NEODYMIUM AND TUNGSTEN ISOTOPE SYSTEMATICS OF MARS INFERRED FROM THE AUGITE BASALTIC METEORITE NWA 8159 T.M. Kayzar[1], L. Borg[1], T.S., Kruijer[2], T. Kleine[2], G. Brennecka[1,2], and C. Agee[3]. [1]Nuclear and Chemical Sciences Division, Lawerence Livermore National Laboratory, Livermore CA USA. [2]Westfälische Wilhelmn-Universität Münster, Institut für Planetologie, Münster, Germany. [3]Institute of Meteoritics, University of New Mexico Albuquerque NM USA.

Synopsis: Samarium-neodymium and tungsten isotopic analysis of martian augite basalt NWA8159 demonstrate that it is derived from a unique martian source region unlike those of the shergottites or nakhlites. The ^{182}W composition is intermediate between the shergottite and nakhlite values, whereas the ^{142}Nd is more radiogenic than all previously analyzed samples. Although NWA8159 is derived from a source very strongly depleted in LREE, it does not lie on the extension of the Nd-Nd isochron defined by the shergottites. This implies that the source of NWA8159 is either substantially younger than the shergottite source regions or that, like the nakhlites, NWA8159 did not evolve in three stages of evolution. The heterogeneous nature of the martian mantle source regions suggests individual martian sources formed in isolation over a period of time.

Introduction: Meteorites from the planet Mars demonstrate abundant evidence for live short-lived isotopic systems such as ^{182}Hf-^{182}W ($t_{1/2}$= 9 Ma) and ^{146}Sm-^{142}Nd ($t_{1/2}$= 103 Ma) [e.g., 1-2]. Although ^{182}W and ^{142}Nd isotopic anomalies observed in martian meteorites clearly indicate Hf/W and Sm/Nd were fractionated early in the history of the Solar System, the geologic environment in which this fractionation occurred is not uniquely constrained. For example, Hf/W could be fractionated or modified by core formation, silicate differentiation, and late accretion [e.g., 3]. Likewise, Sm/Nd fractionation could occur during cooling of a global martian magma ocean or in more regional areas of differentiation associated with the cooling of magma "seas" or the cooling of areas melted by giant impacts. Here we evaluate evolutionary models for martian meteorite NWA8159 using Nd-W isotope systematics.

Petrology, chemistry, and chronology of NWA 8159: Northwest Africa 8159 is a fine-grained martian basaltic meteorite. It consists of about 50% augite, 40% plagioclase/maskelynite, 5% olivine, ~3% magnetite, 2% orthopyroxene with trace abundances of ilmenite, merrilite, apatite, spinel, and alteration minerals [4]. The compositions of oxide minerals present in NWA8159 suggest that it originated from the most oxidized martian magma yet known. The rare-earth element pattern for NWA8159 demonstrates strong LREE depletion similar to the "depleted" shergottite subgroup as represented by the meteorite QUE94201 (Fig. 1). A 2.3 ± 0.5 Ga Sm-Nd age has been reported for this sample by [5] making it substantially older than either the shergottites or nakhlites.

