Preliminary Catalog for Double Drive Tube Samples 73001 and 73002

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Overview

Of the nearly 2200 individual Apollo samples collected by the astronauts during the six Apollo missions that landed on the lunar surface, nearly all of these have been studied to various degrees over the past 5 decades of lunar science [e.g., 1, 2]. Prior to 2019, 6 unopened or unexamined Apollo samples remained: unsealed drive tube samples 73002 and 70012; sealed drive tube samples 73001 and 69001; sealed bulk soil sample 15014; and frozen basalt sample 71036. Moreover, there was an additional collection of Apollo 17 core and soil samples that were frozen shortly after their return to Earth, and largely unstudied since. The Apollo Next Generation Sample Analysis (ANGSA) Program was brought together by NASA and nine PIs were selected to study double drive tube samples 73001 and 73002 and the frozen samples: Jessica Barnes, Katherine Burgess, Barbara Cohen and Natalie Curran (co-PIs), Darby Dyar, Jamie Elsila-Cook, Jeff Gillis-Davis, Alex Sehlke, Charles Shearer, and Kees Welton [3,4]. This program is intended as a multi-generational team using cutting edge techniques to address primary science goals from the Apollo mission, as well as to prepare for the upcoming return of samples from the Artemis missions.

This preliminary catalog will focus only on samples 73001 and 73002 (cold samples will be reported on in a later catalog). The only data presented here are the results of the preliminary examination of the samples, and the results of the more in-depth analyses of these samples from the science team members will be reported in forthcoming peer-reviewed publications.

Collection on the lunar surface

Apollo samples 73001 and 73002 were collected on the South Massif landslide deposit at the rim of Lara Crater at Station 3 during the second EVA of the Apollo 17 mission [5]. Samples 73001 and 73002 are a double drive tube [6], a 4 cm diameter, 70 cm long thin-walled aluminum tube hammered into the surface by the Apollo astronauts. After the double drive tube was removed from the lunar subsurface, the two 35 cm long drive tubes were unscrewed and separated, and each individual drive tube sample was secured for the trip back to Earth. The top half, 73002, was immobilized in its drive tube and returned unsealed; an unknown amount of material fell out the bottom of the 73002 core tube during this process. The bottom half, 73001, was first immobilized in its drive tube (no material was lost), and then placed in a secondary stainless-steel (SS) tube that had a metal knife edge seal (Indium-Silver alloy), known as a core sample vacuum container (CSVC). This CSVC [6] was sealed under vacuum on the lunar surface. Both 73001 and 73002

were transported to Earth in Apollo Lunar Sample Return Container (ALSRC) #2, colloquially known as a rock box, which was also sealed under vacuum on the lunar surface [7].

Handling upon Return to Earth

Upon return to Earth, sample 73002 was removed from the ALSRC inside the nitrogen purged processing cabinets, weighed by difference (430 g), and triply sealed in Teflon bags within that environment. The bagged sample was taken to a medical X-ray scanning facility at JSC in early 1973 to image the material inside the tube. The radiographs showed the length of the regolith material within the tube was approximately 23.5 cm in length, though numerous void spaces were also observed. After these scans, the still bagged 73002 drive tube was placed into special storage within the nitrogen purged cabinets at JSC and left untouched. Eventually 73002 was one of the samples transferred for storage in nitrogen purged cabinets at the Apollo remote storage facilities at Brooks Airforce Base (1976-2002) and White Sands Test Facility (2002-2019). In the spring of 2019, the sample was returned to Johnson Space Center (transported bagged in a nitrogen atmosphere) in preparation for the ANGSA program and stored in a nitrogen purged cabinet within the lunar vault. In the fall of 2019, the Teflon bags surrounding 73002 were briefly opened within the Apollo nitrogen purged processing cabinets and the material within the tube was more securely immobilized using a specially designed materials compliant tool; this resulted in the overall length of the regolith material being compacted to ~20 cm in length (based on whole core XCT scanning; see section (2) below). The sample was then triply resealed in Teflon bags in the nitrogen cabinet. Sample 73002 was transported to the High-Resolution X-ray Computed Tomography (XCT) facility at The University of Texas at Austin (UTCT) where a series of XCT scans were done on the bagged sample (see section (1) below). Upon completion of the XCT scans, the sample was returned to secure nitrogen-purged storage in the lunar vaults until the sample was extruded and processed starting in November of 2019 (see section (3) below).

Upon return to Earth, sample 73001 (in the unopened CSVC) was removed from the ALSRC inside the nitrogen purged processing cabinets, weighed by difference (809 g), and then the CSVC was sealed within a large outer vacuum container (OVC) made of stainless steel that was pumped down to ~10^{-2} Torr, which was in turn sealed inside two large Teflon bags. The OVC was placed in special low-vibration nitrogen purged storage in the lunar curation facility. In the spring of 1976**,** it was suspected that the valve on the OVC was leaking, so the valved flange was removed, replaced with a new valved flange, and the OVC was again pumped down to an atmospheric pressure of 10^{-2}. All this work was done in the nitrogen purged cabinets. After the OVC repair, 73001 sat inside its never opened CSVC, repaired OVC, and two outer Teflon bags, undisturbed in low vibration nitrogen purged storage in the lunar vaults until it was removed for gas extraction, XCT analysis, and extrusion/dissection starting in March of 2022.

Preliminary Examination of samples 73002 and 73001

Sample 73002 was the first drive tube sample to be opened in over 25 years. This meant that all the equipment that was needed for the extrusion and dissection process had to be located, cleaned, assembled, and tested (including procurement of replacement parts where needed) over a period of ~12 months. A similar process was undertaken to renovate and rebuild the entire core vacuum

impregnation and curing devices for making continuous core thin sections at the end of the dissection process. In addition to the hardware upgrades, the procedures for sample dissection had to be reviewed and modernized, which included building a full-sized cabinet mock-up and extensive testing with analog samples [8].

The preliminary examination (PE) of sample 73002 began in November of 2019 and concluded in December of 2021. The protracted nature of the PE was almost entirely because of laboratory access issues related to the COVID-19 pandemic. The PE of sample 73001 began in March of 2022 and concluded in September of 2023. The steps in the PE process, and the detailed work within each PE step, were remarkably similar for samples 73001 and 73002. The only notable exception was the gas-extraction process that was necessary for sealed sample 73001, but not for unsealed sample 73002.

- PE Steps for 73001: (1) Gas Extraction; (2) Whole Core XCT; (3) Extrusion and Dissection of Regolith Materials; (4) XCT of >4 mm individual particles

- PE Steps for 73002: (2) Whole Core XCT; (3) Extrusion and Dissection of Regolith Materials; (4) XCT of >4 mm individual particles

(1) Gas extraction of 73001:

Figure 1: (a) an aluminum drive tube like the one used for 73001 (sealed in Teflon bags under N_2 atmosphere); (b) a CSVC inside the Apollo prcessing cabinet, just like the one that the 73001 drive tube is inside; (c) the 73001 OVC that has the nested Al drive tube and CSVC inside of it.

