Sm-Nd FOR NORITE 78236 AND EUCRITE Y980318/433: IMPLICATIONS FOR PLANETARY AND SOLAR SYSTEM PROCESSES. L. E. Nyquist[1], C-Y. Shih[2], and Y. D. Reese[3], [1]Mail Code KR, NASA Johnson Space Center, Houston, TX 77058, laurence.e.nyquist@nasa.gov, [2]Mail Code JE-23, ESCG/Jacobs Sverdrup, P.O. Box 58477, Houston, TX 77058, chi-yu.shih@nasa.gov, [3]Mail Code JE-23, ESCG/Muniz Engineering, Houston, TX 77058, young.reese@.nasa.gov.

Introduction: Nyquist et al. [1] estimated lunar mantle formation to be 238(+56/-40) Ma later than formation of angrite LEW86010, and bulk present-day ε^{142}Nd = -0.01±0.03 relative to terrestrial standards, assumed equivalent to CHUR (Chondritic Uniform Reservoir [2]). Boyet and Carlson [3] reported a mean value of ^{142}Nd/^{144}Nd of -0.20±0.14 ε-units for several chondrites relative to a terrestrial standard. They suggested that material of sub-chondritic Sm/Nd ratio occurs within inaccessible regions of Earth's mantle. New, high precision data for lunar samples by Boyet and Carlson [4] agree with those of [1], and imply that if Earth and Moon formed in a Giant Impact, then it occurred *after* segregation of material of sub-chondritic Sm/Nd ratio into Earth's mantle. Rankenburg et al. [5], report a chondritic ^{142}Nd abundance for the Moon, implying either that the impact occurred *before* terrestrial differentiation, or that the moon inherited its Nd from an undifferentiated impactor. Mantle formation ages of 254(+30/-25) and 215(+23/-21) Ma, respectively, were reported by [4] and [5] in agreement with [1]. The "mean chondrite" ^{147}Sm/^{144}Nd and ^{143}Nd/^{144}Nd values of [3] yield initial ε^{143}Nd at 4567 Ma ago that is ~+0.6 ε-units higher than obtained from the widely accepted CHUR value [2] also adopted by [4].

Here, we compare ^{147}Sm-^{143}Nd and ^{146}Sm-^{142}Nd data for lunar norite 78236 to those for ~4.54-4.56 Ga old cumulate eucrite Yamato 980318/433 and show that the norite data are compatible with its derivation from an isotopic reservoir similar to that from whence the eucrite pair came. Thus, lunar–like Sm-Nd isotopic systematics are not unique to the Earth-Moon system.

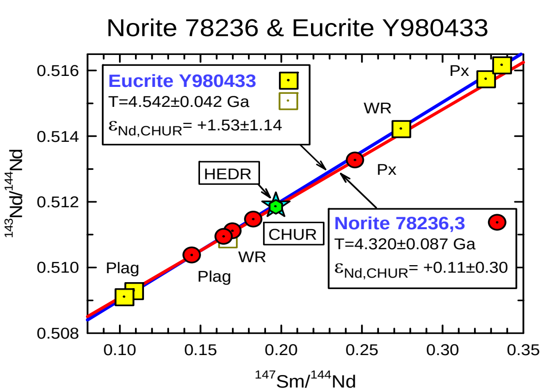

Figure 1. ^{147}Sm-^{143}Nd isochrons for norite 78236 and eucrite Y 980433. Isochron regressions by Isoplot [11].

Samples and analytical procedures: Sm-Nd analyses of lunar highland rocks suggest the rocks were derived from reservoirs with higher ^{143}Nd/^{144}Nd ratios than expected for evolution from CHUR. Sm-Nd analyses of eucrites also show that while the isotopic systematics of many are disturbed, those giving reliable ages indicate initial ^{143}Nd/^{144}Nd higher than CHUR. For example, cumulate eucrite Yamato 980318 gave a Sm-Nd age of 4567±24 Ma, and $\varepsilon_{Nd,CHUR}$ = 1.36±0.53[6]. To verify these results, we repeated the Sm-Nd analyses on paired sample Y980433. We also concurrently re-analysed lunar norite 78236 to provide a direct comparison between the Nd-isotopic systematics of these two samples, which are similar petrologically, and well-suited for Nd-isotopic analysis. Analytical procedures were standard for our group, except that Ce was quantitatively removed from Nd prior to isotopic analysis by a solvent extraction method [7].

