COMPLICATED MAGMATISM OF BASALTIC SHERGOTTITES: IMPLICATIONS FROM PYROXENE ZONING IN ZAGAMI.

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Introduction: The Martian basaltic shergottite, Zagami, contains several different lithologies in a single rock; Normal Zagami (NZ; Fine-grained (FG) and Coarse-grained (CG)), a Dark Mottled lithology (DML), and Olivine-rich late stage melt pockets [1-4]. All lithologies are considered to be generated from a single Martian magma during fractional crystallization from petrological and mineralogical studies [3, 4]. An olivine-rich lithology (late stage melt pocket) was first reported by Vistensen et al. [2] from so-called "David New specimen" and the existence of olivine was confirmed using Mössbauer spsctroscopy and XRD. The olivine-rich lithology is present locally in the DML (occupies ~20 % of Zagami) and detailed petrographic studies were limited. As a result, petrogenesis of the olivine-rich lithology is still unclear. From petrological studies of DML, McCoy et al. [3] concluded that the olivine-rich lithology is a late stage residual melt of fractional crystallization. Niihara et al. [5] studied petrology of the Kanagawa Zagami sample, which contained Pyroxene (Px)-rich and Olivine (Ol)-rich lithologies and concluded that those lithologies could not be derived from a single magma.

Samples and analytical techniques: A slab was chipped from a large block of Zagami (892 g; KPM-NLM000057) stored at the Kanagawa Prefecture Museum of Natural History (we refer to the sample as Kanagawa Zagami). A multi-lithology portion (,01) weighning 3.96 g was selected for petrology, mineralogy and Rb-Sr, Sm-Nd and Ar-Ar isotopic studies. Saw dust samples ,05 and ,55 studies here came from DML and the Ol-rich lithology, respectively. For powder X-ray diffraction analyses, ~15 mg of saw dust samples were used. We conduct powder X-ray diffraction analyses using portable XRD (Olympus Terra) at the University Museum, the University of Tokyo. We used CuKα X-rays (1.5406 Å) with accelerating voltage of 30 kV and total integral time of 5000 sec with sample vibration system with a 2D-CCD detector. XPowder software was used for the data reduction (mineral identification and quantitative analyses). Polished sections ,51-1 and ,51-3 were used for petrological and mineralogical observations [5]. Mineral compositions and zoning profiles were obtained with an electron probe micro anlyzer (Cameca SX-100) at NASA Johnson Space Center.

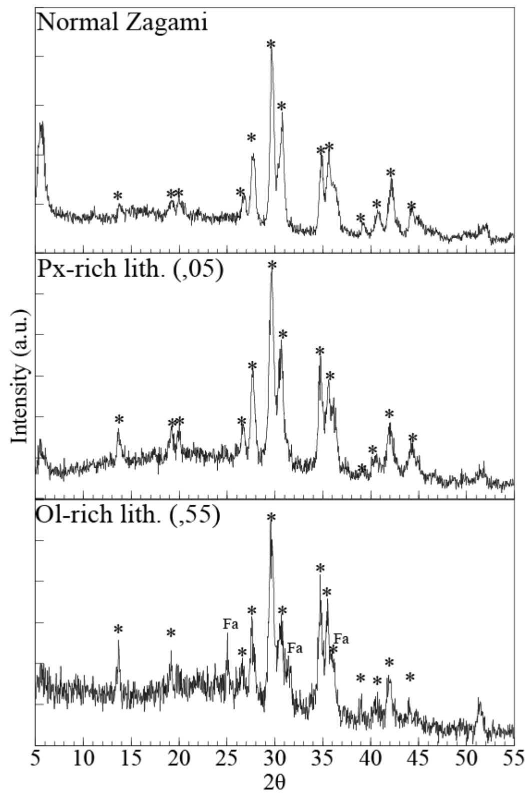

Figure 1. Powder X-ray diffraction patterns for different lithologies in Zagami. Saw dust sample (,55) contains ~10% fayalite, confirming the sample represents the Ol-rich lithology. Fa = Fayalite. Asterisk = pyroxene.

Petrology: The Kanagawa Zagami subsample ,01 consists of two distinct lithologies; Px-rich and Ol-rich lithologies. The section ,51-1 (chipped from ,01) contains a contact region of Px-rich and Ol-rich lithologies although the boundary between the two lithologies is unclear. The Px-rich lithology consists of mostly pyroxene and plagioclase (maskelynite) with minor amounts of titanomagnetite and phosphate. The Ol-rich lithology consisits of pyroxene, plagioclase (maskelynite), and vermicular intergrowth of fayalitic olivine, dendritic spinels, coarse-grained merrillite and fine-grained apatite. Symplectite (breakdown products from pyroxferroite) is observed at the rim of pyroxene grains in the Ol-rich lithology. Intrusion of K-rich melt with some laths of Fayalite and Fe- and Ca-rich pyroxene grains is observed.

X-ray diffrection: All samples contain abundant amorphous phases of maskelynite and interstitial glass especially in the Ol-rich lithology (,55). X-ray fluorence from those glassy materials increase background intensity and hide diffraction peaks from mineral phases. To minimize this effect and identify diffraction peaks from mineral phases, we obtained diffraction patterns using a selected X-ray energy (energy of CuKα). X-ray diffraction patterns from saw dust samples and NZ sample are shown in Fig.1. NZ and Px-rich lithology show similar signatures; most diffraction peaks are pyroxene. Fayalitic olivines are only identified in the subsample ,55 (~8-10 wt.%). These results are consistent with petrological observation.

