MG-SUITE VOLCANICS. A MAGMATIC OR IMPACT ORIGIN?

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Introduction: Mg-suite rocks are generally thought to represent one of the first periods of magmatism associated with crust-building. This event occurred soon after the formation of the ferroan anorthositic crust during the primordial differentiation of the Moon [1-3]. Numerous models have been proposed for the origin of the Mg-suite that include melting during a large basin forming impact event or derivation from a variety of mantle sources (e.g., hybrid mantle) [1-5]. Recent chronology studies [7] distinguish between the timing of FAN and Mg-suite events and imply that the Mg-suite may be petrogenetically related to the generation of alkali suite and evolved magmas, and that these magmatic events occurred over a limited period of time (e.g., 20-30 Ma) [7,8]. The protracted duration to produce these post-FAN magmas has profound implications for their origin. Barboni et al. [9] suggested that this limited time span of melt production may be related to biased sampling, a major mantle event (e.g., LMO cumulate overturn), or a large basin forming event.

Volcanic lithologies associated with Mg-suite magmatism are rare. Prissel et al. [10] explored the potential for Mg-suite volcanics and identified possible volcanic deposit locations. A fine-grained magnesian clast in an Apollo 16 impact melt breccia was proposed to be an extrusive product of Mg-suite magmatism [11]. Yen et al. [12,13] identified a potential Mg-suite extrusive lithology within Apollo 17 core 73001/2 (73002,1017C) and a related glass bead. Pb-Pb chronological results (15-point isochron) reported by Yen et al. [13] yield a crystallization age of approximately 4246 ± 4 Ma for 73002,1017C. Further examination of the 73001/2 core revealed other similar (but not identical) lithic fragments [14,15]. Here, we examine one of these lithic fragments in the <1 mm size fraction. Using a variety of analytical approaches, we explore relationships among these distinct lithologies, evaluate the origin of this particular lithology, and deduce the petrologic implications for Mg-suite magmatism.

Analytical Strategy: Less than 1 mm size fractions produced during preliminary examination of double drive tube (DDT) sample 73001/73002 were allocated to the University of New Mexico (UNM) for sieving [14]. Thin sections of individual size fractions were prepared at UNM or the Johnson Space Center (JSC) before examination with a TESCAN Lyra3 SEM at UNM to determine the proportion of lithologies making up each size fraction [15] and to document individual unique lithologies. In thin section 73001,612 we found an olivine-rich lithic fragment, similar to the >4 mm lithic fragment 73002,1017C reported by Yen et al. [12,13]. A variety of Mg-suite intrusive lithologies were identified in this DDT [14]. The 73001,612 Grain 3 lithic fragment was examined using high resolution BSE imaging, X-ray maps, and individual spot and area chemical analyses using a JEOL 8200 electron microprobe and a TESCAN SEM at UNM. *In-situ* trace element analyses of olivine phenocrysts and surrounding matrix are being made on a Thermo Scientific Element-XR ICPMS coupled to a Photon Machines 193 nm laser ablation system in the Astromaterials Research and Exploration Science (ARES) division at NASA-JSC. Individual spots were ablated using a 40 µm spot size, a 4.0 J/cm^2 fluence, and a repetition rate of 10 Hz. Each spot consists of a 20 s background measurement, 30 s of ablation, and 20 s of washout. NIST 600-series glasses were used as primary calibration standards, while the USGS BHVO-2g and MPI-DING GOR132-G (high Mg) basaltic glasses were used for matrix corrections. Additional USGS basaltic glasses (BCR-2g, BIR-1g) and olivine standards (Sh11-2 [16], San Carlos) were analyzed as secondary standards to ensure accuracy. Data reduction was completed using the '3D Trace Elements' data reduction scheme in Iolite™ [17], while using ^{29}Si for internal standardization.

Results: Lithic fragment 73001,612 Grain 3 consists of large, zoned olivine crystals (up to 180 µm long dimension) immersed in a fabric consisting of fine-grained, locally oriented, elongate olivine + plagioclase (Fig. 1). Plagioclase in this matrix has a length/width ration of ~25 and will be up to 125 µm in length and 5 µm in width. Matrix olivine has similar aspect ratios but appears to be interstitial to the elongated plagioclase. The morphology of these two phases is reminiscent of a plumose to axiolitic spherulite texture. Minor pyroxene, troilite, chromite, and glass occur in the fine-grained matrix.

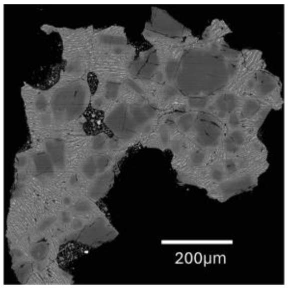

Fig. 1. BSE image of lithic clast 73001,612 Grain 3. In the fine-grained matrix surrounding the olivine phenocrysts, the plagioclase is represented by the darker blade-like phase, whereas Fe-rich olivine is the brighter phase.

