KEEPING UP WITH THE LUNAR METEORITES.

R. L. Korotev and R. A. Zeigler. Campus Box 1169, Department of Earth and Planetary Sciences, Washington University, Saint Louis MO 63130, korotev@wustl.edu

At this writing, we are aware of 104 lunar meteorite stones, 97 of which have names that have been accepted by the Nomenclature Committee of the Meteoritical Society (2 provisionally) and 7 without accepted names that have nonetheless been described in the literature [1] or that we have recently analyzed and know to be of lunar origin (*N*=6). At least 8 other alleged lunar meteorite stones are in the hands of reputable dealers and collectors. Ignoring the latter, the known lunar meteorite stones represent as many 46 meteorites and probably not less than about 35. We have obtained compositional data by INAA for 192 subsamples of 31 lunar meteorite stones since our last reports here [2–7]. Some of the data are reported elsewhere [8–14].

New Meteorites and Analyses: Basalt MIL 05035 (Fig. 1) is compositionally similar to Yamato 793169 (¥ in Fig. 2) and Asuka 881757 ($); it is likely source-crater paired with these Antarctic stones [14]. Dhofar 1428 (L) [8], NWA 2200 (s), NWA 2995 (m) [8], and NWA 2998 (n) are feldspathic breccias. With only 2.7% FeO, NWA 2998 is marginally the most feldspathic of lunar meteorites. Dhofar 1180 (K) [8] is one of several breccias with 9–10% FeO; all the others have higher concentrations of incompatible elements, however (Fig. 2). NWA 4472 and NWA 4485 [12] are paired stones of unique composition. LAP 04841 is compositionally indistinguishable from the other LAP basalts [15] and the NWA 479 [16] basalt is indistinguishable from paired stone NWA 032.

The "regolith breccia" lithology of Dhofar 287 (D) [17] is highly dissimilar in composition to the basalt lithology [18] and, in fact, to any Apollo regolith (Figs. 2,3). Likewise, the breccia portion of NEA 003 (f) [19] is dissimilar to the basalt portion [3] and curiously rich in iron (Fig. 2). On the basis of mass-balance constraints, the regolith breccia portion of SaU 169 [20] contains, at most, only 20% of the impact-melt-breccia lithology. Thus, among the four di- or multi-lithologic lunar meteorites (all of which can be interpreted as small breccias with one or more large clasts), only the components of the NWA 773 clan appear closely related to each other [2, 9,11,13].

Observations: Lunar meteorites provide a different sampling of the Moon than rocks of the Apollo missions. Many of the compositional differences between lunar meteorites and Apollo rocks reflect the geochemical asymmetry of the Moon, the proximity of the Apollo sites to the anomalous PKT (Procellarum KREEP Terrane [21]; Fig. 3), and the (presumably) random distribution of meteorite source craters compared to Apollo landing sites [22]. For example, a large number of Apollo samples (those often identified as "LKFM" or "KREEP") have noritic compositions (8–12% FeO) and high concentrations of incompatible elements (>10 µg/g Sm; Fig. 3). Such a composition is consistent with the PKT, as we infer it from orbital data. Nearly all such Apollo samples are either impact-melt breccias or regolith breccias containing a large proportion of impact-melt breccia. Such rocks are uncommon among lunar meteorites (only SaU 169 [20], NWA 4472/4485 [12], Dhofar 925/961[5], and possibly Calcalong Creek [23], a regolith breccia). Nonmare, polymict samples from the Apollo collection largely reflect mixing (Imbrium? Serenitatis?) between the PKT and the FHT (Feldspathic Highlands Terrane [21]), although many also contain some mare basalt. Breccias that are composed of subequal mixtures of anorthosite and basalt, yet are uncontaminated by PKT material, are rare in the Apollo collection but are not uncommon among the lunar meteorites (Fig. 3). None of the lunar meteorites are mixtures of Sm-rich, noritic melt breccia and mare basalt as, for example, are the soils of Apollo 12 (Fig. 3).

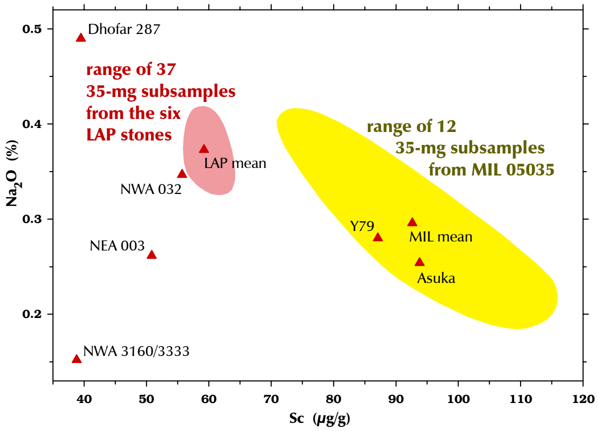

Figure 1. Comparison of compositions of basaltic lunar meteorites. MIL 05035 is so coarse-grained that it would require 8- and 22-g samples to reduce the relative standard deviation in Sc and Na concentrations among such samples to 1% [24]. LAP [15] is much finer grained and small subsamples thereof are much more similar to each other in composition.

