USING X-RAY COMPUTED TOMOGRAPHY TO IMAGE APOLLO DRIVE TUBE 73002.

R. A. Zeigler[1], S. A Eckley[2,3], R. Hanna[2], D. Edey[2], R. A. Ketcham[2], J. Gross[1,4,5], F. M. McCubbin[1], and the ANGSA Science Team, [1]NASA, Johnson Space Center, Houston, TX. [2]Jackson School of Geosciences, University of Texas at Austin, Austin TX. [3]Jacobs Technology, Johnson Space Center, Houston, TX. [4]Dept. of Earth & Planetary Sciences, Rutgers University, Piscataway, NJ. [5]Dept. of Earth & Planetary Sciences, American Museum of Natural History, New York, NY.

Overview: The Apollo missions collected 382 kg of rock, regolith, and core samples from six locations on the nearside of the Moon. Today, just over 84% by mass of the Apollo collection remains in pristine condition within the curation facility at Johnson Space Center. Most Apollo samples have been well characterized, however there are several types of samples that have remained wholly or largely unstudied since their return, and/or that have been curated under special conditions. These sample types are: (1) unopened samples sealed under vacuum on the Moon; (2) unopened (but unsealed) drive tubes; (3) Apollo 17 samples frozen shortly after their return; and (4) Apollo 15 samples opened and stored in a helium atmosphere since their return. NASA solicited proposals for the Apollo Next Generation Sample Analysis Program (ANGSA), and 9 teams were selected to study: (1) unsealed, unopened drive tube 73002; (2) sealed, unopened drive tube 73001 (paired with 73002); and (3) a subset of the frozen and He-purged samples [1].

The first sample opened as part of the ANGSA program was drive tube 73002. This was originally a ~30 cm long, 4 cm diameter drive tube collected on a landslide deposit near Lara Crater at the Apollo 17 landing site. It was part of a ~60 cm long double drive tube collected, and the bottom half of the tube (73001) was sealed under vacuum on the Moon [2]. Prior to opening sample 73002, the sample was imaged with a high resolution X-ray Computed Tomography (XCT) scan of the entire tube. Additional XCT scans have been made of "large" clasts removed from the core as part of the dissection process [3]. Here we present the whole tube and close-up XCT data from 73002, and talk about the utility of the scans as part of the curation process, including the potential for future science returns from the high resolutions scans.

Methodology: Sample 73002 was transported to the University of Texas High-Resolution X-ray Computed Tomography Facility (UTCT) to scan the entire length of the tube using their North Star Imaging cabinet XCT system. The tube was scanned in 6 overlapping volumes, each covering a ~4 cm length of the tube (there was only about 20 cm of regolith inside the tube). Each individual scan was corrected for uneven beam and isometric distortion in Z using a linear rescale for both CT value and geometry across Z (i.e., per-slice basis; central slice used as geometric standard). The different scans were then geometrically matched (rigid translation and rotation) and their CT values rescaled (second degree polynomial) to match the spot directly 'below' (e.g., scan 2 matched to scan 1, etc.). Seams between scans were then blended using a gradual linear combination of 9 overlapping slices centered at the matching reference slice. The voxel size for the combined scan is 25.8 µm and there are a total of 8252 "slices" along the length of the tube [Fig. 1].

In addition to the combined 25.8 µm/voxel resolution scan, each volume was also imaged at 12.9 µm/voxel resolution using sub-voxel scanning, essentially imaging each volume four times while offsetting the detector by ½ of a voxel vertically and/or horizontally, effectively doubling detector density. Due to the large data volumes, these scans are only just starting to be investigated, but the increased resolution has great potential [Fig. 2].

