Abstract - Zagami contains a dark, mottled lithology (DML) which occupies ~20% of the rock. Major, minor, and trace element mineral compositions indicate that this lithology represents an intermediate stage in the crystallization history between the widely-known normal Zagami lithology and the highly-evolved Zagami DN lithology. DML also includes pockets of Zagami DN, pyroxene clumps composed of high-FeO pyroxenes, and shock-melt pockets. The heterogeneity within Zagami suggests that it did not form in a homogeneous, thick lava flow. Concentration of evolved melt may have involved pyroxene clumping, crystal settling, flow differentiation and melt migration, possibly in thin injection units within a thick magma body.

Introduction - The availability of new, large samples of Zagami in the past five years has stimulated research on this poorly-known shergottite [1,2]. Zagami experienced a two-stage magmatic history, crystallizing in both a deep-seated magma chamber and an ~10 m thick, near-surface magma unit [1]. Magma chamber depths and lava flow thicknesses inferred from petrologic studies are consistent with observations of volcanoes and lava flows in the Tharsis region of Mars, the likely source region of the SNC meteorites [1,3]. Subsequent observations of an olivine-rich lithology called Zagami DN [4] showed it to be a late-stage melt pocket [5,6]. Unfortunately, the physical setting of DN within Zagami was unknown. Examination of 5.2 kg of Zagami revealed that DN was not present in the normal Zagami (NZ) lithology described by [1,2], but rather in a volumetrically significant lithology termed the dark, mottled lithology (DML) [6]. DML occupies ~20% of Zagami and borders NZ along a sharp, but sometimes irregular, boundary. We have completed petrographic, microprobe and ion probe studies of this lithology to further elucidate the chemical and physical evolution of Zagami.

Results - DML has an average grain size of 0.30 mm and shows no preferred orientation. Modal analyses reveal that DML is slightly enriched in late-crystallizing phases (e.g., phosphates) when compared to NZ, but is much poorer in these than DN. Pigeonite compositions in DML (Fs29.8) span the entire range from those in NZ (Fs30.54) to DN (Fs55.72). Trace element analyses of pigeonites support this conclusion. Pigeonites in DML span the entire range of rare earth element and other trace element compositions seen in NZ and DN, filling compositional gaps in which NZ and DN did not grade into each other (e.g., for Cr and Ti abundances). Augites in DML (Fs19.43) are similar to those in NZ (Fs19.40) and poorer in FeO than DN augites (Fs45.54) [1,5]. Maskelynite compositions (An38.48) are also intermediate between those of NZ and DN. Whitlockites have FeO concentrations (3.1-3.9 wt.%) intermediate between those of NZ (~3 wt.%) and DN (~5 wt.%).

DML includes a number of features. Most prominent among these are pockets of DN. Four rounded pockets, 100's of mm to 1 mm in diameter, are enriched in mesostases, phosphates and opaques, but lack the fayalite-SiO2 intergrowth characteristic of DN. The largest pocket is 3 mm in diameter and contains all the phases indicative of DN, including a small amount of fayalite-SiO2 intergrowth. These pockets occur in the centers of areas enriched in pyroxene and depleted in maskelynite. Another interesting feature is a pyroxene clump ~4 mm in diameter nearly devoid of maskelynite. The center of the clump is enriched in phosphate, opaques and mesostases. Microprobe analyses reveal that the pyroxenes within this clump do not contain homogeneous Mg-rich cores and, in fact, contain the most FeO rich compositions yet observed in Zagami, surpassing those of DN. Shock-melt pockets have also been observed in DN, ranging in size up to 3 mm in diameter. Petrographic and isotopic analyses of these pockets, including only the second observation of trapped Martian atmospheric gases, are reported elsewhere [7]. Finally, we observed in one hand sample cm-long veins of clear glass which appear to be
maskelynite. These veins occur at and are perpendicular to the boundary between NZ and DML. Studies of these veins in thin section are planned.

**Discussion** - With the recognition of DML, we can now more confidently reconstruct the chemical evolution of the Zagami melt. It appears that the crystallization history for Zagami outlined by [5] is essentially correct. The crystallization sequence was pigeonite (?) → pigeonite + augite → pigeonite + augite + plagioclase = pigeonite + plagioclase + phosphates = augite + phosphates + fayalite-SiO₂ intergrowth = mesostases + opaques. The crystallization sequence is controlled by the increasing iron content of the melt and the competition among phases for the limited amount of calcium. NZ apparently never became enriched enough in iron to cause the cessation of pigeonite crystallization and the onset of the olivine-SiO₂ intergrowth. DN was so enriched in iron that the first stage of crystallization included phosphates. Unlike NZ and DN, DML samples the entire range of crystallization. Major, minor and trace element compositions of pigeonite within DML (and its enclosed DN pockets) span the range from the earliest crystallizing Mg-rich pyroxenes observed in NZ to the highly-evolved compositions observed in DN. Interestingly, DML is very similar to Shergotty in its range of crystallization. Late-stage melt pockets in Shergotty often contain a fayalite-SiO₂ intergrowth, testifying to a prolonged crystallization history. DML and Shergotty are also similar in grain size, although Shergotty exhibits a pronounced foliation absent in DML. It is possible that Shergotty also exhibits the pronounced heterogeneity observed in Zagami and, thus, a detailed examination of the main mass of Shergotty seems warranted.

Deducing the complete physical history of Zagami is more challenging. We find no evidence to refute a two-stage magmatic history for Zagami, with crystallization in both a deep-seated magma chamber and a near-surface magma body ~10 m thick [1]. The gross similarity of previously studied samples of Zagami [1,2] suggested a relatively homogeneous thick lava flow. The cm-scale variability in Zagami now suggests that the near-surface crystallization was complex. DN does not occur as elongated veins indicative of the filling of contraction cracks [5], suggesting that concentration of late-stage melt occurred earlier in the history of Zagami, probably before DML crystallized. The FeO-rich nature of DML and the sharp physical boundary between DML and NZ suggests that NZ formed by concentration of Mg-rich cores into a partially-evolved melt with few cores. Mechanisms to concentrate cores include clumping, crystal settling, flow differentiation and melt migration. Clumps of Mg-rich pyroxenes are found in NZ [1], although these are small and their influence in concentrating late-stage melt is limited. Crystal settling might play a role, although Mg-rich cores should only settle ~2 cm during near-surface crystallization [1]. Flow differentiation might result in some concentration of cores near the margins of the flow. Greater heterogeneity would occur if the 10 m thick cooling unit [1] was, in fact, composed of multiple m-thick crystallization units, each of which experienced crystal settling and flow differentiation. Pulses of new magma injected into a partially-crystallized near-surface magma body, such as might be found in inflating lava fields or shallow magma chambers, could provide such an environment. Processes operating within one of the injection units could account for heterogeneity within Zagami, while EET A79001 might sample the boundary between two injection units [8]. Finally, evolved melts might readily migrate from an area of concentrated Mg-rich cores due to the fluid nature of the Fe-rich magma. This melt could increase the volume of late-stage melt from which DML and DN crystallized. The exact processes which occurred within this evolved melt to form FeO-rich pyroxene clumps and DN pockets are unclear. Liquid immiscibility could have played some role. Whatever this process, it created areas up to 2 cm in diameter which were devoid of Mg-rich cores and from which FeO-rich pyroxene clumps and DN pockets crystallized.