Although half of the lunar meteorites originate from the FHT and are highly feldspathic (70–85 % normative feldspar), none are as feldspathic and poor in incompatible elements as are any of several hand-sized ferroan anorthosites of Apollo 15 and 16 (>95% plagioclase) and many of the small samples of Fig. 3 (i.e., those with <2% FeO and <0.5 µg/g Sm). Also, as we have noted elsewhere [10], the feldspathic lunar meteorites are more magnesian (greater Mg/Fe), on average, than is ferroan anorthosite. These observations suggest that ferroan anorthosite, as it is known from the Apollo collection, may not be as common a constituent of the feldspathic crust as generally assumed.

Some basaltic lunar meteorites have been described as "KREEPy." Such claims are misleading in that none is particularly rich in incompatible elements compared to Apollo mare basalts, e.g., none are as rich in Sm as are most basalts from Apollo 11 and some from Apollos 14, 15, and 17 (Fig. 3).

Assuming that about 5% of the lunar surface lies within the South Pole-Aitken basin [21] and the lunar meteorites represent 35+ source craters, it is likely that one or two of the known but yet-unidentified meteorites originates from within the basin.

Acknowledgement: Thanks to T. E. Bunch, A. J. Irving, M. Farmer, and P. C. Mani for samples of some meteorites. This work was funded by NASA grant NNG04GG10G.

References: [1] Yanai K. (2000) *LPS 31* #1101. [2] Bunch T. E. et al. (2006) *LPS* 37 #1375. [3] Haloda J. et al. (2006) *LPS 37* #2269. [4] Irving A. J. et al. (2006) *LPS 37* #1365. [5] Korotev R. L. (2006) *LPS 37* #1404. [6] Korotev R. L. (2006) *LPS 37* #1402. [7] Zeigler R. A. et al. (2006) *LPS 37* #1804. [8] Bunch T. E. et al. (2006) 69th Met. Soc. #5254. [9] Zeigler R.A. et al. (2006) *Antarctic Meteorites XXX*, 125–126. [10] Korotev R. L. et al. (2006) *GCA* **70**, 5935–5956. [11] Jolliff B. L. (2007) *LPS 38.* [12] Kuehner S.M. et al. (2007) *LPS 38.* [13] Zeigler R. A. et al. (2007) *LPS 38* (NWA 773 et al.). [14] Zeigler R. A. et al. (2007) *LPS 38* (MET/MIL). [15] Zeigler R. A. et al. (2005) *M&PS* **40**, 1073–1102. [16] Barrat J. A. et al. (2005) *GCA* **69**, 5597–5609. [17] Demidova S. I. et al. (2003) *M&PS* **38**, 501–514. [18] Anand M. et al. (2003) *M&PS* **38**, 485–499. [19] Haloda J. et al. (2006) *LPS 37* #2311. [20] Gnos E. et al. (2004) *Science* **305**, 657–659. [21] Jolliff B. L. et al. (2000) *JGR* **105**, 4197–4416. [22] Korotev R. L. (2005) *Chemie der Erde* **65**, 297–346. [23] Hill D. H. & Boynton W. V. (2003) *M&PS* **38**, 595–626. [24] Ingamells C. O. & Switzer P. (1973) *Talanta* **20**, 547–568. [25] Jolliff B. L. et al. (1996) *M&PS* **31**, 116–145.