As part of the ANGSA program, the gas in both the 73001 OVC and CSVC was extracted (Figure 1). The OVC had an external valve in place to help facilitate gas extraction, but the CSVC did not have an external valve. Thus, the CSVC had to be pierced to extract the gas. Gas extraction was achieved using two bespoke pieces of equipment that were built for the ANGSA project: (1) a gas extraction manifold built by the Team at Washington University in St. Louis led by Drs. Alex Meshik, Olga Pravdivtseva, and Rita Parai; (2) a piercing device built by a team at ESA led by Dr. Francesca McDonald. Gas was extracted from the OVC and CSVC using differential pressure between those containers and the gas extraction manifold, which typically achieved pressures in the mid 10^{-9} Torr range (unless otherwise noted). The gas extraction manifold originally had eight ~2-liter SS bottles and two 50 cm^3 SS bottles attached to it for storing the extracted gas; a ninth ~1-liter SS bottle was also added to the system before the extraction was completed. See Table 1 for a summary of all gas samples acquired.

Table 1: List of Gas Samples Taken from ANGSA Sample 73001							
Sample Number		Container number	Container Volume	Container Press (Torr)	Type of Gas in the Container	Equilibration time	Notes
Generic	Specific						
73001	,5001	4	~1.9 liter	~5 x 10-6	System Blank	15 minutes	
73001	,5002	3	~1.9 liter	27	OVC, 1st extraction	15 minutes	
73001	,5003	2	~1.9 liter	7	OVC, 2nd extraction	15 minutes	
73001	,5004	1	~1.9 liter	~0.2	CSVC, Leak Gas 1	15 minutes	Accumulated in the piercing tool for ~24 hours prior to extraction
73001	,5005	8	~1.9 liter	~0.2	CSVC, Leak Gas 2	15 minutes	Accumulated in the piercing tool for ~24 hours prior to extraction
73001	,5006	6	~1.9 liter	4.6	CSVC, 1st extraction	15 minutes	
73001	,5007	7	~1.9 liter	4.6	CSVC, 1st extraction	15 minutes	
73001	,5008	5	~1.9 liter	3.2	CSVC, 2nd extraction	10.75 days	
73001	,5009	9	~1 liter	5 x 10-4	CSVC, 3rd extraction	15 minutes	Piercing Tool/CSVC was pumped down to 2 x 10-7 Torr, and then gas accumulated in sealed piercing tool for 6 days prior to extraction
73001	,5010	10	50 cc	28	OVC, 1st extraction	15 minutes	Consumed for PE
73001	,5011	11	50 cc	4.6	CSVC, 1st extraction	15 minutes	Consumed for PE

Two separate gas extractions from the OVC were done (Figure 2). The initial OVC extraction was done with a background manifold pressure of 4 x 10^{-6} Torr, an equilibration time of 15 minutes (all equilibration times are 15 minutes unless otherwise stated), and the gas was expanded into one 2-liter bottle and one 50 cm^3 bottle. The equilibration pressure observed on gas sample OVC1 was 28 Torr. Just prior to acquiring gas sample OVC1, a system blank was collected under the sample conditions (e.g., similar background manifold pressure and equilibration time). The second OVC extraction was collected into one 2-liter bottle with a background manifold pressure of 5 x 10^{-8} Torr; the gas for OVC2 was passed through a tube sitting in a water ice bath during extraction. The equilibrated pressure on OVC2 was 7 Torr.

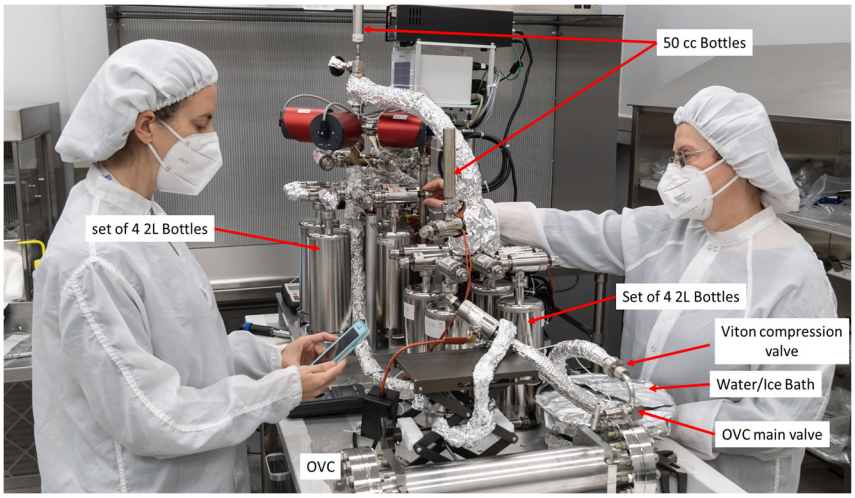

Figure 2: Photo showing the gas extraction manifold with the 73001 OVC attached. The water-ice bath, used to try to remove possible hydrocarbon gas contamination, was only used during OVC2 extraction. Drs. Gross and Pravdivtseva for scale.

After the OVC gas extraction was completed, the OVC was placed back into the N_2-purged curation cabinets, the OVC was opened, the CSVC was removed from the OVC, and the CSVC was sealed within the piercing tool (Figure 3). The piercing tool was then removed from the N_2-

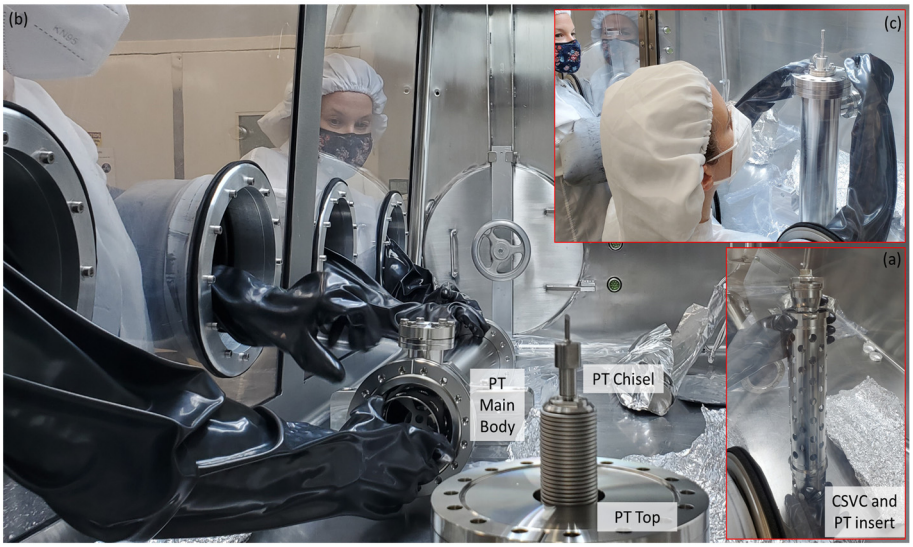

Figure 3: Photos showing the insertion of the CSVC into the Piercing Tool (PT). (a) the CSVC going into the piercing tool insert; (b) the piercing tool insert being placed into the main body of the piercing tool, with the piercing tool top/chisel in the foreground; (c) placing the PT top/chisel on to the PT main body. Drs. Gross and McDonald for scale.