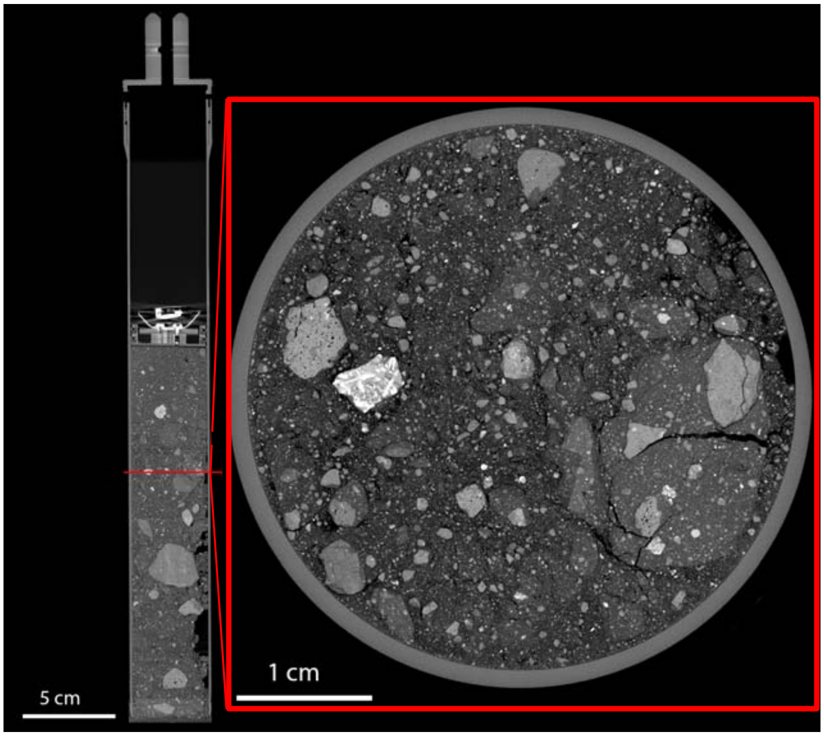

Figure 1: Vertical cross-section view of the combined XCT scan of 73002 (left side) and one of the 8252 horizontal "slices" that comprise the scan on the right.

Individual clasts >4 mm that are separated from the core as part of the dissection process are individually bagged in Teflon under a Nitrogen atmosphere and scanned using the 180 kV nano-focus transmission source on the Nikon XTH 320 XCT system at NASA Johnson Space Center [4]. Each scan has a resolution of 3-7 μm/voxel depending on the size of the clast (Fig. 3).

Results and Discussion: The combined scan of the core tube (as well as the individual higher resolution scans of sections of the core) allows for easy detection and tentative classification of mineral and lithic clasts within the entire length of the drive tube, as well as void spaces. These scans allowed us to identify and avoid potential pitfalls that might have complicated the extrusion process of the core, such as angular clasts near the edges. It also allows for identification of "soil clods" within the core, which typically do not survive the dissection process, but could be targeted in the future. During dissection of each interval of the drive tube, the macroscopic scan is used as a guide for what to expect (voids, large clasts) and gives the processor an idea of any potential complications for each day's work. Although no large scale structural features, such as layering, have been observed, additional analysis of the data (especially the sub-voxel scan data) has the potential to make these discoveries in the future.

To date, 61 individual clasts have been scanned at high resolution from Pass 1, and 25 of the 64 similar sized clasts from Pass 2 have been scanned. A subset of these particles are shown in Fig. 3. A good estimate of the lithology of each clast is readily apparent using the XCT scans, which is not typically possible using optical microscopy due to fine-grained dust coatings. This lithologic information will be invaluable when allocating specific lithologies (e.g., basalts or impact-melt breccias) for detailed analyses and targeted investigations.

References: [1] Shearer et al. (2020) LPSC 51, #1181. [2] Shearer et al. (2018) LPSC 49, #2083. [3] Krysher et al (2020) LPSC 51, #2989. [4] Eckley et al (2020) LPSC 51, #2182.

