Sm-Nd ISOTOPIC STUDIES OF TWO NAKHLITES, NWA 5790 AND NAKHLA.

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Introduction: NWA 5790 is a Martian meteorite recently found in the Mauritania (?) part of the Saharan desert and is classified as a nakhlite [1]. Nakhlites are olivine-bearing clinopyroxenites with cumulate textures, most of them containing a small amount of interstitial plagioclase [e.g. 2]. Unlike other Martian meteorites (*e.g.*, shergottites), nakhlites have been only moderately shocked and their original igneous textures are still well-preserved. Also, these meteorites have older crystallization ages of ~1.35 Ga compared to shergottites with younger ages of ~0.17-0.57 Ga [*e.g.*, 3]. NWA 5790 is characterized by containing abundant (~40 vol %) glassy mesostasis [1], compared to that of ~20% found in MIL 03346 [4]. The glassy materials indicate that these nakhlites cooled rapidly and probably formed near the top [5] or at the bottom [6] of the chilled margin of a thick intrusive magmatic body. The glassy mesostasis quenched from the trapped intercumulus liquid may provide valuable information on the parental magma compositions of the nakhlites. In this report, we present Sm-Nd isotopic data for NWA 5790 and Nakhla, a rare "fall" nakhlite, correlate their ages with those of other nakhlites and discuss their petrogenesis.

Samples and Analytical Procedures: A coarse fines pile of NWA 5790 weighing ~1.45 g and an interior chunk of Nakhla weighing 3.8 g (kindly provided by Monica Grady) were allocated to us for this study. The NWA 5790 sample was not pristine. Examined with a binocular microscope, it was found to be altered and covered with "caliche". A desert sand "ball" weighing 59 mg was present. To eliminate these desert contaminants as much as possible, we washed the sample with ethanol using an ultrasonication bath. Then we picked out the least "caliche'-bearing samples for the study. Mineral separations were made from the 149-74 µm fraction by density separations using heavy liquids. At density fraction 3.32-3.45 g/cm^3, we obtained a clinopyroxene sample (Px1). In the slightly higher density fraction (3.45-3.55 g/cm^3), another clinopyroxene sample (Px2) was obtained. A small sample containing a small amount of olivine + some opaques (Ol) was separated with a heavy liquid of density >3.7 g/cm^3. The black glassy mesostasis sample (Gl) was mainly concentrated in the density fraction <3.32 g/cm^3. In addition, a bulk rock and three mineral separate samples were washed with 2N HCl in an ultrasonic bath for 10 minutes to eliminate possible post-crystallization, pre- or terrestrial, contamination. Both acid-residue (r) and combined mineral leachates (Leach) were analyzed. Similar mineral separation procedures were followed for the Nakhla sample.

Sm-Nd data for NWA 5790: CI-normalized Sm and Nd distributions in bulk and mineral separates of NWA 5790 are shown in Fig. 1. The REE data for a similar mesostasis-rich nakhlite MIL 03346 [4] are shown as comparison. Comparing to other nakhlites, NWA 5790 has the highest Sm (17xCI) and Nd (26xCI) abundances, most likely due to its high abundance of the mesostasis component (Gl), which has very high Sm (37xCI) and Nd (62xCI). The Sm and Nd contents in Gl of NWA 5790 are ~1.5x those in Gl of MIL 04336. The high REE abundance in NWA 5790 may also suggest a close relation with nakhlite NWA 817 [7].

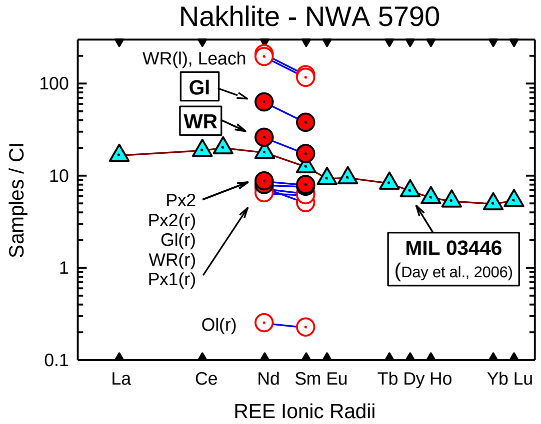

Figure 1. Sm-Nd distributions in NWA 5790 samples.

