MAFIC IMPACT-MELT COMPONENTS IN LUNAR METEORITE DHOFAR 961. B. L. Jolliff[1], R. A. Zeigler[1], R. L. Korotev[1], P. K. Carpenter[1], E. P. Vicenzi[2], and J. M. Davis[3]. [1]Department of Earth and Planetary Sciences, Washington University, Saint Louis, MO 63130; [2]Smithsonian Institution, Department of Mineral Sciences, National Museum of Natural History, P.O. Box 37012, NHB-119, Washington, D.C. 20013; [3]Microanalysis Research Group, National Institute of Standards and Technology, Washington, D.C. 20013. (blj@wustl.edu)

Introduction: Dhofar 961 is an unusual, relatively mafic lunar meteorite from Oman [1] that is likely paired with Dhofar 960 and Dhofar 925, although our section of Dhofar 961 differs substantially in petrographic components from Dhofar 925 as described by [2]. Subsamples of Dhofar 961 are compositionally and petrographically quite variable, however. Previously we reported on the composition [3] and clast makeup [4] of Dhofar 961 and called attention to the dominant mafic impact-melt clast lithology in our subsamples and polished section. We hypothesized - on the basis of its bulk and component compositions - that Dhofar 961 could be from a site within the South Pole-Aitken (SPA) Basin. Here we provide additional detail on the mafic impact-melt breccia clasts, including preliminary results of x-ray fluorescence microprobe measurements of impact-melt clast compositions, and we discuss the implications of an origin in the SPA basin.

Our analyzed subsamples of Dhofar 961 yield a mean of 11% FeO, 18% Al_2O_3, 0.6% TiO_2, and $Mg/(Mg+Fe) = 0.63$. Normatively, it has a composition of gabbronorite. Compared to mafic impact-melt breccias from Apollo sites, it is on the mafic side and has higher Ca/Al than the Apollo groups. With 2.5 ppm Th, concentrations of incompatible elements are low compared to mafic melt breccias of the Apollo collection and lunar meteorites such as SaU 169 [5].

Mafic impact-melt clast lithology: The mafic impact-melt clasts (highlighted with blue outlines in Fig. 1) comprise about 60 vol% of our petrographic section, with other prominent lithic clasts accounting for 8%, and smaller lithic clasts, mineral grains, and glass making up the matrix (32%). The large mafic impact clasts are themselves clast-poor, consisting of a crystalline matrix of fine-grained pyroxene, plagioclase, and olivine, plus accessory chromite, ilmenite, phosphate, troilite, and FeNi metal (6.5 wt% Ni, 0.3 wt% Co). The melt-breccia lithic clasts actually comprise two lithologies, termed "A" and "B" (see Fig. 1). Lithology A contains subhedral phenocrysts of olivine ranging to several hundred μm and a slightly more mafic matrix composition. Olivine phenocrysts range from cores with Fo mainly 70-74 (but as high as 80) and rims ranging to Fo_{55}. Olivine cores have Ni concentrations measured with the electron microprobe of ~200 ppm. Lithology B contains plagioclase clasts ($An_{95-96.5}$) (see Fig. 1, lithic clast on right side) and a slightly more aluminous matrix composition. In both lithologies, matrix olivine ranges from Fo_{73} to Fo_{50}. Matrix plagioclase ranges from An_{97} to An_{89}. Matrix pyroxene typically mantles small olivine grains and pyroxene compositions are mostly pigeonite (Wo_{8-11}, Mg' = 60-70) with lesser subcalcic augite.

