EXTENDING THE RANGE IN AGES AND SOURCE COMPOSITIONS OF SHERGOTTITES: LU-HF AND SM-ND AGE AND ISOTOPE SYSTEMATICS OF NORTHWEST AFRICA 4480.
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Introduction: Northwest Africa 4480 is a small (13 gram) unpaired shergottite recovered in Algeria in 2006 [1]. The texture of NWA 4480 is different from the other shergottites (Fig. 1). The matrix of NWA 4480 is a fine-grained with average grain sizes of about 0.15 mm, which includes larger (0.5-0.8 mm) glomerocrysts. The matrix consists of plagioclase (***not*** maskelynite) laths, olivine, complexly-zoned pyroxene (augite cores, pigeonite rims), Ti-chromite, ilmenite, merrillite and silica. Our earlier isotopic work revealed that NWA 4480 has Nd and Hf isotope compositions between depleted and intermediate shergottites [2], despite the apparent intermediate signature of rare earth element abundances (Fig. 2). The CRE age of ~16 Myr [2] is much older than the CRE ageother shergottites except for Dhofar 019 (18.15 Myr) [3]. Despite its unique petrologic features among shergottites (some 94 unpaired specimens now recognized), NWA 4480 has an oxygen isotopic composition ($\Delta^{17}O$ +0.257 per mil) [4] within the established field for Martian meteorites.

We report new age and mantle source data for this mineralogically different meteorite that has a distinct CRE age compared to other shergottites. These data indicate NWA 4480 has a crystallization age older than most shergottites and comes from a mantle source in between the depleted and intermediate shergottites.

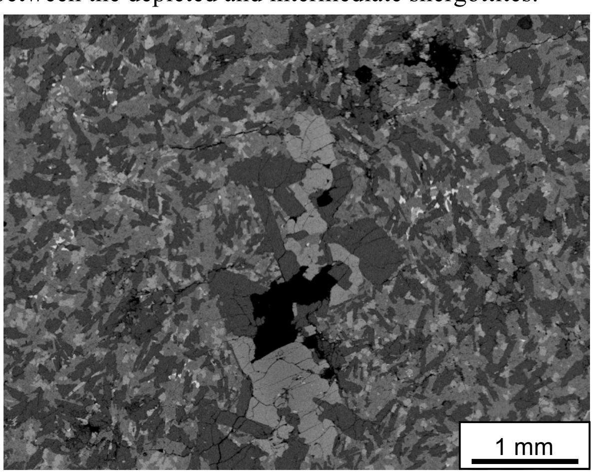

Figure 1. Backscattered electron image of NWA 4480 showing 'glomerocrysts' with coarse grained plagioclase (light gray) and olivine (dark gray) in fine-grained matrix.

Samples and Analytical Procedures: A polished section of NWA 4480 was examined by a SEM and EPMA at NASA-JSC, with a 20kV accelerating voltage and 20~30nA sample current. Trace element microanalysis was performed using a Photon Machines *Analyte.193* laser ablation system coupled to a Varian *810-MS* ICP-MS at University of Houston. Elemental abundances were determined in spot mode. Ablated spots were 50 µm in diameter. The standard used were the BHVO-2G and BIR-1G, with Mg, Ca as an internal standard for normalization. A ~1 g aliquot of NWA 4480 was crushed with an aluminum oxide mortar and pestle. The crushed material was sieved into various size fractions, of which the finest grain size fractions (44 µm or less) were used for whole rock analyses (WR). The 100-200 and 200-325 mesh fractions were used for further mineral separations by density using heavy liquids of 2.96. The 2.96 < ρ g/cm^3 fraction from 200-325 mesh size was further purified by hand-picking. A total of three fractions were used in this study: plagioclase (ρ < 2.96; Plag), ρ > 2.96 fraction, and fine grained bulk fraction (Bulk). All chemical separation procedures were carried out in clean lab facilities at University of Houston and all isotope analyses were carried out using the Nu Instruments *Nu Plasma II* MC-ICP-MS at the University of Houston.