purged cabinets and connected to the gas extraction manifold (Figure 4). The piercing tool was then pumped down by the gas extraction manifold prior to piercing the CSVC to remove the N2 cabinet gas in the piercing tool. During the pump down of the piercing tool over the course of ~48 hours, we were unable to achieve a manifold pressure lower than 10^{-6} Torr, whereas we could achieve a vacuum of 10^{-9} Torr in the manifold when the piercing tool was isolated. The RGA analysis of the gas being pumped out of the piercing tool appeared to be nearly pure N_2 gas and showed no evidence for atmospheric contamination of the system, nor did multiple He-leak checks of the piercing tool and extraction manifold show evidence of an external leak. Thus, it was decided that there was a slow leak of the CSVC bleeding gas out into the piercing tool.

Figure 4: Photo showing the gas extraction manifold with the piercing tool (with the 73001 CSVC inside). Drs. Parai and Zeigler for scale.

The CSVC "leak gas" was accumulated within the piercing tool for ~24 hours and then collected into one 2-liter bottle with a background manifold pressure of 10^{-9} Torr (CSVC Leak Gas 1). This process was repeated under almost identical conditions to collect an additional 2-liter bottle of gas as CSVC Leak Gas 2. In both cases, the observed equilibration pressure in the collection bottle for the leak gas samples was ~0.2 Torr. After the CSVC leak gases were collected, the piercing tool was isolated from the manifold, the piercing mechanism on the piercing tool was successfully used to pierce the bottom of the stainless steel CSVC (making a ~2 mm hole), and a first gas extraction from the pierced CSVC was collected in

two 2-liter bottles and one 50 cm^3 bottle with an equilibration pressure of 4.6 Torr. A second longer gas extraction (CSVC extraction 2) was performed with an equilibration time of 10.75 days, with a final equilibration pressure of 3.2 Torr. Finally, the gas extraction manifold was used to pump down the CSVC/piercing tool to a pressure of 2 x 10^{-7} Torr. The piercing tool was then isolated for 6 days, and a final CSVC extraction 3 was collected into a single 2-liter bottle with a final equilibration pressure of 5 x 10^{-4} Torr. The two 50 cm^3 bottles of gas (OVC1; CSVC1) were subsampled and portions of each distributed for preliminary analyses to ANGSA Team members Dr. Zachary Sharp at the University of New Mexico and Dr. Rita Parai at Washington University in St. Louis [9-10]. Dr. Sharp's results showed that the vast majority of gas within both the OVC and CSVC is N2, and thus there is little evidence for laboratory atmosphere contamination within the samples. The $\delta^{15}N$ value of -4.4‰ relative to air is generally consistent with, albeit slightly lower than, the gas used in our N_2 purged cabinets, suggesting that ^{14}N has preferentially leaked into the system from the cabinet. The CSVC sample has a lower absolute concentration of N_2 than the OVC sample (98.3% vs. 99.9%), suggesting that some of the H_2O, H_2, and Ar within the CSVC could be indigenous in origin (though some of the H_2 would have exsolved from the SS over the years of storage; see [10] for more details). Similarly, Dr. Parai's results for major gas phases measured by RGA showed that N_2 was the dominant gas (presumably curation cabinet gas), with measurable CO_2 and H_2 gas (likely exsolved from the SS containers), and no evidence of significant contamination of the OVC or CSVC gas from laboratory air. Additionally, although there was some evidence of a terrestrial component in some of the noble gas measurements from the CSVC1 sample, there was also clear evidence of a solar wind component apparent in both the Ne and Ar isotopes (see [9] for more details).

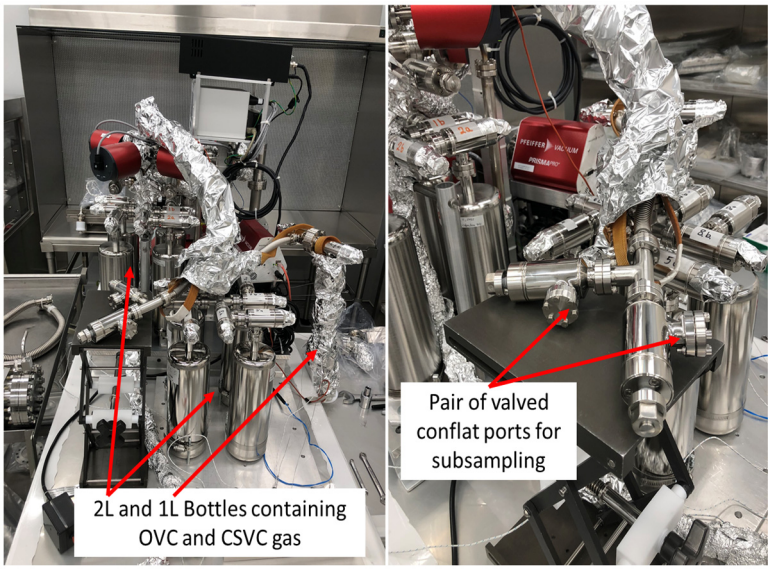

Figure 5: Current configuration of the Gas Extraction Manifold showing the additional SS 2-liter bottle added to the system, as well as the two available conflat distribution ports for PI subsamples to be taken through. No doctors for scale.

Currently, all nine 1- or 2-liter bottle gas samples listed in Table 1 are attached to the gas extraction manifold, which is being maintained at low 10^{-9} Torr pressure (Figure 5). Each bottle is double valved with a "between valve" volume of ~37 cm^3. Requesting PIs will need to provide their own pre-conditioned gas sample bottles for allocation of gas samples. Sample containers should be stainless steel and bakeable to 200 °C. Containers should be equipped with two valves - either bellows or all-metal bakeable valves, with a 1.33" conflat flange to connect to distribution ports. Requesting PIs should determine the internal volume of their container(s) prior to sending to JSC.

