LITHOLOGIES OF THE APOLLO 12 REGOLITH. R. L. Korotev, R. A. Zeigler, B. L. Jolliff, and L. A. Haskin, Department of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University and McDonnell Center for the Space Sciences, St. Louis, Missouri 63130 (rlk@levee.wustl.edu).

Introduction: The Apollo 12 and 14 landing sites are within the Procellarum KREEP Terrane, which the Lunar Prospector gamma-ray spectrometer has demonstrated to be a unique geochemical province [1,2]. The Apollo 14 site is in the Fra Mauro formation and the Apollo 12 site is 180 km to the east in a region where basalt flows cover Fra Mauro or related Alpes material [3].

Data for <1-mm fines indicate that the Apollo 12 regolith consists of subequal proportions of mare basalt and nonmare lithologies mainly of KREEP composition [4,5]. Apollo 12 mare basalts are relatively well studied (e.g., [16]), but in some respects, nonmare rocks of the Apollo 12 site are the least well characterized materials of the Apollo missions. Most of the work on the samples was done shortly after the mission in 1969 – a time when the nature of lunar nonmare rocks was not understood and the term "impact-melt breccia" was not yet used. Only a few post-1980 works deal with the nonmare rocks of Apollo 12 [e.g., 6–11].

We have begun a project to chemically and petrographically characterize 400+ small lithic fragments from the Apollo 12 regolith, as we have done at other sites [12,13]. We hand picked the particles from the 2–4 mm grain-size fraction of several regolith samples (12xxx) at the curatorial facility at NASA-JSC. The selection was biased toward suspected nonmare lithologies, but numerous mare basalts were included so as not to overlook possible dark, nonmare lithologies. Some of the samples had been selectively subsampled in previous studies [6–10], so we do not expect that our subsets of particles are necessarily representative of samples from which they derive.

The <1-mm fines from most Apollo 12 regolith samples have similar compositions (yellow circle, Fig. 1), but anomalous samples 12032 and 12033 are distinct in being richer in elements associated with KREEP (red circle) [4,5]. 33% of the particles thus far studied derive from 12032&3, 44% from samples of typical composition (12001, 12023, 12042, 12044, 12070), and 23% from samples that are atypical in that they probably contain both true regolith as well as fragments abraded from regolith breccias (12030) or basalt rocks (12003, 12037) transported in the same sample bag [4].

Our goals are to (1) determine the nature of the nonmare materials in a global context, particularly KREEP-rich and related rocks, (2) compare the nonmare components of the Apollo 12 and 14 regoliths, (3) identify the important lithologies so that we can account for the composition of the soil (<1-mm fines), and (4) seek lithic fragments of possible nonlocal origin. For example, from combined data from the Clementine and Lunar Prospector missions, we infer that mare basalts with moderate (5 ± 2 µg/g) Th concentrations exist west of Aristarchus in Oceanus Procellarum [14, 15]; samples of such basalts may occur in the Apollo 12 regolith.

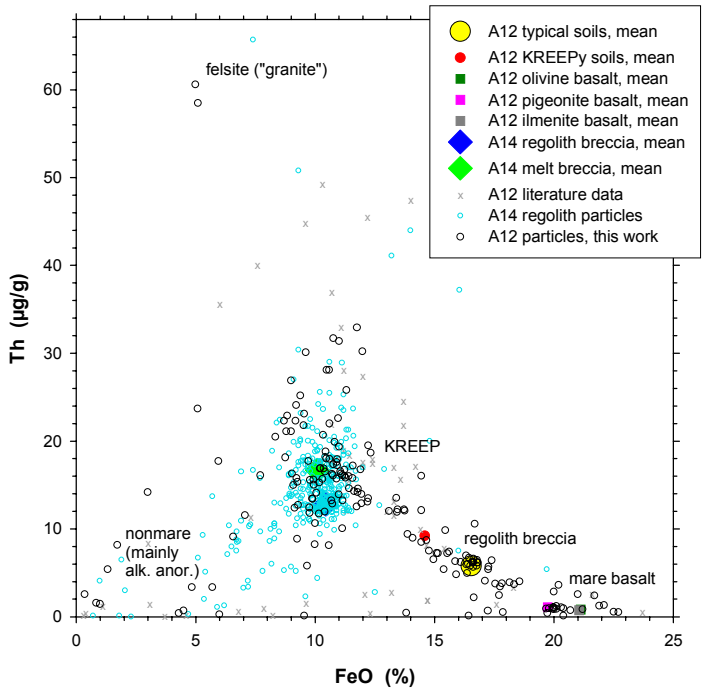

Figure 1. Comparison of compositions of Apollo 12 lithic fragments (black circles), with Apollo 12 mare basalts (squares; means of many sources), literature data for Apollo 12 nonmare rocks (small gray x; many sources), Apollo 14 lithic fragments (small cyan circles [12]), and Apollo 14 impact-melt (green) and regolith breccias (blue, obscured; large diagonal squares, means from [12]).

