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THE DREGS OF CRYSTALLIZATION IN ZAGAMI

T.J. McCoy, K. Keil and G.J. Taylor, Planetary Geosciences, Department of Geology and Geophysics, School of Ocean and Earth Science and Technology, University of Hawaii at Manoa, Honolulu, HI 96822, USA.

Abstract. The Zagami shergottite is a basaltic meteorite [1] which formed when a phenocryst-bearing lava flow was emplaced at or near the surface of Mars [2]. Recently, a cm-sized olivine-rich lithology has been identified in Zagami by Mössbauer spectroscopy [3]. Olivine is extremely rare in shergottites, particularly in Zagami and Shergotty [1], where it occurs only as minute grains. We report petrologic and microprobe studies of this olivine-rich lithology. This material represents the last few percent of melt and is highly enriched in phosphates, opaques and mesostases, all of which are late-stage crystallization products. Phosphates replaced augite as a phenocryst phase when the magma became saturated in P. This late stage melt also includes a fayalite-bearing, multi-phase intergrowth which crystallized after the melt became too rich in iron to crystallize pigeonite. We can now reconstruct the entire crystallization history of the Zagami shergottite from a deep-seated magma chamber to crystallization of the final few percent of melt in a near-surface dike or thick flow. Small pockets (tens of microns) of late-stage melt pockets are ubiquitous but volumetrically minor in Zagami. We do not know the physical relationship between these areas and the cm-sized olivine-rich material described here. It is possible that these small pockets were mobile, forming larger areas. Perhaps inspection of the entire hand specimen of Zagami would clarify this relationship.

Results. The modal mineralogy of the late stage melt, discovered by Mössbauer spectroscopy and called Zagami DN by [3], differs dramatically from the major portions of the Zagami shergottite [2], here called Normal Zagami (NZ). DN contains much less pyroxene (13.6 vol.%) than NZ (77.7 vol.%). Maskelynite abundances are similar in the two. Phases which occur as minor constituents in NZ are highly enriched in DN, including phosphates (11.4 vol.%), mesostases (8.1 vol.%), ilmenite/titanomagnetite (5.9 vol.%) and pyrrhotite (1.6 vol.%). Also found in DN is a fayalite-rich intergrowth (39.9 vol.%), which is unknown from NZ.

DN contains pigeonite, plagioclase and phosphates as phenocryst phases. Although augite occurs as phenocrysts in NZ, it does not in DN. All of these phases in DN are at the compositional extremes of similar phases in NZ: Pigeonite in DN is FeO-rich (Fs_{56-71} vs. Fs_{28-56}), while maskelynite is more sodic (Ab_{56-59} vs. Ab_{42-53}). Whitlockite is the dominant phosphate and contains 5.0 wt.% FeO, comapred to 3.0 wt.% in NZ. Fluorapatite is also present as millimeter long laths. Low sums for microprobe analyses and stoichiometric deficiencies of F and Cl suggest that this apatite may contain significant (~1wt.%) OH, although no direct measurment of the water content has been conducted. Hydroxyapatite has been identified in Shergotty by X-ray studies [4]. The major assemblage in DN is an olivine-bearing intergrowth. Near the pigeonite grains, this intergrowth is dominated by augite, fayalite and a K-rich mesostasis. Augite is more FeO-rich (Fs_{46-54}) than augite in NZ (Fs_{19-39}). Olivine is Fa_{90-96} and makes up 25-30 vol.% of this intergrowth. The K-rich mesostasis is compositionally similar to mesostasis described by [1]. At the edges of the large whitlockite crystals, the intergrowth is coarser-grained and is dominated by olivine (Fa_{96}), which encloses a mixture of mesostases and phosphates. Fayalitic olivine comprises greater than 50 vol.% of this type of intergrowth. DN also contains titanomagnetite with exsolved ilmenite, pyrrhotite and mesostases. Mesostases compositions are similar to those reported by [1]. This material appears to be composed of three phases: maskelynite similar in composition to the maskelynite laths; SiO_2 with about 10% of small maskelynite laths; and K-rich feldspar. The presence or absence of the K-rich feldspar accounts for the difference between K-rich and K-poor mesostases. No baddelyite was identified, despite an extensive search using optical microscopy and X-ray mapping.

Unfortunately, we do not know the original size or shape of this "pocket" of late stage melt. The material we studied has a maximum dimension of 8 mm, suggesting an original size of at least

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1 cm in diameter. We do not know the original shape of this "pocket" of melt (e.g., round bleb, layer, vein).

Discussion.   One of the most remarkable features of DN is its size. While areas rich in whitlockite, titanomagnetite and mesostases are present in all Zagami samples [1,2], these seldom exceed a few hundred μm in size. We do not know the physical relationship between the micron-sized pockets and the cm-sized olivine-rich late-stage melt. One possibility is that the micron-sized materials were mobile and at times formed cm-sized segregations. In terrestrial basalts, such late-stage melts are often found as dikelets [5,6]. Perhaps examination of the entire material of Zagami in hand specimen could clarify this relationship.

The most exciting aspect of DN is that it allows us to reconstruct the entire crystallization history of Zagami (Fig. 1). The rock experienced a two-stage crystallization history [2], in which homogeneous Mg-rich pyroxene cores crystallized in a deep, slowly-cooling magma chamber, which were then entrained in a lava flow emplaced as a near-surface dike or thick lava flow. This magma crystallized pigeonite, augite and plagioclase for most of its history. Late-stage differentiated melt occurs as interstitial areas hundreds of μm in diameter and as a cm-sized pocket. Because of its relatively large size, the cm-sized pocket of late stage melt continued to differentiate. The presence of phosphates and absence of augite as phenocrysts in DN suggests a change in the crystallization history. The magma became saturated in P, which scavenged Ca from the melt and prevented the crystallization of augite. Instead, phosphates crystallized from the magma. The presence of apatite suggests that the magma contained significant amounts of F, Cl and, possibly, water. The next major change in the crystallization occurred when the melt became too Fe-rich to crystallize pigeonite. Instead, fayalite began to crystallize along with an SiO_2-normative mesostases. In some parts of the intergrowth, whitlockite continued to crystallize, due to the availability of sufficient P, while augite crystallized in other parts. This explains both the presence of the olivine-bearing intergrowth and the heterogeneity of this intergrowth. Finally, mesostases and opaque minerals crystallized.

References. [1] Stolper and McSween (1979) *GCA* **43**, 1475-1498. [2] McCoy *et al.* (1992) *GCA* **56**, 3571-3582. [3] Vistisen *et al.* (1992) *Physica Scripta* **46**, 94-96. [4] Fuchs (1969) In *Meteorite Research* (ed. Millman), 683-695. [5] Walker (1940) *Bull. Geol. Soc. Amer.* **51**, 1059-1106. [6] Bunch and Keil (1971) *Contrib. Min. Petrol.* **31**, 267-274.

Figure 1 Crystallization history of Zagami showing percent crystallization (%Xn), location, and the crystallization interval for each phase.

% Xn	0	~15	~98	~99.5	~99.9	100
Location	Magma Chamber		Near-surface flow or dike			

Pigeonite
Augite
Plagioclase
Whitlockite
Olivine
Mesostases
Opaques