Sm-Nd ISOTOPIC SYSTEMATICS OF FERROAN ANORTHOSITE (FAN) 62237: EVIDENCE FOR CO-MAGMATISM OF FANs AT 4.36 Ga. C. K. Sio[1*] and L. E. Borg[2], [1]Lawrence Livermore National Laboratory, 7000 East Ave L-231, Livermore, CA 94550; [*]sio2@llnl.gov.

Introduction: Thermal models for lunar magma ocean require that complete solidification of the Moon occurred within tens of million years of lunar formation [1]. Ferroan anorthosites (FANs) may be used to date this event as they are often interpreted to be the oldest lunar crust, formed after 80% solidification of the lunar magma ocean [2]. However, FANs are notoriously difficult to date as they are almost mono-mineralic, have low abundances of the parent and daughter isotopes, and experienced post-crystallization isotopic disturbances. The Sm-Nd isotopic systems are considered to be the least susceptible to disturbances but the reliability of some of the reported ages have been questioned by [3]. Recently, two FANs, 60016 and 60025, have been analyzed by our group using multiple chronometers and yielded the same solidification ages of 4.36 Ga [4, 5]. These ages require either a young age for lunar formation, or that FANs do not represent floatation cumulates of the primordial lunar magma ocean. Here, we report new Sm-Nd isotopic data for 62237 and discuss its relationship to 60016 and 60025.

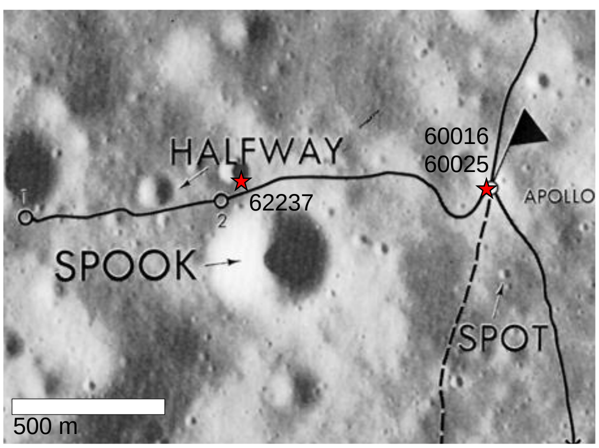

***Figure 1**. Geologic traverse (reprinted from NASA lunar photomap) of the Apollo 16 mission. Black flag shows the location of the lunar module. Red stars show locations where samples 62237, 60016, and 60025 were collected.*

Sample: Sample 62237 was collected at the southern rim of Buster Crater at Station 2, <1 km from the site where 60016 and 60025 were collected (Fig. 1). Sample 62237 is a troctolitic anorthosite comprising 83 vol.% plagioclase and 16 vol.% olivine with minor amounts of pyroxene and trace amounts of Cr-spinel, ilmenite, and troilite [6]. The low-Ca pyroxene composition ranges from En_{52} to En_{66} and plagioclase composition is between An_{95} to An_{99}, placing this sample in the compositional field of ferroan anorthosite [6], along with 60016 and 60025.

The Rb-Sr isotopic systematics for 62237 have been reported to be disturbaced but Sm-Nd ages have not been reported [7]. Sample 62236 is a paired sample of 62237; its age has been determined using the ^{147}Sm-^{143}Nd chronometer. The reliability of the data, however, was later questioned by [3]. Therefore, the Sm-Nd data reported in this study supersedes that of 62236.

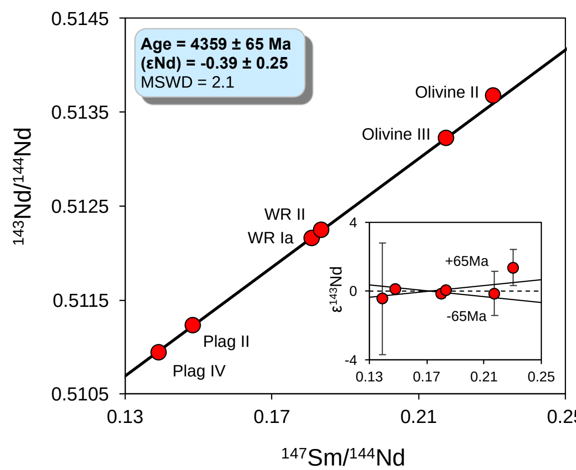

***Figure 2**. ^{147}Sm-^{143}Nd internal isochron for 62237.*

Methods: Plagioclase and olivine mineral separates were obtained using a Frantz magnetic separator, following by handpicking. Samples were spiked with a ^{149}Sm-^{150}Nd tracer allowing Nd isotopic composition and Sm-Nd concentration to be measured in the same fraction. An unspiked whole rock fraction was prepared for Sm isotopic analyses to correct for neutron capture effects. Purification of REE were achieved using AG 50W-X8 resin in 6M HCl and Sm and Nd were separated using pressurized quartz columns filled with AG 50W-X8 resin in NH_4 form using 0.2M α-HIBA (pH = 4.4).

