VHK BASALT PETROGENESIS VIA MAGMA CHAMBER AND IMPACT PROCESSES. S. E. Roberts[1,2] and C. R. Neal[1,2], [1]Dept. of Civil & Env. Eng. & Earth Sciences, University of Notre Dame, Notre Dame, IN 46556, USA, [2]Solar System Exploration & Research Virtual Institute. (sarah.e.roberts.122@nd.edu; neal.1@nd.edu)

Introduction: The Apollo 14 mission to the Fra Mauro region of the Moon in 1971 returned complex breccias that yielded two types of basalt clasts, high-Al and a new basalt type previously uncollected on the Moon, Very High Potassium (VHK) basalts (e.g., [1,2]). Shervais et al. [2] investigated five clasts from breccia 14305 and first proposed the classification "VHK" and the type characterization of these basalts as $K_2O > 0.5$ weight %, $K_2O/Na_2O > 1$, and K/La ratios between 500 and 1300. The five VHK basalt clasts were nearly identical to high-Al basalts with the exception of elevated abundances of K_2O, Rb, and Ba.

Using whole rock data of six VHK mare basalt samples, Shervais et al. [2] hypothesized the formation of VHK basalts through the partial assimilation of lunar granite by a high-Al mare basaltic magma. Goodrich et al. [3] discovered 2 more VHK basalts in breccia 14304 and proposed an additional hypothesis for the formation of VHK basalts through the partial melting of a metasomatized source enriched in K, Rb, and Ba, but otherwise similar to a high-Al basalt source. Neal et al. [4-6] completed two additional studies on 12 VHK basalt samples from breccias 14303, 14304, and 14305 and ultimately derived a model for the production of VHK basalts through the Assimilation and Fractional Crystallization (AFC) of three different parental high-Al basalt parents assimilating granite. In this model three distinct granite assimilant compositions were also required.

All previous models for VHK basalt petrogenesis required enrichment of the alkali elements to generate the high K enrichment as it could not be produced by solely by fractional crystallization of a high-Al basaltic magma [2-6]. The assimilation of granite during the crystallization of high-Al parental magma(s) has been the leading hypothesis for VHK basalt petrogenesis. However, new textural and chemical evidence is identifying a potential secondary source for K enrichment and the possibility that some VHK basalts did not inherit their K-rich signature during magmatic evolution. They could be, in fact, just high-Al basalts that have been enriched in K by secondary processes [7].

Samples and Methods: VHK basalts are represented by coarse-fine fragment 14168,38 and 20 clasts from three Apollo 14 breccias: 14303, 14304, and 14305. Breccia 14303 was originally part of 14304 and breccias14304 and 14305 were collected in the same weigh bag [2,3,8].

The VHK basalts show a variety of textures and characteristics ranging from granular to coarse. Euhedral to subhedral plagioclase crystals from 0.25 to 1 mm long are common in predominantly ophitic to subophitic texture. Olivine is not always present in the VHK basalts. Where present, it occurs as cores to pyroxene crystals and as individual grains. Interstitial K-