Bulk compositions of the mafic impact-melt lithic clasts are difficult to determine because of heterogeneity in the distribution of olivine phenocrysts and coarse plagioclase clasts. The very fine-grain size of the matrix (silicates typically 5-20 μm and accessory minerals of several μm or less) makes modal recombination impractical. We used broad-beam analyses corrected for heterogeneous mineralogy and x-ray fluorescence microprobe analyses [6] to determine mafic lithic clast compositions. FeO concentrations average ~14.0 wt% FeO, 11.7 wt% MgO, and 15.4 wt%
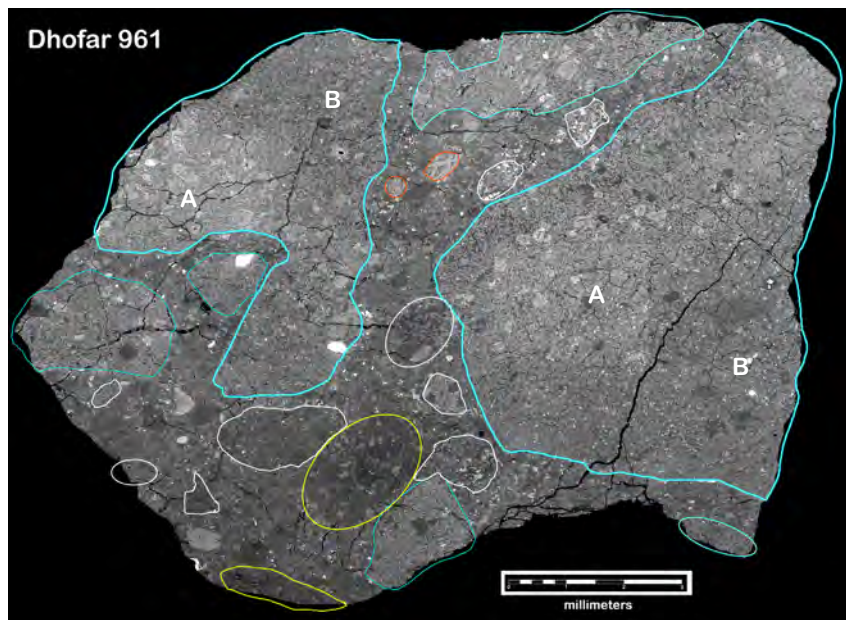

Figure 1. Backscattered-electron image with main lithic clasts outlined. Blue surrounds the prominent mafic impact-melt clast lithologies. Other lithic clasts include granulite (yellow), less mafic impact-melt breccias (white), and small, rounded aluminous basalt clasts (orange). Two bright spots at left-center are Fe-Ni metal. Scale bar is 3 mm.

Al_2O_3. Lithologies A and B differ by ~2.5% Al_2O_3, 1.5% FeO and 1.5% MgO, consistent with the occurrence of olivine phenocrysts in A and plagioclase clasts in B. Nevertheless, both lithologies are considerably more mafic than the Apollo mafic impact-melt breccias (8-11 wt% FeO) [7]. The norms of the full compositions of these lithologies correspond to olivine gabbronorite.

Major- and trace-element analyses of Dhofar 961 provide additional hints of the compositionally unusual character of melt-breccia components. Incompatible-element ratios are not strictly KREEP-like. For example, bulk P/K and P/REE values are high, and we suspect this is also the case for the mafic impact-melt lithology simply because of the volumetric abundance of this component. Sc/Cr is also high relative to Apollo impact-melt breccias. Among the subsamples analyzed by INAA, Th ranges from just over 1 to about 5 ppm, but concentrations do not correlate with FeO content. Even so, judging from the distribution of P, the mafic melt breccia lithic clasts probably carry most of the Th.

Remote sensing and the SPA connection: Several lines of reasoning point to the SPA basin as a plausible source for the origin of Dhofar 961. The mafic character of the melt-breccia lithic clasts (and only minor component of basalt clasts), is consistent with a broadly mafic region such as the interior of SPA away from local basalt ponds, and it rules out the feldspathic highlands. Compositional differences from Apollo impact-melt groups point to a provenance that is separated and perhaps far distant from the Procellarum KREEP Terrane [8]. The SPA basin has several "hot spots" where Th concentrations reach 5 ppm and it has a broad

"background" of about 2 ppm (Fig. 2), so the range of Th concentrations on a broad scale is similar to what we observe in different combinations of lithic clasts from the different Dhofar 961 subsamples.

