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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 87Sr/86Sr 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, Niihara 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 K3O 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 cm3 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).

(Our DML sawdust sample .05 is estimated to contain ~5% ORL admixture). ORL and “ORL Melt” are enriched in Sm and other REE by fourfold compared to the Normal Zagami lithologies. The Rb enrichments in ORL are somewhat smaller. ORL Melt found in association with ORL occurs as dark clusters a few mm2 in volume associated with ORL. Its ~4X enrichment compared to Normal Zagami in the subsample used for isotopic studies is accompanied by an even greater enrichment in K in this lithology. K was found to be heterogeneously distributed in eight subsamples of ~42-315 μg studied for Ar-Ar chronology. The material in those samples had crystallized mostly to pyroxene containing irregular areas of enrichment in K and/or phosphate [8].

Heterogeneity in initial 87Sr/86Sr:
Studies in 1995 and repeated in 2006 [3,4] showed FG Normal Zagami to have a significantly higher initial 87Sr/86Sr ratio than CG Normal Zagami (Fig. 2). A 2010 study of DML from USNM 6545 showed it to have the same initial 87Sr/86Sr ratio as CG [5], but the Rb-Sr study of ORL by [7] yielded initial 87Sr/86Sr lower than in CG, providing further evidence of heterogeneity in the initial Sr-isotopic composition among different lithologies.

Heterogeneity in initial 143Nd/144Nd:
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 147Sm/144Nd ratio, as expected if most of the REE are...
in easily leachable phosphate minerals. However, the residue after leaching (WR2(r)) has a lower 147Sm/144Nd 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 leachates. 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 143Nd/144Nd ratios than for the whole rock and leachate samples. Mineral separation was by heavy liquids. (Plag+Melt) of density <2.85 g/cm³ was observed to contain a significant melt component. “Px” of density 2.85-3.7 g/cm³ 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)”. “Ol” of density 3.7 g/cm³ was observed to contain olivine and melt. “Opq” was observed to contain opaque minerals like spinel. Of these samples, the Sm-Nd data for the leachate Pla(l) plots close to the bulk sample WR1 and the leachate WR2(l). However, Px(r) and Opq have 143Sm/144Nd that are very close to that of ORL Melt and much higher REE abundances than expected. Most of the

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 87Sr/86Sr between DML and CG, initial 143Nd/144Nd, expressed as εNd, was found to be slightly higher in DML than in FG and CG [5]. In this study, we find εNd 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 εNd values of DML-USNM and DML(Ka) is puzzling, but suggests (a) “high” and variable 143Nd/144Nd in DML, and (b) some contribution from DML to ORL Melt. Sawdust DML(Ka) has some contribution from DML, also.

Initial 87Sr/86Sr more strongly distinguishes among shergottite lithologies than do the εNd values, and also distinguishes DML(Ka) from DML-USNM. The high initial 87Sr/86Sr in FG normal Zagami is slightly lower than that measured for Shergotty, whereas the lower initial 87Sr/86Sr 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 40Ar/39Ar ratios close to the Martian atmospheric composition [8] and possibly relic radiogenic 40Ar 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.