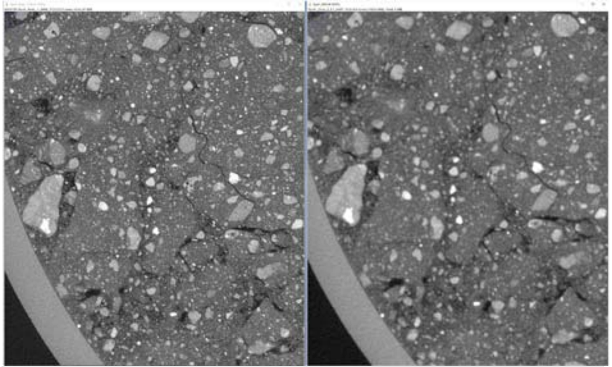

Figure 2: Comparison of the "standard" 25.8 μm/voxel scan on right, with the 12.9 μm sub-voxel scan on the left, which clearly makes lithologic identification easier.

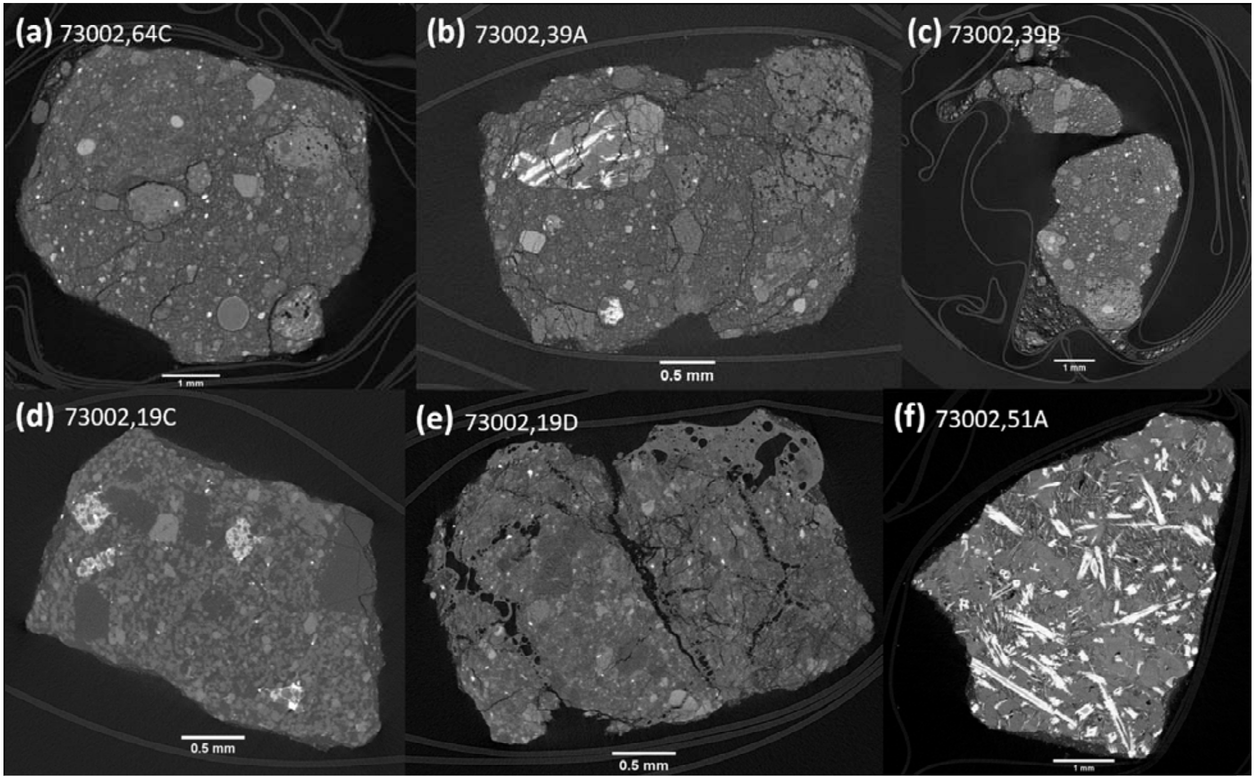

Figure 3: XCT scans of individual clasts: (a) regolith breccia (voxel = 5.9 μm); (b) regolith breccia (4.9 μm); (c) soil breccia (5.9 μm); (d) impact-melt breccia (3.5 μm); (e) Glassy regolith breccia/agglutinate (3.9 μm); (f) basalt clast (5.5 μm).