INVESTIGATING THE MAGMATIC HISTORY OF VOLATILES IN APOLLO 17 BASALTS, APOLLO NEXT GENERATION SAMPLE ANALYSIS.

Z. E. Wilbur[1], J. J. Barnes[1], S. A. Eckley[2,3], J. W. Boyce[4], M. Brounce[5], C. A. Crowe[6], J. L. Mosenfelder[7], T. J. Zega[1], and the ANGSA Science Team. [1]University of Arizona, zewilbur@email.arizona.edu, [2]Jacobs- *JETS*, NASA Johnson Space Center, [3]University of Texas, Austin, [4]NASA Johnson Space Center, [5]University of California, Riverside, [6]University of Colorado, Boulder, [7]University of Minnesota.

Introduction: Lunar missions led by NASA have discovered water ice on the Moon's surface [1-3], revolutionizing views of the abundance, distribution, and potential sources of H_2O and other volatiles. Amidst the developing field of lunar volatiles, there are debates regarding the amount of H_2O in the bulk silicate Moon (BSM), the timing of volatile accretion to the Moon, and the sources of these volatiles.

Investigations of volatiles in the Moon, especially hydrogen, are of major importance to understanding the origin of volatiles in the inner Solar System. Studies of lunar samples over the last decade have proposed that the Moon likely received its volatiles <200 Ma after Solar System formation [4].

Volatile elements and halogens affect the crucial rheologic properties of minerals and melts, thereby changing magma eruption processes. In order to determine the indigenous volatile inventory of the Moon, it is vital to identify the magmatic and secondary processes that may have affected the volatile contents in lunar minerals [5]. This study aims to investigate the volatile inventory and magmatic and post-magmatic history of a group of lunar basalts. Furthermore, with the newly released basalt (71036) as part of the Apollo Next Generation Sample Analysis (ANGSA) Program, it is possible to understand the effects of cold curation practices on volatile elements.

For the first time, this study will compare the isotopic composition and abundances of water in H-bearing minerals and melt inclusions, and the volatile inventories (H isotopes, H, Cl, S contents, and S speciation) of lunar minerals and glasses in basalts collected from Steno Crater on the Apollo 17 mission. In addition, determining the abundances and fabric of vesicles and vugs in these samples will allow for the evaluation of the degassing history of the basalts, which coupled with eruption age dating will create a comprehensive picture of how the Steno Crater basalts are related genetically and temporally.

Samples: This study utilizes four Apollo 17 basalts collected from Station 1A on the rim of Steno Cater. Samples 71035, 71037, and 71055 have been stored at ambient temperatures since their return to Earth in 1972. The newly released rock sample 71036, however, was stored at -20 °C within one month of its arrival on Earth.

Figure 1*. Photograph of rock sample 71036,0. Apollo Photo S73-15675, credit: NASA JSC curation.*

Prior studies of the Steno Crater basalts have shown they are high-titanium (high-Ti) type basalts and are vesicular (20-40 vol.%). Some vesicles or vugs contain minerals (Fig. 1) [6]. The chemical composition of the ambient samples suggests they are type B basalts [7]. Texturally they are fine to medium-grained, porphyritic, and plagioclase-poikilitic (Fig. 2). The major mineral phases include olivine, pyroxene, plagioclase and ilmenite, with accessory phases of tranquillityite, baddeleyite, K-feldspar, apatite, merrillite, residual glass, and troilite (Fig. 2). Most of these samples lack exposure ages, and [8] determined a Rb-Sr age of 3.64 ± 0.09 Ga for 71055.

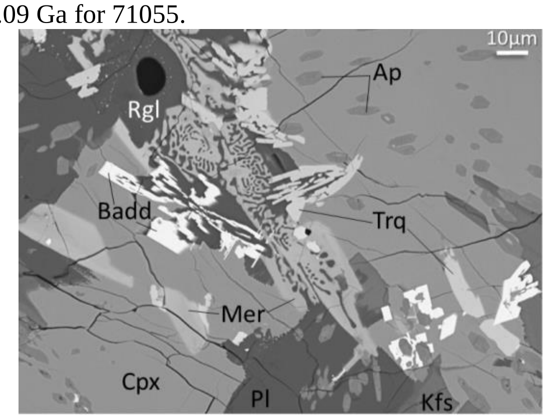

Figure 2*. Backscattered electron image of 71055, major and accessory phases. Ap= apatite, Rgl= residual glass, Badd= baddeleyite, Trq= tranquillityite, Cpx= clinopyroxene, Mer= merrillite, Kfs= K-feldspar, Pl= plagioclase.*

Methodology: This study involves coordinated *in situ* analyses of the mineralogy, volatiles, vesiculation and ages of the four Apollo 17 Steno Crater basalts, including specially curated 71036.

To date, X-ray elemental and BSE mapping of existing, ambient polished thin sections of 71035, 71037, and 71055 was performed at NASA's Johnson Space Center (JSC) using the JEOL 7600F scanning electron microscope (SEM). As a pilot 3D study, subsamples of 71035 and 71055 were scanned using micro-X-ray computed tomography (XCT) by the new Nikon XTH 320 machine at JSC to identify vesicles and vugs. The samples were scanned with a 225 kV rotating reflective target source and 1 mm Cu filter using the following range of conditions: 110-145 kV, 97-208 µA, and a voxel size range of 7.63-22.44 µm. These scans have been reconstructed using CT Agent Pro, and visualized using Avizo and Dragonfly software.

