LUNAR METEORITE DHOFAR 026: A SHOCKED GRANULITIC BRECCIA, NOT AN IMPACT MELT.

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Introduction: Lunar meteorite Dhofar 026 was previously interpreted as an impact melt [1, 2]. Detailed studies of the rock and comparison to Apollo lunar samples 15418 and 60017 indicate that the rock instead is a shocked, partly melted, granulitic breccia. These studies, presented by [3], are summarized herein.

Petrology of Dhofar 026: Most of the rock consists of blocky patches of monomineralic plagioclase, blocky patches of olivine-plagioclase intergrowths, and irregular patches of pyroxene-plagioclase intergrowths (Fig. 1a). Locally the rock contains swirls, streaks, and irregular patches of brownish, plagioclase-rich, devitrified glass and sharply bounded globular bodies that consist of intergrowths of plagioclase and mafic minerals. Vesicles are common throughout the rock.

Monomineralic plagioclase. Patches of monomineralic plagioclase range from 20 to 300 µm across. The plagioclase is a mat of acicular needles; within many of the larger patches, the needles have similar extinctions. Many patches contain vesicles.

Olivine-plagioclase intergrowths. Intergrowths of olivine and plagioclase are as much as 1.5 mm across and consist of small globular olivine grains set in a mat of fine-grained acicular plagioclase. Scattered throughout are sparse 100-µm grains of olivine, which consist of mosaics of small subgrains.

Pyroxene-plagioclase intergrowths. Very fine-grained intergrowths of augitic pyroxene, plagioclase, and minor olivine range from small, well-defined patches to irregular anastomosing patches that fill interstices between patches of olivine-plagioclase intergrowths and patches of monomineralic plagioclase. Textures and mineralogy of the intergrowths indicate crystallization from melt. The plagioclase, olivine, and some augite grains are subhedral and are enclosed by subophitic-poikilitic pyroxene grains, which are zoned to iron-rich compositions at their edges.

Globules. The globules have ovoid to amoeboid to blocky outlines and they average about 100 µm across. Textures and mineralogy indicate crystallization from melt. Olivine forms euhedral or skeletal grains, plagioclase forms subhedral laths, and augitic, strongly zoned pyroxene and mesostasis fill interstices; the minerals are very fine grained and show no shock effects. The globules commonly contain vesicles.

Origin and History of Dhofar 026: The rock is a shocked breccia – a granulitic breccia, or a fragmental breccia consisting almost entirely of clasts of granulitic breccia. During the shock event, all the plagioclase was converted to maskelynite, and the olivine was deformed. Post-shock temperature was above the solidus, and extensive partial melting took place. This melting was concentrated in pyroxene-rich areas, which had the lowest melting temperatures; all the pyroxene in the rock melted. Small patches of plagioclase-rich melt formed locally. Vesicles formed, mostly in maskelynite and the lowest-melting-temperature melt (which later crystallized to form the globules). As the rock cooled, the pyroxene-rich melt crystallized to form pyroxene-plagioclase intergrowths and globules, the deformed olivine recrystallized, the maskelynite devitrified, and the plagioclase-rich melt crystallized or devitrified.

Evidence for the Proposed History of Dhofar 026: The texture of the plagioclase and large olivine grains provide evidence that the rock was subjected to pervasive shock. The largest monomineralic plagioclase patches are clearly devitrified maskelynite, because they have blocky outlines, consist of mats of acicular subgrains with similar extinction, and are monomineralic. The rest of the plagioclase in the monomineralic patches and that in the olivine-plagioclase intergrowths is texturally identical to that in the devitrified maskelynite, except that areas of similar extinction are small; this difference would be expected if the grains in the pre-shock aggregate were small. All olivine grains larger than 20 µm across are mosaics of small subgrains, indicating that they were shocked and subsequently recrystallized.

Evidence that the pyroxene-plagioclase intergrowths crystallized *in situ* is as follows. The intergrowths are highly irregular in outline and penetrate, sometimes on a very fine scale, into surrounding mineral aggregates. Some of the plagioclase grains within the intergrowths grew as extensions of small plagioclase grains at the edges of devitrified maskelynites outside the intergrowths. The pyroxene grains of the intergrowths are zoned toward their margins, and there are no broken grain edges. There is no shock-induced disruption of grain outlines; this observation and the fact that plagioclase grains within the intergrowths grew on grains formed during devitrification of maskelynite indicate that the crystallization took place after the shock event. The absence of shock effects in the globule minerals indicates that the globules also crystallized *in situ*, after the shock.

Evidence for post-shock temperature well above the solidus of the bulk rock is as follows: *in-situ* crystallization of the melts that formed the pyroxene-plagioclase intergrowths and globules (liquidus temperatures of these melts would have been about 1200°C); flowage within maskelynite grains to permit formation of vesicles; and the absence of relict pyroxene in the rock, indicating that all pyroxene melted.

