Rb-Sr AND Sm-Nd ISOTOPIC STUDIES OF LUNAR HIGHLAND METEORITE Y86032 AND LUNAR FERROAN ANORTHOSITES 60025 AND 67075. C.-Y. Shih[1], L. E. Nyquist[2], Y. Reese[1] and A. Yamaguchi[3], and H. Takeda[4], [1]Mail Code C23, Lockheed-Martin Space Operations, 2400 NASA Parkway, P.O. Box 58561, Houston, TX 77258-8561, chi-yu.shih1@jsc.nasa.gov; [2]Mail Code KR, NASA Johnson Space Center, 2101 NASA Parkway, Houston, TX 77058, l.nyquist@jsc.nasa.gov; [3]NIPR, Tokyo 173-8515, Japan, yamaguch@nipr.ac.jp; [4]Research Institute, Chiba Institute of Technology, Narashino, Japan, takeda@pf.it-chiba.ac.jp

Introduction: Lunar meteorite Yamato (Y) 86032 is a feldspathic breccia containing anorthositic fragments similar to ferroan anorthosite (FAN) clasts commonly found in Apollo 16 highland rocks [1-3]. Previous ^{39}Ar-^{40}Ar analyses of a grey anorthositic clast (,116 GC) in Y86032 revealed an old degassing age of 4.39±0.06 Ga [4], which is as old as crystallization ages of some FANs e.g. 60025, 67016 and 67215, as determined by the more robust Sm-Nd radiometric method [5-7]. The calculated initial ε_{Nd} value for the clast is –1.8±0.3 for the age [8]. The old age and its negative initial ε_{Nd} value indicate that Y86032 contains components of the primitive lunar crust related to the lunar magma ocean (LMO). We undertook further Rb-Sr and Sm-Nd isotopic investigation of three major lithologies in the meteorite as described in the mineralogical and petrological studies by [3]. ^{39}Ar-^{40}Ar analyses of these component lithologies are presented by [9] in this volume. Also, we analyzed two Apollo 16 FANs, 60025 and 67075, to compare their ages and isotopic signatures to Y86032. Y86032 probably came from a feldspathic highland terrane (FHT) on the northern farside highlands [10], a locality not sampled by the Apollo and Luna missions.

Samples: Fragments of light-grey lithology (,28 LG) weighing ~292 mg, dark-grey lithology (,44 DG) weighing ~205 mg and impact melt (,33 IM) of ~57 mg from Y86032 were allocated for this study. Powdered samples of lunar cataclastic anorthosites 60026,9002 and 67075,53 were also studied. The ,28 LG and ,44 DG samples were crushed to grain size <149 µm. Bulk rock samples were taken before the rest of the samples were further crushed and sieved for mineral separations. In this report, three bulk lithology samples from Y86032, one plagioclase sample separated from ,28 LG, and two bulk rock samples from 60025 and 67075 were analyzed for Rb, Sr, Sm, and Nd following the chemical procedures of [11] and using Finnigan-MAT 261 or 262 mass spectrometers. Analyses of mineral separates from lithologyies ,28 and ,44 are in progress. Measurements of Sm isotopic compositions for aliquants of samples of Y86032,116 GC [8], 60025 and 67075 do not show significant neutron capture effects for these three rocks.

Rb-Sr isotopic results: The ^{87}Rb/^{86}Sr and ^{87}Sr/^{86}Sr data for five Y86032 samples (circles) including ,116 GC and ,116 matrix from our earlier study [8] are shown in Fig 1. Four Y86032 samples lie close to the reference lunar FAN isochron age of T=4.6±0.9 Ga for $\lambda(^{87}Rb)=0.01402\ Ga^{-1}$ and I(Sr) of 0.699066±43 (solid line), defined by seven plagioclase data from four A-16 FANs (squares) [5-7,12]. Rb-Sr isotopic data clearly indicate that Y86032 is closely related to FANs and contains materials formed during early differentiation of the LMO. The impact melt sample ,33 lying to the far right of the isochron may have gained Rb during its formation. Including the four Y86032 data, the FAN isochron age and I(Sr) becomes 4.7±0.4 Ga and I(Sr)=0.699060±23, respectively. This isochron probably represents the time of the LMO formation and can be used to estimate the lunar initial ^{87}Sr/^{86}Sr. These lunar FAN samples are consistently more evolved than their eucrite counterparts represented by the reference isochron of T=4.44±0.17 Ga and I(Sr)=0.699004±9 (dotted line), defined by eleven plagioclase data from ten eucrites (triangles) studied in this lab [13]. The dashed line shows our reference isochron for CAI E38 of Efremovka using its Sm-Nd age [13]. Efremovka, a CV-type C-chondrite similar to Allende. Its CAI E-38 gives an I(Sr) of 0.698934±15, which is within errors of I(Sr), 0.69892±2, reported for Allende CAI's in [14].

