ANGSA* INITIATIVE. LESSONS LEARNED FOR FUTURE LUNAR EXPLORATION 2019-2021

ANGSA Science and Engineering Team
NASA Johnson Space Center Curation Team

** Apollo Next Generation Sample Analysis*

linking generations of lunar explorers from Apollo to Artemis

ANGSA Lessons Learned

This document covers lessons learned from the first two years (2019-2021) of the ANGSA initiative.

The pandemic did affect the ANGSA timetable and budgets at multiple levels.

The lesson learned document is a team perspective that identifies ANGSA activities and actions that worked well and should be repeated in the future, possible improvements to ANGSA-like initiatives at a variety of levels, and suggestions for mission planning, curation and analyses for future lunar sample return missions.

We anticipate a second lessons learned document following the completion of the ANGSA initiative (2021-2023.

Overview of ANGSA

ANGSA initiative designed to function as a low-cost sample return mission.

Fulfills science goals from the Apollo program.

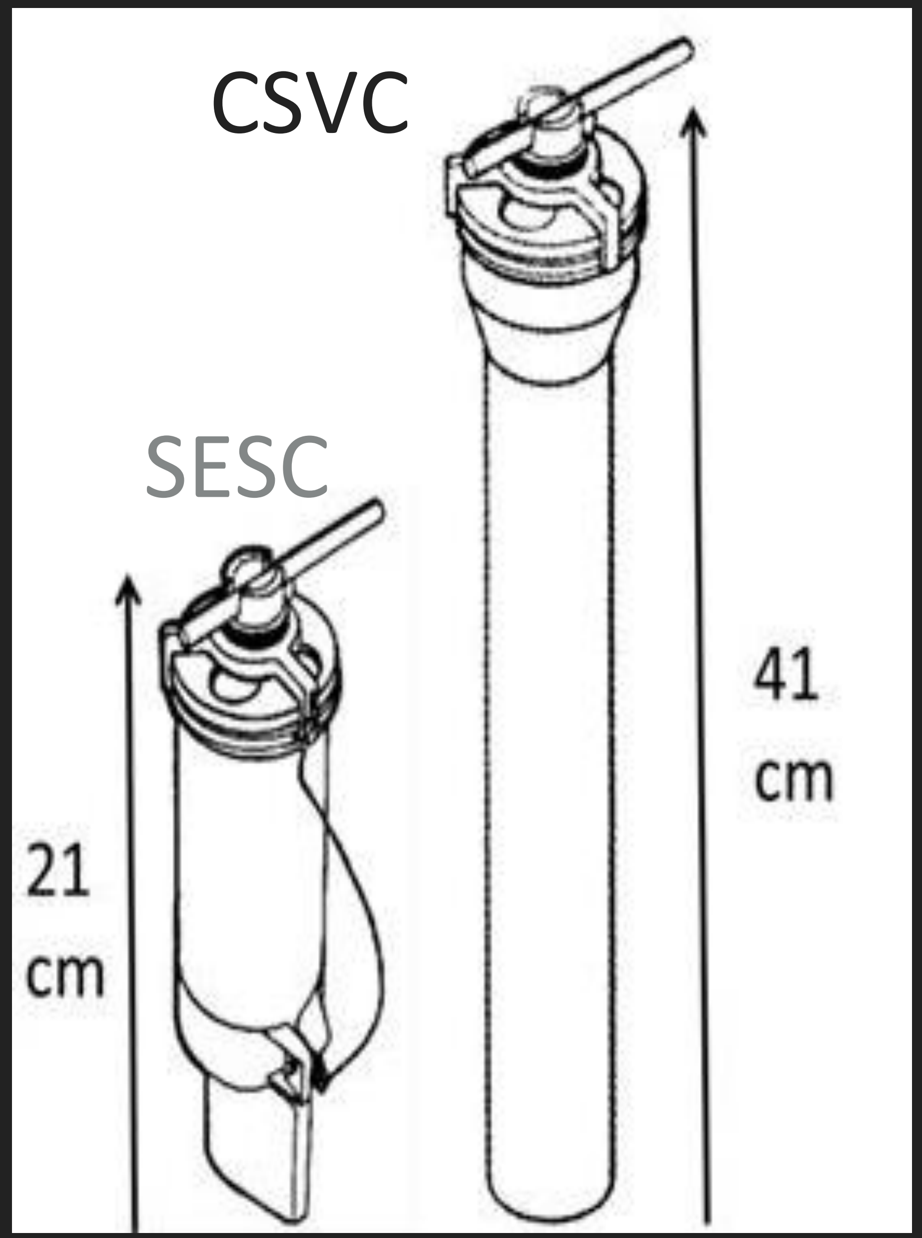
Examines “new Apollo samples” leveraging 50 years of post-Apollo science and new analytical technologies.

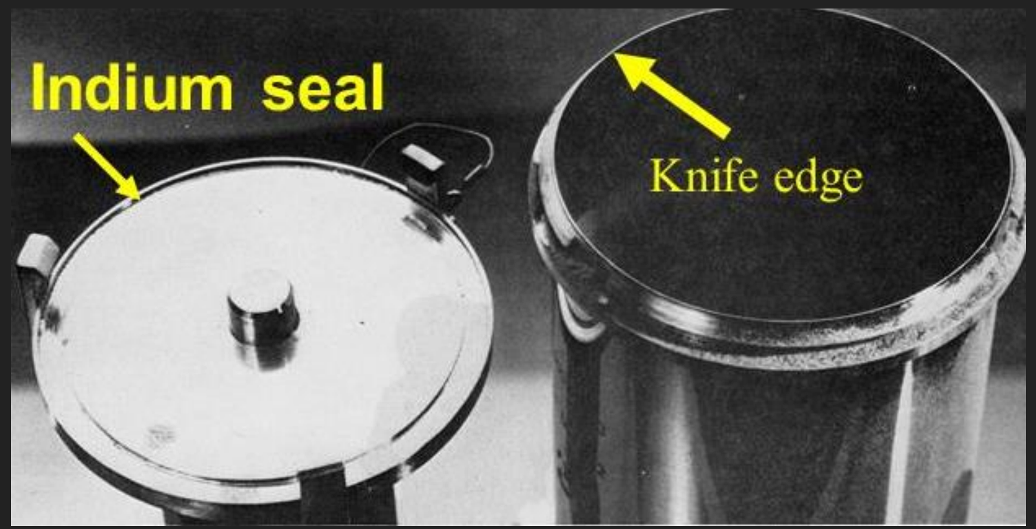
Provides a link between Apollo and Artemis Generations of Lunar Explorers.

COVID-19 did effect sample allocation and lab availability at JSC and analytical lab access at research institutions..