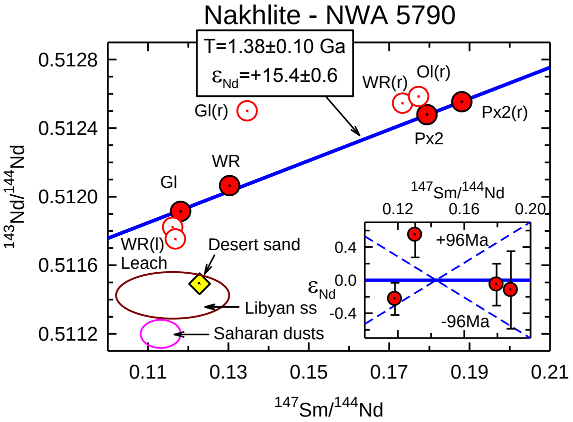

Figure 2. Sm-Nd isochron of NWA 5790.

Sm-Nd isotopic results: The $^{147}Sm/^{144}Nd$ and $^{143}Nd/^{144}Nd$ data of ten samples of NWA 5790 are shown in Fig. 2. The Sm-Nd isotopic system for these samples is highly disturbed probably due to desert alterations. Four samples (solid circles), WR, Gl and Px2 and acid-washed clinopyroxene sample, Px2(r), form a linear array corresponding to an age of 1.38±0.10 Ga for $\lambda(^{147}Sm)=0.00654\ Ga^{-1}$ and initial ε_{Nd} =+15.4±0.6 using the York program [8]. Two leachate samples, WR(l) and Leach (open circles), lie below the isochron, probably containing secondary alteration products. However, three acid washed samples, Gl(r), WR(r) and Ol(r) (open circles), have similarly high $^{143}Nd/^{144}Nd$ and plot above the isochron. The reason is unclear. Our best estimated Sm-Nd age and initial ε_{Nd} value for NWA 5790 are in good agreement with the 1.36±0.03 Ga Sm-Nd age and initial ε_{Nd} =+15.2±0.2 of the MIL 03346 sample [9].

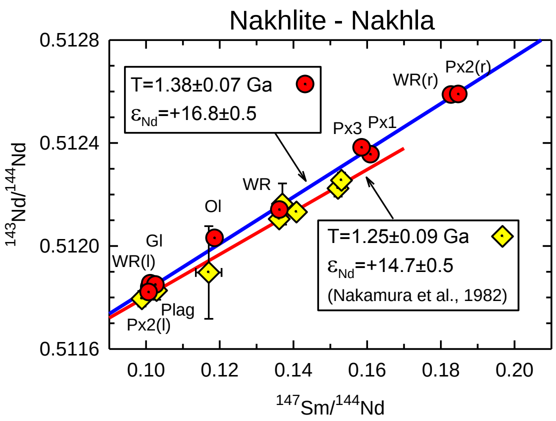

Figure 3. Sm-Nd isochrones of Nakhla.

The ^{147}Sm/^{144}Nd and ^{143}Nd/^{144}Nd data of ten samples of Nakhla are shown in Fig. 3. Contrary to NWA 5790, the Nakhla samples processed similarly do not show such isotopic disturbances. All ten samples form a linear array corresponding to an age of 1.38±0.07 Ga for $\lambda(^{147}\text{Sm})=0.00654$ Ga^{-1} and initial ε_{Nd} =+16.8±0.5, which is in good agreement with other nakhlite ages but slightly older than that reported by [10].

Petrogenetic implications: The ages and ε_{Nd}-values of seven nakhlites are summarized in Fig. 4. The parallelograms defined by the estimated uncertainties for each nakhlite do not overlap significantly, showing that nakhlite parent magmas came from at least three different flows: Nakhla+Gov. Val. ± Lafayette, Y000593 and MIL 03446+NWA 5790. Thus, nakhlite volcanisms probably occurred at 1.35 Ga ago and lasted at least 20 Ma. Alternatively, nakhlites could have come from multiple isotopically distinct sources at different times. Based on two-stage model calculations, the nakhlite source ^{147}Sm/^{144}Nd ratios could have a narrow range from ~0.233 to ~0.237. A recent study of olivine textures and abundances in nakhlites [11] also suggested a complex history of multiple lava flows in the region of the nakhlite source crater (Syrtis Major [12] ?).