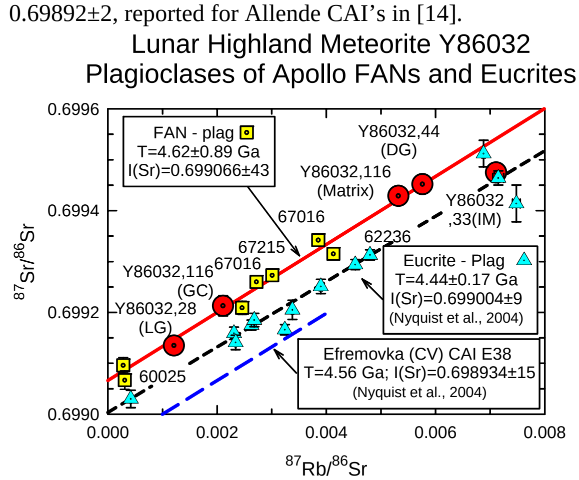

Figure 1. Rb-Sr data for Y86032 samples and FAN and eucritic plagioclases.

Sr isotopic evolution and timescale of lunar formation: Fig. 2 shows the correlation of ^{87}Sr/^{86}Sr and formation time interval ΔT as functions of parent reservoirs with various ^{87}Rb/^{86}Sr ratios. Thick dotted lines represent Sr-isotopic growth curves corresponding to ^{87}Rb/^{86}Sr ratios of ~1.04 (EH, enstatite chondrites), ~0.26 (C-chondrite, CV-type) and ~0.084 (Earth) from the solar system initial ^{87}Sr/^{86}Sr ratio of 0.698934 resembling CAI E-38 from Efremovka (CV). The intersections (circles) of the estimated lunar initial ^{87}Sr/^{86}Sr ratio of 0.699069 (at 4.56 Ga) with these growth curves yield the possible formation time intervals for the Moon. In the context of lunar origin by the giant impact hypothesis, a single-stage evolution of the Sr isotopic composition is most consistent with a CV-type reservoir, for which ~35 Ma of evolution is required. A similarly rapid timescale (20-40 Ma) for lunar formation was proposed recently using the short-lived Hf-W system [15,16]. A longer time of ~105 Ma is needed if the lunar Sr originated from an Earth-like $^{87}Rb/^{86}Sr$ reservoir prior to the giant impact. However, a more complex multi-stage Sr isotopic evolution is also permissible. Fig. 2 shows a first stage of proto-lunar evolution in a high $^{87}Rb/^{86}Sr$ EH-like reservoir for ~6 Ma (open diamond), and follows by a second stage of evolution in an Earth-like reservoir for ~30 Ma (thin dotted line).

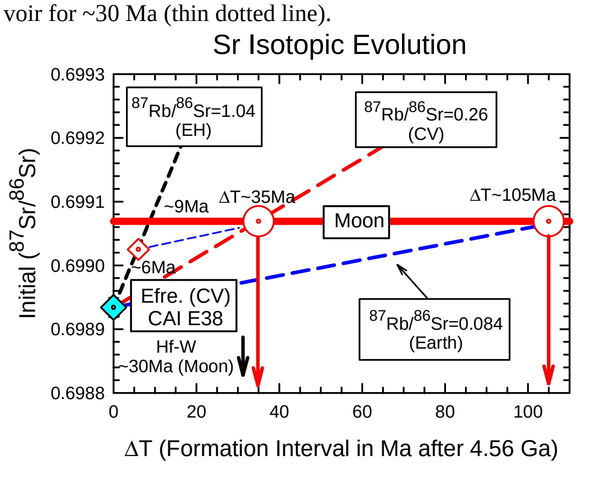

Figure 2. Sr isotopic evolution in Earth-Moon system.