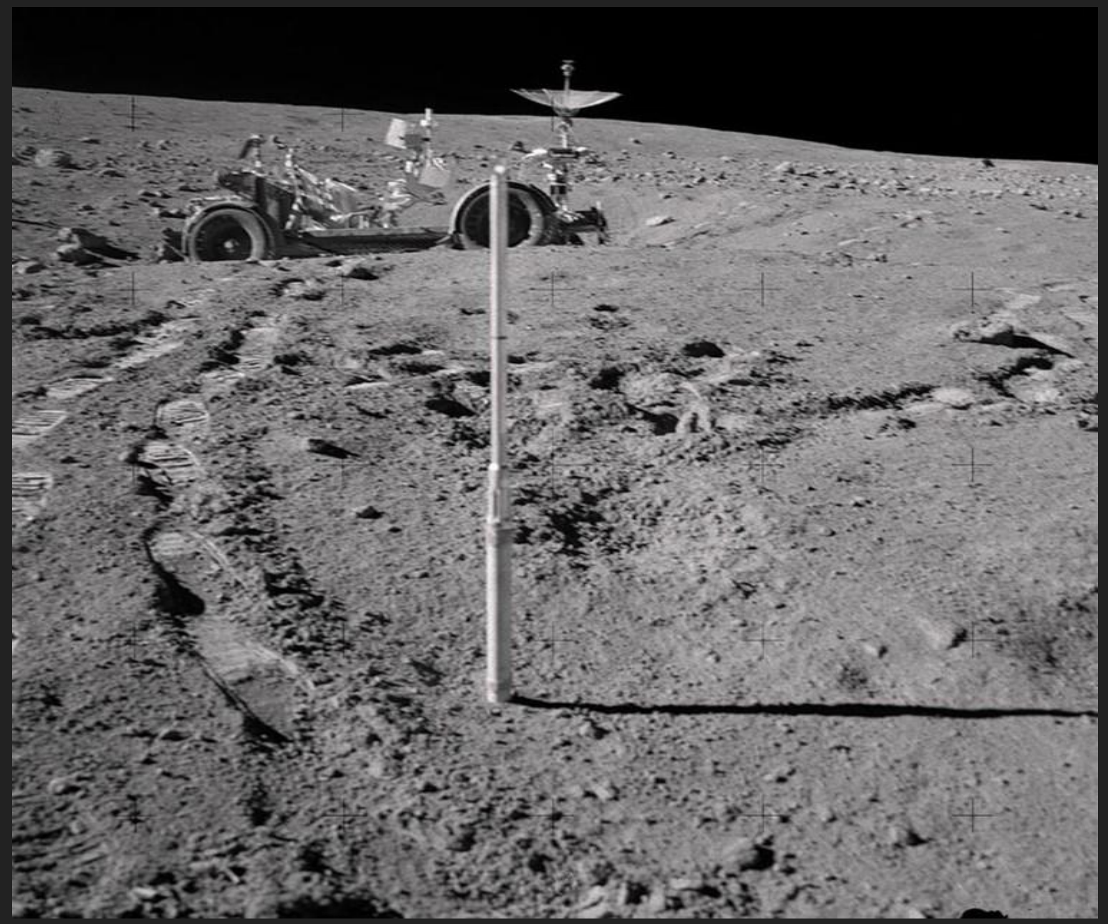
Updates at ANGSA website: *https://www.lpi.usra.edu/ANGSA/*

ANGSA Targets: Specially Collected and Curated Lunar Samples

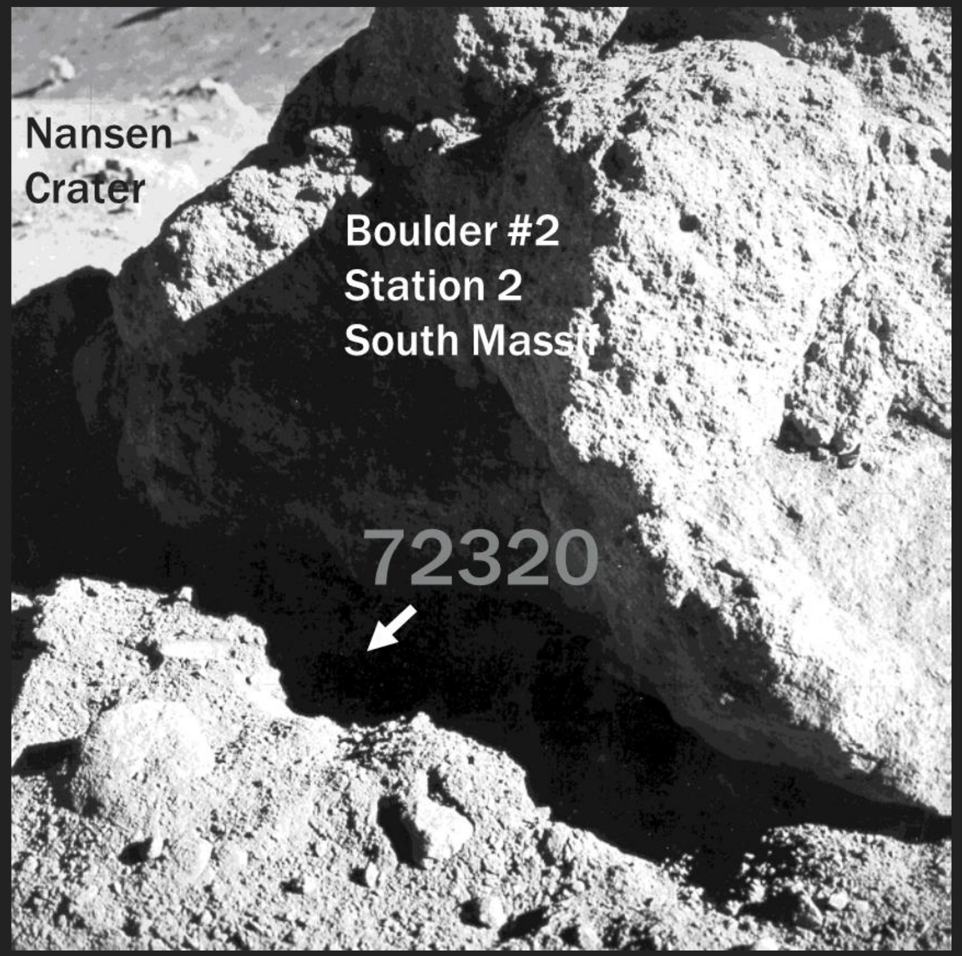


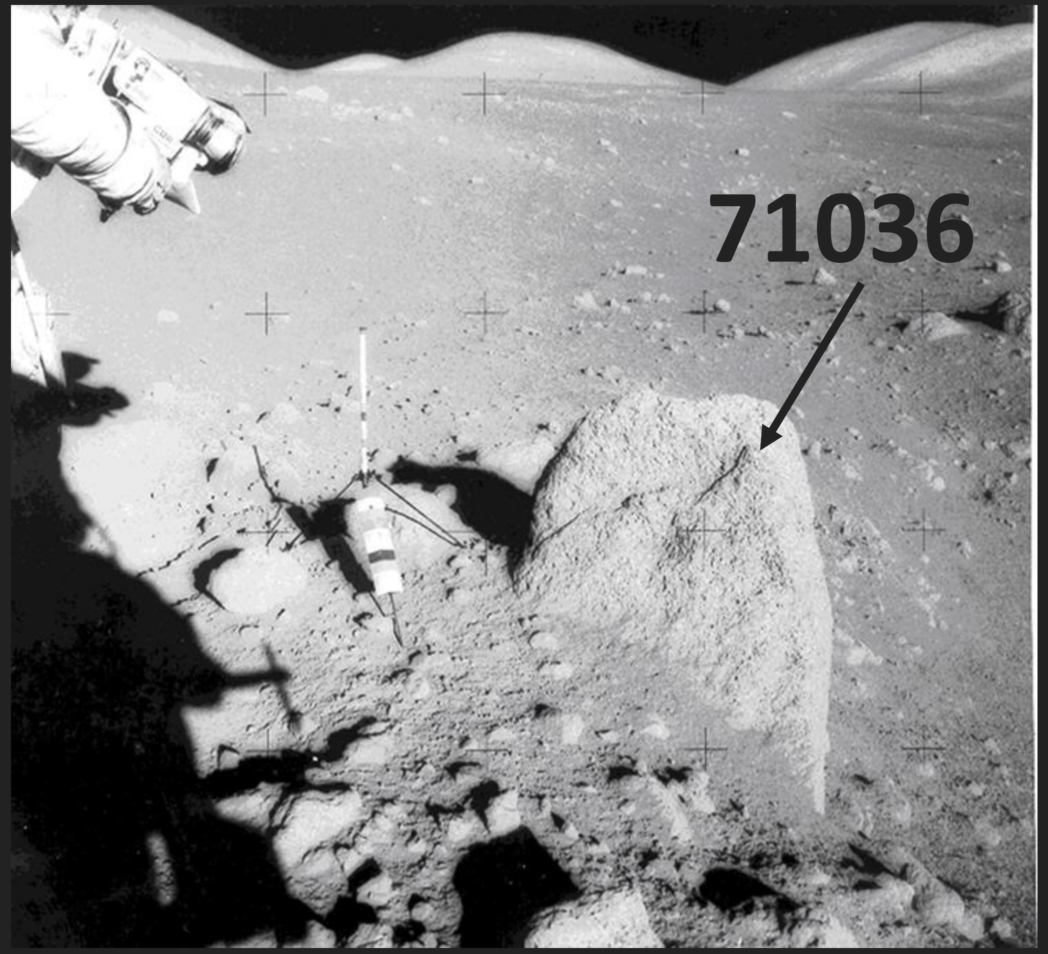


Unopened Vacuum Sealed Apollo Samples: 3 of 9 “special samples” remain sealed: SESC 15014 (333 g), CSVC 69001 (558 g), and CSVC 73001 (809 g).