(2) Whole Core XCT Scanning of 73001 and 73002:

Prior to extruding the regolith material from drive tubes 73001 and 73002 (see section 3 below), each sample was scanned by XCT at the University of Texas High-Resolution X-ray Computed Tomography (UTCT) Facility (Figure 6; [11-13]). This was done in order to: (1) facilitate non-destructive, rapid detection of minerals, lithic clasts, and void spaces within the drive tubes in order to identify any potential complications during the extrusion or dissection process; (2) determine the pre-extrusion length of the tube to better inform the overall sampling depth of the core; and (3) to establish a permanent record of any potential stratigraphy and clast locations prior to extrusion for more in depth studies after PE was concluded. The pre-extruded length of the 73001 core was measured at 35.0 cm and the pre-extruded length of the 73002 core was measured at 20.1 cm based on the XCT scans.

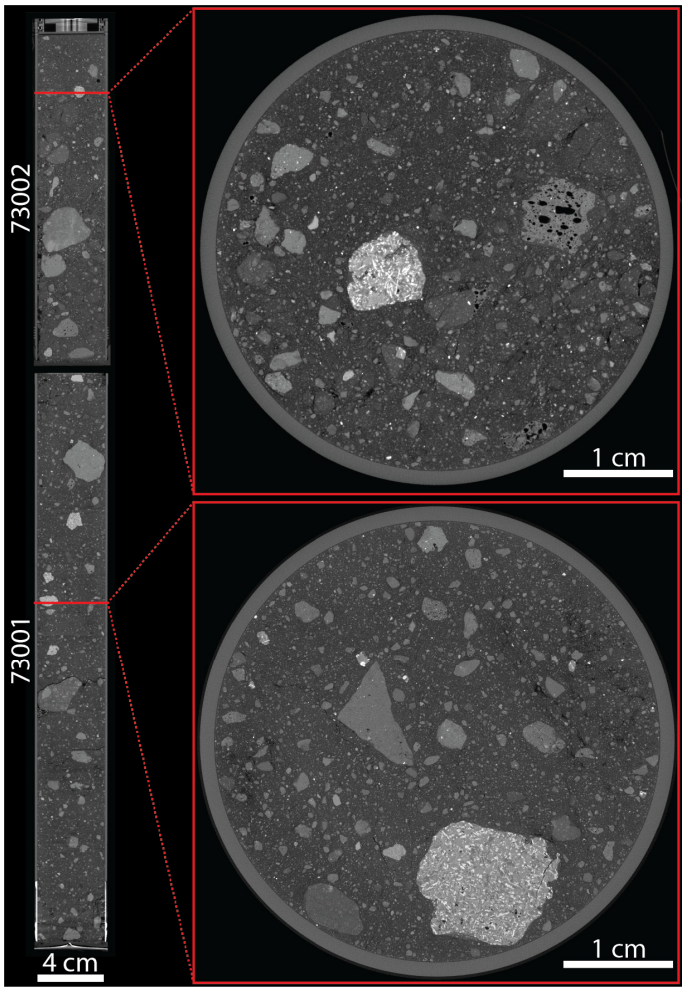

Figure 6: Whole core XCT images of drive tubes 73001 and 73002 (on the left) with representative cross-sectional slices shown (on the right) for 73002 (slice 1748) and 73001 (5446). This image is made from the 51.6 mm per voxel down-sampled data.

Prior to the whole core scan at UTCT, the top and bottom of the 73001 CSVC were scanned by XCT at NASA JSC (Figure 7). These scans were done on a Nikon XTH 320 system using the 225 kV rotating reflection source at 215 kV, 179 µA, and a 38.5 µm voxel size. The purpose of these preliminary "engineering" scans were to: (1) characterize the nature of the piercing at the bottom of the tube; (2) confirm that the regolith at the top of the core was properly immobilized; and (3) image the metal-knife edge seal on the CSVC prior to opening in case this information was needed for future tool design (e.g., Artemis). The scan of the bottom of the 73001 CSVC confirmed that the hole made by the piercing device was large enough to permit gas to freely flow and that the Teflon cap on the bottom of the 73001 Al drive tube that held the regolith in place was undamaged and securely in place. The scan of the top of the 73001 CSVC showed that the tube was overfull, and the part of the tube apparatus designed to keep the regolith in place (the keeper) was not properly seated in the tube. Thus, the only way to safely transport 73001 and preserve its stratigraphy was to leave it within the CSVC.

The whole core XCT scan of sample 73002 was taken through the aluminum drive tube, that had been triply bagged in Teflon within the nitrogen purged atmosphere of the JSC curation processing cabinets. For sample 73001, it was taken through the SS CSVC tube, the Al drive tube, and three sealed Teflon bags. Both samples were scanned at UTCT using a Feinfocus FXE 225.48 micro-focal X-ray source and a 2048x2048 Perkin Elmer XRD 1621 N ES flat panel detector. To achieve maximum spatial resolution, the NSI Subpix^{TM} capability was used, in which four overlapping data sets are gathered with half-pixel vertical and horizontal offsets of the detector, virtually doubling the detector size to 4096x4096. Sample 73002 was scanned mounted vertically in a plexiglass tube, with X-rays at 180 kV and 180 μA and pre-filtered with 0.72 mm Al. Sample 73001 was mounted similarly, however X-ray energy was increased to 190 kV and 180 μA with no filter (to help account for the SS outer tube).