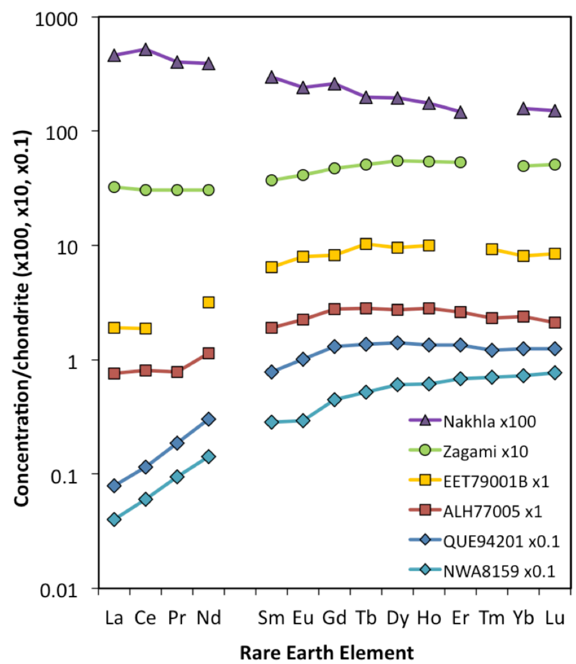

Figure 1. Chondrite normalized REE patterns of representative martian meteorites. Enriched shergottite (Zagami), intermediate shergottites (ALH77005 and EET79001B), depleted shergottite (QUE94201), and nakhlites (Nakhla). Note that absolute values of ploted data are multiplied by 100, 10, and 0.1 for clarity. NWA8159 has a REE pattern that is similar to the depleted shergottites.

Results: The measured ε^{142}Nd, ε^{143}Nd, and ^{147}Sm/^{144}Nd values for NWA8159 are +0.92 ± 0.03, +88.26 ± 0.03, and 0.36888 ± 0.00037, whereas the preliminary ε^{182}W value is +1.3 ± 0.5. The ^{182}W-^{142}Nd whole rock isotopic data for NWA8159 are plotted with previously published data in Figure 2. From these data, it is apparent that NWA8159 is isotopically unique: its ε^{142}Nd is the highest yet measured for any martian meteorite, while its ε^{182}W is intermediate between the shergottites and nakhlites. The ^{142}Nd-^{182}W systematics combined with the age of NWA8159 indicate that this meteorite is derived from a previously unsampled source region on Mars.

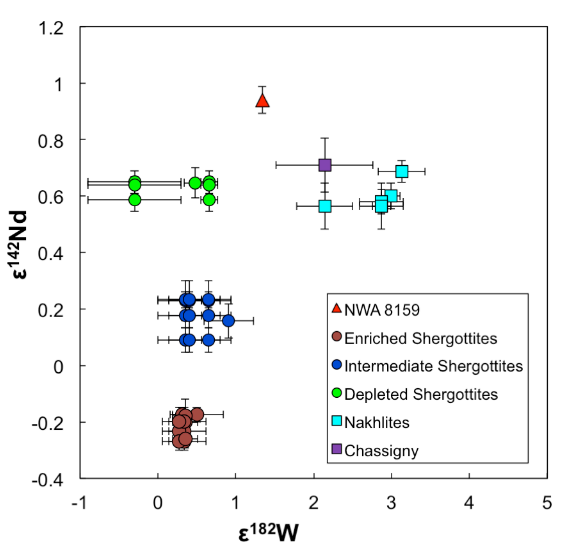

Figure 2. ^{182}W-^{142}Nd isotope plot of martian meteorites demonstrating the presence of multiple isotopic reservoirs in the martian mantle. Reservoirs represented by: (1) enriched shergottite, (2) depleted shergottite, (3) nahhlite/chassingite, and (4) NWA 8159. Intermediate shergottites likely represent a mixture of depleted and enriched end-members and may not constitute a distinct reservoir. Data from [2, 6-12].

Discussion: The measured ^{142}Nd and ^{182}W isotope compositions of the martian meteorites reflect fractionation of parent/daughter elements that occurred during the formation of their source regions [e.g., 1-3], either during differentiation in isolated regions that did not interact after their formation or during crystallization of a global magma ocean followed by variable magma processing.

Neodymium model ages for shergottite source formation have been calculated assuming three stages of Nd isotopic growth: (1) a primordial undifferentiated reservoir, (2) a differentiated reservoir forming early in the history of Mars, and (3) in the bulk rock after crystallization. The whole rock isochron method (Figure 3), using the most recent Nd isotope data, yields an age of 4504 ± 5 Ma for the shergottite source regions [7, 8]. This age is consistent with the absence of resolvable ε^{182}W variations among the shergottites [2, 3, 12], because differentiation occurred when ^{182}Hf was nearly extinct. The much higher ε^{182}W of NWA8159 consequently requires an additional Hf/W fractionation event. If NWA8159 formation was coeval to the shergottite source formation at 4504 Ma, a ^{180}Hf/^{184}W ratio of ~100 would be required for the NWA8159 source to evolve to its ε^{182}W of ca. +1.3. Such high ^{180}Hf/^{184}W could have potentially been established in the deep garnet-bearing mantle of Mars [13].