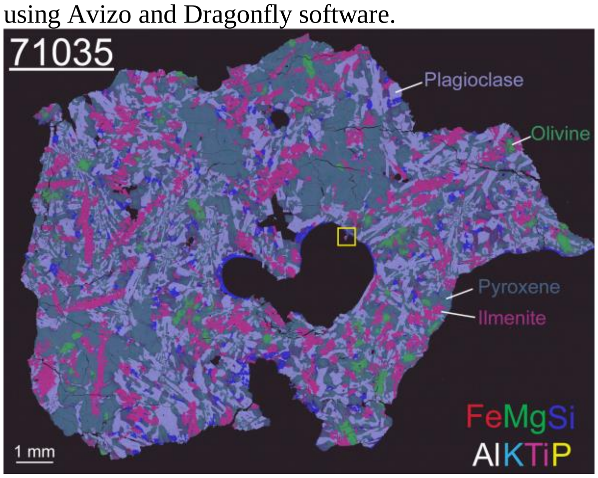

Figure 3. *Composite elemental map of 71035, with Fe in red, Mg in green, Si in blue, Al in white, K in cyan, Ti in magenta, and P in yellow.*

Preliminary Results: Initial modal mineral abundances with 2D X-ray composites for 71035, 71037, and 71055 show a range of 2.2-9.0 vol.% olivine, 37.2-56.4 vol.% pyroxene, 14.0-34.5 vol.% plagioclase, and 17.6-25.7 vol.% ilmenite, with other accessory phases (e.g. apatite) comprising trace abundances. The X-ray composites have allowed us to identify phosphates and other phases that are suitable for our planned coordinated analysis campaign using SEM, electron microprobe, S-XANES, and NanoSIMS.

We anticipated that these basalts would contain mafic minerals that protrude into void spaces. The 6.5 mm vesicle in Figure 3 contains an Fe- and Ti-rich mineral (located in the yellow square) protruding into the void space. In addition to understanding magmatic volatiles, the late-stage crystallizing minerals in vesicles are ideal candidates for the analysis of volatile surface coatings to better understand the volatile species occupying the vesicle during eruption.

Micro-XCT is an invaluable tool used to nondestructively analyze the interior of a sample. Preliminary examination of the XCT results of 71035 and 71055 have allowed for the identification of vesicles and minerals present in their void spaces (Fig. 4). Through the investigation of vesicle morphologies and textures similar to those reported by [9], we can better understand the eruption history of the Steno Crater basalts. Additionally, modal mineral abundances can be extracted from the 3D data set (within ± 0.5% error [10]), which can be compared to abundances measured in 2D to better constrain representative bulk-rock mineral abundances.

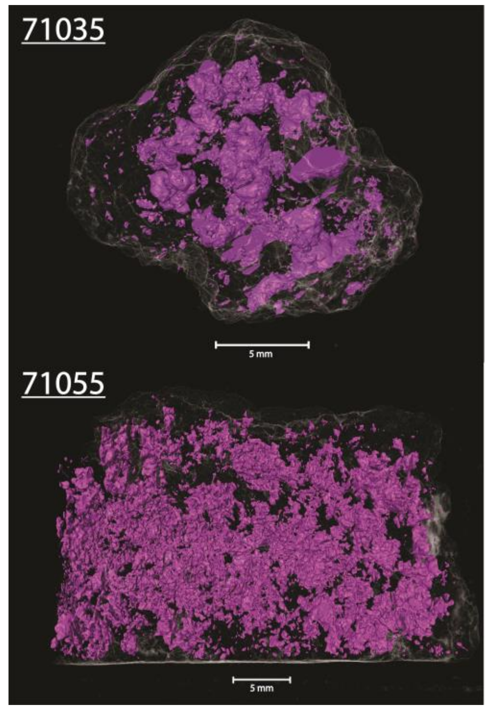

Figure 4. *3D rendered XCT scans of 71035,36 and 71055,10. Vesicles are purple, and the sample matrix is opaque grey. Vesicles with flat surfaces are in contact with the exterior of the sample. Despite originating from the same boulder, the vesicle textures between the two samples appear different.*

Acknowledgments: We thank CAPTEM for allocation of samples to this project. Loan Le and Timmons Erikson are thanked for SEM mapping of Apollo thin sections during this study. This work is partially funded by NASA Grant 80NSSC19K0803.

References: [1] Clark R.N. (2009) *Science*, 326, 562-564 [2] Pieters C.M. et al. (2009) *Science*, 326 (5952), 568-572 [3] Sunshine J.M. et al. (2009) *Science*, 326 (5952), 565-568 [4] Barnes J.J. et al. (2016) *Nature Comm*, 7, 11684 [5] McCubbin F.M. et al. (2015) *Am. Min.*, 100 (8-9), 1668-1707 [6] Neal C.R. and Taylor L.A. (1993) Catalog of Apollo 17 Rocks, Vol. 2 [7] Meyer (2011) Lunar Sample Compendium [8] Tera F. et al. (1994) *EPSL*, 22, , 1-21 [9] Berg S.E. et al. (2006) *Bull Volcanol*, 78, 85-xx [10] Needham A. et al. (2013) *GCA*, 116, 96–110.