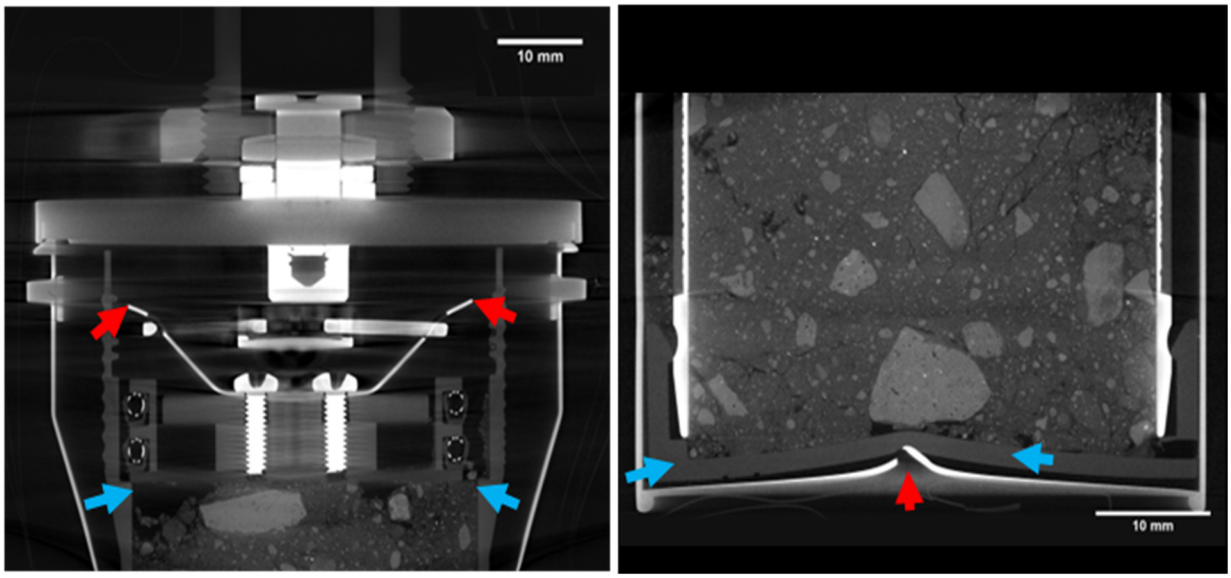

Figure 7: (left) Cross section view of the top of the 73001 CSVC after the gas extraction was done. The SS keeper (red arrows) are supposed to be holding the regolith material in place by grabbing on to the sides of the aluminum drive tube (blue arrows). **(right)** Cross section view of the bottom of the 73001 CSVC after the gas extraction. The SS CSVC has clearly been pierced (red arrow), and while the Teflon cap (blue arrow) on the 73001 drive tube has been dented, it is still intact.

Data were acquired as a series of six (73002) and nine (73001) individual cone-beam volume scans, with overlap (~380 slices) to aid in stitching them together to create a continuous data set for each core. The voxel resolution on all scans was 12.9 microns. There are 27,600 slices in the finished 73001 scan and 15,820 slices in the finished 73002 core scan. 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 (73002) and 80 (73001) overlapping slices centered at the matching reference slice. The CSVC, as well as the SS bit embedded in the 73001 Al drive tube both caused considerable artifacts in the initial XCT

data, and considerable effort was made to develop specific corrections for those effects [see 13 for more details].

Appendix 1 contains fly-through videos of both the whole core 73001 and 73002 scans (at down-sampled resolution of 51.6 µm/voxel), as well as fly-through videos of the engineering scans taken at the top and bottom of the 73001 CSVC (38.5 µm/voxel). In these videos, the brightness of different phases are a result of the attenuation of X-rays by that phase, which is a function of the density and average atomic number of the phase, as well as X-ray energy. Brighter phases have higher density and/or atomic number. Although it does not represent exactly the same phenomenon, the effect is very similar to that observed in back-scattered electron images. Although XCT scans do not provide primary mineralogical information, for the Moon the relative brightness of phases almost always follows the sequence (increasing brightness): silica phases; feldspar; pyroxene; olivine; FeTiCr oxides; Fe sulfides; FeNi metal and stainless steel. There can be overlap between adjacent phases in this list, especially for phases which have considerable Mg-Fe substitutions (e.g., pyroxene and olivine).

Individual TIFF stacks for these videos can be made available by request to the Apollo Sample Curator; please keep in mind that the data volumes involved (408 GB 73002; 711 GB 73001) make this a significant effort.

(3) Extrusion and Dissection of 73001 and 73002:

The extrusion and dissection of both 73001 and 73002 took place in the core processing cabinet in the Apollo sample laboratory facility. Sample 73002 was processed first, from November 2019 till December 2021, and sample 73001 was processed next, from March 2022 till June 2022. The cabinet, equipment, and tools used during extrusion and dissection were cleaned using our in-house cleaning facility following our standard protocols prior to each sample. The one exception to this was that all materials that would be introduced into the core processing cabinet were entirely bagged in Teflon (normal Apollo sample processing uses nylon bags). Separate Si-metal and baked-out Al-foil witness materials were: (1) deployed in the core cabinet for each dissection prior to insertion of any equipment, (2) kept out during the entire process; and (3) preserved as a record of the exposure history of the initial processing of the core samples.

Our standard Apollo sample processing procedures are designed to minimize all types of contamination into the Apollo processing cabinets, but they were developed with inorganic cleanliness foremost in mind. One of the primary goals of the ANGSA program was to measure the organic components of 73001 and 73002. To minimize the introduction of organic or biologic materials into the cabinet during processing, extra care was taken when introducing new materials into the processing cabinet: (1) the airlock was cleaned out with alcohol wipes every third time it was

Figure 8: Very bottom of the 73001 core, showing the small amount of material that fell out during the opening process.

used; and (2) an additional smock and nitrile gloves were worn on top of the normal clean room gear. The core processing cabinet was biotested prior to loading it for each core and after the dissection was completed (and the core removed). The cabinet airlock, and core room flooring was routinely tested once a month during the dissection process to understand biological contamination in the vicinity as well. The testing results showed that the cabinet remained abiotic throughout the entire process [14,15].

The extrusion and dissection process for core samples 73001 and 73002 occurred in several steps, and was identical for both core samples, except for step 1 below, which was only necessary for 73001 (because it was in a CSVC).

1. Sample 73001 was removed from the CSVC. During the process of removing the sample, a small amount of material fell out of the very bottom of the drive tube (Figure 8). This material was preserved as "interval 67", representing the lowermost ~0.5 cm of the 73001 core.