As Sm and Nd concentrations were extremely low in 62237 (0.16 ppm Nd and 0.07 ppm Nd in plagioclase and olivine, respectively), samples were loaded with Ta_2O_5 on single zone refined Re filaments and analyzed as SmO+ and NdO+ on a Triton TIMS, taking advantage of the higher ionization efficiency of oxides. Isobaric interferences from CeO+, PrO+, GdO+ (SmO+ and NdO+, where applicable) were monitored and subtracted from beam intensities. The oxygen isotopic compositions were calculated so that Sm and Nd isotopic compositions of standards (AMES for Sm and LaJolla for Nd) ran as oxides and as metals give identical numbers. All data was fractionation corrected to ^{146}Nd/^{144}Nd = 0.7219 and ^{147}Sm/^{154}Sm = 0.659183 using the exponential law. Uncertainty of measurements are estimated based on repeat NdO+ isotopic analyses of LaJolla.

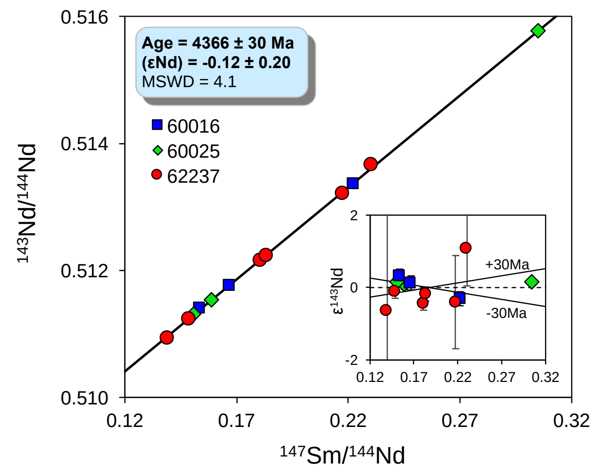

***Figure 3**. ^{147}Sm-^{143}Nd isochron defined by mineral and whole rock fractions of 62237, 60016, and 60025. Sm and Nd in 62237 were analyzed as oxides and those in 60016 and 60025 were analyzed as metals.*

Results and Discussion: Preliminary results suggest that 62237 solidified at 4359 ± 65 Ma with an initial ε^{143}Nd of -0.39 ± 0.25 (MSWD = 2.1; Fig. 2). This age and initial overlap with those previously determined for 60016 and 60025, further suggesting a young solification age of FANs. Sm-Nd isotopic data for all three samples fall on the same isochron defined by an age of 4366 ± 30 Ma with an initial ε^{143}Nd = -0.12 ± 0.20 (MSWD = 4.1; Fig. 3). The linearity defined by all data points suggests that these FANs were derived from the same slightly LREE-enriched source and co-solidified.

The petrogensis of these three FANs can be examined using their REE patterns collected from digested whole rock fractions (62237 from this study; 60016 from [8]; 60025 from [9]). The REE patterns for 60016 and 60025 are almost identical suggesting similar petrogenesis with different degrees of fractional crystallization (Fig. 4). This is unsurprising given the similar petrography and the proximity of these samples (they were collected 3 m apart). However, the REE pattern for 62237 shows more HREE enrichment, suggesting that it crystallized from a less evolved melt of the same parental magma.

It remains to be determined whether co-magmatism of FANs is a wide-spread or a localized event on the Moon. If all FANs were derived from the same parental magma and co-solidified, then their age would mark the timing of crystallization of the lunar magma ocean. On the other hand, if FANs were formed by localized processes such as serial magmatism [10] or prolonged tidal heating exerted from the early Earth [1], then the age presented in this study might only record the crystallization of a single magmatic body. Note that all three samples were collected <1 km apart (Fig. 1). In this case, these FANs are not products of the lunar magma ocean.

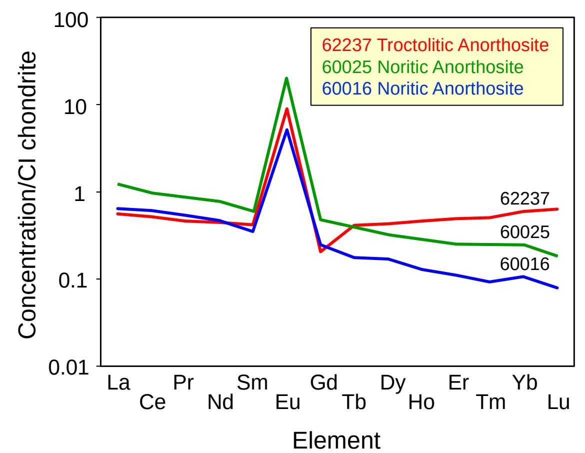

***Figure 4**. REE patterns for 62237, 60025, and 60016 (whole rocks).*

References: [1] Elkins-Tanton L. T. et al. (2011) *EPSL* 304, 326-336. [2] Snyder G. A. et al. (1992) *GCA* 56, 3809-3823. [3] Borg. L. E. et al. (2014) *MAPS*, 1-18. [4] Marks, N. et al. (2014) *LPSC Abstract* #1129. [5] Borg, L. E. et al. (2011) *Nature*, *477*, 70-72. [6] Dymek, R. F., et al. (1975) *LPSC Abstract* #2617. [7] Borg, L. E., et al. (1999) *GCA*, *63*, 2679-2691. [8] N. Marks. Unpublished. [9] Wiesmann, H. and Hubbard N. J. (1975) Unpublished. In Lunar Sample Compendium for 60025. [10] Shirley, D. N. A. (1983) *LPSC* A519-A527.

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