Sm-Nd AND Ar-Ar STUDIES OF DHO 908 AND 489: IMPLICATIONS FOR LUNAR CRUSTAL HISTORY. L. E. Nyquist [1,6], C.-Y. Shih[2], Y. D. Reese[3], J. Park[4], D. D. Bogard[4], D. H. Garrison[2], A. Yamaguchi[5]. [1]KR/NASA Johnson Space Center, Houston, TX 77058. E-mail: laurence.e.nyquist @nasa.gov. [2]ESCG Jacobs-Sverdrup, Houston, TX 77058. [3]Mail Code JE-23, ESCG/Muniz Engineering, Houston, TX 77058. [4]Lunar and Planetary Institute, 3600 Bay Area Blvd. Houston, TX 77058, [5]National Institute of Polar Research, Tachikawa, Tokyo, 190-8518, Japan. [6]Center for Lunar Science and Exploration, NASA Lunar Science Institute.

Introduction: It is widely assumed that ferroan anorthosites (FANs) formed as flotation cumulates on a global lunar magma ocean (LMO). A corollary is that all FANs are approximately contemporaneous and formed with the same initial $^{143}Nd/^{144}Nd$ ratio. Indeed, a whole rock isochron for selected FANs (and An93 anorthosite [1]) yields an isochron age of 4.42±0.13 Ga and initial $^{143}Nd/^{144}Nd$, expressed in ε-units, of $\varepsilon_{Nd,CHUR}$ = 0.3±0.3 relative to the CHondritic Uniform Reservoir [2], or $\varepsilon_{Nd,HEDPB}$ =-0.6±0.3 relative to the HED Parent Body [3]. These values are in good agreement with the age (T) = 4.47±0.07 Ga, and $\varepsilon_{Nd,HEDPB}$ =-0.6±0.5 for FAN 67075 [4,5]. We also have studied anorthositic clasts in the Dhofar 908 and 489 lunar highland meteorites containing clasts of magnesian anorthosites (MAN) with Mg# ~75 [6]. Because of their relatively high Mg#, magnesian anorthosites should have preceded most FANs in crystallization from the LMO if both are LMO products. Thus, it is important to determine whether the Nd-isotopic data of MAN and FAN are consistent with a co-magmatic origin. We previously reported Sm-Nd data for white clast Dho 908 WC [7]. Mafic minerals in this clast were too small to be physically separated for an isochron. However, we estimated initial $^{143}Nd/^{144}Nd$ for the clast by combining its bulk ("whole rock") Sm-Nd data with an ^{39}Ar-^{40}Ar age of 4.42±0.04 Ga. Here we report additional Sm-Nd data for bulk samples of Dho 908 and its pair Dho 489.

Sm-Nd data for Dho 908 clast and 908/489 matrix: The new data for bulk matrix and leached samples

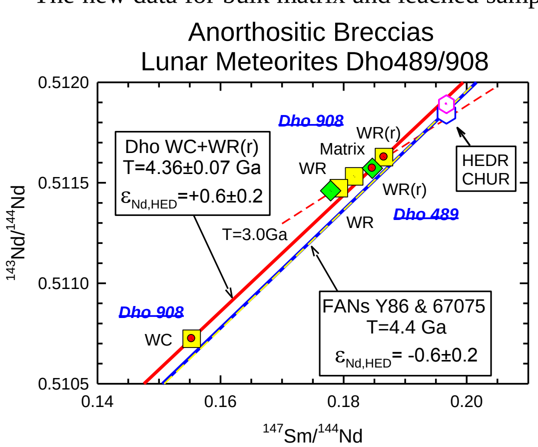

Fig. 1. Sm-Nd data for subsamples of Dho 908 and 489 compared to an ~4.4 Ga reference isochron determined for FAN 67075 [4] and anorthositic clasts in Y86032.

of Dho 908 and 489 are shown in Fig. 1. The samples contain lithic and mineral fragments including olivines and orthopyroxenes with Mg# in the range ~75 to ~85, in addition to plagioclase fragments. With the assumption that these are fragments from co-magmatic anorthosites and troctolites, the residues after leaching define an isochron for an age, T = 4.36±0.07 Ga and $\varepsilon_{Nd,HEDPB}$ = +0.6±0.2. These values are compared to those for lunar anorthositic rocks (Fig. 2).

Variable (T,ε_{Nd}) among lunar anorthosites: Values of (T, ε_{Nd}) for lunar anorthosites as determined in our lab show both "nominal" and "anomalous" characteristics. "Nominal" characteristics can easily be ascribed to Nd-isotopic evolution in the LMO prior to anorthosite crystallization, assuming closure of the Sm-Nd system can be delayed until ~100-150 Ma after formation of the earliest solar system solids. Here we define nominal characteristics as those given by the parameters of the 67075 internal isochron [4] in Fig. 2 (yellow triangle). Internal isochron data for several other lunar anorthosites (60025, Y-86032, 67215) are consistent with these nominal parameters. Moreover, the T = 4.42±0.13 Ga whole rock isochron for 10 FANs also are in agreement. These data define a uniquely lunar reference datum, but one for a later time than usually assumed for planetary "initial" isotopic paramaters. However, there also are a number of lunar anorthosites yielding "anomalous" (T, ε_{Nd}) parameters. The customary interpretation of such data is that they

