Petrologic Comparisons of Lunar Mare Basalt Meteorites Dh-287A and NWA 032

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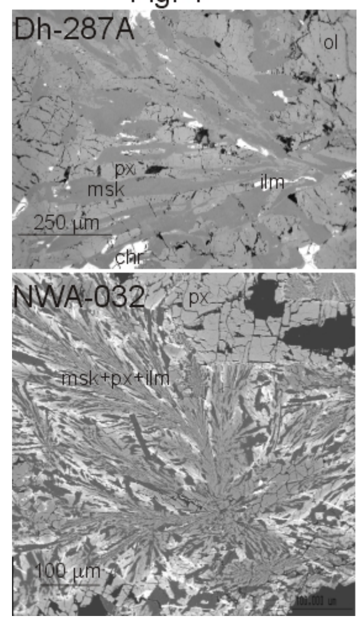
Introduction: It is intriguing that the majority of lunar meteorites (~30) have been discovered in the hot deserts of Middle-East and North Africa. In contrast, of 10s of thousands of meteorite finds from Antarctica over 30 years, only a handful (~5) are lunar. This bias towards the lunar meteorite recovery from the hot deserts may be due to the preferential fall of lunar meteorites in these regions. This may be a direct result of the dynamics of the Earth-Moon system and preferential orbits of the lunar meteorites near the plane of the E-M system. Alternatively, it could be related to limited number of falls comprising a variety of lunar lithologies (e.g., mare-basalts, highlands breccias). Recently, two new mare basalt meteorites have been recovered from the hot deserts, and it is the aim of this study to compare their petrogenetic histories in an assessment of possible source-area pairing.

Dhofar 287 (Dh-287) and North West Africa 032 (NWA 032) were recovered from the desert regions of Oman and the Sahara, NW Africa, resp. Dh-287 consists mainly (> 95%) of a large mare basalt clast (Dh-287A) with a small portion of a breccia (Dh-287B) attached on one side. To date, these rocks represent two out of only 5 mare basalt meteorites in the entire lunar collection, having fallen only a few thousand kilometers apart. Although these two basalts have been studied previously [1,2], no direct comparisons have been made. Therefore, they form an important group of samples that provide clues to the magmatic history of the Moon. Both meteorites are akin to low-Ti basalts of A-12 and 15, but have distinct petrogenesis.

Mineralogy and whole-rock geochemistry: Dh-287A consists mainly of phenocrysts of olivine (>2mm) and pyroxene (up to 0.5mm) set in a fine-grained matrix, composed of elongated pyroxene and plagioclase crystals, radiating from common nucleii (Fig. 1). Accessory minerals include ilmenite, chromite rimmed by ulvöspinel, troilite, and FeNi metal. It is unusually rich in late-stage fractionate (mesostasis) that is composed of fayalite, K-rich glass, and F-apatite. In appearance, this is a low-Ti mare basalt, with similarities to Apollo 12 and 15 basalts; however, all plagioclase is now present as maskelynite, and its composition is atypical for such basalts. In contrast, NWA 032 possesses a finer-grained texture. It contains relatively few and smaller olivine (~0.4mm) and pyroxene (~0.2mm wide) phenocrysts in a very fine-grained (<20µm) groundmass of pyroxene, plagioclase, and ilmenite. Groundmass minerals show typical plumose/variolitic texture (Fig. 1). Accessory minerals are ilmenite, chromite with a thin rim of ulvöspinel, traces of troilite, and FeNi metal. Ilmenite grains are acicular and show hopper growth, due to rapid crystallization. No typical, late-stage basaltic fractionate is obvious in this sample. One of the main textural features of NWA 032 is the presence of abundant (6 modal%) impact-melt veins throughout the sample. These veins have sharp contacts with host minerals that also lack any resorption features. In addition, this sample is more weathered than Dh-287A, as evidenced by the presence of many calcite-rich veins from terrestrial origin.

Fig. 1



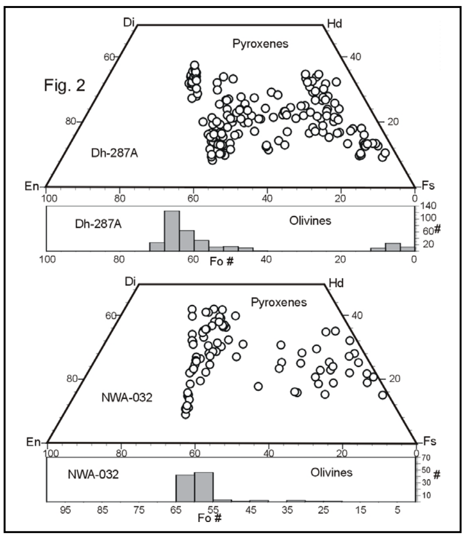
The modal mineralogy of Dh-287A and NWA 032, as determined by EMP mapping [3], are listed in Table 1. Both samples have similar modal amounts of pyroxene and plagioclase. However, Dh-287A is distinctly higher in modal olivine and in the amount of mesostasis (3 modal%).

