WHAT LUNAR METEORITES TELL US ABOUT THE LUNAR HIGHLANDS CRUST. R. L. Korotev[1], B. L. Jolliff[1], and R. A. Zeigler[2], [1]Dept. of Earth & Planetary Sciences, C/B 1169, Washington University, 1 Brookings Dr, Saint Louis MO 63130, [2]NASA Johnson Space Center, KT, 2101 NASA Pkwy, Houston TX 77058 korotev@wustl.edu.

The first meteorite to be found[1] that was eventually (1984) recognized to have originated from the Moon is Yamato 791197 [1]. The find date, November 20, 1979, was four days after the end of the first Conference on the Lunar Highland Crust [2]. Since then, >75 other lunar meteorites have been found, and these meteorites provide information about the lunar highlands that was not known from studies of the Apollo and Luna samples.

1: Of 50 feldspathic lunar meteorites (>20% Al_2O_3; Fig. 1), all breccias, the average *Mg'* (mole % MgO/ [(MgO + FeO] of the nonmetal phases) is significantly greater (66.4 ± 1.5; 95% confidence interval) than that of the FAS (ferroan-anorthositic suite [3]) rocks of the Apollo collection (60.1 ± 2.5; Fig. 1). Mare basalt and glass (low *Mg'*, low Al_2O_3) occur in many of the "highlands" breccias of Fig. 1, thus the nonmare components of the feldspathic lunar meteorites have even greater *Mg'* than the figure implies. For 11 of the feldspathic meteorites, *Mg'* is in the range of magnesian-suite plutonic rocks (>70), yet the meteorites are much more feldspathic than the high-*Mg'* norites, troctolites, and dunites of the Apollo collection and poorer in KREEP elements. These 11 meteorites are much more mafic (mean: 75% normative plagioclase), however, than Apollo FAS rocks. The meteorites tell us that magnesian troctolitic and noritic anorthosites are an important component of the crust at some locations in the feldspathic highlands [4–7].

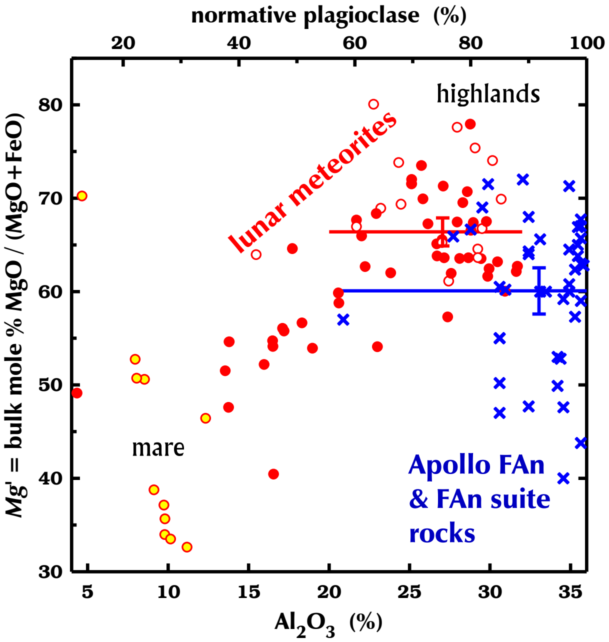

Figure 1. Comparison of *Mg'* in lunar meteorites (red, from whole-rock analysis) to mafic minerals in Apollo ferroan anorthosites and ferroan-anorthositic suite rocks (blue, 41 samples with pristinity "confidence class" >6 [22]). The horizontal lines represent the average *Mg'* for samples with Al_2O_3 >20; the error bars are 95% confidence intervals positioned at the mean Al_2O_3 concentration. For the lunar meteorites, red-filled symbols represent regolith, fragmental, and glassy-matrix breccias, unfilled symbols represent impact-melt and granulitic breccias, and yellow-filled symbols represent igneous rocks.

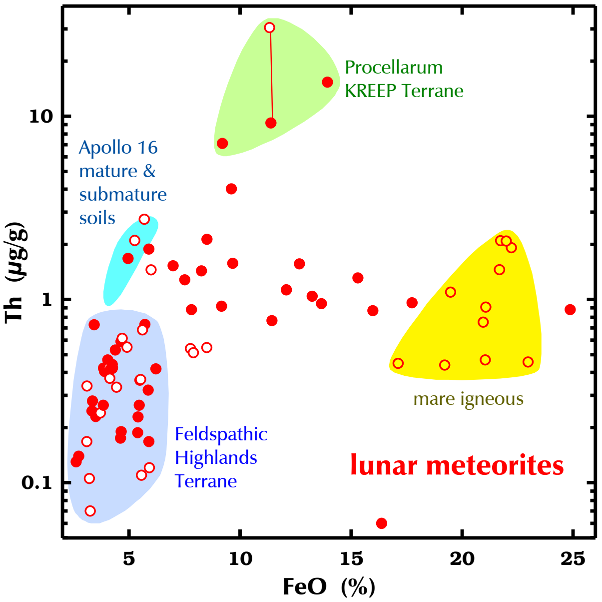

Figure 2. Th and FeO concentrations in lunar meteorites. All meteorites plotting outside the "mare igneous" field are breccias. At least three lunar meteorites are almost certainly from the PKT. (The two lithologies of SaU 169 are plotted as two points connected by the red line.) Most of the feldspathic lunar meteorites (<7% FeO) have <0.8 µg/g Th (mean of 40 meteorites in FHT field: 0.34 µg/g). This value is significantly less than that of Apollo 16 soils (mean of 36 surface and trench soils with I_s/FeO >30: 2.0 µg/g Th).

