AGE AND ISOTOPE SYSTEMATICS OF NORTHWEST AFRICA 4898, A NEW TYPE OF HIGHLY-DEPLETED MARE BASALT.
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Introduction: Many lunar basaltic meteorites originate from mantle sources that are not represented in the Apollo and Luna sample collections. Thus, this family of lunar samples provides an important perspective on the formation and evolution of the lunar mantle. Northwest Africa 4898, a newly-recovered mare basalt meteorite, has relatively low abundances of FeO (17.3 wt. %) and TiO_2 (2.4 wt. %) [1]. These characteristics, combined with its high Al_2O_3 content (12.0 wt. % [1]), indicate a compositional affinity to the Apollo 14 high-Al basalts. However, our preliminary Rb-Sr isotopic results show that NWA 4898 formed during a younger episode of magmatism than the Apollo 14 basalts. The very high preliminary initial Nd isotopic composition of NWA 4898 indicates that this sample may originate from the most incompatible element-depleted mantle source yet identified in the Moon.

Methods: A 30 mg aliquot of NWA 4898 was crushed to a powder in a sapphire mortar and pestle for whole rock analysis. The powder was leached in 2N HCl at room temperature for 10 minutes. This leachate was decanted, and the sample was washed with 18 mΩ water. The HCl leachate and water wash were combined and reserved for analysis; this fraction is designated WR(2L). The sample was then leached in 4N HCl, at 45° C, for 10 minutes, and washed again with water. The 4N HCl leachate and subsequent water wash were combined for analysis; this fraction is designated WR(4L). The leached whole rock residue is designated WR(R) in the subsequent discussion.

All three fractions were spiked with mixed Rb-Sr and Sm-Nd tracers. The whole rock fraction was digested with HF-HCl-HNO_3. One drop of HF was added to each of the leachate solutions to ensure that any minute amount of silicate material included in the leachate was also digested. Rubidium, Sr, Sm and Nd were separated using standard ion exchange techniques [2] at Lawrence Livermore National Laboratory. Isotopic analyses were completed at the Center for Isotope Geochemistry, UC Berkeley, using either the VG Sector 54 thermal ionization mass spectrometer (Rb-Sr), or the ThermoElemental Triton thermal ionization mass spectrometer (Sm-Nd).

Results: The Rb-Sr compositions of the WR(R) and WR(4L) fractions define a tie-line that corresponds to an age of 3.578 ± 0.040 Ga. The WR(2L) fraction lies above this line, and presumably contains a component of radiogenic Sr derived from terrestrial contamination. The low $^{87}Rb/^{86}Sr$ and unradiogenic Sr of the WR(4L) fraction indicate that this leachate is composed primarily of dissolved plagioclase, and that it does not contain a significant proportion of terrestrial contamination. This is consistent with our observations from another mare basalt desert meteorite, NWA 032, for which the (4L) fractions fall on the Rb-Sr isochron defined by leached mineral fractions [3]. Therefore, the two-point age presented in Figure 1 probably represents the actual crystallization age of this sample. This isochron corresponds to an initial $^{87}Sr/^{86}Sr$ of 0.69925 ± 1. The Rb-Sr age determined for NWA 4898 is a minimum age, as unidentified terrestrial contamination in the WR(4L) fraction would result in an age that is younger than the true (uncontaminated) age. Analysis of mineral separates is underway to provide additional data to constrain this age.