Fig. 5 shows the age and ε_{Nd}-value of MIL 03346 + NWA 5790 (MIL+NWA) with evolution paths calculated for a two-stage model (solid lines) and for multiple-stage models (broken lines) of [13,14]. The calculated two-stage source ^{147}Sm/^{144}Nd (μ_s) for MIL+NWA is ~0.233, or ~18% depleted in LREE relative to an assumed undifferentiated primitive Martian mantle similar to chondrites (CHUR). Similar to discussions in [15], we assume this depleted MIL+NWA source is a garnet-bearing peridotitic cumulate having Nd=1.2xCI, Sm=1.4xCI, and ^{147}Sm/^{144}Nd=0.233 at 1.37 Ga ago. We suggest that such a depleted source was an early cumulate from a thick magma ocean established very early, probably soon after Martian core formation, and while ^{182}Hf still was alive [16-18]. The MIL+NWA source evolved until 1.37 Ga ago, when a partial melting event occurred, forming MIL+NWA parental magma similar in composition to the glassy mesostasis found in NWA 5790. We suggest this magma was intruded upward to the Martian subsurface. As it cooled down, crystals of clinopyroxene and olivine settled, trapping significant but different amounts of the parent magma to form NWA 5790 and MIL 04336. The 0.5% melt required in this model for the MIL+NWA-forming event at ~1.37 Ga has 38xCI Sm and 63xCI Nd, matching the NWA mesostasis(Gl) composition very well. In order to accommodate the small positive ^{142}Nd anomalies (~+0.6 ε) of nakhlites [14,19,20], multiple-stage evolution models [e.g. 13,14] which are more likely, also yield similar small-percentage melts for the parental magmas of nakhlites. Other alternatives are also permissible for slightly different source mineralogy, chemical composition, and degrees of melting.

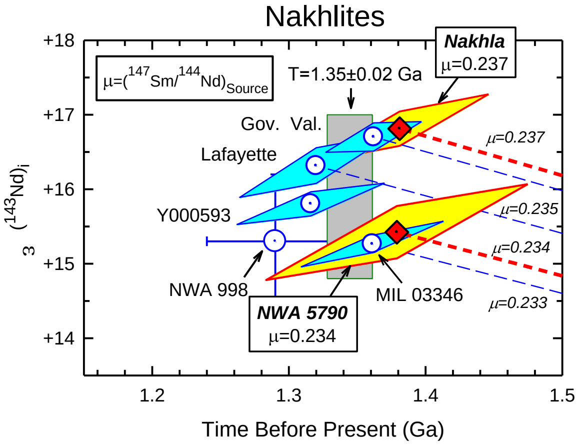

Figure 4. Age and initial ε_{Nd}-values for nakhlites.

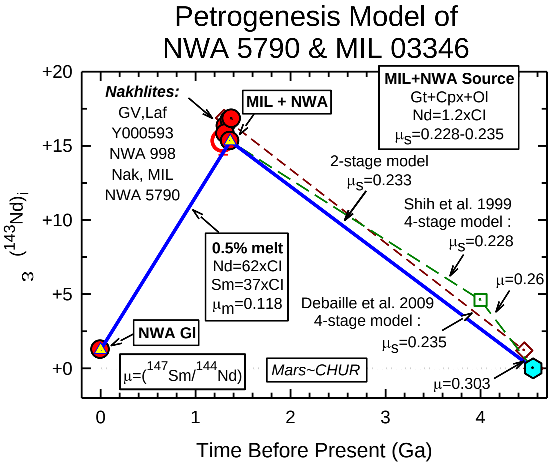

Figure 5. Petrogenesis model of NWA 5790 & MIL 03346.

References: [1] Jambon A. et al. (2009) this vol. [2] Treiman A.H. (2005) *Chemie der Erde* **65**, 203-270. [3] Nyquist L.E. *et al.* (2001) *Chronology and Evolution of Mars*, 105-164. Kluwer Academic Publ. Dordrecht/ Boston/London. [4] Day J.M.D. et al. (2006) *MPS* **41**, 581-606. [5] Mikouchi T. *et al.* (2005) *LPS* **XXXVI**, CD-ROM #1944. [6] Grady M.M. *et al.* (2005) *MPS* **40**, A59. [7] Sautter V. *et al.* (2002) *EPSL* **195**, 223-238. [8] York D. (1966) *Can. J. Phys.* **44**, 1079-1086. [9] Shih C.-Y. (2006) *LPS* **XXXVII**, CD-ROM #1701. [10] Nakamura N. *et al.* (1982) *GCA* **46**, 1555-1573. [11] Lentz R.C.F. *et al.* (2005) *MPS.* **40**, A91. [12] Harvey R.P. and Hamilton V.E. (2005) *LPS* **XXXVI**, CD-ROM #1019. [13] Shih C.-Y. *et al.* (1999) *MPS* **34**, 647-655. [14] Debaille V. et al. (2009) *Nature Geoscience* **2**, 548-552. [15] Shih C.-Y. *et al.* (2005) *Ant. Met. Res.* **18**, 46-65. [16] Lee D.C and Halliday A.N. (1997) *Nature* **388**, 854-857. [17] Kleine T. et al. (2004) *GCA* **68**, 2935-2946. [18] Foley C.N. *et al* (2005) *GCA* **69**, 4557-4571. [19] Harper C.L. Jr. *et al.* (1995) *Science* **267**, 213-217. [20] Caro G. et al. (2008) *Nature* **452**, 336-339.