Results and Preliminary Conclusions: We present compositional results for the first 186 fragments studied. None of the fragments identified as mare basalt (mainly >19% FeO) have moderate or high concentrations of Th (Fig. 1), although one vesicular glass of mare composition (20.2% FeO) contains 3.6 µg/g Th. One particle is compositionally indistinguishable from the heretofore unique feldspathic mare basalt, sample 12038 [16]. Most of the particles are of high-Th KREEP composition (~10% FeO, 12–33 µg/g Th). Under the binocular microscope the majority of these appear to be crystalline impact-melt rocks or breccias,

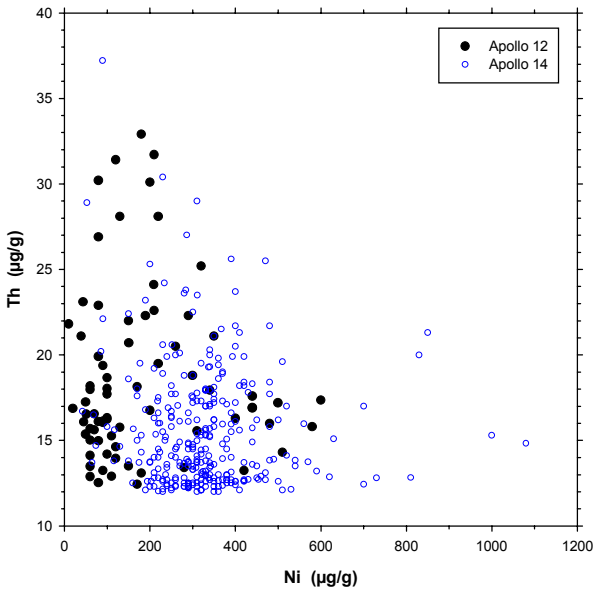

Figure 2. Comparison of lithic fragments from Apollos 12 and 14 which have KREEP-like absolute concentrations of major elements, KREEP-like relative concentrations of incompatible elements, and >12 µg/g Th. Siderophile element concentrations (Ni, Ir, Au) in the Apollo 12 samples average approximately half those of the Apollo 14 samples. Apollo 14 data are from [12]. For Apollo 14 particles for which Ni concentrations were not reported by [12] because they was below detection limits, the concentrations were estimated from Co. This yields a mean for the data set of 328 µg/g, essentially the same as that obtained from literature data for large samples (332 ppm, [18]). We observe no significant difference in Ir/Au ratios between the Apollo 12 and Apollo 14 samples.

although some are glassy. We encountered no samples of ropy glass of KREEP composition in the coarse fines, despite that this lithology is prevalent in the <1-mm grain-size fraction of samples 12032 and 12033 [17].

Most of those lithic fragments which appear to be regolith or fragmental breccias do, in fact, have compositions similar to Apollo 12 soils (Fig. 1). Five of the seven particles from 12030 are regolith breccias, suggesting that 12030 is indeed largely a disaggregated regolith breccia, not a true soil. Several of the regolith breccias contain a greater proportion of KREEP and others contain a greater proportion of mare basalt than do typical Apollo 12 soils. This diversity suggests that regionally, the range in regolith compositions is greater than that observed in the Apollo 12 soils.

Based on composition, nonmare, non-KREEPy lithic fragments include 2 felsites (~60 µg/g Th; Fig. 1), 1 or 2 monzogabbros ("quartz monzodiorite," 11–13% FeO, low Th/Sm), 13 fragments of alkali-suite affinity (1–11 % FeO, high Na/Sm and Eu/Sm), and 2 or 3 fragments of troctolitic composition. Despite our sampling bias toward light-colored particles, only 2 fragments have compositions characteristic of material of the Feldspathic Highlands Terrane (4–6% FeO, <4 ppm Th [2]). Overall, the nonmare lithologies of the Apollo 12 regolith are very similar to those observed at Apollo 14 [12]. This observation explains our previous observation that, among various KREEP components tested to account for the composition of <1-mm fines of Apollo 12, the Apollo 14 soil provided a better fit than did any rock type of KREEP composition [5].

Apollo 12 lithic fragments with KREEP-like compositions are very similar in composition to impact-melt breccias from Apollo 14 (e.g., Fig. 1) except that in the Apollo 12 samples (1) concentrations of siderophile elements are about half as great (Fig. 2), (2) Th/REE and Ta/REE ratios are ~5% less, and (3) Fe and Sc concentrations are 5–10% greater (Fe normalized to zero Ir). The difference in siderophile element concentrations may reflect real differences in units of impact melt ejected from a given basin, presumably, Imbrium. Alternatively, it may indicate that some of the KREEP samples are unbrecciated. Low-Ni KREEP samples will be primary targets of subsequent petrographic study. The slightly lower Th/REE and Ta/REE ratios of the Apollo 12 KREEP samples suggests that the breccias contain a lower proportion of felsite component than do their Apollo 14 counterparts. The greater Fe and Sc concentrations may be an artifact of inadvertent inclusion in the subset of "KREEP-like compositions" particles which are regolith breccias that contain a component of mare basalt.

Compositions of some of the presumed KREEP-rich impact-melt breccias deviate from the composition of the main cluster of points in the direction of felsite or alkali anorthosite, suggesting that these minor lithologies occur as clasts in the melt breccias.

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