LATE-STAGE PHASES AND TEXTURES AS TOOLS FOR STUDYING THE ORIGIN OF THE MG-SUITE AND THE NATURE OF KREEP FROM APOLLO 17 SAMPLES.

D. F. Astudillo Manosalva[1] and S. M. Elardo[1], [1]The Florida Planets Lab, Department of Geological Sciences, University of Florida, Gainesville, FL 32611, USA. daniel.astudillo@ufl.edu.

Introduction: The samples from Apollo 17 have been the primary source of study of the Mg-suite rocks for over 50 years now, given the pristinity and large number of the recovered samples. Even though it has been a long time that these rocks have been studied, there are still recent discoveries of new textures and chemical features from which to obtain additional constraints on the formation of the Mg-suite rocks [1,2], which suggests that there are still aspects and features in them that have yet to be considered and could prove useful for studying. Our recent work has been focused on assessing whether there could be a co-genetic relationship between the Apollo 17 Mg-suite samples. During this research, we have observed textures and phases that have little to no mention in previous literature, some of which can be found present in multiple samples. Perhaps the most significant one is the presence of a late-stage K and Rb-rich melt phase that is present in most norites and gabbronorite samples. We have also identified variations in the compositions of melt pockets in cumulate rocks and melt inclusions that can provide significant insight into the later stages of evolution of the Mg-suite rocks, the nature of KREEP, and the highly evolved magmatism that has been identified in the lunar surface and in rock samples like the Alkali-suite.

Methods: We have examined 35 thin sections from 20 samples of Apollo 17, encompassing the range of Mg-suite rocks that include dunites, troctolites, norites, and gabbronorites. Textural analysis is performed via optical microscope and back scattered electron (BSE) imaging in both scanning electron microscopy and electron-probe microanalysis (EPMA). Analysis of major and minor elements in most phases were conducted using a Cameca SXFive FE EMP at the University of Florida at 15 kV and 20 nA. A 2-5 nA defocused beam was used for the K-Rb-rich glasses to minimize alkali migration during measurement.

Melt pockets and a late-stage phase: Cumulate rocks trap melt in between their settling crystals, which then crystallizes and evolves in a similar way to the parental magma. This means that as the cumulates that settle from the melt become more evolved, the melt pockets in them record a similar, though not identical, progression. In the case of the Mg-suite, which follows a troctolite-norite-gabbronorite and alkali-suite rocks progression [3], the trapped melt pockets in them seem to follow the same progression with the addition of minor phases like phosphates, SiO_2 and zircon. Most melt pockets in troctolite 76535 are mostly orthopyroxene, with clinopyroxene in some, and SiO_2, zircons and phosphates in the most evolved pockets. The pockets in norites are mostly clinopyroxene and SiO_2, with minor phases such as phosphates, baddeleyite, ilmenite and Nb-bearing rutile. It is in the norites where we first observe K-rich glass trapped between grain boundaries in orthopyroxene of sample 78235. Further inspection led to the finding of this phase in all of the norite samples, most times as a partially recrystallized glass (Fig.1A), but in some cases completely crystallized as an SiO_2 polymorph and K-feldspar, forming myrmekitic arrangements. This phase also appears in melt pockets with SiO_2 and clinopyroxene, and also in melt inclusions in plagioclase, with one of them exhibiting liquid immiscibility with two different glass compositions. The gabbronorite samples we have studied do not appear to have melt pockets like norites and troctolites do; however, the same K-rich glass is found permeating through cracks in crystals that seem to predate the impacts that brecciated the sample (Fig. 1B).

Chemical compositions: The K-rich glass has a compositional range between 5-8 wt. % K_2O, ~65-75 wt. % SiO_2, ~10 wt. % Al_2O_3 and most surprisingly, variable, but extremely high Rb_2O in the range of multiple wt. %. Although it has small amounts of most other common elements, Na_2O never exceeds 0.7 wt. %, which is odd given the amount of plagioclase in the Mg-suite and its progressive Na enrichment as it evolves. Some of the K-feldspars also contain Ba. Although there are variations between samples in the composition of this phase, they all remain fairly similar, especially given the varying degrees of crystallization they show. In some cases, volatile bubbles are also present (Fig.1A).

Discussion: Compositionally, the origin of the K-Rb-rich melts is not consistent with continuous fractional