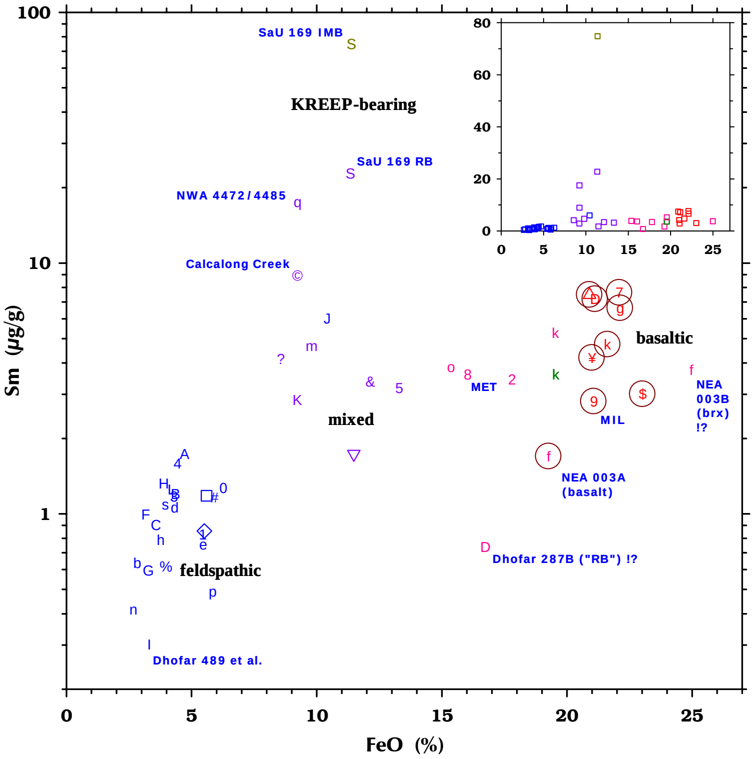

Figure 2. Compositions of 45 lunar meteorites. Each "point" represents a meteorite (all stones for which there are data) or a lithology in a meteorite for those meteorites that are multilithologic (SaU 169 [S], NWA 773 [k], Dhofar 279 [D], NEA 003 [f]). Numbers represent Antarctic ANSMET meteorites and keyboard symbols ($, %, #, ?, etc.) represent Antarctic NIPR meteorites, except © is Calcalong Creek [23]. Capital letters represent meteorites from Oman and lowercase letters represent those from Africa. Geometric symbols represent unnamed meteorites for which we have obtained data (the basalt [Δ] may be paired with NWA 032/479 [g]). Circled points represent unbrecciated mare basalts (Fig. 1); all other points represent breccias. The inset shows the same data on a linear Sm scale.

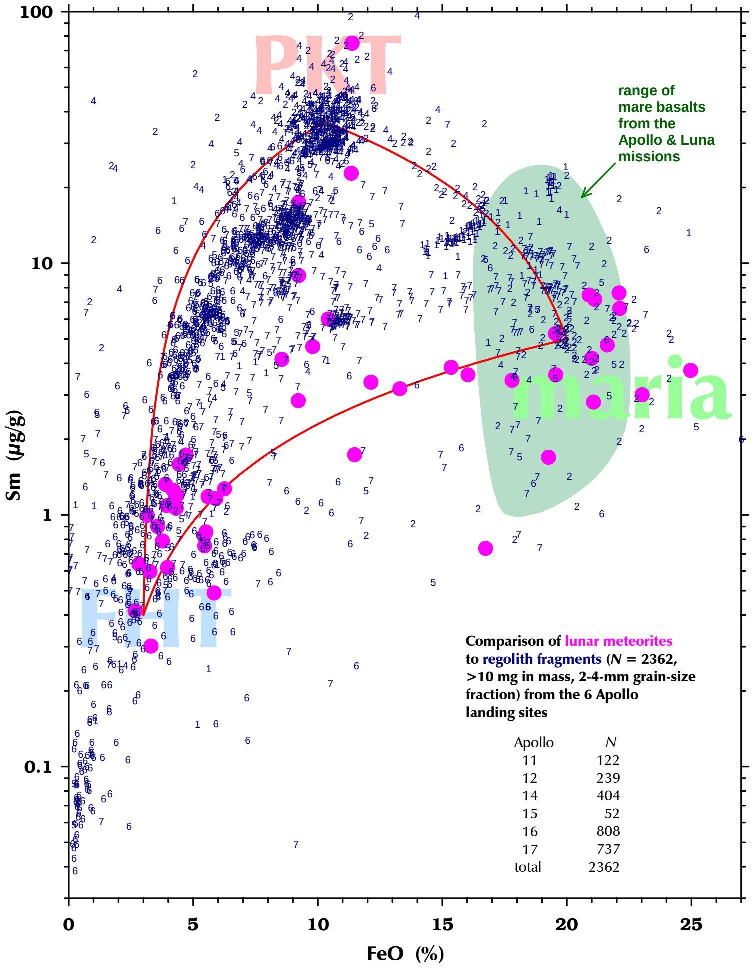

Figure 3. Comparison of compositions of meteorites (pink circles) of Fig. 2 with Apollo samples (dark blue numbers). Each Apollo point represents a 2–4-mm lithic fragment from the regolith (all data this lab, e.g., [25]). The numbers designate mission numbers (6 = Apollo 16, etc.). The range of compositions of mare basalts from the Apollo and Luna missions is shown by the green field. The red lines are mixing lines between the three implied components: typical material of the Feldspathic Highlands Terrane, typical material of the Procellarum KREEP Terrane, and mare basalt, which occurs in both terranes [21]. For two reasons, at least, the distribution of compositions of Apollo samples plotted here is not ideally representative of the rocks of the Apollo landing sites. The number of points for each site varies considerably, from 52 to 808, and for both Apollo 15 and 17 the analyzed samples were from the highlands sampling stations, not stations on the maria. Both biases lead to under representation of mare basalt compared to nonmare lithologies.