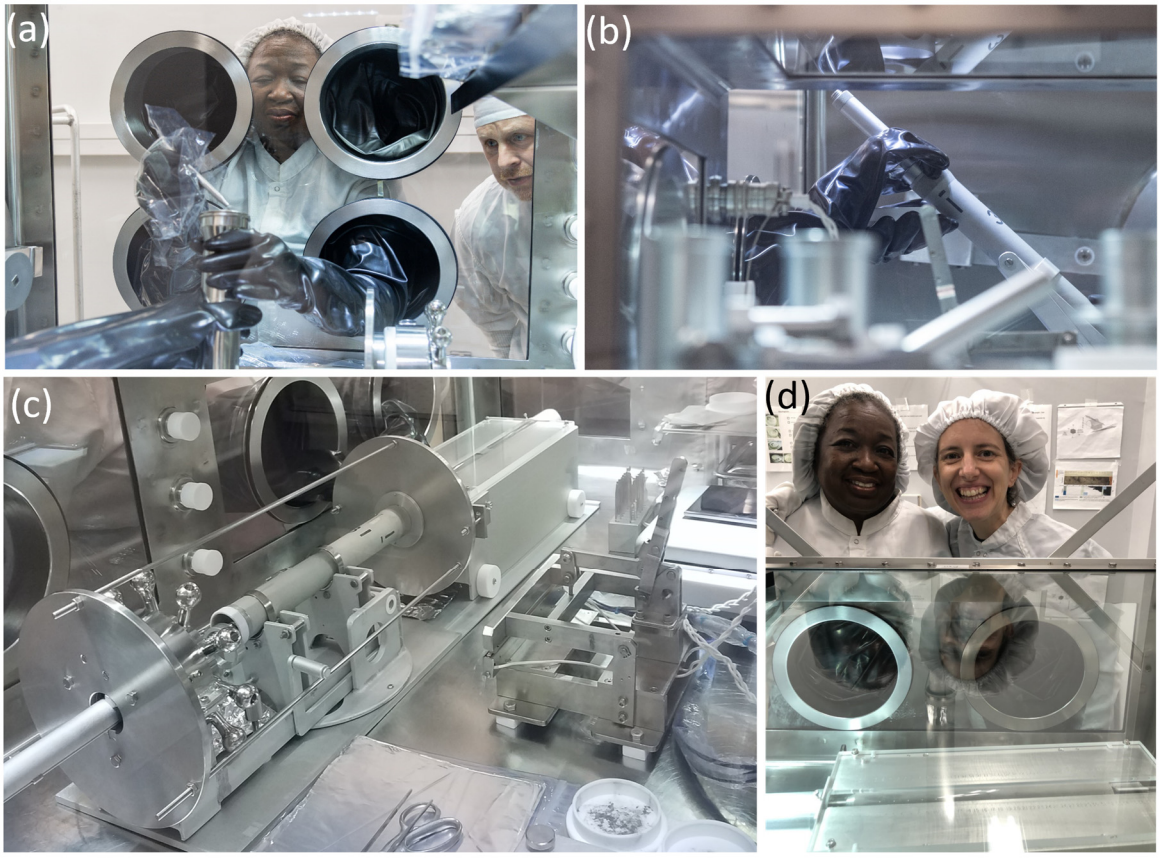

Figure 9: (a) Lunar processor Andrea Mosie preparing to remove the 73001 drive tube from the CSVC; **(b)** adding the end effectors to the drive tube to enable the extrusion; **(c)** drive tube inside the extrusion apparatus and core being pushed onto the receptacle; **(d)** extruded core with quartz top, on dissection table with happy extrusion team Andrea Mosie and Juliane Gross.

2. The ends of the drive tubes were removed, and special end effectors were added to aid with the extrusion process. These modified drive tubes were then mounted into an extrusion

mechanism that was aligned with a receptacle, and slowly extruded from the drive tube into the receptacle, which consisted of an aluminum base that has removeable aluminum plates, with a quartz top (Figure 9).

The post extrusion length of 73001 was 33.1 cm and the post extrusion length of 73002 was 18.5 cm.

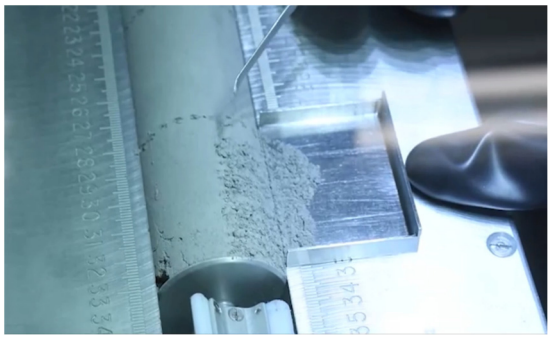

Figure 10: De-rind processes to expose the pristine core material by removing the outermost 1-2 mm rind. The core is marked in 5 cm intervals.

3. After extrusion into the receptacle, the aluminum base with the extruded core and quartz top were carefully lifted onto the dissection table, and the quartz top was removed from the core. Because the regolith was in contact with the aluminum core tube and quartz top, the first step in the dissection process is to "de-rind the core". This is achieved by removing the outmost 1-2 mm of material to expose the underlying pristine material (Figure10). De-rinding was done in 5 cm intervals.

4. Each core was dissected in three passes: Pass 1, Pass 2, and Pass 3 (Figure 11; [20]). A pass accounts for approximately 1/4 of the material in the core (a pass is about 1 cm "tall"). Each pass was subdivided into intervals that are each 0.5 cm wide, starting with the end of the core that was closest to the lunar surface. Each interval represents a unique depth within the core, and the same interval in different passes represents the same depth (i.e., Pass 1, interval 27 and Pass 2, interval 27 are from the same depth beneath the lunar surface).

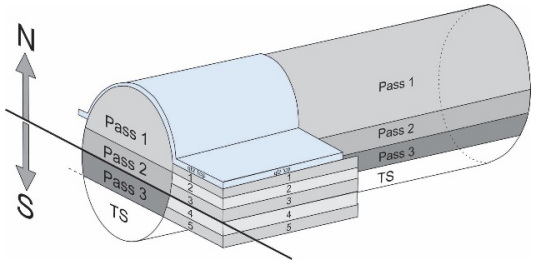

Figure 11: Sketch of 73001/73002 core with locations of each pass. For pass 1 the quartz top (light blue) and the first plate (gray) was removed. Two more plates are removed for each subsequent pass. TS = Thin Section. From [20].

There are 37 intervals total for 73002 and 66 intervals for 73001 (as well as interval 67 that fell out at the beginning; see above). After each pass was dissected down to plate level, two plates were removed from the table so that the core stuck out ~1 cm above plate level again (Figure 12). The sides were then de-rinded, and the pass dissected afterwards in the same manner as the previous pass.

During the dissection process, several non-standard dissection procedures were implemented such as time-sensitive sampling for organics and D/H ratio measurements on Pass 1 of both 73001 and 73002 (i.e., they were dissected "out of order") [15-17], and mm-scale subsampling of a portion of the top two intervals on Pass 3 of 73002 [18].

5. The material removed from each interval in Pass 1 and Pass 2 were sieved into <1 mm fines and >1 mm particles. The >1 mm particles were manually subdivided into the following size fractions: 1-2 mm; 2-4 mm; 4-10 mm; and >10 mm particles (Fig. 13). All particles were sorted into their respective size fraction onto a Teflon cap and photographed from multiple angles and different lighting conditions to best capture their shape and color shade, though most particles are mostly or entirely obscured by adhering dust. All particles >4 mm (352 total particles) were individually triple bagged in Teflon (Figure 13) and scanned by XCT at NASA JSC (see section (4) below).

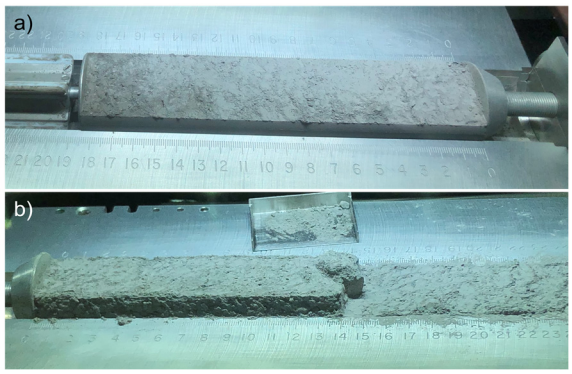

Figure 12: (a) The core sticks out above plate level for Pass 2 after removal of two table plates. (b) The smooth sides of the core have been derinded to expose the pristine material underneath. The core is mid dissection of Pass 2 when imaged.