Pyroxene zoning: Pyroxene grains in both lithologies display chemical zoning in major and minor elements. However, detailed signatures are different each other (Fig. 2).

Pyroxne grains in the Px-rich lithology show complex zoning patterns indicating multi-stage crystallization (at least 4 stages): (1) homogeneous magnesian core with the composition of $En_{56}Fs_{32}Wo_{12}$, similar with NZ [1]; (2) Fe, Al and Ti contents increase toward $En_{38}Fs_{47}Wo_{15}$ (normal zoning) from core to mantle; (3) Al and Ti contens decrease (showing reverse zoning; Fig. 2); (4) Fe and Ca contents increase again toward $En_{26}Fs_{53}Wo_{21}$ (normal zoning) from mantle to rim.

Pyroxene grains in the Ol-rich lithology can separate into at least 3 stages: (1) homogeneous core with relatively ferroan composition ($En_{38}Fs_{48}Wo_{14}$); (2) increase Fe, Al, and Ti contents (normal zoning) toward $En_{17}Fs_{65}Wo_{18}$; (3) a compositional gap in Al and Ti contents, and increase Fe, Al, and Ti contents.

Petrogenesis: The Ol-rich and Px-rich lithologies have no clear boundaries. However, mineral assenbrages and mineral compositions are significantly different. Vermicular intergrowth of fayalite which crystallized in the final stages of crystallization, are found only in the Ol-rich lithology. Pyroxene grains in both lithologies have homogeneous cores but compositions are different, indicating that these two lithologies crystallized and homogenized in different magma composition (pyroxene grains in the Ol-rich lithology have Fe-rich compositions relative to those in the Px-rich lithology). Mantles of pyroxene grains in the Px-rich lithology show a reverse zoning trend in Al and Ti contents (Fig. 2). The chemical composition changes toward the same composition as the cores of pyroxene grains in the Ol-rich lithology, thus two lithologies might mix in this sequence. After mixing of the two lithologies, pyroxene grains in both lithologies recorded the similar chemical zoning signature. The rim of pyroxene grains in the Ol-rich lithology have Fe- and Ca-rich compositions (merastable phase; pyroxferroite) which rapidly crystallized from the melt. Some parts of the pyroxne rim broke down into symplectite. We suggest intrusion of K-rich melts as the possible heat souce to generate breakdown of pyroxferroite to symplectite. On the basis of Rb-Sr isotope systematics of NZ (CG and FG) and DML, Nyquist et al. [e.g. 6] suggested that Zagami formed from magma mixing and/or wallrock assimilation. Our petrological and mineralogical observations are consistent with those isotopic signatures.

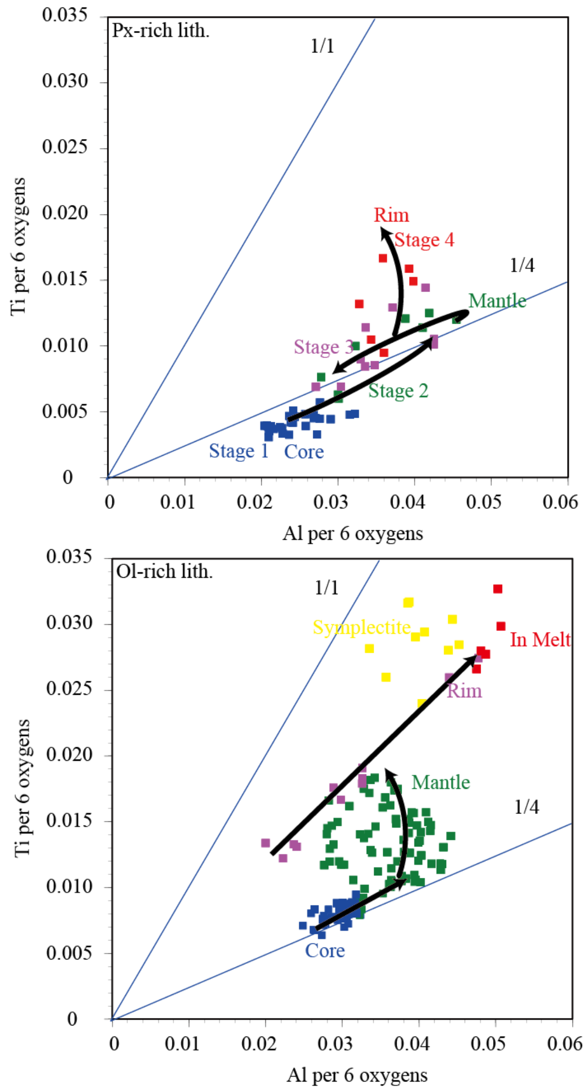

Figure 2. Pyroxene zoning trend in the Px-rich and Ol-rich lithplogies. A reverse zoning is observed in mantle of pyroxene grains (Px-rich lithology).

References: [1] McCoy T. J. et al. 1992. *Geochim. Cosmochim. Acta* 56, 3571–3582. [2] Vistisen L. et al. 1992. *Physica Scripta* 46, 94–96. [3] McCoy T. J. 1999. *Geochim. Cosmochim. Acta* 63, 1249–1262. [4] Treiman A. H. and Sutton S. R. 1992. *Geochim. Cosmochim. Acta* 56, 4059–4074. [5] Niihara et al., 2012. *Meteorit. Planet. Sci.* 47, #5074. [6] Nyquist L. E. et al. 2010. *Meteorit. Planet. Sci.* 45, A154.