Sm-Nd isotopic results: Fig. 3 shows $^{147}Sm/^{144}Nd$ and $^{143}Nd/^{144}Nd$ data of five bulk rock samples (,44 DG, ,28 LG, 33 IM, 116 GC[8] and ,116 matrix[8]) and one plagioclase (,44 Plag) sample for Y86032. Two ,44 and one ,28 samples define a tie-line corresponding to an age of 4.55±0.17 Ga for $\lambda(^{147}Sm)=0.00654\ Ga^{-1}$. This age is in agreement with the old Rb-Sr age for Y86032 bulk samples. The corresponding initial ε_{Nd} value is very primitive, -0.38±0.40, relative to HED PB [12], the updated JSC CHUR reference. Two samples ,116 GC and ,33 IM plot significantly below the tie-line and on a 4.39 Ga isochron calculated for the ,116 GC ^{39}Ar-^{40}Ar age [4] with a distinctly negative ε_{Nd} value of -1.8±0.3,. The ,116 matrix sample does not lie on neither isochron. Its isotopic systematics probably were reset by impact. Thus, our Sm-Nd isotopic data also suggest that the meteorite is a complicated breccia [3]. It contains some very old anorthositic components probably formed in the LMO and some components that underwent complex brecciations [4,9]. The 60025 bulk rock sample plots near the 4.55 Ga isochron, but, the 67075 sample lies to the far left of the 4.55 Ga isochron. Both samples plot outside the scale of the figure.

Petrogenetic implications: The ε_{Nd}-values and age data for Y86032 and Apollo 16 FANs and KREEP basalts are summarized in Fig. 4. The 67075 bulk sample has a highly positive ε_{Nd} value of ~+8 for its ^{39}Ar-^{40}Ar age of 3.98±0.05 Ga [17]. It and 62236 [12] were probably derived from comparatively young LREE-depleted sources, not related to the LMO. Our 60025 bulk sample, and Y86032,44DG and ,28LG data plot near the KREEP evolution line of $^{147}Sm/^{144}Nd$ = ~0.17. A REE model calculation shows that the ,28 LG sample can be a plagioclase cumulate, with ~5% trapped liquid, crystallized from an LMO having $^{147}Sm/^{144}Nd$ =~0.18 after ~94% differentiation. However, high $^{147}Sm/^{144}Nd$ of ,116GC and ,33IM, can not be produced from a melt with $^{147}Sm/^{144}Nd$ = ~0.12, as indicated by its negative ε_{Nd} value at ~4.39 Ga by a similar plagioclase accumulation process, suggesting an older primary crystallization age.

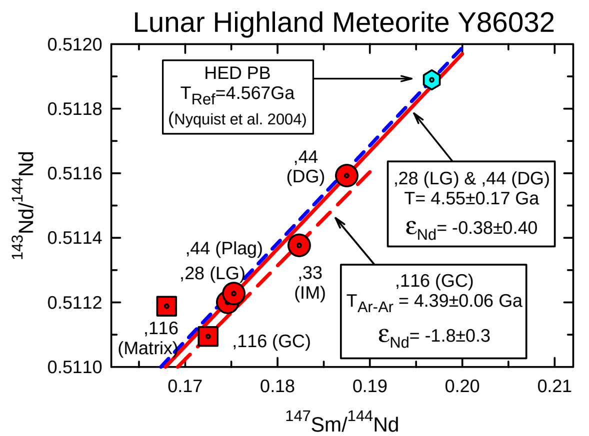

Figure 3. Sm-Nd data for Y86032 samples.

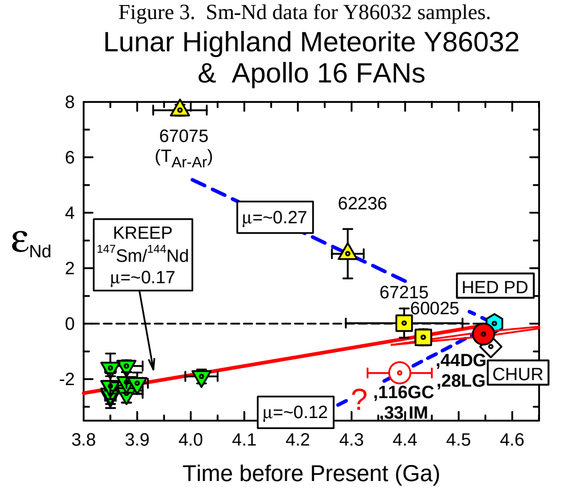

Figure 4. ε_{Nd} vs. T(age) for Y86032, FANs, and KREEPs.

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