GEOCHEMISTRY AND PETROGRAPHY OF HIGH-TH, MAFIC IMPACT-MELT BRECCIA FROM APOLLO 12 AND SAYH AL UHAYMIR 169.

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Introduction: Th-rich, mafic IMBs (impact-melt breccias) have long been recognized as an important lithology at the Apollo sites in or near the lunar highlands (Apollos 14, 15, 16, and 17; [see 1 for summary]). Even at mare sites, i.e. Apollos 11 and 12, IMBs constitute a significant proportion of the regolith [2,3]. Mafic IMB vary in composition, but all are rich in incompatible trace elements (ITE; e.g., 3-16 ppm Th [1]). In a study of nonmare lithologies at Apollo 12 and 14 [3,4], we found a group of IMB rock fragments with exceptionally high incompatible trace elements ~30 ppm Th, which herein we refer to as the high-Th IMBs. Here we characterize the high-Th IMB group, and compare it to the IMB lithology of lunar meteorite SaU (Sayh al Uhaymir) 169 [5], which is compositionally identical.

Methods: We obtained quantitative mineral compositions by electron microprobe analysis on polished thick sections of five A12 high-Th IMBs. Bulk chemistry was determined for trace and selected major elements by INAA [4]. We have also obtained INAA data for 4 subsamples of the IMB lithology and 8 of the regolith breccia lithology of SaU 169 [5].

Geochemistry: The nonmare component of the regoliths of Apollo 12 and 14 is dominated by mafic impact-melt breccias. At both sites, the sample compositions cluster about 10% FeO and 17 ppm Th (Fig. 1). The high-Th group is at the Fe- (10.6 wt%) and ITE-rich (30 ppm Th; 68 ppm Sm) end of the IMB compositional spectrum (Fig. 1). On the basis of mineral compositions, the bulk Mg' of the high-Th IMB group is ~65, which is low among the mafic IMBs. The interelement ratios among the ITEs are in KREEP-like proportions, albeit at ~1.5x the level of high-K KREEP [6]. The alkali and alkali-earth elements are not as enriched relative to KREEP, however (~1.1x).

Petrography: All of the Apollo 12 high-Th IMBs studied have similar textures (Figs. 2,3), mineral assemblages and compositions (Fig. 4), and clast populations. The matrix consists mostly of low-Ca pyroxene ($En_{61-69}Wo_{2-7}$) and plagioclase ($An_{55-82}Or_{<2.7}$) in a subophitic to micropoikilitic texture. Also present are minor amounts of ilmenite, RE-merrillite, apatite, and barian K-feldspar ($Or_{63-78}Cn_{5-10}Ab_{12-17}$), as well as trace amounts of zircon and baddeleyite. The clasts are dominantly plagioclase ($An_{60-96}Or_{<2.5}$), with minor amounts of pyroxene ($En_{43-83}Wo_{1-40}$) and olivine (Fo_{33-44}), and rare lithic clasts. The lithic clasts are mainly recrystallized clasts dominated by plagioclase ($An_{79-90}Or_{<0.8}$) with minor pyroxene ($En_{44-61}Wo_{4-41}$).

Discussion: The high-Th IMB group represents a new type of lunar impact-melt breccia, which is among the most ITE-rich samples yet found on the Moon. There is considerable variation in Na_2O (0.7-1.1 wt%) and Eu (2.5-4.4 ppm) concentrations among individual group members (all of the Apollo 14 samples have lower Na_2O and Eu), possibly due to variable amounts of an alkali anorthosite component. Cr (780-1200 ppm), Co (17-31 ppm), and Ni (50-350 ppm) also show a range in concentrations, likely due to variable amounts of a meteoritic component or an olivine component or both. The high-Th IMB group has a KREEP-like Th:Sm ratio (0.44), however, the individual high-Th IMB samples define a trend that diverges from the KREEP line, towards higher Th relative to Sm. This trend may indicate that a granitic component is relatively more abundant in the source region of this IMB group than other IMB groups, something Jolliff [7] found to be the case for Apollo 14 IMBs.