Looking through the effects of the shock, the overall texture of Dhofar 026 indicates that the rock was originally a granulitic breccia. The distribution of grains in the olivine-plagioclase intergrowths (small globular olivine grains set in plagioclase) is typical of granoblastic granulitic breccias [4] and is not found in lunar rocks formed by other processes. The texture is similar to that of poikilitic-granoblastic granulitic breccias [4], and the original granulitic breccia may have been a poikilitic-granoblastic breccia.

Lunar Granulitic Breccia 15418: Lunar granulitic breccia 15418 had a history like that proposed for Dhofar 026 [5], but, because the original 15418 granulitic breccia was coarse grained, evidence for this history is more apparent than in Dhofar 026. In 15418, original grain boundaries were well preserved after the shock event, even after considerable melt formed (Fig. 1b).

The textures of 15418 demonstrate that, in a shocked rock with post-shock temperatures above the solidus: melting is highly localized and concentrated at the loci of pyroxene grains; melting begins at contacts between plagioclase and orthopyroxene grains; the melts incorporate significant plagioclase and crystallize with igneous textures; considerable numbers of partly melted, relict olivine grains remain after all pyroxene has melted; and melt remains at the loci of the original mafic-mineral grains, unless there is significant shear.

In 15418, the extent of post-shock melting is exceptionally varied. In the interior of the rock, melting occurred only at plagioclase-orthopyroxene contacts. Toward the exterior of the rock, the extent of melting increased progressively: first all pyroxene, plus some plagioclase, melted; then olivine melted as well. As the proportion of melt increased, the melt blobs coalesced, and locally shear formed complex swirls of blobs of melt and devitrified maskelynite. Some areas near the exterior consist of feldspathic impact melt that has been interpreted as a total melt of the granulitic breccia [5]; some of this melt may represent a melt coating deposited on the rock during the shock event.

The textures of 15418 clearly demonstrate the validity of the proposed history of Dhofar 026. The textural variations within 15418 establish that shock, post-shock partial melting, and crystallization of the partial melt can all be the result of a single impact event; reheating or heat retention by burial is not required.

Lunar Feldspathic Breccia 60017: A clast of very strongly shocked breccia from within sample 60017 contains bodies texturally like the globules in Dhofar 026. The textures within the breccia clast indicate that: these bodies formed by post-shock melting of mafic-mineral aggregates that initially filled interstices between plagioclase grains in coarse-grained anorthosite clasts; and the anorthosite clasts were disaggregated by shear during the shock event, separating the melt globules from their parent anorthosites. The observations indicate that globules like those in Dhofar 026 can form by post-shock melting of aggregates of mafic minerals and plagioclase derived from clasts.

Conclusion: Shocked lunar rocks can develop very complex textures that may superficially resemble the textures of impact melts. Extreme care is required in resolving the processes and sequence of events that operated in the history of such rocks.

References: [1] Cohen B. A. et al. (2001) *LPS XXXII,* Abstract #1404. [2] Taylor L. A. et al. (2001) *LPS XXXII,* Abstract #1985. [3] Cohen B. A. et al. (in preparation) *Met. Planet. Sci.* [4] Cushing J. A. et al. (1999) *Met. Planet. Sci., 32,* 185-195. [5] Nord G. L. Jr. et al. (1977) *The Moon, 17,* 217-231.

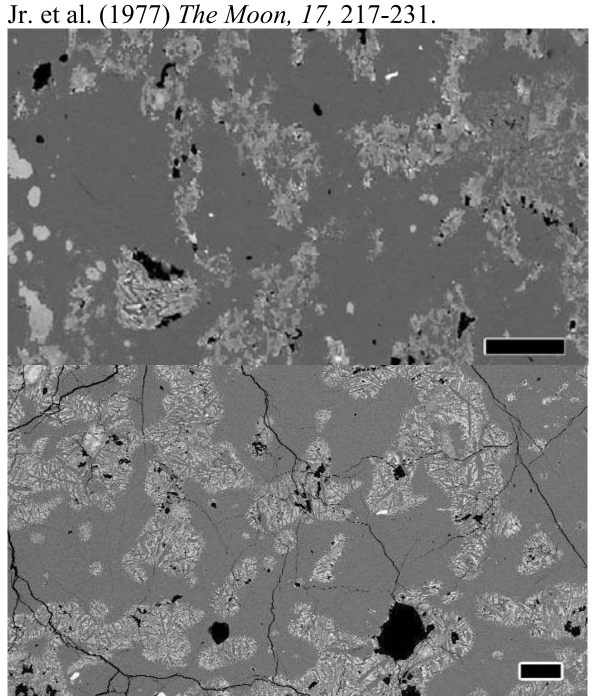

Figure 1. Backscattered-electron scanning electron microscope images of Dhofar 026 (top) and shocked granulitic breccia 15418 (bottom); scale bar 100 µm. Colors as follows: dark gray, plagioclase; medium gray, magnesian pyroxene; light gray, olivine and ferroan pyroxene; white, oxides and troilite; black, voids. Fine-grained intergrowths of mafic minerals and plagioclase, which represent crystallized melts formed by *in situ* post-shock melting, wrap around grains of devitrified maskelynite.