2: The most feldspathic of the meteorites has "only" 89% normative (~91 vol%) plagioclase. This value compares with 87% for the "prebasin" components of the Apollo 16 regolith [8, Tables 6 & 7]. On average, the meteorites are 3× more mafic than Apollo FAS rocks (Fig. 1). Clasts of highly feldspathic ferroan anorthosite are not common in most of the meteorites [9]. The meteorites are telling us that the Apollo 16 site is unusual in having such a high proportion of highly feldspathic ferroan anorthosite in the regolith and that the highlands megaregolith is more mafic, on average, than the ubiquitous ferroan anorthosites of Apollo 16.

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[1] Calcalong Creek may have been found before Y-791197, but the find date is not actually known [20]. It was not recognized to be a lunar meteorite until 1991 [21].

3: Some lunar meteorites with intermediate FeO concentration (8–15%, Fig. 2, or 14–23% Al_2O_3, Fig. 1) and low Th concentrations (<2 µg/g) are polymict breccias consisting of FHT material and mare basalt with little or no KREEP. Others, however, appear to contain little mare material on the basis of petrographic descriptions. (Most of these are woefully understudied with respect to detailed petrography, however.) The lunar meteorites tell us that there are regions of the nominally feldspathic highlands that are moderately mafic (noritic, gabbroic).

4: Most feldspathic lunar meteorites have lower concentrations of incompatible elements than does the Apollo 16 regolith because the Apollo 16 regolith (Fig. 2) contains a substantial component of Th-rich material from the PKT (Procellarum KREEP Terrane) as Imbrium ejecta [9,10]. Along with orbital geochemistry [5,11], the meteorites tell us that, with regard to incompatible elements, the Apollo 16 site is not as typical of the FHT (Feldspathic Highlands Terrane) as was assumed in the immediate post-Apollo era and that the meteorites provide a better picture of the composition of the feldspathic highlands [4].

5. Lithologies like alkali anorthosite and magnesian-suite norite, troctolite, and dunite are found in the Apollo collection but are nearly absent as clasts in the feldspathic lunar meteorites. These rocks occur in the Apollo collection because they were formed in the PKT, not the FHT, and the Apollo sites are all in or near the PKT [10,12]. There is no evidence that any high-*Mg'* clasts in feldspathic lunar meteorites crystallized from KREEP-rich magmas, as did the Apollo magnesian-suite rocks [13,14]. The lunar meteorites tell us that magnesian-suite plutonism of the style that leads to mafic cumulates was rare in the FHT. (A few clasts of spinel troctolite have been found in feldspathic lunar meteorites, however [15,16].)

6. The composition, particularly the high Th/Sm ratio, of some brecciated lunar meteorites of intermediate FeO concentration (Fig. 3) cannot be explained as mixtures of the materials of the FHT (as represented by the feldspathic lunar meteorites), materials of the PKT, and mare basalt; they (pink) plot outside the triangle defined by these components (yellow-blue-green) in Fig. 3 [17]. These meteorites evidently contain some lithic component(s) that differ from rocks of the Apollo collection. Most of these meteorites have concentrations of FeO and Th consistent with an origin in the South Pole-Aitken basin, and at least a few probably do originate from SPA [17]. The lunar meteorites tell us that there are moderately mafic regions of the nonmare (but perhaps not "highlands," in the literal sense) crust that differ from the nearside highlands sampled by Apollo.

7. Ages of clasts of impact-melt breccias in lunar meteorites have been determined [18,19]. The lunar meteorites tell us that the age spectrum of meteorite impacts on the lunar surface is more complicated than the ubiquitous 3.9 Gy obtained from most Apollo samples.

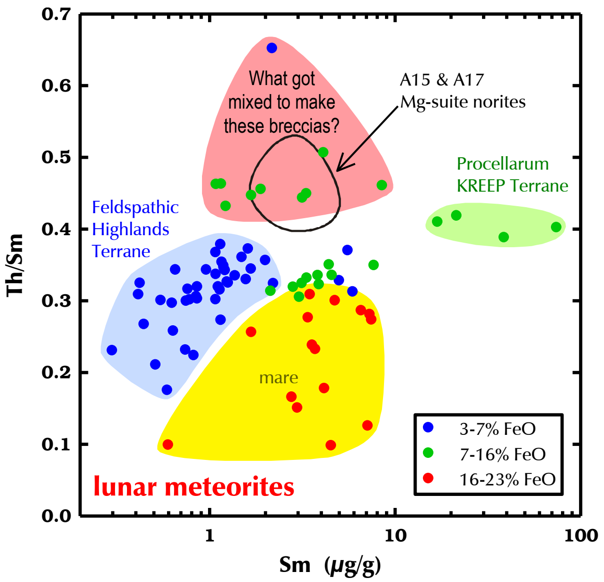

Figure 3. Ten lunar meteorites (pink field), all breccias with 6-12% FeO, have greater Th/Sm than any mixture of feldspathic breccias (blue, <7% FeO), KREEP breccias (green), and mare basalts (yellow, >16% FeO). Among Apollo samples, magnesian-suite norites are similar. The blue point in the "What got mixed to make these breccias?" field represents Dhofar 1528 with *Mg'* = 74, a value consistent with a magnesian-suite norite (mean *Mg'*: 79; range: 71–88; 17 samples of confidence class >6 [3]). The mean *Mg'* of the other 9 (green points), however, is 64 (range 54–69), well below the range of magnesian-suite norites. (Other 9: Calcalong Creek, Dhofar 1527, Dhofar 1528, Dhofar 925/ 960/ 961, NWA 4819, NWA 4932, SaU 300, SaU 449, Y-983385, and an unnamed NWA stone.) The igneous precursors of these breccias must include some that differ geochemically from rocks of the Apollo collection and rocks typical of the feldspathic highlands.

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