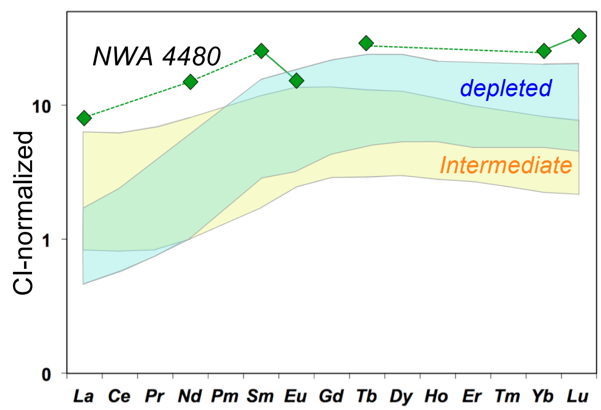

Figure 2. The chondrite-normalized bulk REE profile of NWA 4480 [1 and this work] with ranges for depleted (blue) and intermediate (yellow) shergottites.

Results: The chondrite-normalized REE abundances of the primary phases are presented in figure 3. NWA 4480 is composed of relatively fine grained (~150 µm) pyroxene, plagioclase and olivine plus accessory minerals. Both pyroxene and olivine have light REE depleted signatures with pyroxene being more REE enriched compared to olivine. Plagioclase also shows light REE depletion with positive Eu anomalies. Overall, NWA 4480 REE compositions are similar to those of other basaltic shergottites characterized by light REE depleted compositions.

Lu-Hf Isotope Systematics: The Lu and Hf isotopic data are shown in Figure 4. All three points define a linear array corresponding to a Lu-Hf date of 716 ± 81 Ma (MSWD = 0.70) for $\lambda(^{176}Lu)$ = 1.865 x 10^{-11} yr^{-1} with an initial $^{176}Hf/^{177}Hf$ value of 0.283542±0.000031 using the Isoplot regression program [5].

Sm-Nd Isotope Systematics: Sm-Nd analyses of NWA 4480 whole rock (< 44 µm fraction) yield a present-day $\varepsilon^{143}Nd$ = 39.59 and a measured $^{147}Sm/^{144}Nd$ = 0.3399. The $\varepsilon^{142}Nd$ value is 0.59 ± 0.05 (n = 5).

Discussion: The Lu-Hf date of 716 ± 81 Ma determined by the mineral fractions reported here is interpreted to represent one of the oldest crystallization ages among shergottites except for NWA 7635 and NWA 8159 [6, 7]. This age is equivalent to an Ar-Ar date of 700 ± 140 Ma determined by Turrin et al. [this meeting]. The crystallization ages of intermediate shergottites (166-340 Ma) [8, 9] are generally younger than those of depleted shergottites (327-574 Ma [10, 11]).

The modeled source $^{176}Lu/^{177}Hf$ and $^{147}Sm/^{144}Nd$ isotope ratios are calculated using two stage model assuming a differentiation age of 4.513 Ga [12] and the CHUR parameters of [13]. The calculated source $^{176}Lu/^{177}Hf$ and $^{147}Sm/^{144}Nd$ compositions of 0.0495 and 0.2504, respectively, are plotted on a three component mixing array (Fig. 5). The source compositions of NWA 4480 suggest that it is derived from source mixtures that are more similar to those that produced the depleted shergottites than the intermediate shergottites. Moreover, when compared to other shergottites on a $\varepsilon^{142}Nd$ vesus present-day source $\varepsilon^{143}Nd$ values, NWA 4480 will fall much closer to the field of depleted shergottites than intermediate shergottites. However, the distinct ejection age as well as other unique characteristics suggest that it represents a sample from a unique location on Mars.

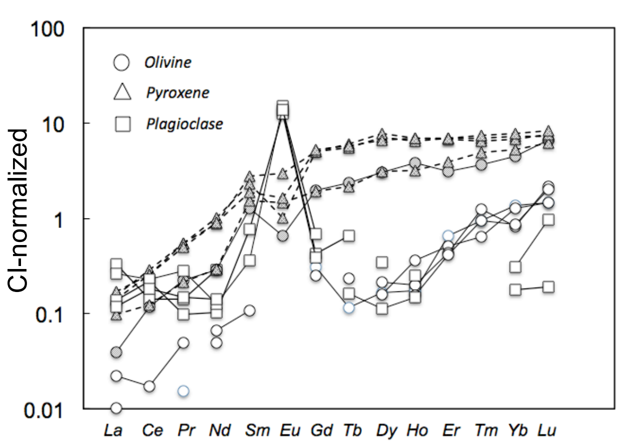

Figure 3. Range of rare earth element abundances in olivine, pyroxene and plagioclase of NWA 4480.