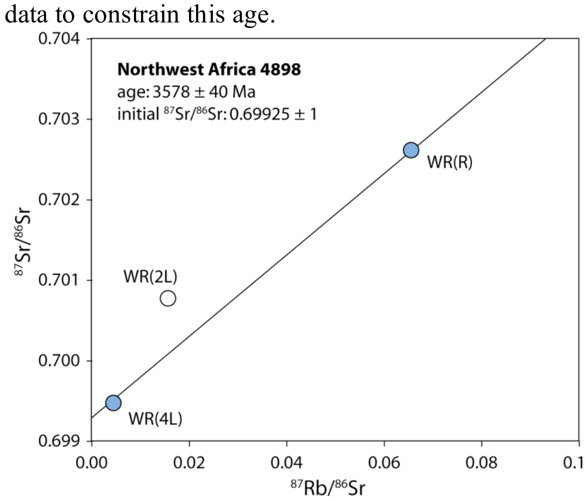

Figure 1: Rb-Sr isochron diagram for NWA 4898. Solid symbols are included in the age calculation. Age calculated using Isoplot/Ex rev. 2.49 [4], and $\lambda_{87Rb} = 0.01402$ Ga^{-1}.

Only the WR(R) and WR(4L) fractions were analyzed for Sm-Nd compositions. The WR(4L) fraction appears to be strongly affected by terrestrial contamination, which lowers the $^{143}Nd/^{144}Nd$ of this fraction, thus generating an artificially old and meaningless age for the whole rock-leachate tie line: 4.783 ± 0.025 Ga. However, based on observations from NWA 032, for which leached mineral fractions define an Sm-Nd crystallization age that is concordant with the Rb-Sr age, we infer that the leached whole rock fraction of NWA 4898 should likewise fall on an isochron that defines the crystallization age of the sample. Using the Sm-Nd composition of the WR(R) fraction and the age defined by the Rb-Sr system, we calculate an initial Nd isotopic composition for NWA 4898 of ε_{Nd} = + 16.0. Because terrestrial Nd contamination in this fraction would lower this value, the initial ε_{Nd} value presented here is a minimum estimate.

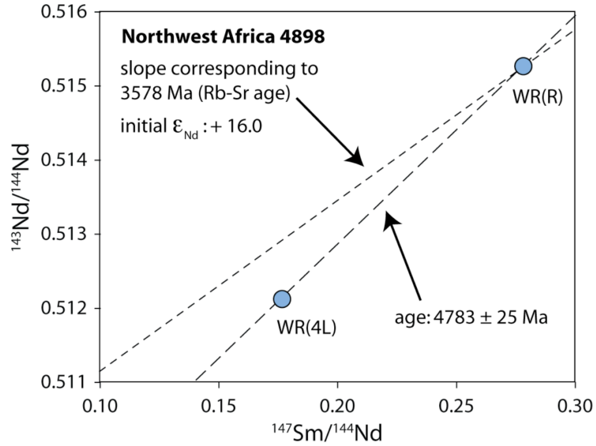

Figure 2: The WR(4L) fraction is affected by terrestrial contamination, and therefore the age defined by the two analyzed fractions is geologically meaningless. Tie-line age calculated with Isoplot/Ex rev. 2.49 [4].

A newly-identified, extremely depleted mantle source for mare basalts: The compositional characteristics of the mantle source of NWA 4898 can be calculated from the initial isotopic composition of the basalt. Using a single-stage model and LUNI as the initial composition of the Moon ($^{87}Sr/^{86}Sr$ = 0.69903), we calculate $^{87}Rb/^{86}Sr$ of the NWA 4898 mantle source to be 0.015. Using a two-stage model assuming chondritic growth from 4.558 to 4.42 Ga, we calculate the $^{147}Sm/^{144}Nd$ of the NWA 4898 mantle source to be 0.34. This is the highest Sm/Nd value determined for the mantle source of any mare basalt, and thus represents the most depleted mantle source yet identified for the Moon. Furthermore, given the currently sparse data set and the resulting inability to conclusively eliminate the possibility of unrecognized terrestrial contamination in some of these fractions, this calculated source Sm/Nd ratio represents a minimum estimate.

