Curation Challenges Associated with the Apollo Next Generation Sample Analysis Program

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Introduction and Overview

From 1969 to 1972, the Apollo missions collected 2196 individual samples of rock and regolith from the Moon (382 kg total mass). Over the past 50 years, there have been over 3300 Apollo sample requests, utilizing >10,000 subsamples from 2190 of the original 2196 samples. These myriad studies have shaped our understanding not only of the Earth-Moon system, but also of the terrestrial planets, airless bodies like asteroids, the formation locations of the gas giants, and have even acted as a record of the radiation history of our solar system as it has revolved around the galaxy for the past 4.6 Ga. Despite all of these studies and all of this knowledge gained, there is still more to be learned from the Apollo samples. To this end, NASA solicited proposals to study unopened or specially curated Apollo samples as part of the Apollo Next Generation Sample Analysis (ANGSA) Program. Prior to the ANGSA program being initiated there were six Apollo samples that had never been opened: (1) unsealed regolith drive tubes 73002 and 70012 (drive tubes are 35 cm long and 4 cm in diameter); (2) vacuum sealed regolith drive tubes 69001 and 73001; (3) vacuum sealed bulk soil sample 15014; and (4) frozen basalt sample 71036. Additionally, there were portions of other Apollo 17 regolith samples that have been stored frozen since shortly after they were returned, as well as a suite of Apollo 15 sealed regolith samples (15012/15013) that were opened, processed, and continuously stored since then in a He-purged environment (all other pristine Apollo samples are stored in N_2-purged environments). These samples were purposefully saved to be opened or studied at a future date where instrumentation had improved enough to give scientists the chance to maximize the scientific return on the samples.

NASA selected nine consortia of scientists to study a subset of the previously unexamined samples. The samples selected were: unsealed drive tube 73002, sealed drive tube 73001 (part of a double drive tube pair with 73002), and a suite of frozen samples including unexamined basalt sample 71036. These samples were selected for a variety of reasons, including: (1) The 73001/2 drive tubes were collected near Lara Crater at Station 3 in the Taurus Littrow Valley, and are spatially associated with both landslides and a fault; (2) the sealed and cold samples have obvious ties to the upcoming Artemis missions; and (3) from a practicality standpoint, having an unsealed core that could be studied immediately (without having to extract the gas) would allow for the program to start more quickly.

Curation Methodology

Each of the samples included in the ANGSA program had their own unique challenges during the curation process. Sample 73002 was the first drive tube sample to be opened in over 25 years. This meant that all of the equipment that was needed for the extrusion and dissection process had to located, cleaned, assembled, and tested (including procurement of replacement parts where needed). Similarly, 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. During the actual dissection process, several non-standard dissection procedures were implemented such as time-sensitive sampling and mm-scale subsampling in the top two intervals (top 1 cm). Multi spectral imaging was performed on the 73002 core [1] during processing, as well as on the 73001 core from outside the cabinet [2], as well as inside the cabinet (after dissection was complete [3]).

After dissection was complete, making continuous core thin sections required that the entire core vacuum impregnation and curing devices had to be rebuilt. Additionally, a Keyance automated petrographic microscope was used to map all eight of the 73002 continuous core thin sections at a resolution of a few microns per pixel (and will similarly be used when the 16 of the 73001 sections are complete). These maps were provided to the ANGSA science teams to serve as base maps for the electron- and ion-beam work that would come later.

With sample 73001, the most obvious hurdles were related to how to get the gas out of the outer vacuum container (OVC) and Core Sample Vacuum Container (CSVC) prior to opening the samples. This involved building two bespoke pieces of hardware, a gas-extraction manifold built at Washington University in St. Louis [4] and a piercing tool built at ESA [5], as well as the actual assembly, integration, and operation of this equipment within the materials constrained environment of the JSC clean rooms.