Pass 3 is considered the most chemically clean portion of the core (since it was the farthest from the tube, and the intervals in Pass 3 were not sieved, though particles >1 cm were removed using tweezers.

6. After each pass was dissected down to plate level, multispectral measurements of the core were taken by placing a spectrometer built at the University of Hawaii on top of the core cabinet [19]. This multispectral imager comprised a monochrome imaging camera, a 6-position motorized filter wheel equipped with 6 narrow band interference filters, lenses and light source. The center wavelengths of the six filters were: 415 nm, 570 nm, 750 nm, 900 nm, 950 nm, and 990 nm. These wavelengths share some of the bands used by the Clementine UVVIS camera, the Lunar Reconnaissance Orbiter Camera Wide Angle Camera and the KAGUYA Multiband Imager (for details see [19]).

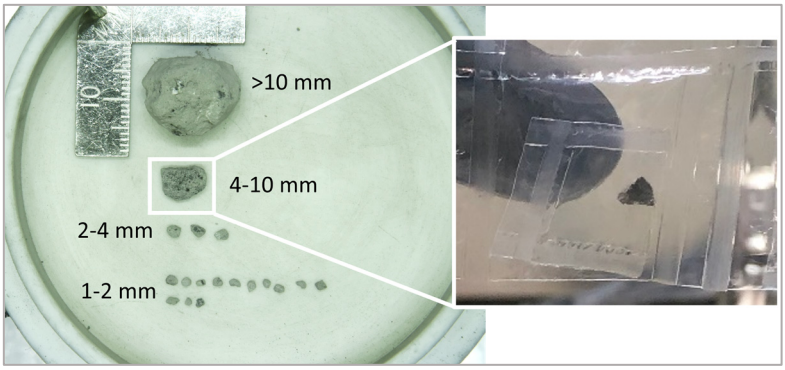

Figure 13: Sieved and sorted >1 mm particles into their respective size fractions on the Teflon cap (left); example of triple bagged 4-10 mm particle (right).

7. Each size fraction from each interval was given a unique subsample number, placed inside individual SS and Teflon containers, and weighed. The weight of each subsample is recorded in the Apollo sample database. The subsamples are in SS racks that are sealed in Teflon Bags and are stored in the nitrogen purged Apollo sample cabinets. An inventory spreadsheet was created that contains the general information of each Pass and each Interval including: (1) depth of the interval within each core; (2) dissection date; and (3) total interval mass [see 3, 20]. In addition, the spreadsheet contains: (1) the weights of each size fraction; (2) the number of particles in each (>1 mm) size fraction; (4) the percent of sample mass per size fraction (Figure 14); (5) the parent number of each size fraction; and (6) the individual information about each particle that was >10 mm (e.g., if XCT scanned, its individual weight, name/number, origin, etc.).

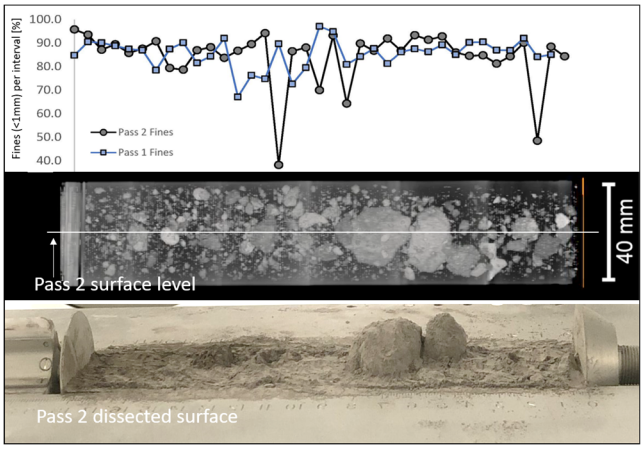

Figure 14: The combination of digital image (bottom), XCT scan (middle), and relative % of fines per interval (top) can reveal important information about clast densities, stratigraphy, and compression within the core (from [20]).

The Excel spreadsheets containing this information can be found in Appendix 2.

8. Detailed photographs and notes were taken to document the dissection process. Variations in core properties were noted and recorded, such as changes in grain size, color, compactness, looseness, friability, clast locations, etc. For 73002 Pass 1, detailed sketches were made for each dissection interval, for later passes in 73002 and 73001 this step was omitted due to time constrains. At the end of each dissection pass the full core was photographed with a colored chart to create a permanent record of each dissected surface and best capture any changes.

   Appendix 3 contains a subset of the images taken during the dissection of core samples 73001 and 73002. Appendix 4 contains the processing notes taken during the dissection of core sample 73002.

9. After dissection was complete, the portion of core remaining in the dissection table (again, about ¼ of the overall core material) was taken to the Apollo thin section laboratory and impregnated with Araldite epoxy under vacuum. After curing for several weeks, the epoxy-impregnated regolith material was removed from the dissection table and a secondary epoxy layer was added to encapsulate the core more fully. The impregnated core was then sawn in half (using ethanol as a lubricant) along the long axis of the core. One of those two halves was further divided into 4-5 cm long potted butts (4 potted butts for 73002; 9 potted butts for 73001). Two sets of continuous standard rectangular thin sections were made down the length of the core for both 73001 and 73002.

(4) Individual particle XCT of 73001 and 73002

Each of the >4 mm particles that were separated and bagged as part of the dissection process for samples 73001 and 73002 (see details in (3) above) were individually scanned by XCT at NASA JSC using a Nikon XTH 320 with a 180 kV W transmission target source. There were 132 particles scanned for 73002 at x-ray energies ranging from 90-155 kV and 18-39 μA and resolutions from 2.8-20.6 μm/voxel. There were 220 particles scanned for 73001 at x-ray energies ranging from 90-145 kV and 33-37 μA and resolutions from 2.8-22.6 μm/voxel.

