LUNAR METEORITES AND THE LUNAR CRUSTAL Sr AND Nd ISOTOPIC COMPOSITIONS: L.E. Nyquist¹, H. Wiesmann², C.-Y. Shih³, and J. Dasch³. Code SN41, NASA Johnson Space Center, Houston, TX, 77058,²Lockheed-Martin Engineering and Sciences Co., 2400 NASA Road 1, Houston, TX 77258, ³Code FEH, NASA HQ, Washington, DC.

We have analyzed lunar meteorites QUE93069 (bulk), MAC88105, (clast W1) and Y86032 (matrix and clast) for $^{87}$Sr/$^{86}$Sr and $^{143}$Nd/$^{144}$Nd isotopic ratios, as well as for Rb, Sr, Sm, and Nd concentrations. The maximum $^{87}$Rb/$^{86}$Sr value for the samples is -0.013 as found for QUE93069. $^{87}$Rb/$^{86}$Sr ratios of these lunar meteorites are less than those of most pristine norites and other Mg-suite rocks, and overlap the range for pristine ferroan anorthosites. The low values of $^{87}$Rb/$^{86}$Sr are consistent with the absence of a KREEP component, as has been concluded from prior geochemical investigations. On a Rb-Sr isochron diagram, the data form a good linear array which is best interpreted as a mixing line. The best fit linear regression has a slope of 0.068, within 3% of that of a reference isochron for a 4.56 Ga age. The ordinate intercept for the best fit line is $^{87}$Sr/$^{86}$Sr = 0.699083 ± 0.000053, identical within error limits to initial $^{87}$Sr/$^{86}$Sr = 0.699078 ± 0.000015 derived from data reported for ferroan anorthosite 60025 at ~4.4 Ga [1]. A similar initial $^{87}$Sr/$^{86}$Sr = 0.69907±0.00002 for pristine norite 78236 at 4.34 Ga ($\lambda$($^{87}$Rb) = 0.01402 x 10$^{-11}$ yr) [3] was reported by [2]. This value of $^{87}$Sr/$^{86}$Sr apparently characterized the lunar crust ~4.4 Ga ago, and is elevated relative to the initial $^{87}$Sr/$^{86}$Sr in angrite meteorites [4,5].

$^{143}$Nd/$^{144}$Nd and $^{147}$Nd/$^{144}$Nd ratios of the lunar meteorites are nearly identical to those for pristine norites, and lower than values for those ferroan anorthosites for which high precision data have been reported [1,6].

**Samples:** MAC88105 clast W1 is an unusually large clast described as a coarse-grained, highly anorthositic impact melt breccia [7,8] composed of ~85% plagioclase, 10% medium-Ca pyroxene, 5% olivine, and traces of opaques [7]. Compositional data for subsamples [54 and 55, adjacent to our subsample 53, have been reported [7,8]. Y86032 has been described as a feldspathic fragmental breccia containing almost no regolith component [9,10]. Our subsample 116 consisted of a dark grey clast (GC) in a darker matrix (M). Both lithologies were sampled. Compositional data for Y86032 were reported by a number of investigators [9,11,12]. U-Pb isotopic data for Y86032 were reported by Tatsumoto and Preemo [13], who concluded that its Pb isotopic composition was similar to that of anorthositic lunar rocks like 60025. QUE93069 is a regolith breccia which is very similar in composition to the MAC88104/105 breccias [14]. We analyzed a bulk sample consisting of numerous mm-sized white clasts in a dark matrix.