Implications of an SPA source: As argued in the previous section, the SPA basin is a potential source region for Dhofar 961 in terms of FeO and Th. Other compositional characteristics are not as well constrained, especially Mg and the Mg/Fe ratio. In Dhofar 961, the mafic melt-breccia components are relatively ferroan (Mg' of ~60). If the SPA basin incorporated a substantial mantle component, we might expect to see it reflected in a higher Mg value. On the other hand, if the mafic character of the basin derived largely from lower crustal rocks, they could be magnesian (i.e., magnesian-suite intrusives) or ferroan (e.g., ferroan gabbro complement to ferroan anorthosite). The mafic components and ferroan composition compare well with Lunar Prospector gamma-ray Fe-Mg data for the interior of SPA basin [9,10], thus we can make the argument that these compositions (if Dhofar 961 is from SPA) support the presence of a ferroan lower-crustal component. However, the LP-GRS Mg data are among the least-well determined and have very low resolution (5-degree pixels). Furthermore, the olivine component in the Dhofar mafic impact-melt lithology could still represent a contribution from upper mantle material. Considering the pyroxene makeup (or, put another way, the Ca/Al ratio), the ratio of high-Ca to low-Ca pyroxene in the Dhofar 961 mafic impact-melt component could be important if from SPA. Although a predominantly noritic mafic mineralogy was advocated by [11] for SPA, mineral models of [12] suggest abundant high-Ca pyroxene and minor olivine. Pigeonite is common in Dhofar 961 and could be an important part of the solution to the mafic mineralogy of SPA basin. It may not be possible to determine unambiguously if Dhofar 961 comes from SPA basin until a sample of basin floor material has been collected and its lithology studied in detail.

References: [1] Russell et al. (2005) The Meteoritical Bulletin No. 89, *M&PS* 40, A201-A263. [2] Demidova et al. in [1]. [3] Korotev et al. (2007) 70th Ann. Mtg. Met. Soc., Abst. 5257. [4] Jolliff et al. (2007) 70th Ann. Mtg. Met. Soc., Abst. 5311. [5] Korotev (2005) *Chemie der Erde,* 65:297–346. [6] Vicenzi et al. (2008) this Conf. [7] Jolliff (1998) *IGR* 40, 916-935. [8] Jolliff et al. (2000) *JGR* 105:4197-4216. [9] Jolliff and Gillis (2005) #5330, 68th Ann. Mtg. Met. Soc., *M&PS* 40, A77. [10] Prettyman et al., 2006. *JGR* 111, E002656. [11] Pieters et al. (2001) *JGR* 106, 28,001–28,022. [12] Lucey, P. et al. (2005) *Lunar Planet. Sci.*, 36, #1520.
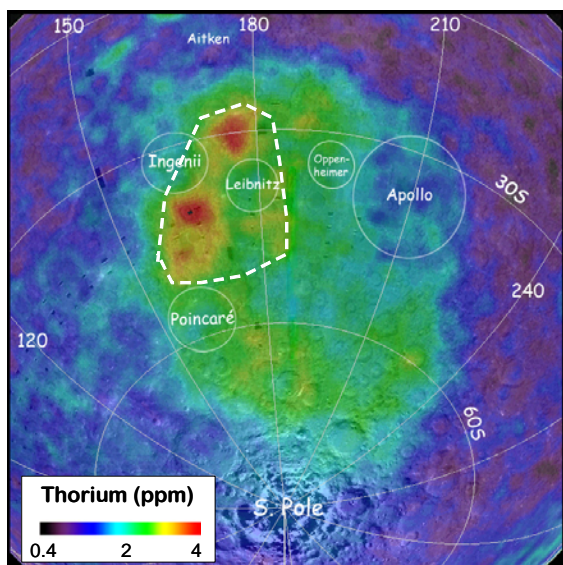

Figure 2. Thorium concentrations in the South Pole-Aitken Basin from the Lunar Prospector gamma-ray spectrometer. An area with suitable Th and FeO corresponding to Dhofar 961 shown by the dashed white boundary.