DHOFAR 301, 302 AND 303: THREE NEW LUNAR HIGHLAND METEORITES FROM OMAN.

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Introduction: Several lunar meteorites, Dhofar 025, 026, 081, 280 and 287, have been discovered in the hot desert of Oman [1,2]. This year, three new meteorites, Dhofar 301, 302 and 303, of lunar origin were recognized by our group among stones collected in the same Dhofar region. Here we report the first data on the mineralogy and petrology of these meteorites. They are highland impact breccias, but each is distinct and distinguishable from other lunar meteorites collected nearby. We estimate that there should be at least 5 different falls of lunar meteorites in the Dhofar region.

Dhofar 301 is a brownish-gray moderately weathered stone weighing 9 g. The meteorite is a clast-rich impact melt breccia containing numerous mineral fragments and lithic clasts embedded in a fine-grained impact-melt matrix. The lithic clast population is dominated by impact-melt breccias. Primary igneous rocks and granulites of mostly anorthositic and gabbronoritic compositions are rare. Mineral chemistries are: feldspar, An_{90-98}; orthopyroxene, $Wo_{1-4}En_{70-99}$; clinopyroxene, $Wo_{6-43}En_{1-74}$; and olivine, Fo_{58-86}. Accessory minerals are Ti-rich chromite, ilmenite, troilite, and FeNi metal (7-48 wt% Ni; 0.4-1.4 wt% Co). Terrestrial secondary phases are gypsum, calcite, celestite, barite, and Fe hydroxides. Composition of the impact-melt matrix (wt%) is: SiO_2 44.1; TiO_2 0.36; Al_2O_3 28.6; Cr_2O_3 0.10; FeO 4.27; MnO 0.07; MgO 4.83; CaO 16.5; Na_2O 0.39; K_2O 0.04; and P_2O_5 0.07. The compositions of co-existing mafic phases and plagioclase from lithic clasts reside in the FAN-HMS gap on the MG#-An plot (Fig. 1). Two unique lithic clasts were found in the meteorite. The first one is of gabbronoritic composition and consists of feldspar (An_{90-93}) and practically pure enstatite and diopside with minor FeNi metal and silica. The second one is a VLT basalt consisting of feldspar (An_{91-96}) and clinopyroxene ($Wo_{13-40}En_{1-53}$). Dh301 was found near Dh025. Although both meteorites are similar in degrees of terrestrial weathering, they are different lithologically Dh025 seems to be higher in Mg-rich lithologies.

Dhofar 302 is a dark-gray stone weighing 3.83 g, virtually free of terrestrial weathering. The meteorite is a clast-rich impact-melt breccia. Mineral fragments and lithic clasts are set within a poorly-crystallized impact-melt glassy matrix. Impact-melt breccias are most abundant in the lithic clast population. Fragments of primary igneous rocks and granulites of anorthositic, gabbro-noritic and troctolitic compositions are also common. Rare glass fragments of KREEP composition were found. Mineral chemistries are: feldspar, An_{90-99}; orthopyroxene, $Wo_{1-4}En_{45-88}$; clinopyroxene, $Wo_{6-46}En_{2-83}$, and olivine, Fo_{8-94}. Accessories are Ti-rich chromite, Mg-Al-spinel, ilmenite, baddeleyite, silica, troilite, and FeNi metal (0.7-44 wt% Ni; 0.2-1.4 wt% Co). The composition of the impact-melt glassy matrix (wt%) is: SiO_2 44.5; TiO_2 0.27; Al_2O_3 28.1; Cr_2O_3 0.09; FeO 4.02; MnO 0.06; MgO 4.84; CaO 16.5; Na_2O 0.41; K_2O 0.09; and P_2O_5 0.12. The characteristic feature of Dh302 is its distinct polymict composition (Fig. 2) that distinguishes it stone from Dh081/280 collected nearby.