The larger olivine grains range in composition from Fo$_{96}$ to Fo$_{83}$ (Fig. 2 and 3). Cores are fairly homogenous (Fo_{96-94}) and the relationships between cores and rims are illustrated in Figs. 1 and 3. CaO, MnO, Cr_2O_3 (Fig. 3), Al_2O_3, and TiO_2 exhibits enrichments in the low Fo rims. The matrix olivine has a composition of Fo_{90-66} (average=$Fo_{74.3}$). Plagioclase has a composition of $An_{93.1\text{ to }91.6}$ (Fig. 2). Pyroxene has a composition of $En_{37.1}Fs_{24.3}Wo_{38.5}$ (Fig. 2).

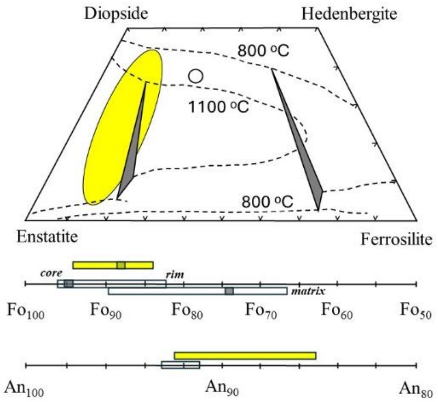

Fig. 2. Composition of phases in lithic fragment 73001,612 grain 3. Mineral data from this fragment are in white data points or fields. Data from 73002,1017C [12,13] are highlighted in yellow.

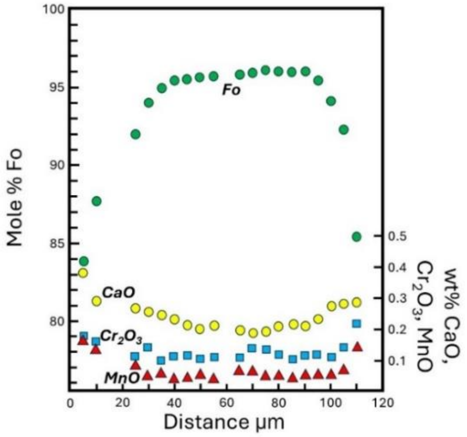

Figure 3. Microprobe traverse across olivine grain # 1 in 73001,612 grain 3.

Bulk rock and bulk matrix compositions reveal the matrix to be high in both MgO (23.75 wt.%) and Al_2O_3 (16.58 wt.%) with a Mg# of 85.

Discussion:

Crystallization history: The crystallization sequence in 73001,612 Grain 3 is olivine phenocryst cores→ olivine phenocryst rims → blade-like plagioclase → blade-like plagioclase + olivine + spinel → plagioclase + olivine + pyroxene + troilite. Unlike the crystallization sequence proposed for Mg-suite rocks, the melt was not saturated with plagioclase until substantial olivine had crystallized. Although the matrix texture is partially a product of cooling rate and undercooling, the texture also reflects the composition of the melt [e.g., 18-20].

Comparison to other lithologies in 73001/73002 double drive tube: The lithology represented by 73001,612 Grain 3 has many textural and mineralogical similarities to the > 4 mm lithic fragment 73002,1017C found near the top of the same double drive tube. The olivine phenocrysts in both have high Fo contents and are immersed in matrices with similar textures. However, in 73001,612 Grain 3 the olivine cores are slightly more Mg-rich (Fig. 2). Although the matrix textures are similar in overall appearance, 73001,612 grain sizes differ somewhat and the accessory phases such as pyroxene, sulfides, and phosphates are much more limited in abundance. These differences imply a slightly more primitive melt composition for 73001,612 Grain 3.

Relationship to the Mg-suite: Mineral chemistries in this lithic fragment reflect many of the characteristics of the highlands intrusive Mg-suite. For example, the Mg# of the olivine and the mole% An in plagioclase plot within the Mg-suite field [1-6]. In addition, many other geochemical characteristics are similar to those of the Mg-suite (e.g., Mg#, Cr_2O_3) [2,5]).

Origin of extrusive and intrusive Mg-suite: There has been a long debate over the magmatic versus impact origin for the Mg-suite (see [5,6]). More recently, [9] interpreted that the peak in ages for the Mg-suite identified by [7,8], and by conjecture the rocks identified here and by [12,13], represent melts associated with a substantial basin-forming event rather than a magmatic event. Therefore, an important question posed for the samples identified in 73001/73002 is: Are they extrusive magmas with petrogenic links to the intrusive Mg-suite, or are they impact melts? Thus far, our observations suggest that they only can represent impact melts under unique circumstances. Most of the observations and data above suggest a magmatic origin, with melt derived from the lunar mantle. If this conclusion is further substantiated by additional observations, it has fundamental implications for the origin of the Mg-suite and the interpretation of the duration of this style of lunar magmatism.

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