**Rb-Sr Data:** Rb-Sr data for the lunar meteorites are shown in an isochron diagram in Fig. 1. Data for a number of pristine lunar rocks are shown for comparison. This comparison is illustrative rather than exhaustive, data from the JSC lab have been emphasized to avoid uncertainties due to interlab biases. Data for norites, an anorthositic norite, a spinel troctolite, and a troctolitic anorthosite from [15], and for norite 78236 from [16] are shown as open squares, with the exception of 78236, shown as a grey square. $^{87}$Rb/$^{86}$Sr ratios for these Mg-suite samples are equal to or greater than that for the crustal average composition from Palme [9], shown as a vertical line. Data for plagioclase from ferroan anorthosite 60025 are shown as a reference for lunar highland samples with Rb/Sr ~0, data for ferroan or anorthosites 67016 [6] and 62236 [19] are shown as examples of ferroan rocks of higher Rb/Sr ratio. Rb/Sr for regolith breccia QUE93069 is similar to the crustal average, the other lunar meteorites plot at significantly lower $^{87}$Rb/$^{86}$Sr, suggesting that the crustal compositions in their source areas contain a greater proportion of ferroan than Mg-suite rocks. The grey clast from Y86032 has the lowest Rb/Sr ratio of the lunar meteorites studied here. The data for this sample control the $^{87}$Sr/$^{86}$Sr intercept of the regression line, which is within error limits of the value measured for 60025. Thus, the Rb-Sr isotopic data for this sample are consistent with the U-Pb data [13] in resembling data for 60025. The best fit line is best considered to be a mixing line between the ferroan anorthosite and Mg-suite components of the lunar crust. Its slope is similar to that of a 4.56 Ga reference isochron through the angrite initial $^{87}$Sr/$^{86}$Sr (Fig. 1) and corresponds to an age of 4.74±0.49 Ga. Interestingly, the Rb-Sr systematics of ferroan noritic anorthosite 67016,328 (grey circle) are very similar to those of MAC88105,53 and Y86032 matrix. The Sm-Nd age of sample 67016,328 is
4.56±0.07 Ga [6]. Ferroan noritic anorthosites like 67016 have been suggested to be a major component of the lunar crust [17]. Since the Rb-Sr data of the lunar meteorites are similar to those for 67016, they may be considered to be consistent with that suggestion.

Sm-Nd Data: Sm-Nd data for the lunar meteorites are shown in an isochron diagram in Fig. 2. At this writing, the $^{147}\text{Sm} / ^{144}\text{Nd}$ data require a small correction for lunar neutron irradiation effects, and in that sense are preliminary. Nevertheless, some general conclusions are apparent. First, all the lunar meteorite samples have sub-chondritic Sm/Nd ratios, and, second, their Sm-Nd isotopic data are well matched by those of the pristine norites. (Compare the data for 78236 (grey square) in Fig. 3 to those for the lunar meteorites (black squares). Other norite data are obscured by the meteorite data.) It is probable that $^{147}\text{Sm} / ^{144}\text{Nd} = 0.172-0.175$ for these two types of materials better reflects the lunar crust than $^{147}\text{Sm} / ^{144}\text{Nd} = 0.194$ as derived from the “crustal average” proposed by Palme et al. [9]. The latter is close to the Chondritic Uniform Reservoir (CHUR) value [18], and also to that for ferroan noritic anorthosite 67016,328.

Although the “crustal average” of [9] was derived from lunar meteorite data, it is probably inaccurate in regard to the Sm/Nd ratio. The analysis of many highland rocks by mass spectrometric isotope dilution analysis (cf. [20]) shows that the LREE including Nd in such rocks are most often enriched relative to chondritic abundances.

Discussion: The Sm-Nd systematics of the lunar highland meteorites studied here are much better matched by those of the Mg-suite rocks than by those of the ferroan anorthosites for which high precision data are available, the reverse of the Rb-Sr situation. It seems likely that the isotopic data shown in Fig. 2 for ferroan anorthosites are affected by sampling biases, however, and that the Nd-isotopic compositions of such rocks also are more typically sub-chondritic. If this is not the case, it is difficult to reconcile the lunar meteorite data with a mixture of known ferroan and Mg-suite rocks, since the present Rb-Sr and Sm-Nd isotopic data would require different proportions of the end member components. Data for three of the four lunar meteorites fall along a reference 4.56 Ga isochron calculated from data for the LEW86010 angrite [4], and thus suggest very early differentiation of the lunar crust from a magma ocean presumed to have chondritic relative abundances of the REE. This conclusion is tentative until the $^{147}\text{Sm} / ^{144}\text{Nd}$ data are finalized, however. Finally, an elevated $^{87}\text{Sr} / ^{86}\text{Sr}$ ratio for lunar anorthosites at ~4.4 Ga allows calculation of a bulk-moon $^{87}\text{Rb} / ^{86}\text{Sr}$ ratio. $^{87}\text{Sr} / ^{86}\text{Sr} = 0.70408$ at 4.44 Ga ago, for example, would require a bulk moon $^{87}\text{Rb} / ^{86}\text{Sr}$ ratio of 0.056 for evolution from the angrite value of 0.70408 [4,9] at 4.56 Ga ago. Additional high precision Sr and Nd-isotopic data obtained with modern techniques are required to clarify the chronology and processes of lunar crust formation.

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