Unopened Unsealed Drive Tubes: 2 unopened, unsealed drive tubes: 73002 (430 g) and 70012 (485 g)





Frozen Apollo Samples: 6 subsamples of A17 drill core 70001,5-70006,5, 9 subsamples of permanently shadowed soils 72320 and 76240, soil 70180, and vesicular high-Ti basalt 71036.

Sample Team 1

ANGSA

Designed to function as a low-cost sample return mission.

Nine teams were selected through review of individual proposals submitted to the ANGSA program.

Nine teams were combined and organized as a single multi-generational and international Science-Engineering Team with a well-defined leadership structure. This approach was important in that (a) Provided a multi-generation link between the Apollo generation and future generations. (b) Trained many members in mission planning and curation activities in preparation for Artemis.

Teleconferences were held for various subsets of team members: (a) Team PIs, (b) Complete ANGSA science, curation and engineering team members, (c) various subcommittees (e.g., gas extraction and organics subcommittees), (d) Individual funded teams (e.g., nine funded teams). This helped to coordinate sample allocation and measurement activities, and to exchange data and ideas.

Sample Team 2

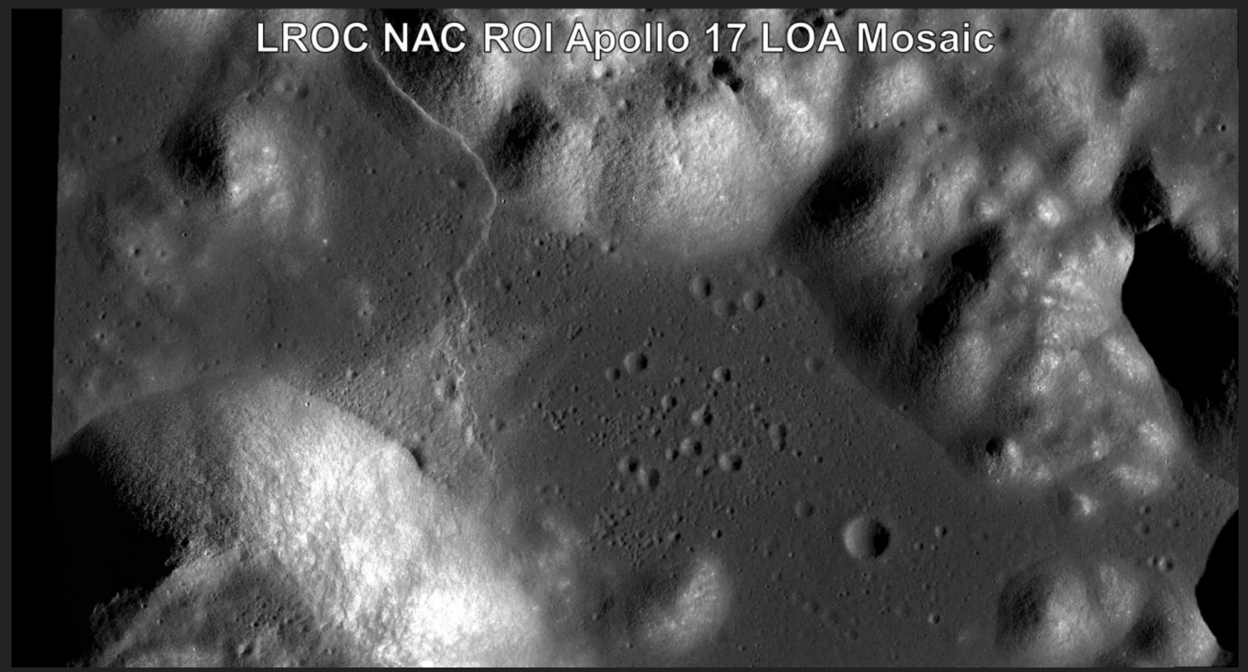
<u>ANGSA</u>

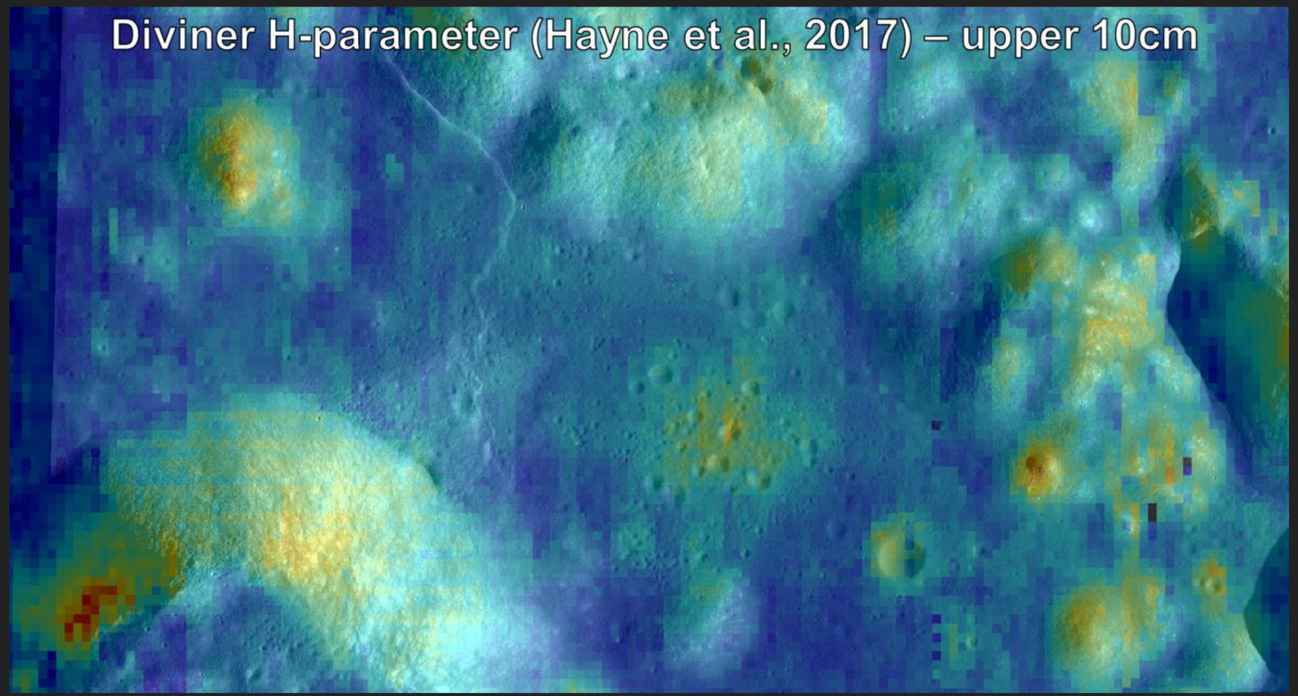
Team influence on ANGSA curation protocols and tool design occurred during the 3 year funding cycle.

The Lunar and Planetary Institute (LPI) provided office space, meeting space, and technical support for ANGSA team activities.

Sample Team 3

Lessons Learned





Science team(s) should be organized early with two step funding (e.g., initially funded at lower level approximately 2 years before the samples are opened) to support planning (e.g., sampling and curation tools, curation strategy and protocol). This would allow science funding and sample allocation to be better coordinated.

