**CONNECTING LUNAR METEORITE DHOFAR 961 TO THE SOUTH POLE–AITKEN BASIN THROUGH LUNAR PROSPECTOR GAMMA-RAY DATA.** B. L. Jolliff[1], R. L. Korotev[1], R. A. Zeigler[1], and T. H. Prettyman[2], [1]Department of Earth and Planetary Sciences, Washington University, St. Louis, Missouri 63130; [2]Planetary Science Institute. (blj@wustl.edu).

**Introduction:** Lunar meteorite Dhofar 961, a complex, lithic-clast-rich impact breccia [1,2], was called out by [3-6] as a candidate for an origin in the South Pole – Aitken (SPA) Basin region of the Moon (the SPA Terrane) on the basis of its relatively mafic, but nonmare lithologic and major-element chemical composition. It also has an incompatible-element signature that differs from the KREEP-dominated signature of the Apollo samples [3] and most incompatible-element-rich lunar meteorites. For example, it has $P_2O_5/K_2O$ ~2, about twice that of Apollo impact-melt groups. Moreover, Dhofar 961 contains a prominent impact-melt-breccia lithic-clast component that is significantly more mafic than the Apollo mafic impact-melt breccia groups [4-6] (Fig. 1).

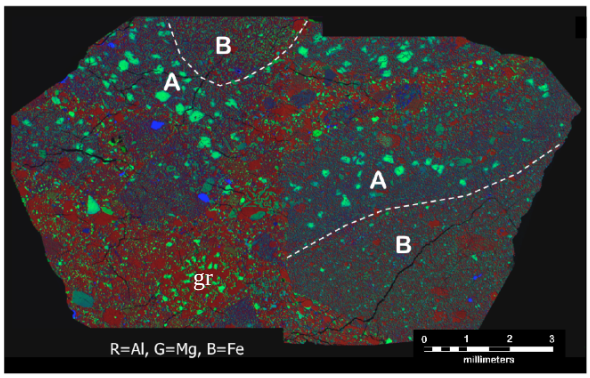


**Figure 1.** RGB composite X-ray image of Dhofar 961. Areas marked A and B are two lithologies of mafic impact-melt breccia. Grains with green color are mostly olivine. Reddish areas represent more feldspathic components. Brightest blue are grains of meteoritic Fe metal. Feldspathic granulite occurs at lower left center (gr).

We suggested that this meteorite might have a source in the SPA region because impact melt generated by SPA or by subsequent impacts into SPA basin materials would be expected, on the basis of orbital remote sensing, to have a relatively mafic composition. Also, the bulk Th concentration of Dhofar 961 is 2.8 ppm, similar to the average composition of this element in SPA materials as determined from orbit by the Lunar Prospector Gamma Ray Spectrometer (LP-GRS) [7]. In this abstract, we use major- and trace-element concentrations determined by the LP-GRS at 5-degree resolution and optimized by Prettyman et al. (2006) [8] to better constrain the case for an origin in the SPA Basin. It is important that we use this latest data set because of improvements made as part of the optimized data reduction.

**Connecting Dhofar 961 bulk composition to the SPA Basin:** Previously we relied on the generally mafic compositional character of the bulk meteorite (11% $FeO_T$) and especially the mafic impact-melt-breccia lithic-clast component (13-14 wt% FeO) to make the connection to the SPA region. Within the SPA Basin, FeO (5-degree-resolution LP-GRS data) ranges from 6 to 11 wt%, and averages ~8 wt%. Here, we use all the major elements plus Th and U included in the data processing by [8] to determine the regions that show the best match to the Dhofar 961 bulk composition. For this calculation, we used Si, Ti, Al, Fe, Mg, Ca, K, Th, and U. For Dhofar 961, we used average concentrations of these elements determined on multiple subsamples by INAA or fused-bead electron-microprobe analysis (FB-EMPA). We treat Fe as FeO ($FeO_T$), realizing that Dhofar 961 contains significant Fe metal especially in the mafic impact-melt lithology. If present in these materials on the surface of the Moon, the LP-GRS would also sense this source of Fe.

