A THORIUM-RICH MARE BASALT ROCK FRAGMENT FROM THE APOLLO 12 REGOLITH: A SAMPLE FROM A YOUNG PROCELLARUM FLOW? B.L. Jolliff[1]; R.A. Zeigler[1], R.L. Korotev[1], F. Barra[2], and T.D. Swindle[3], [1]Dept. of Earth & Planetary Sciences & the McDonnell Center for Space Sciences, Washington University, One Brookings Drive, St. Louis, MO 63130, [2]Department of Geosciences, University of Arizona, Tucson, AZ 85721, [3]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721. (blj@levee.wustl.edu)

Introduction. In this abstract, we report on the composition, mineralogy and petrography of a basaltic rock fragment, 12032,366-18, found in the Apollo 12 regolith. Age data, collected as part of an investigation by Barra et al. [1], will be presented in detail in [2]. Here, only the age dating result is summarized. This rock fragment garnered our attention because it is significantly enriched in incompatible elements, e.g., 7 ppm thorium, compared to other known lunar basalts [3]. Its mineral- and trace-element chemistry set it apart from other Apollo 12 basalts and indeed from all Apollo and Luna basalts. What makes it potentially very significant is the possibility that it is a sample of a relatively young, thorium-rich basalt flow similar to those inferred to occur in the Procellarum region, especially northwestern Procellarum, on the basis of Lunar Prospector orbital data [4-7]. Exploiting the lunar regolith for the diversity of rock types that have been delivered to a landing site by impact processes and correlating them to their likely site of origin using remote sensing will be an important part of future missions to the Moon. One such mission is *Moonrise*, which would collect regolith samples from the South Pole-Aitken Basin, concentrating thousands of rock fragments of 3-20 mm size from the regolith, and returning the samples to Earth [8,9]. Although sample 12032,366-18 is at the small end of this size range (41 mg, ~4 mm), much can be done to determine the origin and age of small rock samples such this as using modern analytical methods. This sample from the Apollo 12 regolith serves as a reminder that the Moon is a complex, differentiated planet and we have not yet sampled and understood all of its complexity.

Background. Although it is considered a mare site, the Apollo 12 regolith contains some 46% non-mare material [10], thus it has significant externally derived materials in addition to the immediately underlying basalt flows. Regolith samples 12032 and 12033 are very similar to each other and contain the largest proportion of KREEP-rich non-mare materials, especially KREEPy ropy glass, compared to the other sample stations [10]. Additional details of these samples are given by Korotev et al. [10]. Although 12032,366-18 may come from the same general location as other KREEP-rich components of these soils, it is also possible that it comes from an different source, but within the Procellarum region.

The Apollo 12 basalts comprise three groups, olivine basalt, pigeonite basalt, and ilmenite basalt [11]. These have been well characterized on the basis of large hand samples, and among the basalt fragments found in the regolith, most of the basaltic ones can be ascribed to one of the three main groups. Even among very small rock fragments, the chemical signatures that correspond to the larger rock samples are useful to distinguish the small rock fragments and relate them to the main groups. From the analysis of many small lunar rock fragments, we find that samples in the 3–4 mm diameter range (greater than about 30 mg) typically retain a fairly representative compositional signature. It is the trace-element composition that really sets 12032,366-18 apart from the others. Of approximately 100 basaltic rock fragments surveyed, it is the only one with its particular chemical signature (Fig. 1).

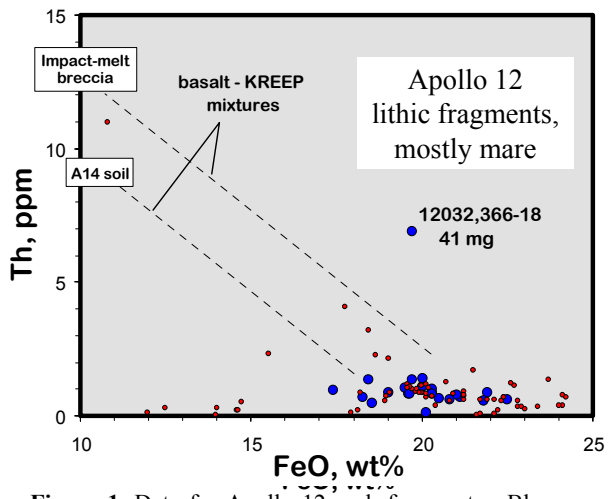

Figure 1. Data for Apollo 12 rock fragments. Blue symbols are >20 mg and red, <20 mg. The composition of 12032,366-18 does not appear to result from KREEP mixing with common basalt types or by assimilation.