The sample analysis teams should have a diversity of disciplines, beyond petrology and geochemistry, to include remote sensing and spectroscopy, engineering, geomorphology and mapping expertise. This integration of expertise will enable samples to be placed within a planetary and technology context.

Interactive team science, data/sample sharing, and publications should be guided by a Rules of the Road document and coordinated by team meetings at various levels.

Sample Team 4

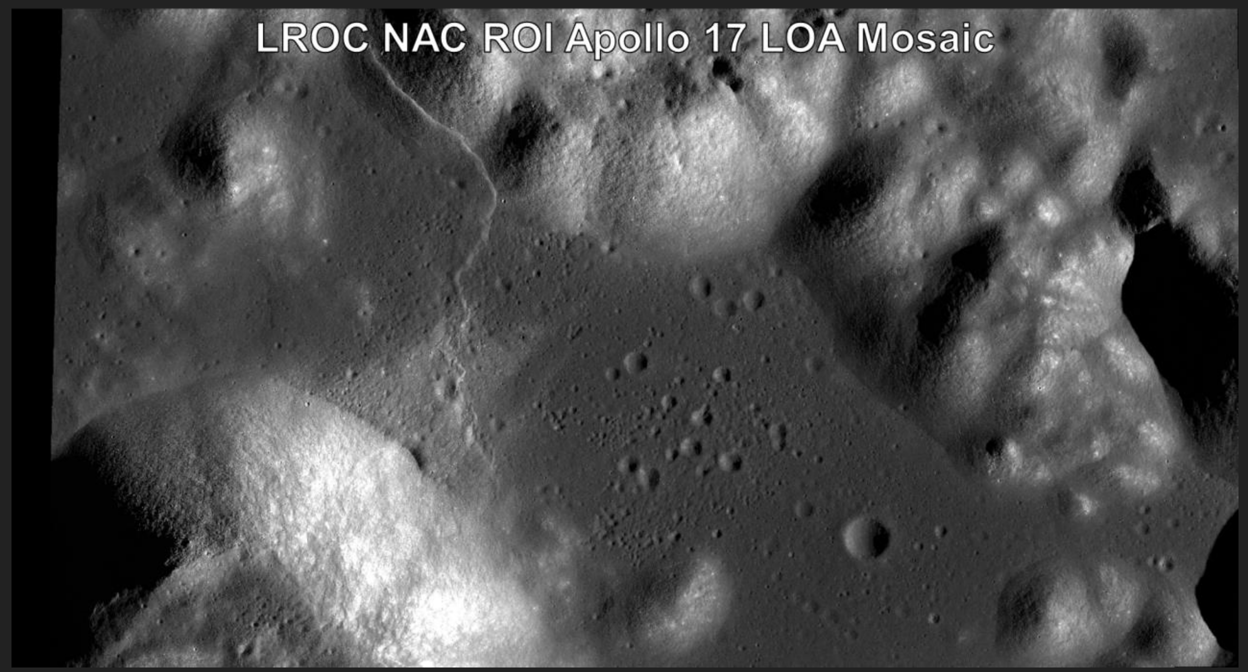
Lessons Learned

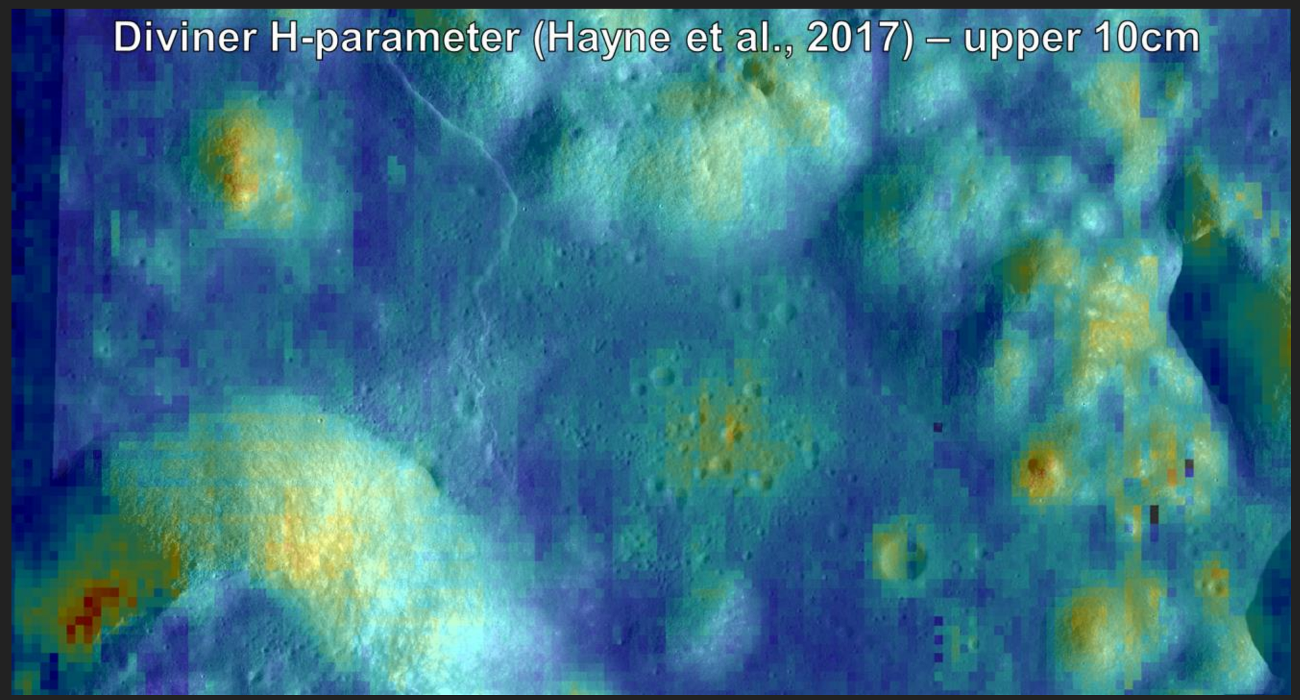
Science team should play an integral part in Preliminary Examination (also see curation).

After team selection, identify other potential measurements that are critical to mission success. Add appropriate team members through a participating scientist program.

Early selection of science team members to be involved in both team website and PE documents.

LPI support critical to ANGSA success. Therefore, use LPI or similar organization as part of the infrastructure to support lunar sample return activities.





Curation 1

ANGSA

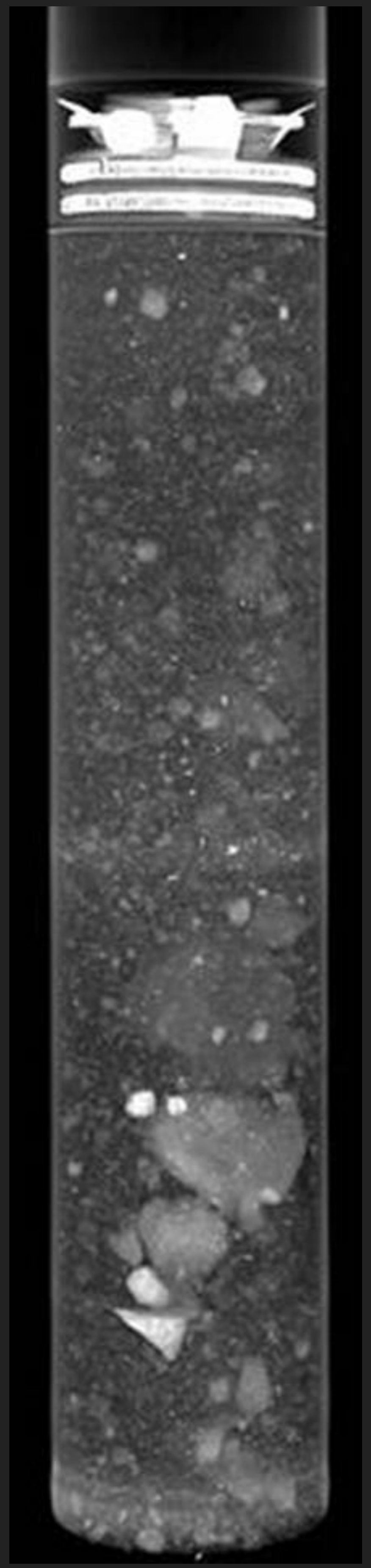
ANGSA enabled by the overarching philosophy of preserving samples for future generations.