The formation age of the NWA8159 source region is calculated to be $4451^{+20}/_{-13}$ Ma using the same three-stage ^{142}Nd-^{143}Nd evolution model used for the shergottite source age. The error on this age primarily reflects the uncertainty in the crystallization age of the sample. This model age of the NWA8159 source is younger than the Nd-Nd isochron age of the shergottite source region (Fig. 3). However, formation of the NWA8159 source at ~4451 Ma would have been too late to generate its elevated ε^{182}W of ca. +1.3, because ^{182}Hf was effectively extinct at this time. Thus, in order to account for the W isotope composition of NWA8159, an earlier fractionation event is required. This implies that a three-stage Nd-Nd model age may not accurately record the age of formation of the NWA8159 soure region, and that the evolution of NWA8159 was likely complex. For instance, a melting event in which a LREE-enriched magma is extracted from the NWA8159 source region could have raised the ^{147}Sm/^{144}Nd of the source region after ^{146}Sm had decayed away. In this scenario the ε^{142}Nd of the source would be unaffected, but the ε^{143}Nd value could be raised shifting NWA8159 to the right of the shergottite isochron (Fig. 3). Therefore, the ^{142}Nd and ^{182}W composition of NWA8159 may have been established earlier than the Nd-Nd model age, consistent with the elevated ε^{182}W of NWA8159.

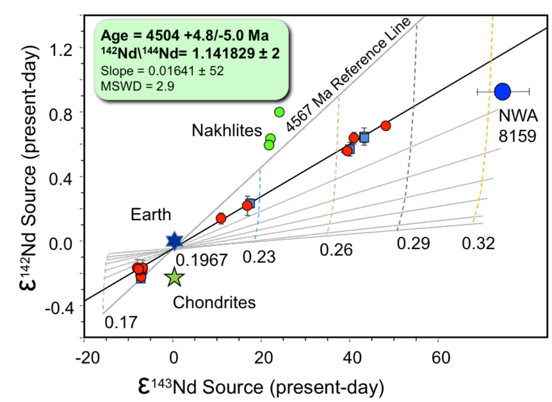

Figure 3. Nd-Nd isochron plot of martian meteorite samples. Curves represent Nd evolution in reservoirs with different ^{147}Sm/^{144}Nd ratios. Grey lines are modeled isochrons with ages of 4.20, 4.25, 4.30, 4.35, 4.40, 4.45, and 4.567 Ga.

References: [1] Harper et al. (1995) *Science* **267,** 213-7. [2] Foley et al. (2005) *GCA* **69,** 4557-4571. [3] Mezger et al. (2013) *Space. Sci. Rev.* **174,** 27-48. [4] Agee et al. (2014) 45th LPSC abstract #2036. [5] Simon et al (2014) 77th MetSoc Meeting abstract #5363. [6] Borg et al. *GCA* (in revision), [7] Symes et al. (2014) 45th LPSC, abstract #2063. [8] Debaille et al. (2007) *Nature* **450,** 525-8. [9] Caro et al. (2008) *Nature* **452,** 336-9. [10] Debaille et al. (2009) *Nat. GeoSci.* **2,** 548. [11] Lee & Halliday (1997) Nature 388, 854-7. [12] Kleine et al. (2004) *GCA* **73,** 2935-46. [13] Righter et al. (2003) GCA 67, 4775-89. Work performed under the auspices of the U.S. DOE by LLNL under contract DE-AC52-07NA27344.