Lunar meteorite SaU 169 is dilithologic, consisting of regolith breccia and IMB lithologies [5]. On the basis of our INAA data, the SaU 169 IMB lithology is indis-

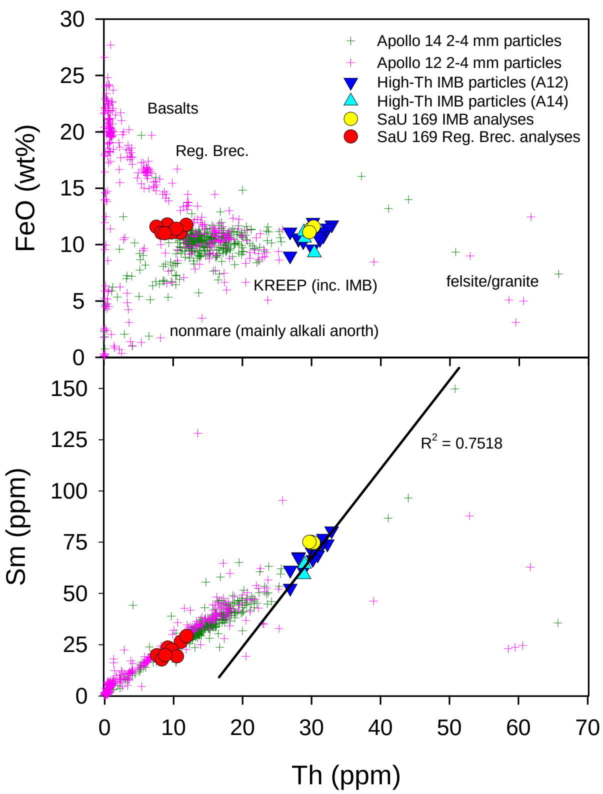

Figure 1: Th vs. FeO (top) and Sm (bottom) for the high-Th IMB particles found during surveys of 2-4 mm particles from the Apollo 12 [3] and 14 [4] sites. The other 2-4 mm particles analyzed in those studies are shown as magenta and green crosses, respectively. Also included are the IMB (yellow circles) and regolith breccia (red circles; Reg. Brec.) lithologies of the lunar meteorite SaU 169.

tinguishable from the Apollo 12 and 14 high-Th IMB group. The texture, mineral assemblage, and mineral compositions of the IMB lithology in SaU 169 are similar to those in the high-Th IMB group [5]. Pb-Pb ages of zircons in the SaU 169 IMB have an average age of 3.909 ± 0.013 Ga. This is similar to the Ar-Ar age for one of the high-Th IMBs of 3.981 ± 0.026 Ga [8]. Although these ages are different within error, it is intriguing that both have ages older than the accepted age of Imbrium (3.85 Ga [9]).

Given the similarities in bulk composition, texture, age, mineral assemblage and composition, as well as their dissimilarity from other lunar samples, it is likely that the SaU 169 IMB and the high-Th Apollo IMB group are different samples of a single unit of impact-melt breccia Gnos et al. [5] advocate the region near Lalande crater as the source region of the meteorite. The Apollo 12 site, where we found most of the high-Th IMBs, is 450 km away, however. Thus the meteorite could originate from anywhere in the Fra Mauro formation, which underlies the Apollos 12 and 14 sites and is exposed near Lalande. The composition of the regolith breccia lithology of SaU 169 does not correspond to any mixture of lithologies at the Apollo 12 or 14 sites, however, which suggests that the meteorite does, in fact, originate from a point distant from the Apollo sites.

