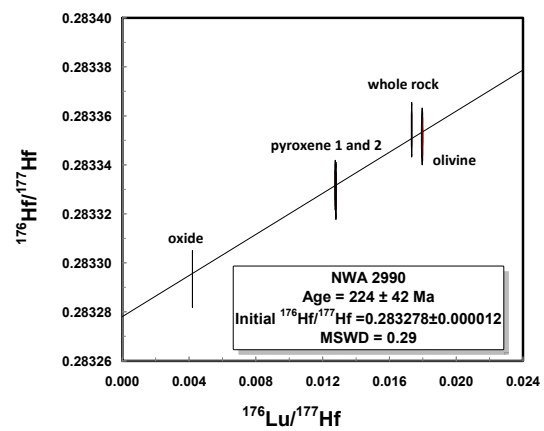

Figure 2. Lu-Hf isochron diagram of the intermediate shergottite NWA 2990. Oxide = a bulk oxide mineral fraction; Pyroxene 1 and 2 = two hand-picked aliquots with identical isotope compositions; Whole Rock = bulk powder from an interior piece of the stone; Olivine = hand picked olivine aliquot. All data are presented with 2σ uncertainties.

Clean, representative cutting dust of NWA 2990 and NWA 6234 and powder from an interior slice of NWA 5960 were analyzed by XRF spectrometry at Washington State University or the University of Cologne using well-established standards for calibration. The new major element data reported here for NWA 2990 supersede the data reported by [5], which evi-

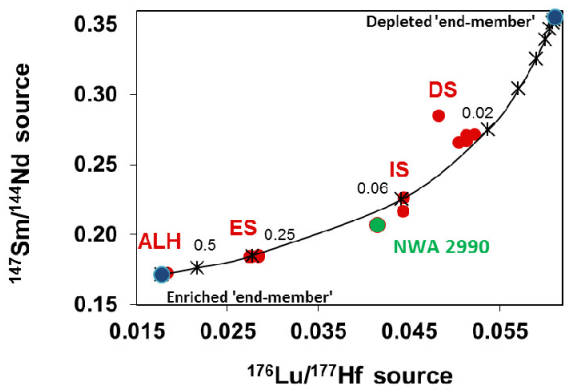

Figure 3. Mixing diagram for shergottites and ALH 84001 $^{147}Sm/^{144}Nd$ and $^{176}Lu/^{177}Hf$ source compositions. Red dots are shergottites; DS = depleted shergottites; IS – intermediate shergottites; ES = enriched shergottites; ALH = ALH 84001. The black binary mixing line is based on source compositions of cumulates (depleted end-member) and liquids in equilibrium with the cumulates (enriched end-member) in the upper mantle assemblage (UM1) of [2] produced in a 2000 – 1350 km deep magma ocean. Isotope data used for the source calculations of shergottites come from [2, 7-12]. Labeled mixing proportions (black symbols) are based on the fractions of residual trapped liquid.

dently was in error. The likely cause of this issue was the very small sample size used for the first powder, but the new results are very consistent with those for the paired specimens.

Results: The Lu-Hf isochron age of NWA 2990 defined by oxide, two pyroxene fractions, whole rock and olivine is 224 ± 42 Ma (2σ, MSWD = 0.29; Fig. 2) with an initial $\varepsilon^{176}Hf$ value of +22.8. Based on this age and Sm-Nd isotope data from the whole rock, the initial $\varepsilon^{143}Nd$ is +5.6. Additional Sm-Nd isotope analyses are in progress. The calculated source $^{176}Lu/^{177}Hf$ and $^{147}Sm/^{144}Nd$ ratios are 0.0415 ± 0.0004 and 0.2063 ± 0.0011 (2σ), respectively (Fig. 3). Source $^{176}Lu/^{177}Hf$ isotope ratios of NWA 2990 as well as for other shergottites are determined following [12].

Table 1. Major element compositions

	NWA 2990	NWA 5960	NWA 6234
SiO_2	43.21	44.53	44.68
TiO_2	0.81	0.78	0.74
Al_2O_3	5.07	4.77	4.52
Cr_2O_3	0.67	0.66	0.76
FeO*	23.24	21.54	22.64
MnO	0.52	0.51	0.50
MgO	16.04	16.91	16.31
CaO	6.60	6.52	6.41
Na_2O	0.90	0.88	0.84
K_2O	0.08	0.06	0.08
P_2O_5	0.91	0.82	0.80
SUM	98.05	97.98	98.27
Mg/(Mg+Fe)	0.552	0.583	0.562
Equil. Ol Mg#	77.60	79.76	78.33

Although we do not have age information yet on NWA 6234, 6342, and 7042, the measured present-day Hf isotope compositions of bulk rock powders indicate that NWA 6234 and 2990 are, as expected, identical within analytical uncertainty. The Hf and Nd isotope compositions of NWA 6342 are +23.5 and +5.55, respectively, and for NWA 7042 are +24.3 and +11.5. Although NWA 6342 and 7042 are not paired with 2990, they appear to come from similar, but distinct source materials.

Table 1 lists the major element compositions of paired stones NWA 2990, 5960, and 6234 and the predicted olivine Mg# olivine using $K_{D(olivine/melt)}$ = 0.355 [13].

Discussion: The crystallization age of NWA 2990 is consistent with those of many shergottites (i.e. within the range of 150-220 Ma). The Lu-Hf and Sm-Nd source compositions of NWA 2990 are unusual in that they are between the groups of enriched and intermediate shergottites (Fig. 3). Based on the two-component mixing model, the ratio of 'enriched' to depleted' end-members is about 0.1:0.9. It is probable that, with additional samples analyzed, the calculated source compositions will spread across the mixing array. This calls into question the notion of discrete end-member compositions as distinct lithologies versus variable melt extraction from a single ancient mantle source.

NWA 6342 presents a dilemma in that its REE pattern [14] and measured $^{147}Sm/^{144}Nd$ of 0.2417 imply an affinity to 'enriched' shergottites, yet its isotopic composition is clearly 'intermediate'. This suggests the possibility that NWA 6342 experienced an addition of a young LREE-enriched "metasomatic" component after separation of the primary magma from its 'intermediate' source.

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References: [1] Borg et al. (2003) GCA, 67, 3519-3536. [2] Debaille et al. (2008) EPSL. [3] Irving et al. (2011) MetSoc (abs# 5232). [4] Filiberto et al. (2012) MAPS, 47, 1256-1273. [5] Bunch et al. (2009) LPSC XL (abs#2274). [6] Lapen et al. (2004) G^3, v.5, no.1. [7] 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] Lapen et al. (2010) Science, 328, 347-351. [13] Filiberto and Dasgupta (2011) EPSL, 304, 527-537. [14] Irving et al. (2011) 42nd LPSC (abs# 1612).