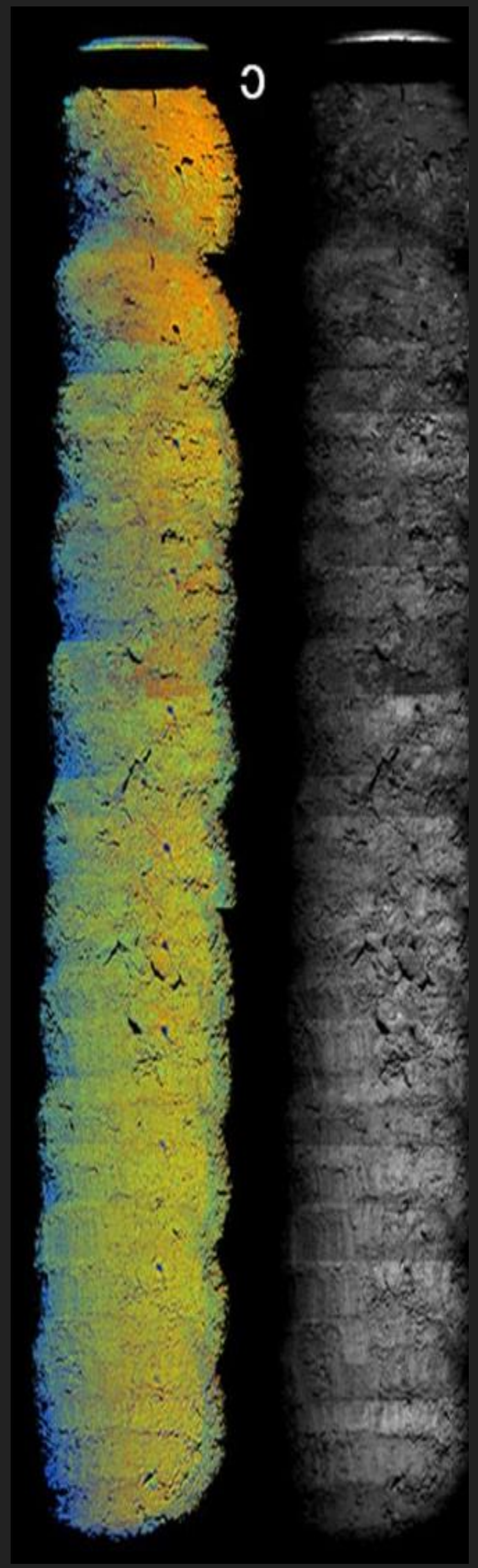
Multiple types of curation environments are being used (Nitrogen glove box, cold curation (-20° C)).

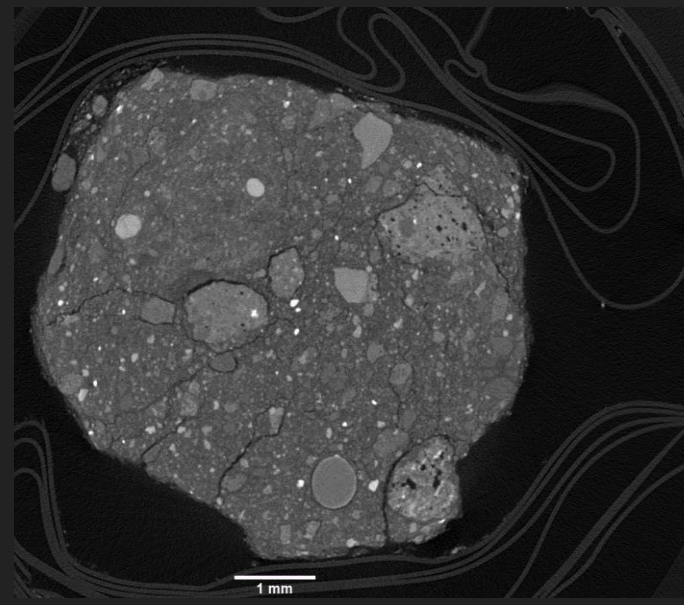
Any team influence on ANGSA curation protocols and tool design occurred during the 3-year funding cycle.

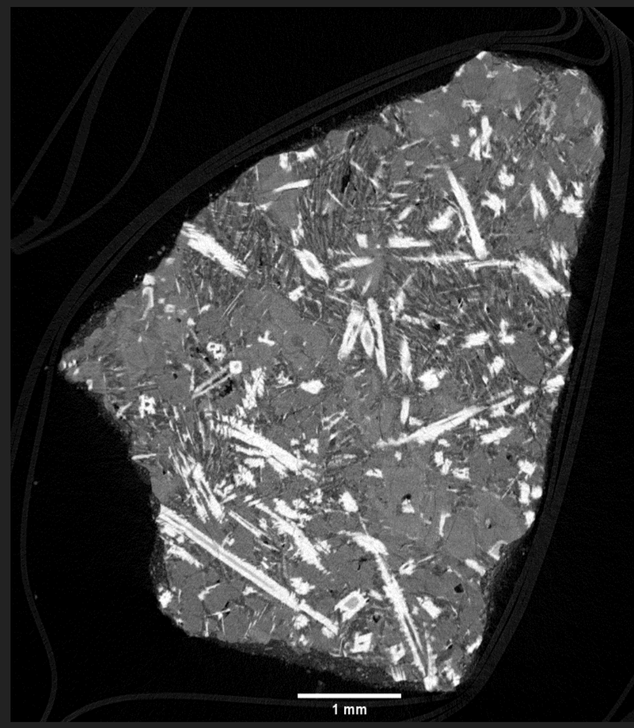
A variety of tools and instruments were used during curation that helped development of a dissection strategy and enabled science. These included X-ray computed tomography (XCT) imaging of core and individual fragments and multispectral imaging of core.

XCT data allowed examination of clasts during COVID shutdowns (i.e., enabled remote science).