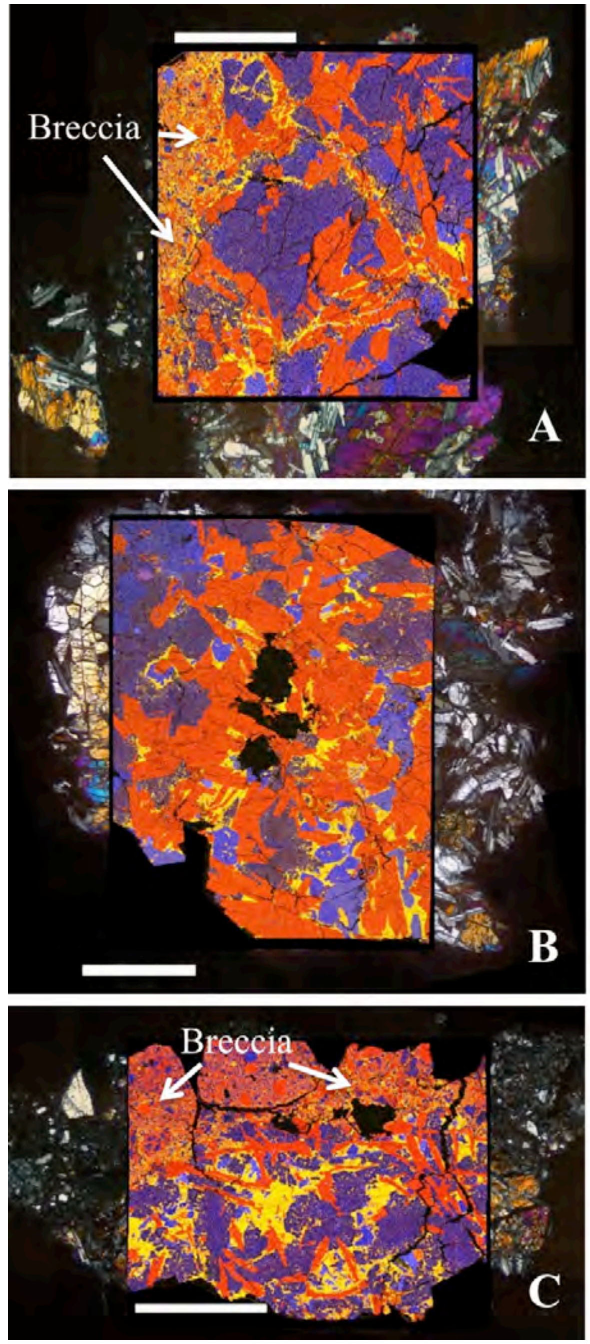

Figure 1. Element maps shown over cross-polarized photomicrographs of VHK Basalts 14303,328 (A), 14304,187 (B), and 14305,380 (C). Red = Al; blue = Fe; yellow = K. Scale bars represent 1 mm.

rich glass is found in varying abundances between the samples. K-feldspar is an interstitial phase (Fig. 1A-C). Some VHK basalt thin sections also have attached breccia matrix that is clearly distinguishable from the VHK basalt clast. Thirteen VHK basalts were analyzed for this study: 2 clasts from breccia 14303, 7 clasts from breccia 14304, and 4 clasts from breccia 14305.

Major element analyses, backscatter electron images and elemental maps were collected on a JEOL JXA-8200 electron microprobe at Washington University in St. Louis. Analyses were collected using a 3 µm beam, accelerating voltage of 15 kV and a probe current of ~25 nA. Additional major element analyses were collected at the University of Notre Dame on a Cameca SX-50 electron microprobe using an accelerating voltage of 15 kV, probe current of 25 nA, an 6 µm beam diameter for pyroxene and olivine analyses, and an 8 - 10 µm beam diameter for analyses of feldspar and areas of K-rich glass.

Results: Element maps of VHK samples show a heterogeneous distribution of K-rich material among the samples (Fig. 1A-C). Some VHK samples have K-rich areas predominantly within the attached breccia matrix that appear to permeate into the clast (Fig. 1A - 14303,328). Some samples such as 14304,187 (Fig. 1B) show large areas of interstitial K-rich material usually associated with plagioclase, while other samples such as 14305,380 (Fig. 1C) feature a combination of both K-rich areas within the matrix along with interstitial K-rich areas within the clast.

Plagioclase ranges in composition from An_{61} to An_{97}, with an average of An_{93}. Olivine compositions range Fo_{21} to Fo_{68} with an average of Fo_{42}. There does not appear to be a bimodal distribution of olivine compositions (Fo-rich and Fa-rich populations) as reported by Shervais et al. [2] and a continuum is apparent. Analyses of K-rich areas as identified by the element maps range from Or_{62} to Or_{93}, with an average of Or_{83}. BaO concentrations range from 0 to 5.4 wt %. The weight percentages of oxides measured in the K-rich areas were normalized to 8 oxygens in an attempt to differentiate crystalline K-feldspar from K-rich glass using the structural formula of feldspar. Spot analyses on K-rich areas with cation values of <4.9 are assigned the designation of glass. BaO abundances of >1 wt % are found in K-rich areas that are not glass and approximately > 13 wt % K_2O.