Methods: The sample was irradiated for INAA determination of trace elements. Flux monitors were included so that selected samples could later be analyzed by Ar-Ar isotopic analysis. After a suitable cool down period, the sample was sectioned, with part made into a polished probe mount for electron microprobe analysis (EMPA) and part used for Ar-Ar geochronology. Details of the analytical methods are given in [1,2,12,13].

Description. The sample is an olivine-bearing, clinopyroxene-rich, and relatively aluminous basalt with an intermediate Ti content (see below). It contains olivine (Fo_{38}) up to about 400 μm in size and smaller blebs of olivine extending to Fo_{16} surrounded by pyroxene and in a reaction relationship. Pyroxene consists of subequal proportions of pigeonite and augite, ranging from augite with Mg/(Mg+Fe) = 0.68, Wo_{37} and pigeonite with Mg/(Mg+Fe) = 0.58, Wo_{11} to ferropyroxene with Mg/(Mg+Fe) = 0.27, Wo_{20}. Plagioclase masses and laths

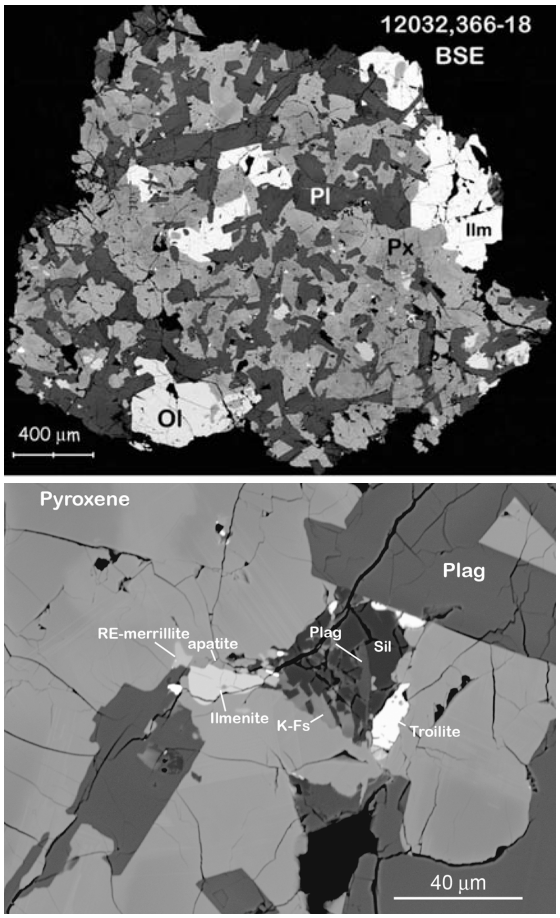

Figure 2. Upper: Backscattered-electron image of probe mount with major phases labeled. Most of the brightest grains (highest mean atomic number) are ilmenite. Lower: Higher magnification image showing an area of mesostasis and very fine-grained accessory minerals including RE-merrillite, which is a likely host for Th as well as REE.

range in size, with the largest lath in the section about 150 µm wide by 500 µm long (Fig. 2a). Plagioclase grains are strongly zoned with compositions ranging from An_{90} to An_{60}. The most sodic plagioclase (An_{54}) occurs in mesostasis. Pyroxene partially encloses plagioclase in a subophitic texture. Ilmenite forms coarse masses, reaching about 500 µm size (e.g., Fig. 2a).

