

INVESTIGATING THE MAGMATIC HISTORY OF VOLATILES IN APOLLO 17 BASALTS, APOLLO NEXT GENERATION SAMPLE ANALYSIS. Z. E. Wilbur¹, J. J. Barnes¹, S. A. Eckley^{2,3}, J. W. Boyce⁴, M. Brounce⁵, C. A. Crow⁶, J. L. Mosenfelder⁷, T. J. Zega¹, and the ANGSA Science Team⁸. ¹University of Arizona, zewilbur@email.arizona.edu, ²Jacobs- JETS, NASA Johnson Space Center, ³University of Texas, Austin, ⁴NASA Johnson Space Center, ⁵University of California, Riverside, ⁶University of Colorado, Boulder, ⁷University of Minnesota. ; ⁸ list of co-authors includes all members of the ANGSA Science Team (<https://www.lpi.usra.edu/ANGSA/teams/>).

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 H₂O and other volatiles. Amidst the developing field of lunar volatiles, there are debates regarding the amount of H₂O 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 within 200 Ma of solar system formation [4].

Volatile elements and halogens affect the crucial rheologic properties of minerals and melts, thereby influencing 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 [6]) 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 Crater. 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) [7]. The chemical composition of the ambient samples suggests they are type B basalts [8]. 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 [9] determined a Rb-Sr age of 3.64 ± 0.09 Ga for 71055.

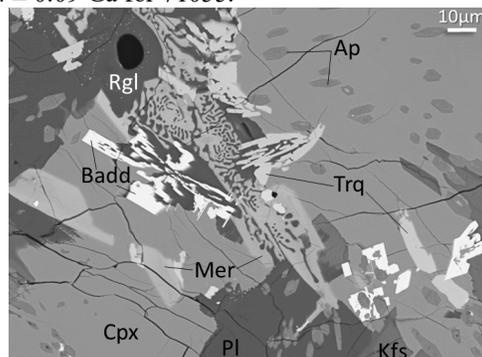


Figure 2. Backscattered electron image of 71055, major and accessory phases. Ap= apatite, Rgl= residual glass, Badd= baddeleyite, Trq= tranquillityite, Cpx= clinopyroxene, Mer= merrillite, Kfs= K-feldspar, Pl= plagioclase.

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). Electron probe microanalysis was conducted on the main rock-forming minerals (olivine, pyroxene, ilmenite, feldspar), mesostasis glasses, and trace minerals like apatite (Fig. 2) within these samples using the University of Arizona's Cameca SX100 electron microprobe. For 3D study, subsamples of 71035, 71037, and 71055 were scanned using micro-X-ray computed tomography (XCT) by the Nikon XTH 320 machine at JSC to identify 3D mineralogy and vesiculation textures. 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 μ A, and a voxel size range of 7.63-22.44 μ m. These scans have been reconstructed using CT Agent Pro and visualized using Dragonfly™ software.

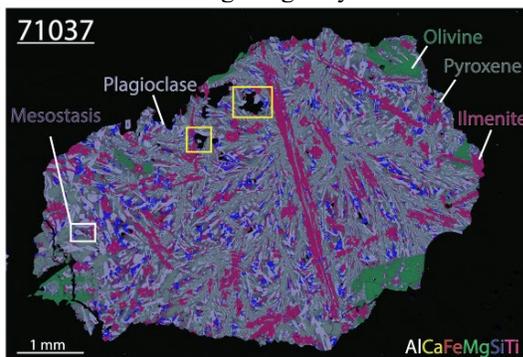


Figure 3. Composite elemental map of 71037, with Fe in red, Mg in green, Si in blue, Al in white, Ti in magenta, and Ca in yellow.

Preliminary Results: 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 phases within mesostasis 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 <1 mm vesicles in Figure 3 contain Fe- and Ti-rich minerals (located in the yellow squares) protruding into the void spaces. 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 non-destructively analyze the interior of a sample. Preliminary examination of the XCT results of 71035, 71037, and 71055 have allowed for the identification of 3D modal mineralogy (Fig. 4) and vesiculation textures. Through the investigation of vesicle morphologies similar to those reported by [10], 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 $\pm 0.5\%$ error [11]), which can be compared to abundances measured in 2D to better constrain representative bulk-rock mineral abundances.

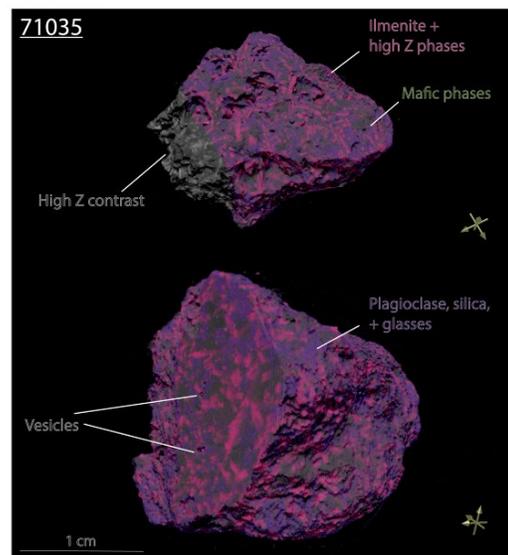


Figure 4. 3D rendered XCT scan of 71035, 36 showing 3D mineralogy. Mafic phases are green, ilmenite and high Z phases are magenta, and plagioclase, silica, and glasses are purple. Sample is clipped to show greyscale high Z contrast among major phases and a 2D slice of minerals and vesicles.

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