THE RELATIONSHIP OF NORTHWEST AFRICA 4468 TO THE OTHER INCOMPATIBLE-ELEMENT-ENRICHED SHERGOTTITES INFERRED FROM ITS Rb-Sr and Sm-Nd ISOTOPIC SYSTEMATICS. N. E. Marks[1], L. E Borg[1], A. M. Gaffney[1], and D. DePaolo[2]. [1]Institute of Geophysics & Planetary Physics, Lawrence Livermore National Laboratory, 7000 East Ave. L-231 Livermore CA 94550 (marks23@llnl.gov), [2]Center for Isotope Geochemistry, University of California, Berkeley.

Introduction: Shergottites are the most numerous of the martian meteorites, and are characterized by a variety of mineralogies ranging from olivine-bearing primitive basalts and lherzolites (e.g., Y98405, DaG 476, NWA 1068/1110) to significantly more evolved pyroxene-plagioclase bearing basalts (e.g., QUE 94201, Los Angeles, and Shergotty). The shergottites fall into three groups based on their trace element and isotopic compositions. One group is defined by samples with light REE-depleted patterns and low initial Sr and high initial Nd isotopic compositions (e.g., QUE 94201), whereas another group is defined by samples with light REE-enriched patterns and high initial Sr and low Nd isotopic compositions (e.g., NWA 1068/1110) [1-3; Figure 1]. The third group has characteristics that are intermediate between the other two.

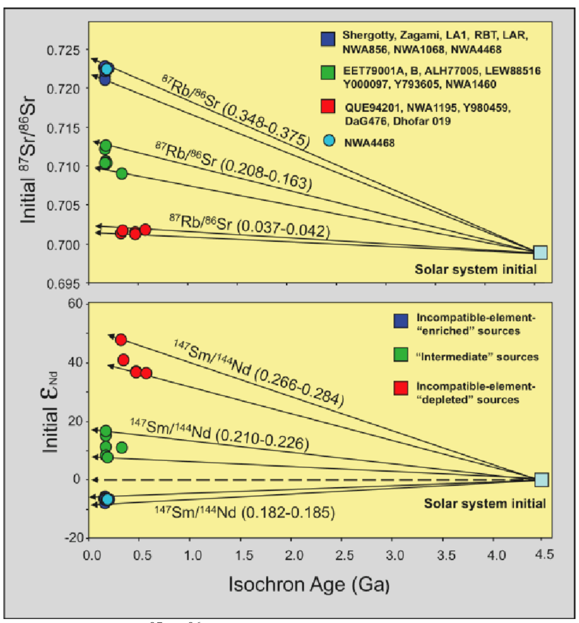

Figure 1. Initial $^{87}Sr/^{86}Sr$ ratios and ε_{Nd} indicate three separate mantle source regions for meteorites of the shergottite suite.

These compositional differences have been interpreted to reflect either varying degrees of assimilation of the martian crust and fractional crystallization (AFC) [4-5], or compositional heterogeneity in the mantle sources and variable degrees of fractional crystallization experienced by the mantle melts upon leaving their source regions [1-3]. In order to constrain the mechanisms responsible for the observed compositional diversity in the shergottite suite, we have begun Rb-Sr and Sm-Nd isotopic analyses on the primitive, incompatible element-enriched olivine-bearing shergottite NWA 4468.

Petrology and geochemistry: NWA 4468 is an olivine basaltic shergottite and contains 35% Fo_{59-71} olivine, ~35% clinopyroxene, ~25% maskelynite, and minor amounts of chromite, ilmenite, and phosphate [6]. Bulk major and trace element analysis provide the basis for geochemical models in this study. NWA 4468 has a Mg# of 64 and a flat to slightly LREE enriched REE pattern making it one of the more primitive meteorites in the enriched sub-group.