Dhofar 303 is a light-gray moderately weathered stone weighing 4.15 g. The rounded lithic clasts give this meteorite a typical conglomerate texture. These clasts are cemented by a fine-grained impact-melt matrix. Clasts of impact- melt breccias are most abundant and commonly show "breccia-in-breccia" textures. Primary igneous rocks and granulites are rare and are anorthosites and troctolites. Mineral chemistries are: feldspar, An_{94-99}; orthopyroxene, $En_{19-89}Wo_{1-5}$; clinopyroxene, En_{29-70} Wo_{6-46}; and olivine, Fo_{48-88}. Accessory minerals are Ti-rich chromite, ilmenite, armalcolite, rutile, troilite, and FeNi metal (1-37 wt% Ni; 0.2-2.3 wt% Co). Terrestrial secondary phases are celestite, barite, gypsum, calcite, and Fe hydroxides. Composition of the impact-melt matrix (wt%) is: SiO_2 44.0; TiO_2 0.15; Al_2O_3 29.7; Cr_2O_3 0.06; FeO 3.20; MnO 0.06; MgO 4.97; CaO 16.9; Na_2O 0.34; K_2O 0.01; and P_2O_5 0.03. The conglomerate texture and the weathering degree distinguish Dh303 from Dh302, Dh081, and Dh280 found nearby.

Source regions. All these new lunar meteorites from Dhofar are of highland origin. However, there are prominent differences among the meteorites. The **Dh301** lithic clasts are similar to mixed impact-derived rocks of the lunar highland crust (Fig. 1). The population of mineral fragments of Dh301 has mainly the same MG# value and probably originated from the same rocks (Fig. 1). The Dh301 impact-melt matrix is slightly lower in MG#, pointing to a higher amount of FAN in its composition (Fig. 1). In addition, the Ti enrichment of the matrix indicates an admixture of a mare-basalt component. In support of this, a VLT basalt clast was recognized in Dh301. These features suggest that Dh301 may be derived from the eastern limb of the Moon, near Mare Crisium. This region contains VLT basalts and is poor in KREEP. In contrast, **Dh302** contains KREEP and the Dh302 clasts indicate a certain contribution of HMS (Fig. 2). FAN and impact-derived lithologies are also present, and the MG# shows that FAN is more abundant in the matrix (Fig. 2). The KREEP presence suggests that Dh302 could be ejected from the western limb of the lunar nearside. No KREEP and mare basalt components were found in **Dh303**. HMS and granulitic material dominates this meteorite, but FAN is also present (Fig. 3). Therefore, it is suggested that Dh303 may be derived from the lunar farside, with its absence of KREEP and mare basalts.

Lunar volatiles. The Dh301 gabbro-noritic clast, containing Fe-free pyroxenes, cannot be formed by crystal-liquid fractionation. Therefore, this lithic clast is probably of metamorphic origin. The association of the pyroxenes + Fe metal + silica indicates highly reducing conditions. In such an environment, pyroxenes can have their iron reduced to Fe metal, with a corresponding amount of a silica phase being formed. Similar reduction of pyroxenes and olivine was documented in ureilites [3], some chondrules [4], the Budulan mesosiderite [5], and was reproduced experimentally [6]. The absence of water-bearing phases in the rock suggests that the reducing fluid did not contain any H. Therefore, CO seems to be the most probable reducing agent. Thus, this clast gives possible evidence for some role of volatiles and dry metasomatism in lunar petrogenesis. It is suggested that metasomatism could take place in ejecta blankets or in deep crustal rocks and could modify MG# values of primary lunar rocks.

Pairing. The lithologic composition, the weathering grade, and isotopic studies [7] suggest that some of the stones found in the Dhofar region are not paired. Dh025 and Dh026 were certainly ejected by different impacts [7]. The fragmental highland breccias Dh081 and Dh280 and the mare basalt Dh287 are distinctly different from Dh025 and Dh026 and very probably were derived by independent events. Dh303, Dh081, and Dh287 found nearby also are probably independent because they are very different in lithologies and degree of terrestrial weathering. Dh301 and Dh025 are similar and probably paired. The pairing of Dh302 with Dh081/280 is unlikely but possible. Thus, it would seem that there are at least 5 non-paired lunar meteorites, weighing totally 1.5 kg, in the Dhofar collection, indicating to a concentrated lunar-material flux to this portion of Earth.

References: [1] Grossman J.N. (2000) *MAPS, **35***, A199-A205; [2] Grossman J.N. & Zipfel J. (2001) *MAPS,* **36**, A293-A322; [3] Goodrich C.A. et al. (1992) *MAPS, **27**,* 327-352; [4] Weisberg M. et al. (1994) *MAPS, **29**, 362-373;* [5] Lorenz C. et al. (1999) *LPS **XXXI**,* 1315.pdf; [6] Nagahara H. (1986) *LPS **XVII**,* 595-596; [7] Nishiizumi K. and Caffee M.W. (2001) *MAPS,* **36**, A148-A149.