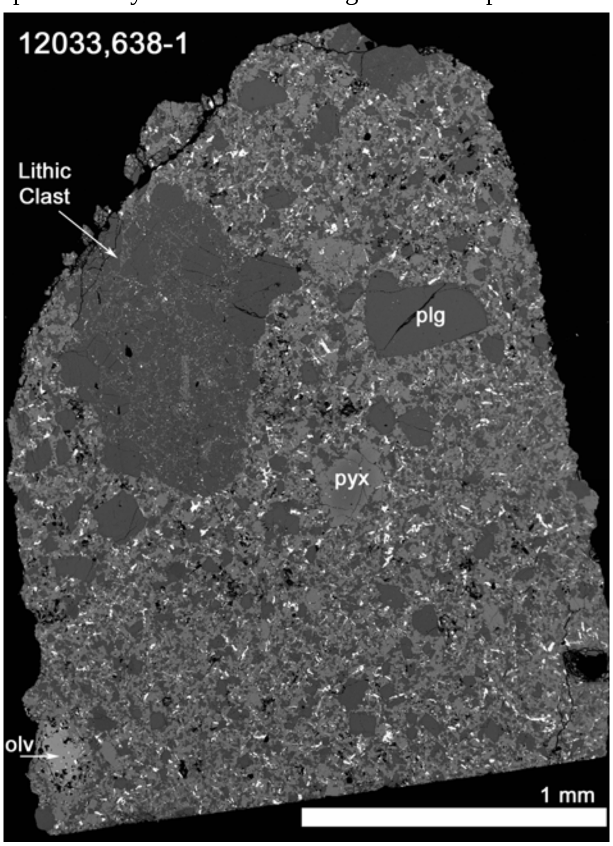

Figure 2: Back-scattered electron (BSE) image of an A12 high-Th IMB. One large lithic clast and plagioclase (plg), pyroxene (pyx), and olivine (olv) mineral clasts in a matrix dominated plagioclase and pyroxene. Small bright phases in the matrix are ilmenite, RE-merrilite, and apatite.

References: [1] Korotev R. L. (2000) *JGR, 105*, 4317-45. [2] Korotev R. L. and Gillis J. J. (2001) *JGR., 106*, 12,339-53. [3] Korotev R. L. et al. (2002) *LPS XXXIII*, Abstract #1395. [4] Jolliff et al. (1991) *PLPSC, 21*, 193-219. [5] Gnos et al. (2004) *Science*, *305*, 657-9. [6] Warren P. H. (1989) *LPI Tech. Rep.*, *89-03*, 149-53. [7] Jolliff B. L. (1998) *Int. geo. Rev.*, *10*, 916-35. [8] Barra F. et al. (2004) *LPS XXXV*, Abstract #1365. [9] Stöffler D. and Ryder G. (2001) *Space. Sci. Rev.*, *96*, 9-54. **Acknowledgements:** This work was supported by NASA grant NNG04GG10G. We would like to thank the Natural History Museum Bern for providing the SaU 169 samples.

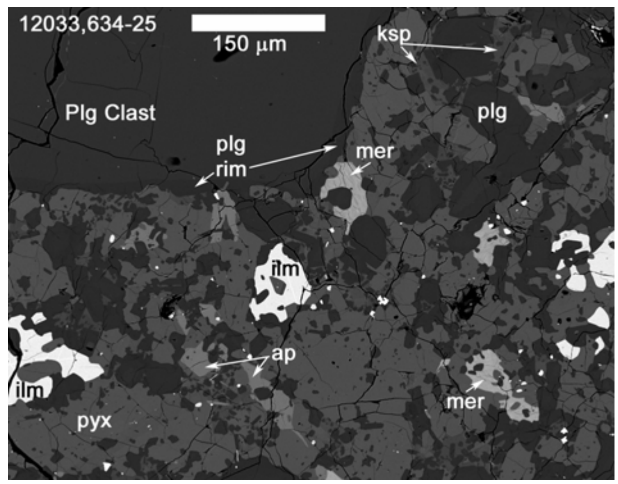

Figure 3: Close-up BSE image of an A12 high-Th IMB. One large plagioclase (plg) clast rimmed by more sodic plagioclase, in a matrix of mostly pyroxene (pyx) and plagioclase with minor amounts of ilmenite (ilm), RE-merrilite (mer), apatite (ap), and K-feldspar (ksp).

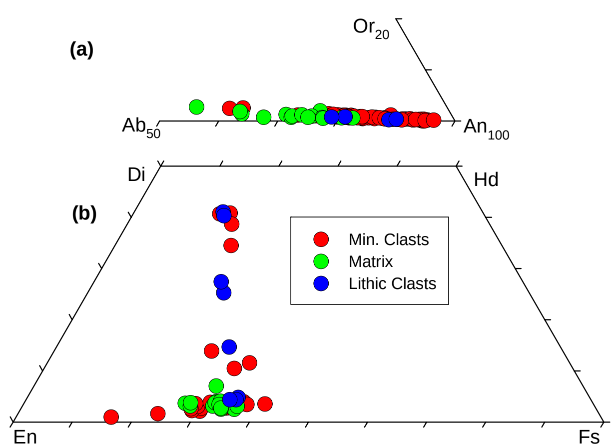

Figure 4: Mineral (Min.) compositions in the Apollo 12 high-Th IMB group. **(a)** portion of the An-Or-Ab feldspar ternary. **(b)** Pyroxene quadrilateral.