In addition to pyroxene, plagioclase, ilmenite, and olivine, the sample contains chromian ulvöspinel, troilite, barian K-feldspar, silica, RE-merrillite, and apatite. Small areas of mesostasis such as shown in Fig. 2b are widely dispersed, although Ba-K-feldspar–silica intergrowths are fairly common, and in one occurrence, forms a fairly large ~200 µm "patch."

Modal recombination using mineral compositions determined by EMPA and proportions determined from BSE and X-ray image analysis converted to mass fractions gives the following major-element composition: 44.3% SiO_2, 4.2% TiO_2, 11.7% Al_2O_3, 0.2% Cr_2O_3, 19.5% FeO, 0.3% MnO, 7.2% MgO, 11.5% CaO, 0.7% Na_2O, and ~0.25% each of K_2O and P_2O_5. Although TiO_2 is in the range of Apollo 12 ilmenite basalts, the alkalis and Al_2O_3 are significantly higher, consistent with the occurrence of Ba-K-feldspar and relatively sodic plagioclase, as well as elevated incompatible trace element concentrations (see below).

Incompatible trace element concentrations are at a level of about 0.3–0.4 × average high-K KREEP (Fig. 3); however, the major-element composition precludes them resulting from assimilation (Fig. 1).

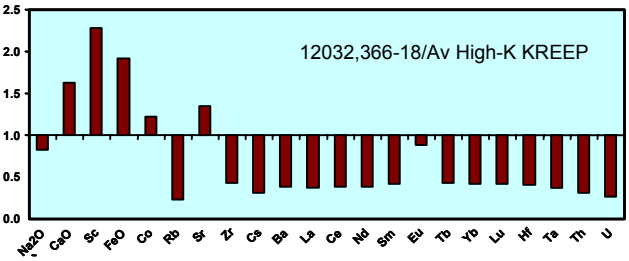

Figure 3. Selected concentrations divided by high-K KREEP [14] for reference. The compatible elements are enriched as expected for a basalt and the incompatible elements have a KREEP-like pattern.

Preliminary Ar-Ar analysis of two splits of 12032, 366-18 yields the following results. One split (1.88 mg) shows two consecutive steps with 50% ^{39}Ar have an age of about 695 ± 5 Ma and an oldest apparent age of 2314 ± 39 Ma. The sample also shows increasing ages with increasing extraction temperature, indicating a possible crystallization age of 2.3 Ga and degassing at ~ 700 Ma. The second split (0.34 mg) shows the same pattern, with increasing ages at increasing extraction temperature. A single extraction with 17% of ^{39}Ar gives an age of 500 Ma and the following extraction with 30% of ^{39}Ar gives 615 Ma. The oldest apparent age is 1530 Ma. Although not definitive at this time, the apparent ages of both splits suggest that the rock could be considerably younger than the common Apollo 12 basalts, which range in age from ~3.2 to 3.4 Ga [reviewed by 15]. An origin in one of the more distant flows northwest of the Apollo 12 region where crater counts indicate younger volcanism [16] is a significant possibility.

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References: [1] Barra et al. (2004) *LPSC35*, #1365; [2] Barra et al. (2005) *manuscript in preparation*; [3] Jolliff (2004) *LPSC35*, #2032; [4] Jolliff et al. (2001) *LPSC32*, #2144; [5] Gillis et al. (2002) *LPSC33*, #1934; [6] Flor et al. (2002) *LPSC33*, abstract #1909; [7] Flor et al. (2003) *LPSC34*, abstract #2086; [8] Duke (2003) #1684; [9] Jolliff et al., (2003) #1989; [10] Korotev et al. (2000) *LPSC31*, #1363. [11] *Basaltic Volcanism Study Project* (1981) 236-267; [12] Korotev et al. (2003) *GCA* **67**, 4895-4923; [13] Jolliff et al. (2003) *GCA* **24**, 4857-4879; [14] Warren (1989) *Workshop on Apollo 14*, *LPI Tech Rpt 89-03*, 153; [15] Nyquist and Shih (1992) *GCA* **56**, 2213-2234; [16] Hiesinger et al. (2003) *JGR* **108** (E7):DOI 10.1029/2002JE001985.