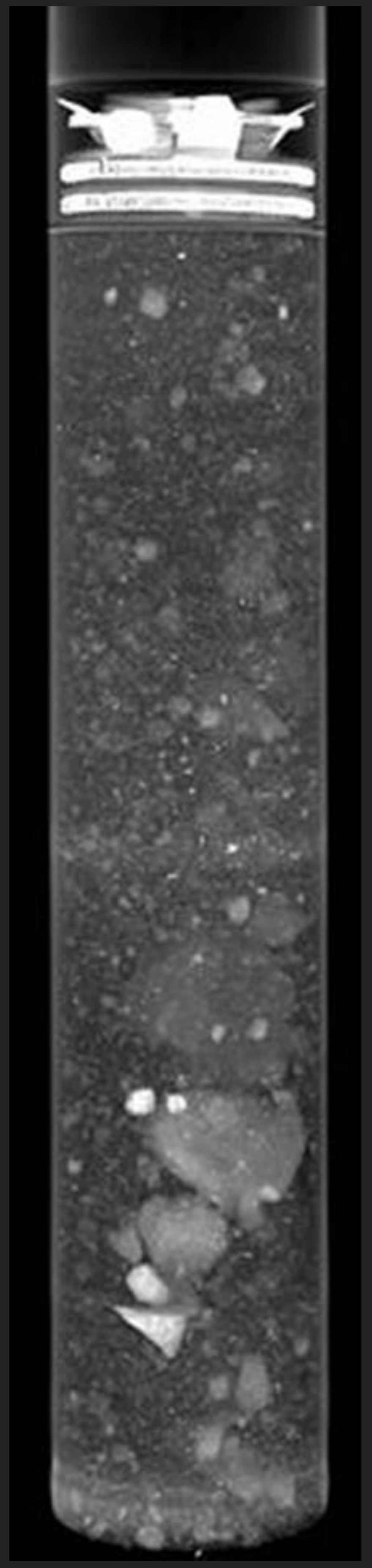
Curation 2

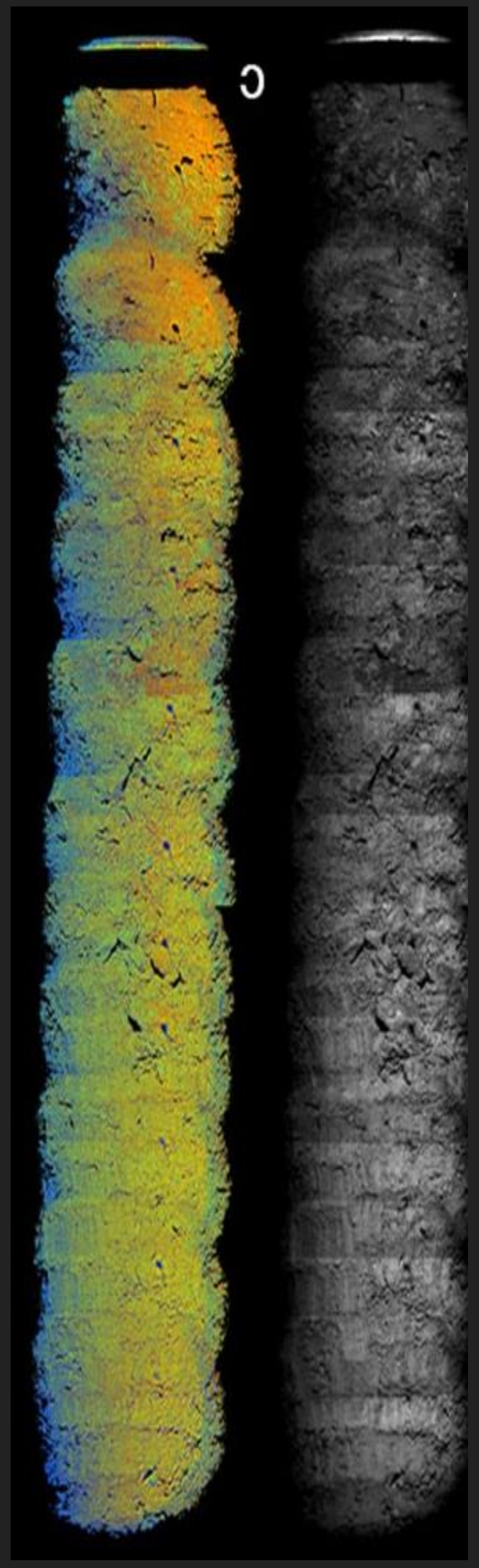
ANGSA

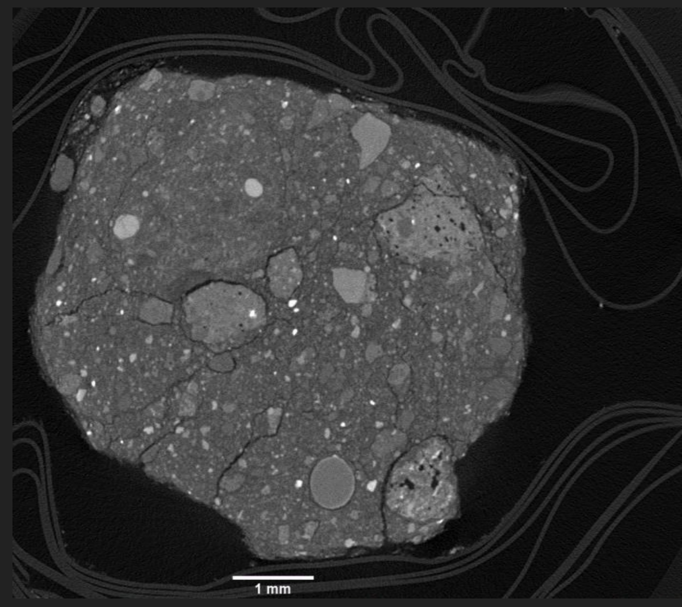
An overarching philosophy taken for curation, sample preparation, and allocation was to do no harm to the samples that would affect current and future studies. However, this approach was difficult to follow in some cases. For example, XCT analyses that were carried out for the benefit to most science and curation activities could compromise a smaller set of analyses (e.g., thermal luminescence). On the other hand, processing samples in order to do no harm potentially complicated some important science (e.g., gained through heating CSVC to 90°C or ultrasonic vibration of CSVC to extract volatiles), as other important proposed measurements would have been compromised by these extraction methods.

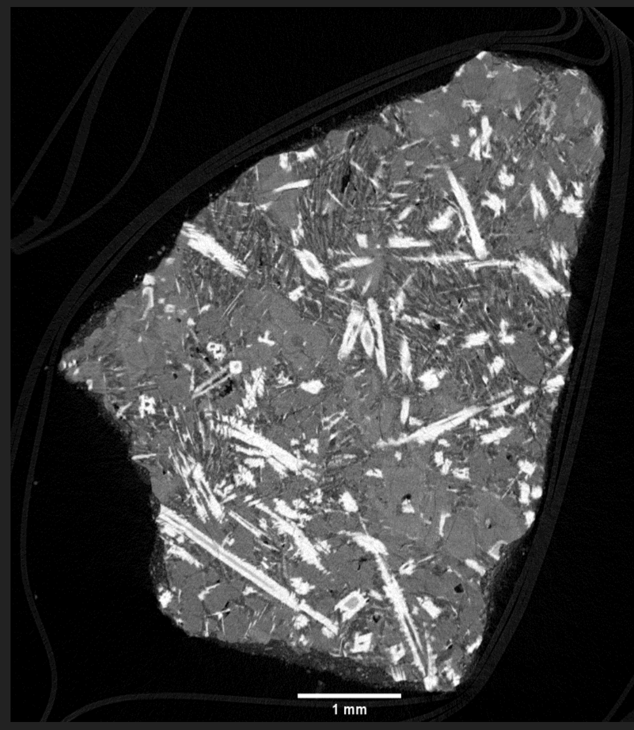
A curation-storage plan for CSVC extracted gas was not considered. It was anticipated that all gases would be analyzed during ANGSA activities.

In preparing to design and build tools for opening and sampling the CSVC, it was critical to have access to highly accurate schematics and physical duplicates of flight hardware.