We computed differences between Dhofar 961 and LP-GRS data (whole Moon) in percentages and used the sum of squares of the differences to sort for the best matches. For the global data set and using just the major elements, the sum of squares of the best 6 matches are located in the SPA Basin (Fig. 2) and among the top 25 matches, 14 are in the SPA region.

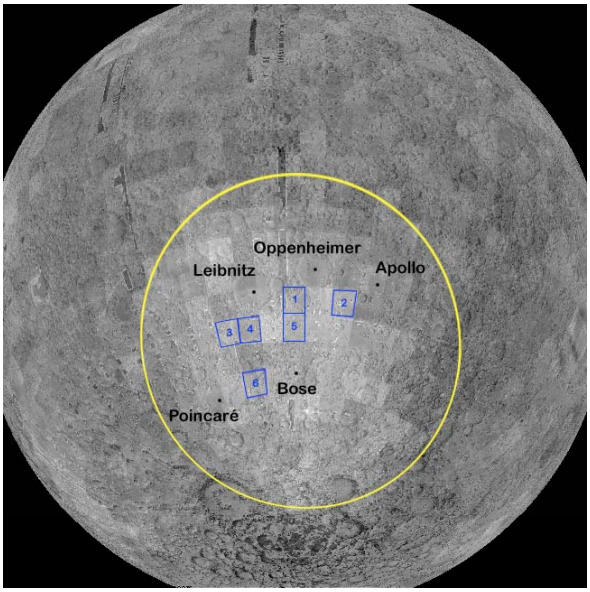


**Figure 2.** Locations of the best match 5-degree "pixels" from the LP-GRS data processed by [8] superimposed on an image of the SPA region consisting of the following layers: shaded relief, Clementine 750 nm, and LP-GRS FeO. The yellow circle marks the outline of the SPA interior region of elevated FeO. Several prominent basins and Bose Crater are labelled and located with black dots for reference. Image centered on 171° W and 41° S.

Including Th, U, and K, we find the top 8 matches to occur in SPA and 19 of the top 25. The Mg′ value [Mg/(Mg+Fe)×100] of Dhofar 961 compares well to the LP-GRS calculated Mg′ (62.6 compared to 63.4 +/- 0.7 for the top 6 major-element matches). Of the top 6, Mg′ ranges 62.6-65.8, and the best match has Mg′ of 62.3 (65.1 after correcting for Fe metal). We consider this to be, to first order, an excellent match. In Figure 2, location 1 is the best match for FeO and location 3 is the best match for Th, U, and K.

**Variations of component compositions in Dhofar 961:** Our laboratory analyses of Dhofar 961 included subsamples so that any compositional trends obtained would also provide information on the compositions of the different components. We analyzed multiple subsamples by INAA and by FB-EMPA. We also analyzed a polished section using micro-XRF [6] to obtain compositions of the mafic impact-melt lithology. Among the subsamples we found significant variation in FeO from 9–13 wt%; these variations correspond in part to different proportions of mafic impact-melt lithic clasts and other, mostly more feldspathic lithic and glass components. Among the subsamples, many elements correlate well with FeO (some are positive and some are negative correlations, e.g., $Al_2O_3$, Fig. 3). Extrapolating to high FeO, e.g., 17-20%, the extrapolated compositions begin to look like some volcanic materials, e.g., Ap 14 green or VLT glass, or Ap 12 olivine basalts; however, several compositional characteristics are distinctive and in some cases differ significantly from known volcanic materials. The extrapolated composition has low Ti, very-low Al, and relatively high Ca. In the extrapolated composition, at 20% FeO, $CaO/Al_2O_3$ exceeds any known basalts or volcanic glasses. The alkalis, Na and K, and P are also high compared to most lunar basalt compositions.