Rb-Sr and Sm-Nd isotopic analysis. Rubidium-Sr isotopic systematics of NWA 4468 are partially disturbed as a result of terrestrial weathering. Nevertheless, Rb-Sr isotopic analyses on the whole rock and maskelynite leached residues (Wr-1 R, Mask-2 R) and yield an age of 187 ± 6 Ma (Figure 2). These fractions are likely to be minimally disturbed by alteration because they either contain large amounts of Sr or were strongly leached in 4N HCl. The initial $^{87}Sr/^{86}Sr$ of NWA 4468 is determined to be 0.722390 ± 19 and is in good agreement with values determined on other enriched shergottites.

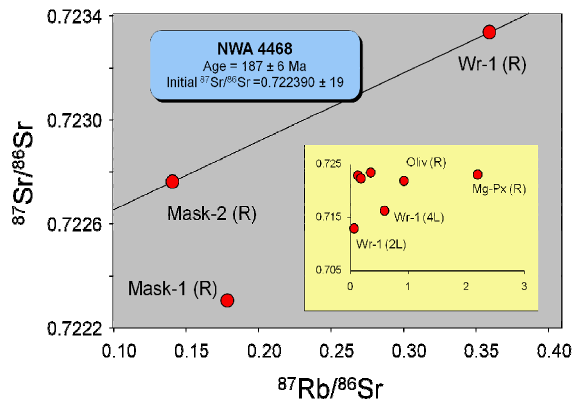

Figure 2. Rb-Sr Plag-2-whole rock residue tie-line for NWA 4468 yielding an age of 187 ± 6 Ma and an initial $^{87}Sr/^{86}Sr$ of 0.722390 ± 19. Insert plots all analyzed data.

Preliminary Sm-Nd isotopic analyses on the whole rock residue (Wr-1 R) and 2N HCl leachate (Wr-2L) yield an age of 150 ± 29 Ma and an initial ε_{Nd} value of -6.9 ± 0.3 [7]. This age is nearly concordant with the Rb-Sr age in Figure 2. The maskelynite and olivine fractions appear to be contaminated with terrestrial Nd, and therefore do not constrain the Sm-Nd isochron ages any better than we reported previously. The data from NWA 4468 lie within error of the Sm-Nd isochron defined for NWA 1068 and suggest that these samples have similar ages [6, 8]. Note that both NWA 4468 and NWA 1068 appear to be slightly older than most other enriched shergottites which are predominantly ~165Ma [3]. Further Sm-Nd measurements are currently underway on mineral separates from NWA 4468 and will provide additional constraints on the age of this meteorite.

Calculated $^{87}Rb/^{86}Sr$ and $^{147}Sm/^{146}Nd$ ratios of the NWA 4468 source are 0.371 and 0.184, respectively, and closely match those calculated for other enriched shergottite sources (Figure 2). By investigating how this relatively primitive and unfractionated meteorite obtained its enriched incompatible element signature, we will be able to constrain the mechanism(s) by which incompatible element variability is produced in the shergottite suite.

MELTS models: Northwest Africa 4468 shares many trace element and isotopic characteristics with other martian meteorites such as Shergotty, Zagami, Los Angeles (LA1), NWA 1068/1110, RBT 04262, LAR 06319, and NWA 856. All have relatively elevated incompatible element abundances and initial Sr and Nd isotopic compositions that indicate derivation from a source with high Rb/Sr and low Sm/Nd ratios (Figure 2). In contrast to the incompatible trace element abundances and Sr-Nd isotopic systematics, the major element abundances of these meteorites are quite variable. For example, MgO varies from 3.5 wt. % in LA1 to 20.8 wt. % in NWA 4468 and 21.6 wt. % in RBT 04261. Similar major element, trace element, and isotopic systematics observed in the depleted martian meteorite sub-group led Symes et al. [1] to suggest that these meteorites could be related to a similar parental magma by fractional crystallization. In order to determine if the enriched sub-group of martian meteorites could be related to a similar parental melts by fractional crystallization, the MELTS algorithm [11] was used to assess whether iron-rich, incompatible element-rich shergottites, such as Los Angeles, could be produced by fractional/equilibrium crystallization from a more magnesian parent (i.e. NWA 4468 or NWA 1098).

