Introduction:
Textural variations in the shergottite Zagami were initially interpreted as evidence that it formed in a heterogeneous lava flow [1, 2]. Variations in initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios between a Coarse Grained (CG) and a Fine Grained (FG) lithology [3,4] and evidence for more extensive fractionation of the Rb/Sr ratio in a Dark Mottled Lithology (DML) [2, 5] are consistent with such an interpretation. More recently, Nihara et al. [6] and Misawa et al. [7] have reported the mineralogy and Sr-isotopic systematics of an Olivine Rich Lithology (ORL) found in association with the coarse-grained DML lithology in the Kanagawa Zagami specimen [6,7]. Here we call this lithology DML(Ka) to maintain a distinction with DML(USNM) as studied by [2]. An Ar-Ar study by Park et al. [8] of a late stage K-rich melt enriched in K$_2$O to ~7% and intruded into ORL yielded an Ar-Ar age of 202±7 Ma. The present work extends the study of Kanagawa Zagami to Nd-isotopes.

Alkali (e.g., Rb) and REE (e.g., Sm) abundances:
Distinguishing features of the Kanagawa Zagami lithologies are their enrichments in trace elements compared to so-called Normal Zagami. Even the Dark Mottled Lithology (DML (Ka ,05)) that is host to the volumetrically smaller ORL (~1 cm$^3$ in .54) appears to be somewhat enriched in Sm compared to the CG and FG Normal Zagami lithologies and a DML subsample obtained from the US National Museum specimen USNM 6545 (Fig.1).

Basaltic Shergottite - Zagami

Figure 2. Initial $^{87}\text{Sr}/^{86}\text{Sr}$ vs. Rb-Sr isochron age for Zagami lithologies.

Heterogeneity in initial $^{144}\text{Nd}/^{144}\text{Nd}$:
Fig. 3 shows Sm-Nd-isotopic data for ORL(Ka .55) and DML(Ka ,05) sawdust, ORL Melt, and subsamples of ORL (Ka .54). The data for the two sawdust samples are nearly identical, consistent with differentiation of ORL from its host DML(Ka), although ORL is greatly enriched in trace elements (Fig. 1). As expected, WR1, a bulk sample of ORL(Ka .54) also shares very similar Sm-Nd isotopic data. WR2(1), a leachate of a second whole rock (bulk) sample has only a slightly lower $^{147}\text{Sm}/^{144}\text{Nd}$ ratio, as expected if most of the REE are


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in easily leachable phosphate minerals. However, the residue after leaching (WR2(r)) has a lower $^{143}\text{Sm} / ^{144}\text{Nd}$ ratio than expected, suggesting that phosphates were not totally removed in the leaching process. ORL is observed petrographically to contain coarse-grained merrillite, probably the phosphate mineral contributing most REE to the leaches. These data are slightly displaced beneath an 165±17 Ma reference isochron calculated from the combined data for (FG+CG) Normal Zagami (Fig 4).

The data for ORL Melt and mineral separates are displaced towards higher $^{143}\text{Nd} / ^{144}\text{Nd}$ ratios than for the whole rock and leachate samples. Mineral separation was by heavy liquids. (Plag+Melt) of density 2.85 g/cm$^3$ was observed to contain a significant melt component. “Px” of density 2.85-3.7 g/cm$^3$ was observed to contain pyroxene, melt, and phosphates. This sample was leached in 2N HCL for 10 min. to generate a leachate “Px(l)” and residue “Px(r)”.

Zagami FG, CG and Olivine-rich Lithology

Figure 3. Sm-Nd data for ORL and ORL Melt. Red circles: Bulk samples and leachates, except for WR2(r). Dark blue square: ORL Melt. Light blue squares: density separates. Light green diamond: Bulk samples and leachates, except for WR2(r). Black triangles: Bulk samples and leachates, except for WR2(r).

Figure 4. Sm-Nd data for combined CG, FG, ORL, and ORL Melt.

Sm and Nd in these samples came from melt contaminants. Melt was observed in thin section to intrude maskelynite and elsewhere in ORL. The K-rich melt was observed to contain fine-grained phosphates, which would contribute REE to these samples.

As shown in Fig. 5, in spite of the similarity in initial $^{87}\text{Sr} / ^{86}\text{Sr}$ between DML and CG, initial $^{143}\text{Nd} / ^{144}\text{Nd}$, expressed as $\varepsilon_{\text{Nd}}$, was found to be slightly higher in DML than in FG and CG [5]. In this study, we find $\varepsilon_{\text{Nd}}$ of both DML (Ka) and ORL to be slightly lower than in CG and FG, but perhaps within uncertainty of the value for these Normal Zagami samples. The disagreement between the $\varepsilon_{\text{Nd}}$ values of DML(USNM) and DML(Ka) is puzzling, but suggests (a) “high” and variable $^{143}\text{Nd} / ^{144}\text{Nd}$ in DML, and (b) some contribution from DML to ORL Melt. Sawdust DML(Ka) has some contribution from DML, also.

Initial $^{87}\text{Sr} / ^{86}\text{Sr}$ more strongly distinguishes among shergottite lithologies than do the $\varepsilon_{\text{Nd}}$ values, and also distinguishes DML(Ka) from DML(USNM). The high initial $^{87}\text{Sr} / ^{86}\text{Sr}$ in FG normal Zagami is slightly lower than that measured for Shergotty, whereas the lower initial $^{87}\text{Sr} / ^{86}\text{Sr}$ for ORL is slightly greater than that of Los Angeles (Fig. 5).

Conclusions:

Localized differentiation was important in producing the variety of lithologies observable in Zagami. Heterogeneity in initial Sr- and Nd-isotopic compositions and initial trapped $^{39}\text{Ar} / ^{36}\text{Ar}$ ratios close to the Martian atmospheric composition [8] and possibly relict radiogenic $^{39}\text{Ar}$ suggest that complex models are required to understand the petrogenesis of Zagami and other enriched shergottites. Such models may involve magma recharge, magma mixing, and crustal assimilation occurring in an upper crustal magma chamber.


Figure 5. Summary of initial $^{87}\text{Sr} / ^{86}\text{Sr}$ and $\varepsilon_{\text{Nd}}$ values in Zagami lithologies for an age of 169 Ma.