Table 2: Lithologic Classification of >4 mm particles by XCT

73001				
Lithology	# of particles	% of particles	Mass of particles (g)	% of mass
Agglutinate	1	0.5%	0.112	0.1%
Anorthosite	4	1.8%	0.200	0.2%
Basalt, High-Ti	28	12.7%	6.736	7.6%
Basalt, Low-Ti	3	1.4%	0.216	0.2%
Granulite	2	0.9%	0.194	0.2%
Impact Melt	2	0.9%	1.528	1.7%
Impact Melt Breccia	115	52.3%	50.745	56.9%
Regolith Breccia	64	29.1%	29.360	32.9%
Soil Breccia	1	0.5%	0.086	0.1%
73002				
Lithology	# of particles	% of particles	Mass of particles (g)	% of mass
Agglutinate	6	4.5%	0.143	0.3%
Anorthosite	0	0.0%	0.000	0.0%
Basalt, High-Ti	9	6.8%	1.639	2.9%
Basalt, Low-Ti	4	3.0%	0.291	0.5%
Granulite	0	0.0%	0	0.0%
Impact Melt	5	3.8%	0.247	0.4%
Impact Melt Breccia	42	31.8%	18.732	33.1%
Regolith Breccia	62	47.0%	35.118	62.1%
Soil Breccia	4	3.0%	0.361	0.6%

For each particle: (1) a fly-through video was produced; (2) a description of the main features in the particle was recorded in the data table in Appendix 5; and (3) a preliminary lithologic classification (Figure 15) was determined based on the features observed (also Appendix 5).

The particles of 73002 fall into the following preliminary lithologic categories: agglutinates (n = 6); impact melts (5); impact-melt breccias (42); high-Ti basalts (9); low-Ti basalts (4); regolith breccias (62); soil breccias (2). The particles of 73001 fall into the following preliminary lithologic categories: agglutinates (1); anorthosites (4); granulites (2); impact melts (2); impact melt breccias (115); high-Ti basalts (28); low-Ti basalts (3); regolith breccias (64); and soil breccias (1). In addition to the main lithologic category, an attempt was made to recognize some sub-groups of particles that shared similar characteristics, primarily among the impact-melt breccias (e.g., the poikolitic ilmenite group). Because the lithologic determinations are being determined using only the XCT information, they are: (1) not intended to be the final determination of the lithology of each fragment, but rather serve as a guide for investigators to request particles for follow up analysis; and (2) not intended to be overly specific, placing samples into broad lithologic categories based primarily on suspected mineral abundances, with less weight given to other factors (e.g., texture). See Table 2 for more details about the classifications.

The fly-through video that was produced for each particle are provided in Appendix 6. The descriptions of the particles and the specific analytical conditions for each particle is provided in Appendix 5. See the list of the relative brightness of the phases in section (2) above. The individual TIFF stacks for each particle can be made available by request to the Apollo Sample Curator.

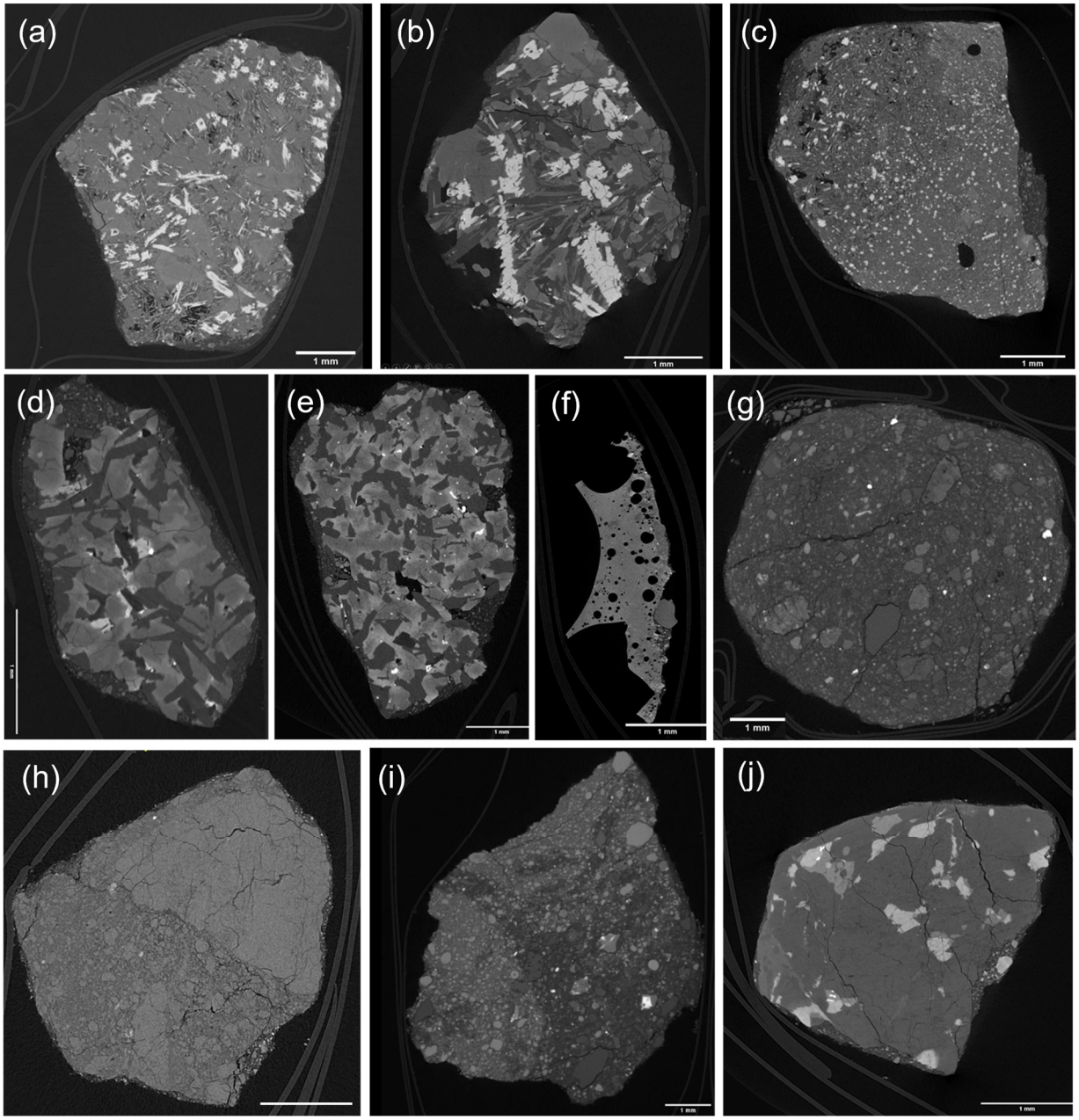

Figure 15: Single slice XCT image views of 10 of the 352 >4 mm particles scanned. (a) high-Ti basalt (b) high-Ti basalt (c) recrystallized high-Ti basalt (d) low-Ti basalt (e) low-Ti basalt (f) agglutinate (g) regolith breccia (h) cataclastic anorthosite (i) regolith breccia dominated by black glass (j) anorthosite. Scale bars are 1 mm.

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