

**A MULTIFACETED APPROACH TO INVESTIGATING THE MAGMATIC AND POST-MAGMATIC HISTORY OF VOLATILES IN BASALTS FROM THE RIM OF STENO CRATER.** J. J. Barnes<sup>1</sup>, Z. E. Wilbur<sup>1</sup>, I. J. Ong<sup>1</sup>, S. A. Eckley<sup>2,3</sup>, M. Brounce<sup>4</sup>, S. J. Pomeroy<sup>5</sup>, C. A. Crow<sup>5</sup>, J. W. Boyce<sup>6</sup>, J. L. Mosenfelder<sup>7</sup>, T. Erickson<sup>2</sup>, T. Hahn<sup>2</sup>, M. Fries<sup>6</sup>, T. J. Zega<sup>1</sup>, and the ANGSA Science Team<sup>8</sup>. <sup>1</sup>Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, 85721, USA (jjbarnes@arizona.edu); <sup>2</sup>Jacobs- *JETS*, NASA Johnson Space Center, Houston, TX, 77058, USA; <sup>3</sup>University of Texas, Austin, TX, 78712, USA; <sup>4</sup>University of California, Riverside, CA, 92521, USA; <sup>5</sup>University of Colorado, Boulder, CO, 80309, USA; <sup>6</sup>NASA Johnson Space Center, Houston, TX, 77058, USA; <sup>7</sup>University of Minnesota Minneapolis, MN, 55455, USA; <sup>8</sup>List of co-authors includes all members of the ANGSA Science Team (<https://www.lpi.usra.edu/ANGSA/teams/>).

**Introduction:** Investigations of volatiles in the Moon, in particular H, are of major importance to understanding the origin(s) of volatiles in the inner Solar System ~4.5 billion years ago. Volatile elements like hydrogen, carbon, and the halogens influence the physical properties of magmas, the thermal stabilities of minerals and melts, and exert a control over magma eruption processes. Hydrogen is also crucial to habitability and therefore holds importance in extra-terrestrial in-situ resource utilization efforts.

The field of lunar volatiles research is still in its adolescence and consequently there are numerous topics that are currently debated, including (1) discrepancies regarding the amount of H<sub>2</sub>O in the bulk silicate Moon (BSM) with estimates ranging from 64 ppb up to several hundred ppm H<sub>2</sub>O; and (2) lack of consensus on the timing of accretion of volatiles to the Moon and (3) their potential source(s) which range from a cometary origin, to the proto-Earth, or delivery by volatile-rich carbonaceous chondrites (see review by [1] and references therein).

Compounding the challenges in determining the indigenous volatile inventory of Moon are observations that there are a variety of magmatic and secondary processes that may have affected the abundance and speciation of various volatile elements in lunar minerals and glasses (e.g., [1] and references therein). Such secondary processes include interaction with the regolith, space weathering, and possible terrestrial effects.

To help address some of these issues we are using a multi-technique approach to analyze the volatile systematics of a suite of Apollo lunar samples that were collected together from the rim of Steno Crater during the Apollo 17 mission, but which have been curated under different conditions.

**Goals:** (1) Compare, for the first time, the isotopic composition of and abundance of water in H-bearing minerals and melt inclusions from lunar basalts curated at room temperature and a lunar basalt that has been frozen for almost fifty years;

(2) Compare the volatile inventories (H isotopes, H, Cl, F, and S abundances and S speciation) of lunar

minerals and glasses from samples prepared using different preparation techniques;

(3) Determine the abundance and physical form of vugs and vesicles as well as the composition of minerals they contain, which together with H abundance and H isotope data (from goals 1+2) will be used to critically evaluate the degassing history of the Steno Crater basalts; and

(4) Define the eruption age of each of the four basalts to determine if they are from the same lava flow and how they are related temporally.

The expected data will permit us to quantify the magnitude of the effects of warm curation on the ability of lunar samples to record indigenous volatile chemistries, knowledge of which is uniquely available with this ANGSA solicitation. These data will be critical for the planning of the curation of future samples from sample-return missions. The results will further serve the community by providing a comprehensive dataset on the abundance, distribution, and isotopic compositions of volatiles, as well as age data for a previously unstudied Apollo basalt. This, in combination with previously published data on lunar volatiles, will provide us with a more complete picture of the magmatic and post-magmatic evolution of volatiles in a group of basalts from the Apollo 17 site.

**Samples:** Sample 71036 has been made available for study through the ANGSA program. This presents a unique opportunity to study volatiles in a basalt that has been frozen (at -20°C) and specially preserved since its return, and to compare the results gained with data from basalts of similar bulk chemistries (71055, 71035, & 71037) that have been stored at room temperature. All of these basalts were collected from the same boulder at Station 1A during the Apollo 17 mission. This exceptional suite of basalts also offers a chance to unravel the history of volatile loss on the Moon, from the onset of mineral crystallization through vesicle formation, sampling, and subsequent curation.

**Methods:** To address the goals of this study we were allocated basalts in different forms: as existing thin sections, newly made thick sections, metal mount-

ed anhydrous mounts, and bulk chips. Our study utilizes a range of microanalytical techniques to analyze the samples in situ. These include optical microscopy, scanning electron microscopy (SEM), sulfur X-ray absorption near edge structure (S-XANES), electron probe microanalysis (EPMA), nanoscale secondary ion mass spectrometry (NanoSIMS), SIMS, Raman spectroscopy, electron backscattered diffraction (EBSD), and noble gas mass spectrometry (NGMS). In addition, we have utilized x-ray computed tomography (XCT) to study the 3D mineralogies and textures of the basalts.

**Progress-to-date:** At the meeting we will summarize our progress to date including the following key observations:

*Mineralogy and textures.* Overall, we find good agreement between 2D and 3D modal mineralogies for all four basalts [2-3]. The samples are all dominated by pyroxene, olivine, plagioclase, ilmenite, and an array of minor to trace minerals including apatite, merrillite, K-feldspar, Zr-bearing minerals, troilite, Fe metal, silica, and late-stage glass.

*Vesiculation.* In 3D, we find the Steno Crater basalts contain ~ 5.5 to 14.9 vol.% vesicles [4]. We are investigating the fabrics of the void spaces and their interconnectivity to understand flow shear, viscosity, cooling history and lava flow stratigraphy.

*Sulfur speciation.* We find that sulfur exists mostly as S<sup>2-</sup> in lunar minerals and glass. We find that sulfate exists in cracks and pits in the existing thin sections and is present in the epoxy [5-6]. We find at the sulfate is extremely rare in newly made thick sections and points to the importance of either the use of fresh epoxy to make sections or the rapid timescale under which the samples were analyzed (~3 weeks from sectioning to S-XANES analysis).

*Crystallization ages.* Most of the samples investigated lack exposure ages, and only 71055 has an age reported. The Rb-Sr age of Tera et al. [7] was  $3.56 \pm 0.09$  Ga. We investigated the U-Pb and Pb-Pb ages of the phosphates and baddeleyite in 70135 and 71055 using SIMS (Pomeroy et al., 2022). We find the samples have consistent ages and yield an isochron age of  $3841 \pm 28$  Ma. The discrepancy between the Rb-Sr age and the new age may be related to shock resetting, although we are assessing other possibilities too.

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