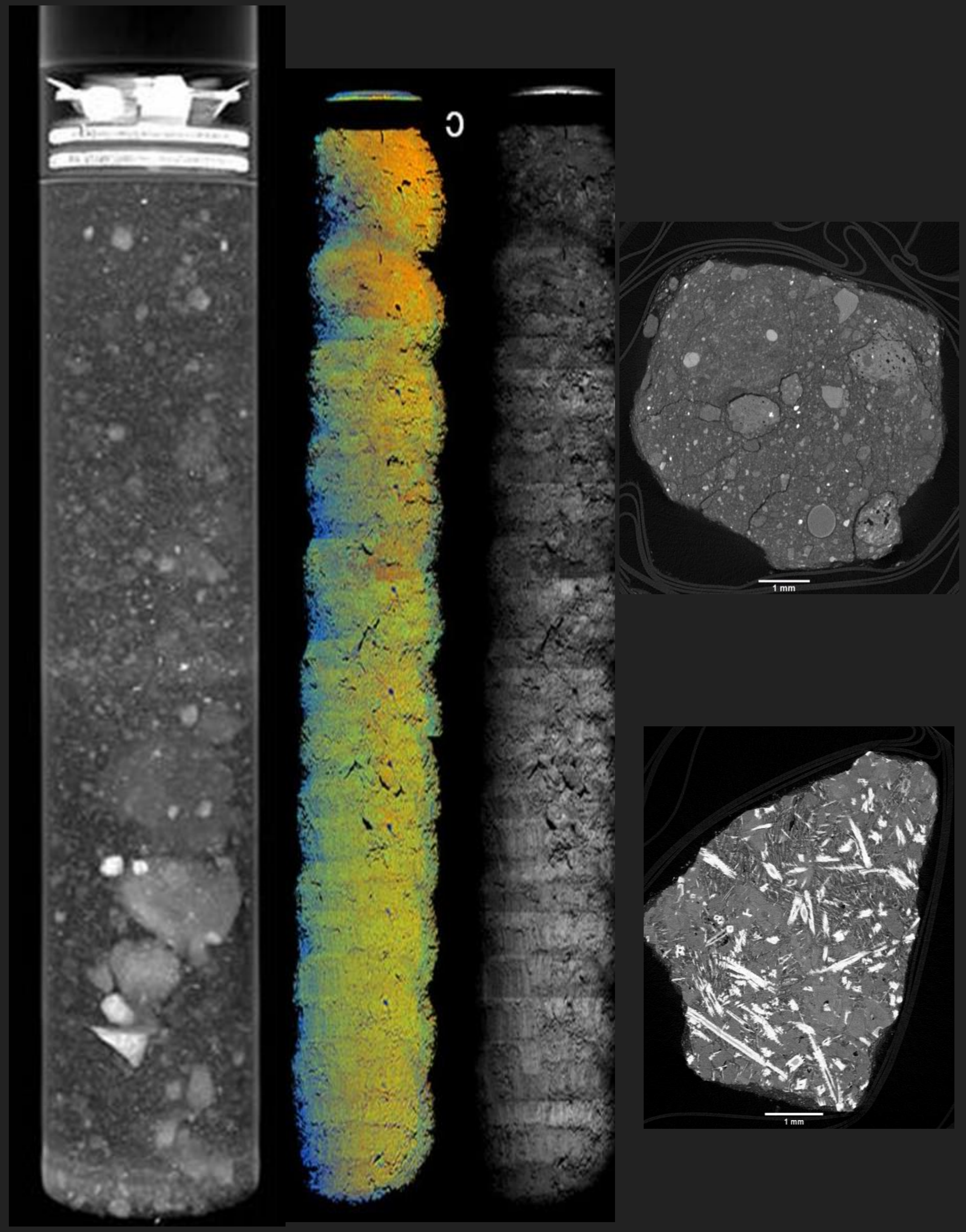


Curation 3

Lessons Learned

Preserve samples for future generations of planetary scientists as analytical approaches and science questions will constantly evolve.

Early definition of mission goals will influence the curation facilities and protocols (organic contamination, cold curation requirements, glove box gases and gas quality).



Early definition of mission goals and selection of science team will influence tools designed, built and used during curation (new tools for handling frozen or gas samples).

Early training and cross-training of curation staff is critical. This training needs to start early and be closely linked to potential samples and mission science.

Curation team staffing and curatorial processes should be streamlined well before sample return especially for “unique” sample types.

Curation 4

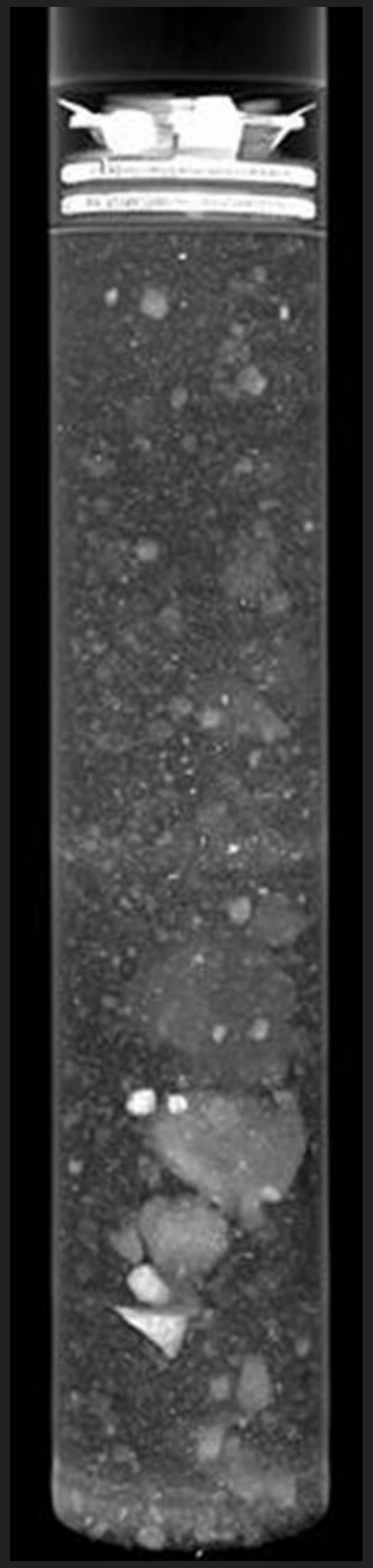
Lessons Learned

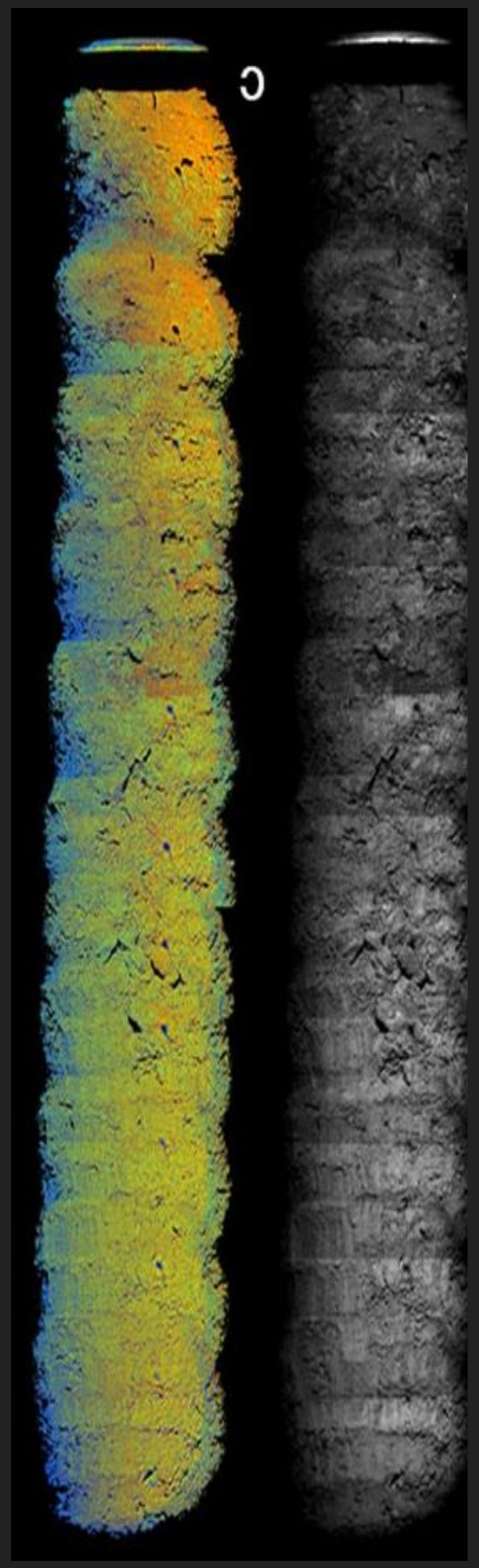
New curation tools (e.g., XCT, multi-spectral imaging) are a benefit to curation strategy. There are several examples of this benefit to core dissection. XCT analysis identified locations of many lithic fragments in the core. Multi-spectral analysis identified a diagonal change to core stratigraphy.

Witness plates should be used to identify and reduce contamination (e.g., organics, volatile elements).

During the dissection of the 73001 core, it was advantageous to have a single processer dissecting the core with several processors assisting in this activity. However, with multiple types of samples (core, frozen, gas, rocks) being returned processing can be handled by multiple processors. This would reduce sample processing time.

Gas sampling dilemma faced during ANGSA opening of the CSVC 73001, could be avoided in the future by defining the science associated with each sealed sample container and designing not only the container, but also the sampling strategy, allocation and longer-term preservation.