Although NWA 4898 shares many petrographic and geochemical characteristics with the Apollo 14 high-Al basalts, NWA 4898 is distinct from these basalts both in age and mantle source. Whereas the Apollo 14 high-Al basalts erupted between 3.95 and 4.33 Ga [6, 7], NWA 4898 is apparently much younger at 3.58 Ga. The initial isotopic compositions of the Apollo 14 high-Al basalts indicate they are derived from a mantle source with higher $^{87}Rb/^{86}Sr$ ratios (~0.02-0.05 [7]) and $^{147}Sm/^{144}Nd$ ratios that are close to chondritic [7]. This constrasts with the low $^{87}Rb/^{86}Sr$ and highly super-chondritic $^{147}Sm/^{144}Nd$ values calculated for the NWA 4898 mantle source, which indicate a very high degree of incompatible element depletion.

Among the mare basalts collected during the Apollo missions, the samples representing the highest source Sm/Nd ratios are high-Ti basalts. Conversely, the low-Ti Apollo and Luna basalts have only moderately super-chondritic Sm/Nd ratios (Fig. 3). Thus, NWA 4898 is unusual among mare basalts not only in its very high source Sm/Nd ratio, but also because this source characteristic is accompanied by low TiO_2 as well as high Al_2O_3 contents [1]. Two other meteorites, Asuka 881757 and MIL 05035, also show some of these distinctive compositional characteristics [5, 8, 9]; however, while these meteorites have source $^{147}Sm/^{144}Nd$ ratios lower than that of NWA 4898, their source $^{87}Rb/^{86}Sr$ ratios are also lower (~ 0.006; recalculated after [5] and [9]), indicating additional heterogeneity among the high-Sm/Nd lunar mantle sources. The very high Sm/Nd ratio of the NWA 4898 mantle source, coupled with high Al_2O_3 and low TiO_2, indicates that this source is dominated by clinopyroxene + plagioclase magma ocean cumulates in which ilmenite and KREEPy trapped liquid are absent. This source may be a region of magma ocean cumulates that has not been sampled by any basalt yet analyzed. The construction of a complete history of the formation and evolution of lunar mantle sources will require continued investigations of NWA 4898 as well as other newly-discovered lunar meteorites.

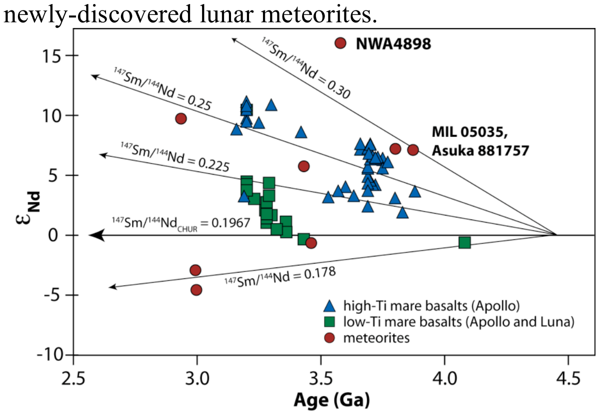

Figure 3: Age vs. initial Nd isotopic composition for mare basalts [10]. Arrows labeled with different $^{147}Sm/^{144}Nd$ ratios represent ε_{Nd} growth curves for mantle sources with the specified ratio.

References: [1] Greshake A. et al. (2008) This conference. [2] Borg L. E. et al. (2005) *GCA, 69*, 5819-5830. [3] Borg L. E. et al. (2007) *MAPS,* 42, 5232. [4] Ludwig K. L. (2001) *Berkeley Geochron. Ctr.* Spec. Pub. 1a. [5] Misawa K. et al. (1993) *GCA*, *57,* 4687-4702. [6] Papanastassiou D. & Wasserburg G. (1971) *EPSL*, 12, 38-48. [7] Dasch E. J. et al. (1987) *GCA*, 51, 3241-3254. [8] Yanai K. (1991) *PLPSC*, 21, 317-327. [9] Nyquist L. E. et al. (2007) *LPSC*, 37, #1702. [10] Author's data compilation, references available upon request.

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.