The models were run assuming the system was at 1 kbar pressure with the starting temperature of the host magma (NWA 4468) at 1480 ºC. The results of the MELTS calculations are presented in Figure 3. The liquid evolution paths for fractional and equilibrium crystallization models based on the MELTS algorithm indicate that NWA 4468 is unlikely to be related to many of the other meteorites with enriched trace element and isotopic characteristics by simple fractional crystallization. This is illustrated on Figure 3 where CaO/Al_2O_3 versus Mg# for several of these meteorites are plotted. Most meteorites do not fall on a single array on this diagram and fractionation paths calculated using MELTS and assuming a parental composition of NWA 4468 do not intersect NWA 1068, RBT 04261, Zagami or NWA 856. . It is important to note that most of these meteorites are cumulates and that accumulation of olivine, pyroxene, and plagioclase will have significant effects on these models. This is illustrated on Figure 3 by the inset. The range of potential melt compositions resulting from plagioclase and olivine accumulation encompasses most of compositions of the suite of enriched shergottites. Even modest (<15%) amounts of accumulation of plagioclase results in significantly higher CaO/Al_2O_3 ratios. These calculations suggest that accumulation of plagioclase and olivine may account for some of the diversity of bulk compositions in the incompatible element-enriched shergottites. Better estimates of parental melt compositions are clearly needed to assess the role of accumulation on these models.

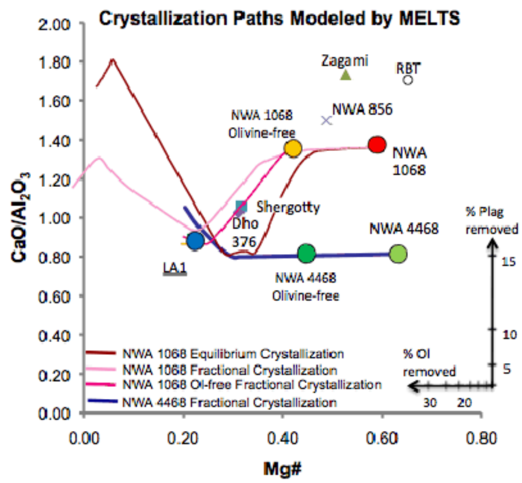

Figure 3. Compositional evolution of liquids during crystallization as modeled by MELTS. Olivine-free compositions account for accumulation and are calculated by subtracting 30% Fo_{71} olivine.

A few compositions, such as LA1, Shergotty, and Dho 376 lie near the fractionation path and could be produced from a NWA 4468 -like parent by fractional crystallization. Interestingly, MELTS is also able to reproduce the composition of these meteorites from a parent with the composition of NWA1068 [Fig. 3; 7]. These modeled liquids closely mimic the composition of LA1 and suggest that NWA 4468-1068 could serve as parent compositions of LA1. This is consistent with the observation that these samples have similar REE patterns and initial Sr-Nd isotopic compositions. This is also consistent with the suggestion of [1] that the trace element and isotopic systematics of the shergottites are derived from their mantle sources, and their major element compositions reflect fractional crystallization of the parental melts upon leaving the mantle.

References: [1] Symes et al. (2008) *GCA* **17**, 1696-1710; [2] Borg et al. (2005) *GCA* **69,** 5819-5830, [3] Borg et al., (2003) *GCA* **67,** 3519-3536; [4] Jones (1989) *19th PLPSC* 465-47; [5] Herd et al. (2002) *GCA* **66,** 2025-2036; [6] Irving et al., (2007) LPSC XXXVIII, Abstr.# 1526; [7] Borg et al., (2008) LPSC XXXIX, Abstr.# 1851; [8] Shih et al. (2003) LPSC XXXIV, Abstr.# 1439; [9] Shirai & Ebihara (2004) *Ant. Met. Res.* 17, 55-67; [10] Rubin et al. (2000) *Geol.* **28**, 1011-1014; [11] Ghiorso & Sack (1995) *CMP* **119**, 197-212. This work performed under the auspices of the U.S. DOE by LLNL under Contract DE-AC52-07NA27344.