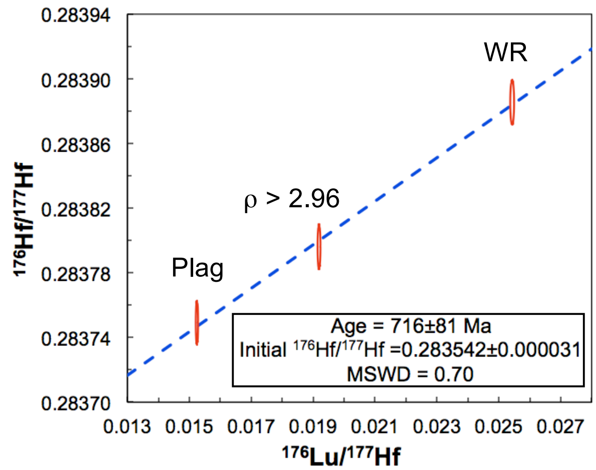

Figure 4. Lu-Hf isochron diagram for NWA 4480. Error bars are 2σ. 'Bulk' = fine-grained (< 44µm) fraction. 'Plag' = Hand picked plagioclase after density separation using ρ < 2.96 g/cm³ fraction. 'ρ > 2.96' = fraction heavier than ρ > 2.96 including oxide minerals, olivine and pyroxene.

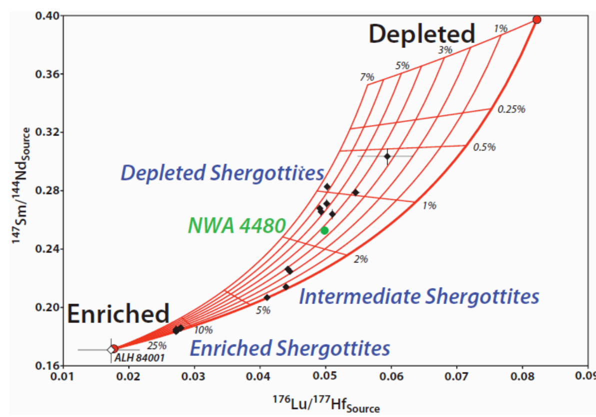

Figure 5. Source mixing array for shergottite Lu-Hf and Sm-Nd source compositions calculated using equations of [14] and mantle source compositions of [15]. NWA 4480 (Green), all other shergottites (black diamond) and ALH 84001 (ALH; open). DS = depleted shergottites; IS = intermediate shergottites; ES = enriched shergottites. Isotope data used for the source calculations of shergottites are from [6] .

References: [1] Irving A. J. et al. (2007) Meteoritics & Planetary Science 42: A73. [2] Irving A. J. et al. (2016) LPS XLVII , Abstract #2330. [3] Herzog G. F. and Caffee M. W. (2016) Treatise on Geochemistry : Meteorites and Cosmochemical Processes (Elsevier, 2014) vol. 1, 419–454. [4] Rumble D. and Irving A. J. (2009) LPS XL, Abstract #2293. [5] Ludwig K.R. (2003) *Berkeley Geochronology Center Spec. Pub.* 1a, 59. [6] Lapen T. J. et al. (2017) Science Advances 3, e1600922. [7] Herd et al. (2017) Geochim. Cosmochim. Acta 218, 1–26. [8] Borg L. E. et al (2002) Geochim. Cosmochim. Acta 66, 2037–2053. [9] Nyquist et al. (2006)LPS XXXVII, Abstract #1723. [10] Borg et al. (1997) Geochim. Cosmochim. Acta 61, 4915–4931. [11] Brennecka at al. (2014) Meteoritics & Planetary Science 49: 412–418. [12] Borg L. E. et al. (2003) Geochim. Cosmochim. Acta 67, 3519–3536. [13] Bouvier A. et al. (2008) Earth Planet. Sci. Lett. 280, 285–295. [14] Nyquist L. E. et al. (2001) Chronology and Evolution of Mars (Springer), vol. 96, 105–164. [15] Debaille et al. (2008) Earth Planet. Sci. Lett. 269, 186–199.