Discussion: The distribution and texture of the K-rich areas within the VHK basalts has suggested an alternative to K enrichment via granite assimilation for at least some of the VHK basalts. Samples such as 14303,328 (Fig. 1A) have large amounts of K within the attached breccia matrix and fluid-like veins penetrating the VHK basalt samples. Although the K-rich areas in the breccia matrix are inherently small and difficult to analyze, three analyses were possible and show that the matrix K-rich areas are compositionally indistinguishable from those within the clast. Structures such as these suggest that K enrichment could be a secondary process unrelated to basalt petrogenesis [7]. Impact induced heating following breccia formation could provide sufficient heat to melt the low melting point components, such as K-feldspar, present in Apollo 14 breccias [9]. The K-rich impact melt infiltrated high-Al basalt clasts, preserving the basaltic texture but altering the whole rock chemistry. A similar hypothesis was suggested by [3] after observing K-rich vein areas in an alkali norite clast from breccia 14304.

Major element analyses of K-rich areas indicate two modes of potassium enrichment within the VHK basalts: interstitial mesostasis glass and K feldspar (Fig. 2). VHK basalts clasts that contain fluid-like K-rich veins also have elevated BaO, suggesting that the source of the BaO was externally derived and secondary to the petrogenesis of the VHK basalt. Alternatively, the VHK basalt clasts could be the source of the K-rich areas in the breccia matrix. Partial meting of K-feldspar within the VHK basalts would produce K-rich glass with low Ba contents (Fig. 2) as Ba is strongly partitioned into K-feldspar. It is evident that at least some samples have textures consistent with obtaining the K (and Ba) enrichment through AFC with granite and that remobilization of K-rich material occurred during breccia formation.

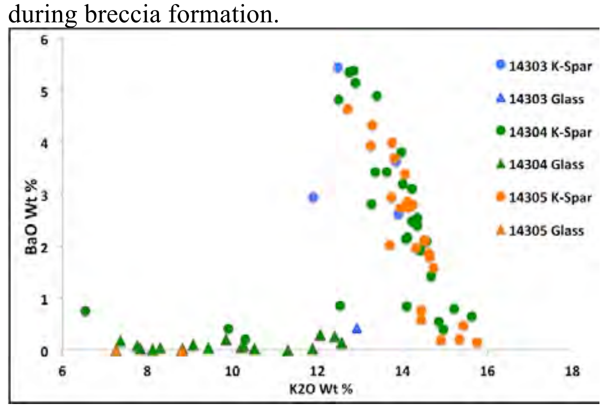

Figure 2. K-rich phase compositions from breccias 14303, 14304, and 14305.

References: [1] Shervais J.W. *et al.* (1985) *PLPSC 16 in JGR 90*, D3-D18. [2] Shervais J.W. *et al.* (1985) *PLPSC 15 in JGR 90,* C373-C395. [3] Goodrich C.A. *et al.* (1986) *PLPSC 16 in JGR 91,* D305-D318. [4] Neal C.R. *et al.* (1988) *PLPSC 18,* 121-137. [5] Neal C.R. *et al.* (1989) *PLPSC 19,* 137-145. [6] Neal C.R. *et al.* (1989) *PLPSC 19,* 147-161. [7] Roberts S.E. & Neal C.R (2014) *LPSC XLV*, Abstract #1282 [8] Meyer, C. (2007) lunar sample compendium 14304 http://curator.jsc.nasa.gov/lunar/lsc/14304.pdf [9] Warren P.H. *et al*., (1983) *EPSL 64,* 175-185).