^{147}Sm-^{143}Nd results: ^{147}Sm-^{143}Nd isochrons are shown for both norite 78236 and eucrite Y980433 in Fig. 1. The data for Y980433 reproduces the earlier data for Y980318. Analyses of 78236 are incomplete at this writing, but the isochron age is in agreement with earlier analyses of this norite and paired sample 78238. Fig. 1 shows that the Sm-Nd ages of Y980433 and 78236 are similar, but distinguishable.

Fig. 2 shows data useful for defining a "meteoritic" value of ^{143}Nd/^{144}Nd at 4568 Ma ago. In addition to the results for Y980318/433, Fig. 2 shows JSC data for "non-eucrite" Ibitira, the Efremovka CAI E38, and eucrite analyses from [3]. These data are used to define ε^{143}Nd for the HED Reservoir, HEDR, = +0.87±0.25

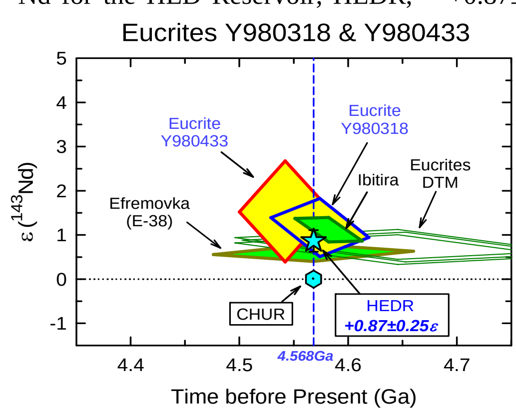

Figure 2. Initial ε^{143}Nd for the Y98 pair, Ibitira, and Efremovka CAI E-38 (JSC) and DTM data for eucrites (Boyet and Carlson, [3]).

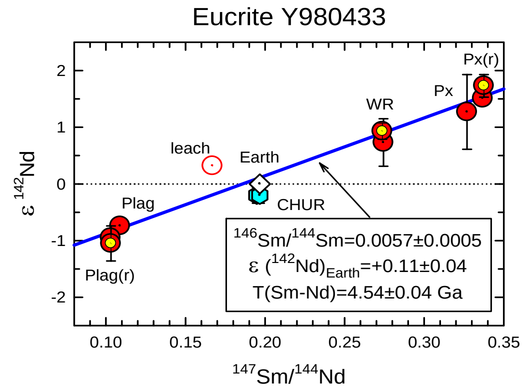

Figure 3. ε^{142}Nd analyses for spiked (red) and unspiked (yellow) samples of Y980433.

for ε^{143}Nd relative to CHUR. This value is essentially unchanged from [6], which shows an earlier data base. We call it HEDR because HED meteorites make up the majority of meteorites used in its definition, but data for other meteorite types are consistent with it (Fig. 2).

^{146}Sm-^{142}Nd results: Fig. 3 shows a ^{146}Sm-^{142}Nd isochron for Y980433. Several of the data are for spiked samples, a customary procedure in our group for less-critical samples. The data for spiked and unspiked samples are in complete agreement. The isochron (Isoplot regression) determines initial ^{146}Sm/^{144}Sm = 0.0057±0.0005 in agreement with ^{146}Sm/^{144}Sm = 0.0060±0.0008 for Y980318 [8]. For the more carefully and precisely determined value for Y980433, the calculated ^{146}Sm/^{144}Sm for CHUR at 4568 Ma is 0.0069±0.0005. Fig. 4 compares the ^{146}Sm-^{142}Nd isochron obtained for norite 78236 to that for Y980433. Using ^{146}Sm/^{144}Sm = 0.0069 at 4568 Ma ago, the ^{146}Sm-^{142}Nd age for 78236 is ~4.31 Ga, in agreement with its ^{147}Sm-^{143}Nd age. Determined ε^{142}Nd values are +0.11±0.04 (HEDR) and -0.16±0.05 relative to terrestrial standards at CHUR ^{147}Sm/^{144}Nd = 0.1967.