The ability to process frozen samples at -20°C was not a capability that existed at JSC prior to ANGSA, and an existing Apollo glovebox had to be retrofit to work at those temperatures. Significant facility modifications to the walk-in freezer in the JSC Experimental Impact Lab to make it material and environmentally compliant with processing of Apollo samples was also required [6]. Similarly, the procedures for how to process the samples under these extreme conditions had to be developed and implemented [7].

This was the first time that X-ray Computed Tomography (XCT) was used as part of the curation process for drive tube dissection. Whole-core scans were made of both 73002 and 73001 prior to extrusion and dissection at the University of Texas High-Resolution X-ray Computed Tomography (UTCT) Facility for high-resolution scanning (Figure 1). Both of these scans had unique challenges that were overcome to give excellent data sets that proved invaluable to both the curation and mission science teams [8]. Over 350 particles in the 4-10 mm and >10 mm size particle size fractions were separated during dissection, individually bagged in Teflon (3 bags), and scanned by XCT at NASA JSC [9]. These scans allowed for the identification of different lithologies within the particles (Figure 1), which greatly helped with the request and allocation process [10].

Summary
The ANGSA program was designed to help us prepare for the upcoming Artemis missions, while at the same time getting important new scientific results from the Apollo samples. Each of the samples included in the ANGSA program had their own unique challenges related to the curation process, and the work on this program has greatly enhanced our readiness for the next batch(es) of lunar samples to come back.

References

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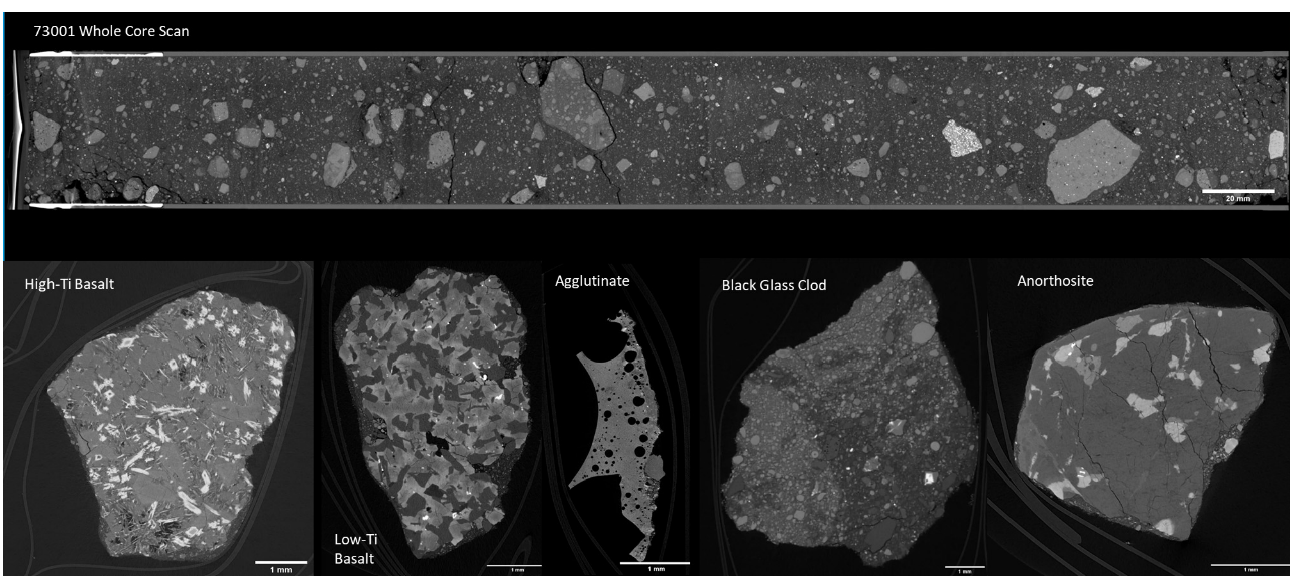

Figure 1. X-ray Computed tomography images of the entire 35 cm long 73001 core (top image), as well as individual soil particles sieved from the 73001 and 73002 cores representing a variety of lithologies observed.