Table 1: Mineral Modes

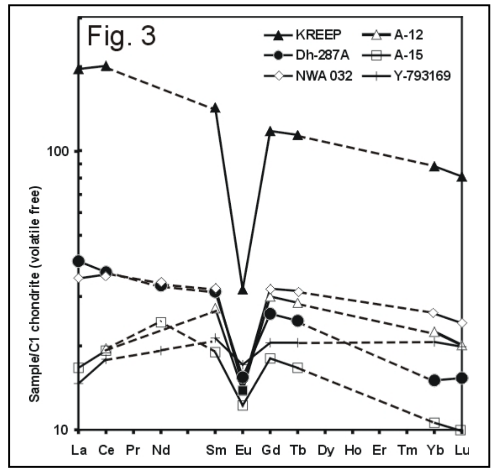
Phases	Dh-287	NWA-032
Olivine	20.6	8.07
Pigeonite	29.3	3.32
Fe-Cpx	2.4	9.06
Mg-cpx	15.7	39.6
Plagioclase	25.9	29.3
Ilmenite	2.3	2.57
Chromite	1.2	0.25
Troilite	0.1	0.17
Fe-Metal	trace	Trace
Mesostasis	>3	0.30
Phosphate	0.6	0.00
carbonate	trace	1.30
silica/fayalite	0.4	none
Impact Melt	1.4	6.05
Total	99.9	99.9

The majority of the olivine grains in Dh-287A is chemically zoned and shows asymmetrical zoning with iron enrichment within 50µm of the rims. Similarly, pyroxene compositions show extreme variation in chemistry following a typical mare-basalt fractionation trend (Fig. 2). In contrast, the NWA 032 olivines show less zoning, with Fe-enrichment near the edge (~5µm), and the pyroxenes show bimodal distribution in their compositions. One group varies in composition from pigeonite to augite;

the second group plots near the Fe-rich end of the pyroxene quad indicating ferrohedenbergite and pyroxferroite (Fig. 2). Plagioclase is present as maskelynite (Msk) in both meteorites. Msk compositions in Dh-287A are An-poor (An 74-84) compared to NWA 032 (An 80-90). In NWA 032, Msk compositions show some deviation from plagioclase stoichiometry, indicating modification in chemistry by impact melting of plagioclases during a shock event. The same shock event may be responsible for the formation of the impact-melt veins present in the rock. A few isolated plagioclase grains in the rock are An-rich (up to An 96) and still preserve perfect stoichiometry. One of the striking petrographic features of Dh-287A is the over abundance (3%) of late-stage mesostasis throughout the sample, typically 300 x 300µm in size and composed of fayalite, both Si-rich and K- Ba-rich glasses, ilmenite, F-apatite, and tranquilityite. Pyroxene grains surrounding mesostasis areas show extreme iron enrichment, all the way to pyroxferroite. NWA-032, however, has no such mesostasis areas, which may suggest differences in source regions of these two meteorites. Opaque minerals are abundant (i.e., 3%) throughout Dh-287A and NWA 032. Ilmenite is most common, followed by spinels. These show fractionation trends similar to those of low-Ti mare basalts.



The whole-rock, major-element composition of Dh-287A (13.2wt% MgO) reflects its olivine-rich nature, compared to NWA 032 (8.45wt% MgO) [1,2]. Other major elements also show similar behavior: higher abundance of Na_2O and K_2O (0.53 and 0.19wt% resp.) in Dh-287A bulk-rock is most likely due to abundant mesostasis. In terms of REE contents, both Dh-287A and NWA 032 have similar chondrite-normalized LREE patterns (Fig. 3). However, they show distinct HREE patterns; Dh-287A is more depleted than NWA-032. The REE pattern of Dh-287A is similar to KREEP and suggests KREEP assimilation either in its source region or during the emplacement of the lava flow. This is in agreement with other geochemical and petrographic data. On the other hand, the HREE pattern of NWA 032 is similar to A-12 low-Ti basalts and does not require any KREEP assimilation. However, it has elevated LREE contents, which could partly be ascribed to the effects of terrestrial weathering or source characteristics.



Discussion: Dh-287A and NWA 032 are low-Ti mare basalt meteorites that are similar in many petrological respects, yet they have distinct mineral and geochemical characteristics, indicative of completely different petrogenetic histories. Dh-287A is an olivine-rich rock that crystallized relatively slowly, thereby permitting development of a range in mineral compositions, also reflected by grain size and shape. It contains an over-abundance of late-stage mesostasis that, along with the whole-rock REE contents, suggests possible KREEP assimilation. NWA 032, on the other hand, differs from Dh-287A in having finer-grained texture and lack of mesostasis. It contains notably less modal olivine and has whole-rock REE contents similar to low-Ti A-12 mare basalts. It has been affected more extensively by shock-melting than Dh-287A, which is apparent through numerous impact-melt veins. Step-heating Ar-Ar analysis resulted in an age of 2.7 Ga for this rock, which is interpreted to be the age of the shock event [1]. The crystallization age of Dh-287A has been determined by Sm-Nd isotope systematics to be 3.46 Ga [4], consistent with the ages obtained for A-12 and 15 low-Ti mare basalts.

In summary, Dh-287A and NWA 032 mare basalts appear to have been derived from two different source regions of the Moon with distinct petrogenetic histories. Although they have some similarities, they possess many differences in terms of their geochemical and petrologic characteristics.

References: [1] Fagan et al. (2002), *MAPS*, 37, 371-394; [2] Anand et al. (2003), *MAPS*, in press; [3] Taylor et al., 1996, Icarus; Shih et al. (2002), LPSC XXXIII, Abstract #1344.