Discussion: Fig. 5 compares ε^{143}Nd and ε^{142}Nd for lunar norite 78236, FAN 60025, and Y86032 anorthositic lithologies ("An93 and An97 anorthosites" [9]) to HEDR and CHUR reference values. The simplest interpretation is that the lunar data are consistent with single-stage evolution from HEDR values between 4568 and ~4430 Ma ago for crustal anorthosites. Alternatively, for evolution from CHUR, two (or more) stages of Nd-isotopic evolution in a super-chondritic Sm/Nd reservoir are required by both the ε^{143}Nd and ε^{142}Nd data. For a two stage model, a value of μ (^{147}Sm/^{144}Nd) >~ 0.22 is required. This lower limit is constrained by the necessity to evolve from CHUR to the 60025 ε^{143}Nd and ε^{142}Nd values in ~140 Ma, and is similar to μ = 0.21 inferred for the EDR [3]. The upper limit shown in the figure is the maximum μ-value in-

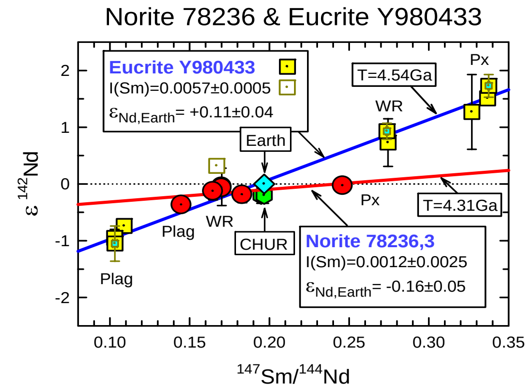

Figure 4. ε^{142}Nd for Y980318 (yellow), Y980433 (green), and lunar norite 78236 (red).

ferred for the lunar mantle for basalt Asuka 881757 by [1]. Its growth curve intersects the lunar evolution lines at ~50 Ma post-CAI, consistent with the Hf-W age for lunar formation of 62(+90/-10 Ma) [10].

Conclusions: Either (a) The Moon, HED meteorites, and accessible terrestrial samples came from reservoirs of super-chondritic Sm/Nd ratios, or (b) the CHUR reference values need revision, or (c) both of the above. Super-chondritic Sm/Nd ratios may result from solar system rather than terrestrial processes.

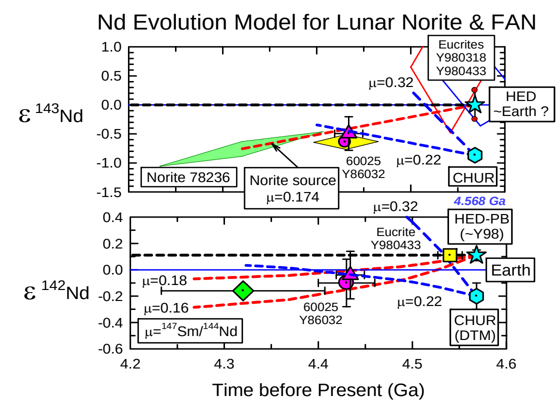

Figure 5. Initial ε^{143}Nd and ε^{142}Nd in lunar highlands rocks and model Nd-isotopic ingrowth curves.

References: [1] Nyquist L. E. et al. (1995) *GCA, 59,* 2817-2837. [2] Jacobsen S. B. and Wasserburg G. J. (1984) *EPSL 67*, 137-150. [3] Boyet M. and Carlson R. W. (2005) *Science 309*, 576-580. [4] Boyet M. and Carlson R. W. (2007) *EPSL*, *262,* 505-516. [5] Rankenburg K. et al. (2006) *Science 312*, 1369-1372. [6] Nyquist L. E. et al. (2004) *28th Symp. Antarctic. Met.* 66-67. [7] Rehkaemper M. et al. (1996) Chemical Geology, 129, 201-208. [8] Nyquist L. E. et al. (2007) *31st Symp. Antarctic. Met.* 80-81. [9] Nyquist L. et al. (2006) *GCA 70*, 5990-6015. [10] Touboul M. et al. (2007) *Nature 450*, 1206-1209. [11]Ludwig K. (2003) Isoplot software package.