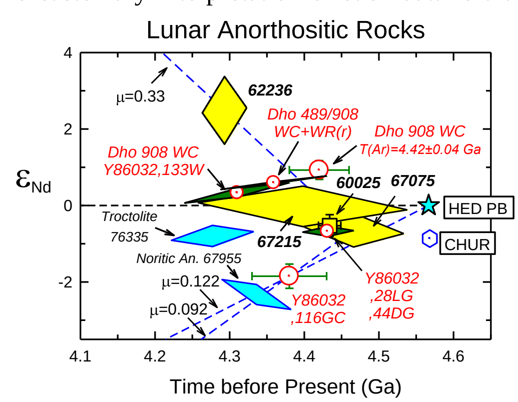

Fig. 2. (T, ε_{Nd}) diagram for lunar anorthositic rocks including troctolite 76335. The location of the Dho 908 WC anorthositic clast is shown for its ^{39}Ar-^{40}Ar age and also for assumed "isochrons" with bulk rock samples after leaching, and with also with samples of anorthositic clast Y86032,133W[1].

require "source regions" with compositions varying from LREE-depleted, as for 62236, to LREE-enriched as for the Y86032,116 GC. (T, ε_{Nd}) of Dho 908WC also appears to be "anomalous" by ~1 ε-unit at a given age relative to the nominal value. Moroever, this appears to be a common lunar feature shared by the Y86032,133 "white clast" [1] as well as by the troctolitic components of the Dho 908 and 489 matrices. We attribute these features to troctolitic anorthosites poorly represented among the Apollo anorthosites.

Occurence of troctolitic anorthosites: Troctolites *per se* are relatively rare among large samples of the Apollo collection, but olivine grains and grain fragments frequently occur in the matrices of lunar highland meteorites as well as in Apollo highland breccias. Fig. 3 characterizes some ANT (anorthosite, norite, troctolite) suite samples in terms of their plagioclase, olivine and pyroxene compositions using the summary compilation in the Lunar Sample Compendium [8]. Troctolite 76535, norite 78235, and anorthosite15415 define end-member compositions for the plotted samples. 76335, 67075, and 62237 have higher plagioclase abundances and higher olivine/pyroxene ratios than 76535; essentially troctolitic anorthosite compositions. The large plagioclase grain size of the Apollo anorthosites in comparison to the areas of typical polished thin sections (PTSs), plus the rarity of mafic minerals in the anorthosites make determining the mafic mineral abundances and the ol/px ratio very uncertain for them. However, mafic minerals, and in particular, olivine, has been observed in the PTSs of several. These observations correspond to our experience with some samples of lunar highlands meteorites, notably the Dho 489 family and Y-86032.

Also plotted in Fig. 3 are the compositions of central peaks of several large lunar craters from the compilation of [9]. Among five crater central peaks that are particularly anorthite-rich (data encircled), two have

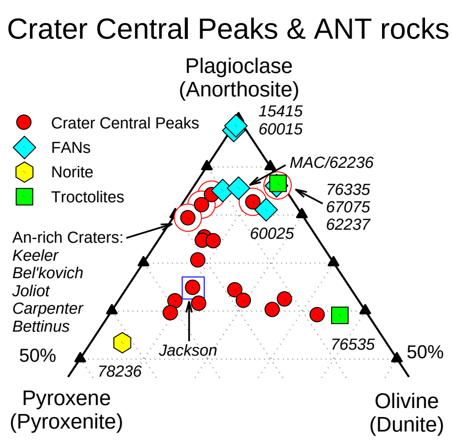

Fig. 3. Olivine and pyroxene abundances for lunar anorthositic samples and crater central peaks [9].

olivine enriched over pyroxene, and one (Keeler) has a composition nearly identical to that of 76335, etc. We use Clementine data [9] instead of the higher spatial resolution Kaguya data [10] to show "average" peak compositions. The Kaguya authors emphasized the presence of "purest anorthosite" (PAN) in their central peak data, for example, of the Jackson central peak [10]. Their data show an impact melt cap on the Jackson central peak containing ~10-20% opx. Without the impact melt cap, the Jackson datum (open blue square in Fig. 3) moves to the ~98% plagioclase composition of 15415 [10]. Similar considerations probably apply to other central peak compositions.

^{39}Ar-^{40}Ar ages: Apollo vs. lunar meteorites: ^{39}Ar-^{40}Ar ages of ~4.26 Ga were obtained both for the MAN clast in Dho 489 [6], and for a matrix sample of paired Dho 908 [7]. This age likely dates a major impact event, probably on the lunar farside. Highland meteorites seem to have retained somewhat older ages than Apollo ANT suite rocks (Fig. 4).

Concluding remark: J. Meyer et al. [11] argue that evolution of the lunar eccentricity and inclination could have led to tidal heating and prolonged thermal effects in the initial lunar anorthositic crust. This work may provide a promising context in which to evaluate the "anomalous" (T, ε_{Nd}) values of some anorthosites.

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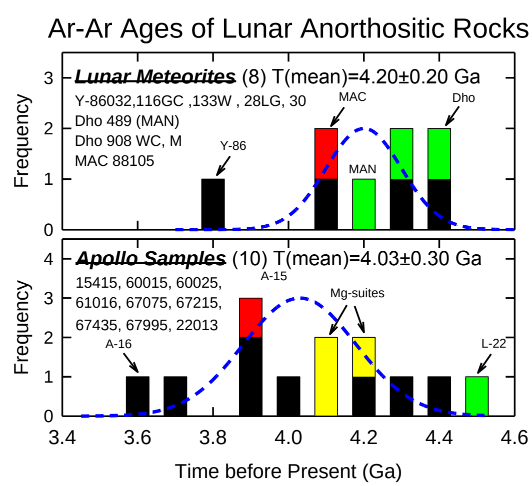

Fig. 4. Ar-Ar ages of lunar highland samples.