There may be no need to extrapolate beyond the ~14 wt.% concentration of FeO of the mafic impact-melt-breccia composition (lithology A, olivine-phenocrystic composition). Taking the composition at 14-15% FeO from the correlation among subsamples, the derived composition is that of a gabbronorite and is in fact close to the composition computed to be the mafic residual melt crystallizing within the lunar magma ocean at the time when plagioclase was accumulating and rising to form the feldspathic upper lunar crust. A likely origin for the precursor of this impact-melt breccia is in the lower crust as a gabbronorite that is complementary to the ferroan-anorthositic rocks that segregated efficiently to form the feldspathic upper crust.

**Variations of composition within SPA according to LP-GRS 5 degree data:** In the LP-GRS 5 degree data, concentrations of the major elements also correlate (roughly) with FeO. For example, $Al_2O_5$ ranges from ~25 to 15 wt%, and MgO, ~5 to 11 wt%. CaO is high, especially in the most Fe-rich pixels, consistent

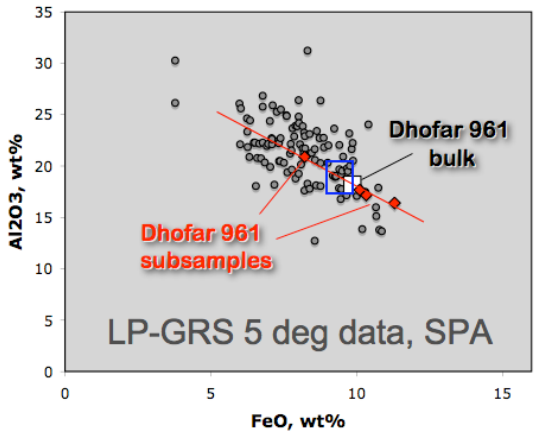


**Figure 3.** FeO vs. $Al_2O_3$ for SPA (LP-GRS) and Dhofar 961 (INAA, FB-EMPA, corrected for meteoritic metal). Blue box encloses "best fit" pixels in SPA.

with basaltic or gabbroic components (high-Ca pyroxene). $TiO_2$ ranges up to ~1.2 wt%, $K_2O$ to ~0.15 wt%, Th to ~3.7 ppm, and U to ~1 ppm at 5-degree resolution. Pixels that match best the Dhofar 961 bulk composition do not have the highest FeO, but are very similar in all measured elemental concentrations. The major-element compositions of these pixels also correspond to ferroan gabbronorite or gabbro for those with the highest CaO. At the low-FeO end $Al_2O_3$ values range from 21-28 wt% and Mg′ ranges up to about 75. These values could represent mixing into SPA of upper crustal materials from outside the basin by large impacts subsequent to the SPA event. At the high FeO end, Mg′ values extend as low as 50 and the lowest values correspond to areas with extensive mare basalt flows such as Ingenii, Leibnitz, and Apollo.

**Implications:** Although Dhofar 961 contains a few small basaltic lithic clasts of (aluminous, very-low Ti), the predominant mafic component is the olivine-gabbronorite impact-melt breccia. The composition of this component is clearly ferroan and is consistent with residual melt of gabbronoritic composition such as would have coexisted with late-stage ferroan-anorthosite plagioclase. Relatively high Na, K, P, Th, and U concentrations for this rock type favor a lower crustal origin as opposed to an upper mantle origin.

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**References:** [1] Russell et al. (2005) Meteoritical Bulletin No. 89, *M&PS* 40, A201-A263. [2] Demidova et al. (2005) *Lunar Planet. Sci.* **36**, #1607. [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] Jolliff et al. (2008) *Lunar Planet. Sci.* **39**, #2519. [6] Jolliff et al. (2008) Microscopy & Microanalysis 2008, Aug. 3-7, Albuquerque, #941. [7] Lawrence et al. (2007) *Geophys. Res. Lett.*, 34, L03201. [8] Prettyman et al., 2006. *JGR* 111, E002656.