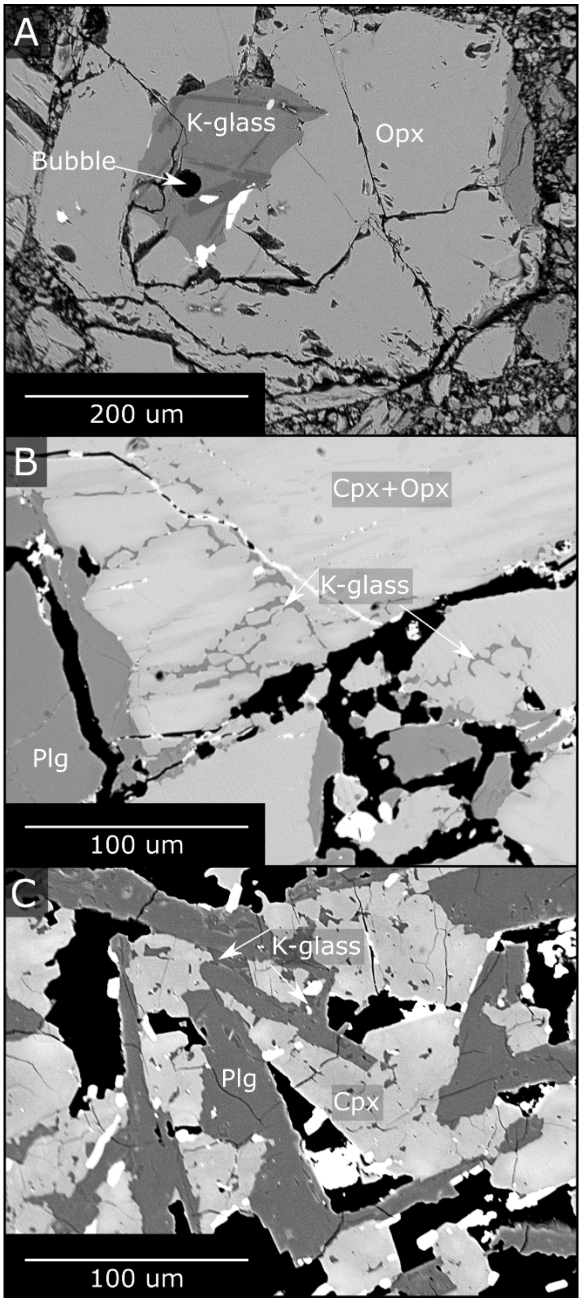

Figure 1 BSE images showing A) A partially recrystallized K-Rb-rich glass inclusion in orthopyroxene in norite 77215-100. B) K-Rb-rich glass in cracks of crystals of the gabbronorite clast of sample 76255-72. C) Basaltic clast with plagioclase, clinopyroxene, ilmenite and K-Rb-rich glass in breccia 76255-72.

crystallization from a mafic source, but are more akin, with the exception of Rb, to those found in silicate liquid immiscibility in lunar basalts [4-7] or even granitic pegmatites [8]. Such high Rb contents in this phase are orders of magnitude higher than even Rb-rich pegmatites [9], but given the high K abundances it is most logical that this phase is directly related to KREEP.

The remobilization of this phase into the gabbronorite as a secondary process (Fig. 1B) rather than primary entrapments such as in the case of the norites, suggests that this phase accumulated separately from the gabbronorite. Further evidence of this is found on a basaltic clast found in sample 76255-72 (Fig. 1C), which is the same sample as one of the most pristine gabbronorites. This is a coarse-grained basalt mostly composed of plagioclase, clinopyroxene, and ilmenite, and is also abundant in the K-Rb-rich glass, which is trapped inside plagioclase crystals and accumulates between clinopyroxenes. What is significant about this basaltic clast is that it not only has the same mineralogy as the gabbronorite but it also has nearly identical compositions for all phases, which would imply three things. Firstly, this clast is probably an extrusive manifestation of the Mg-suite, with a composition akin to the very-high-K (VHK) basalts of Apollo 14 [10], and in line with the hypothesis of Arai et. al. (2006) [11] that VHK basalts are directly related to Mg-suite gabbronorites. Secondly, the gabbronorite is most likely formed by the same magma erupted in the basaltic clast and its composition could represent that of its parental melt. Finally, that the extremely differentiated K-Rb-rich melts are a product of late-stage evolution of the Mg-suite.

The accumulation of highly evolved magmas, such as the phase we describe here, is a potential process that could explain the origin of the granitic magmatism and highly silicic volcanism that is observed throughout the lunar crust, such as the Gruithuisen domes, although the volumetric significance of evolved melt formation through this process is unclear. Therefore, the study of this phase could prove essential for understanding the nature of KREEP, the Mg-suite, and quite possibly the origin of evolved magmatism in the Moon.

References: [1] McCubbin, F.M. et al. (2011), *Geochim. Cosmochim. Acta* 75, 5073-5093. [2] Nelson, W.S. et al. (2022) *Nat. Commun.12(1), 1-9.* [3] Shearer, C. K., *et al.* (2015) *Am. Min.* 100, 294–325. [4] Roedder, E. (1970), *Science 167, 641-644* [5] Taylor, G.J., et al. (1980) *Lunar Highlands Crust 339-355* [6] Jolliff. B.L., *et al.* (1999) *Am. Min.* 84, 821–837. [7] Shearer, C.K., *et al.* (2001) *Am. Min.* 86, 238-246. [8] Černý, P., *et al.* (2012) *Elements* 8, 289–294. [9] Nie, X., *et al.* (2020) *Minerals* 10, 582. [10] Shervais, J.W. *et al.* (1985) *JGR: Sol. Earth,* 90, 3-18. [11] Arai, T. (2006) *LPSCXXXVII*, 2387.
Acknowledgements: The authors acknowledge support from NASA Solar System Workings grant 80NSSC19K0752 and UF.