Curation 5

Lessons Learned

Sealed samples should have a valve or valve port that eases volatile sampling on Earth during curation activities, but does not hinder lunar surface operations by astronauts. Test hardware prior to flight.

Dust is detrimental to the proper operation of seals and valves. All designs and testing should consider this factor.

Coordination/collaboration between ANGSA gas extraction team and Artemis curation to ensure lessons learned from ANGSA are incorporated into Artemis curatorial procedures.

High accuracy digital twins of flight hardware, including how flight hardware interface with each other (e.g. drive tube position within the CSVC based on spider spring strength and condition was not known)

Physical duplicate of flight hardware including outer components/lids etc. (e.g. similar to the drive tube flight spare, which also provided valuable information regarding the extraction approach)

Additional research and curation of hardware components to learn more about degradation during flight and with time (e.g. degradation of Teflon cap elasticity and plasticity; degradation of CSVC ductility at weld seams).

Preliminary Examination of Samples 1

ANGSA

Designed to function as a low-cost sample return mission that included the science team to be involved in the Preliminary Examination.

The Preliminary Examination Team was organized as a multi-generational and international Science-Engineering Team with a well-defined leadership structure.

During the Pass 1 PET activities, team members participated in PE for one week at a time.

Each week PET members were trained during the first day of the PE and review of PE observations were made during the last day of the week.

Preliminary Examination of Samples 2

ANGSA

PE activities were slower with PET members involvement but such visits are important for training the next generation of scientists and engineers.

PET activities (7002) were sharply curtailed from early 2020 through early 2021 due to COVID-19 protocols.

Team influence on ANGSA Preliminary Examination protocols and tool design occurred during 3 year funding cycle. Tools constructed for PE and allocation during ANGSA activities are illustrated in Appendix 1.

Preliminary Examination of Samples 3

Lessons Learned

A well-define set of preliminary examination data that will be readily available to science team and science community will increase scientific return and efficient use of samples. Some of the following questions need to be reevaluated: How quickly and fully should this PE data be released to the research teams? When should PE be released to the world?

Analytical facilities at the Johnson Space Center are important for PE being carried out by team scientists and curation. They should be integrated into missions and funded appropriately.

A variety of imaging (XCT, multi-spectral) is needed during PE.

PE and sample science will need to overlap to some degree.

Preliminary Examination of Samples 4

Lessons Learned

Some sample measurements may be time-sensitive and will need to be released early to science community or utilize new technologies that will prevent terrestrial effects (atmosphere, temperature).

Although the integration of science team into preliminary examination activities increases the duration of this activity, it is scientifically additive. Perhaps having longer cycles for science team members to be involved in curation PE activities would increase efficiency of PE and increase the science benefit.

Sample Allocation 1

ANGSA

Samples were allocated in year 2 of many team budgets.

Samples were made available to the funded ANGSA teams. Samples will be available to the rest of the science community at a set time after ANGSA teams started their work.

Samples for organics and hydrogen isotopes allocated soon after extrusion of sample.

Samples were allocated for preliminary examination and science purposes nearly simultaneously.

Early dissection and allocation of samples for science were not always based on PE documentation.

Sample Allocation 2

<u>ANGSA</u>

Sample containers are being developed for the transport of sample materials from a clean curation environment to high-vacuum instruments without terrestrial contamination.

There were several potential approaches for sampling and allocating potential gases from the CSVC. These included sampling at room temperature, warming the CSVC to 90°C, and ultrasonic vibration of the core. The dilemma was that sampling by any of these approaches could affect other science to varying degrees. The selection was based on what approach effected the sample the least. However, important science was potentially lost with this choice.

Sample Allocation 3

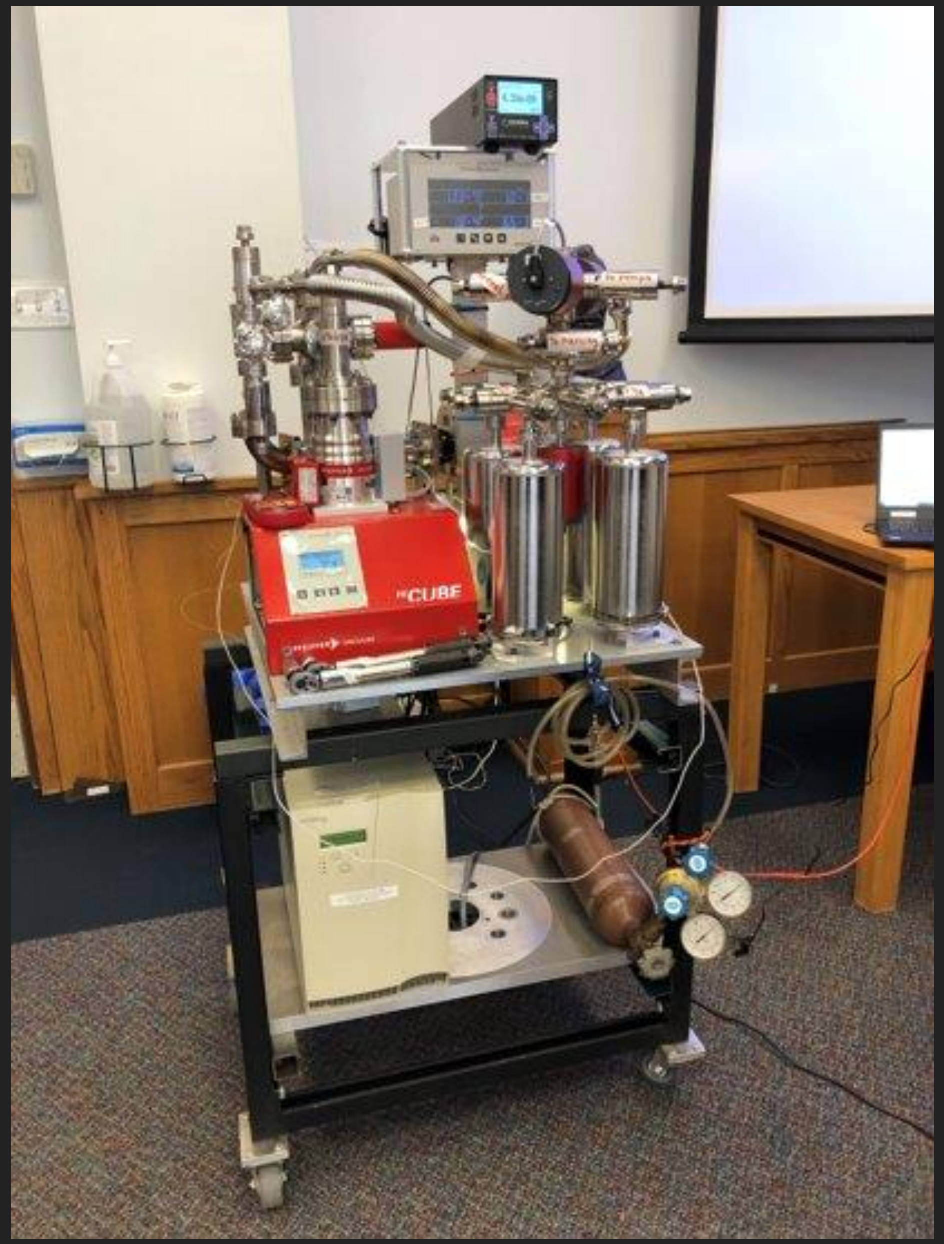
Lessons Learned

New curation tools (e.g., X-ray computed tomography (XCT), multi-spectral imaging) will benefit allocation.

Particular sample measurements may be time sensitive and will need to be allocated early to science community. These measurements will need to be defined early.

An examination of potential containment vessels for terrestrial transportation should be made within the context of science goals.

Gas sampling dilemma faced during ANGSA opening of the CSVC 73001, could be resolved in the future by defining the science associated with each sealed sample container and designing not only the container, but also the sampling strategy, allocation, and curation.



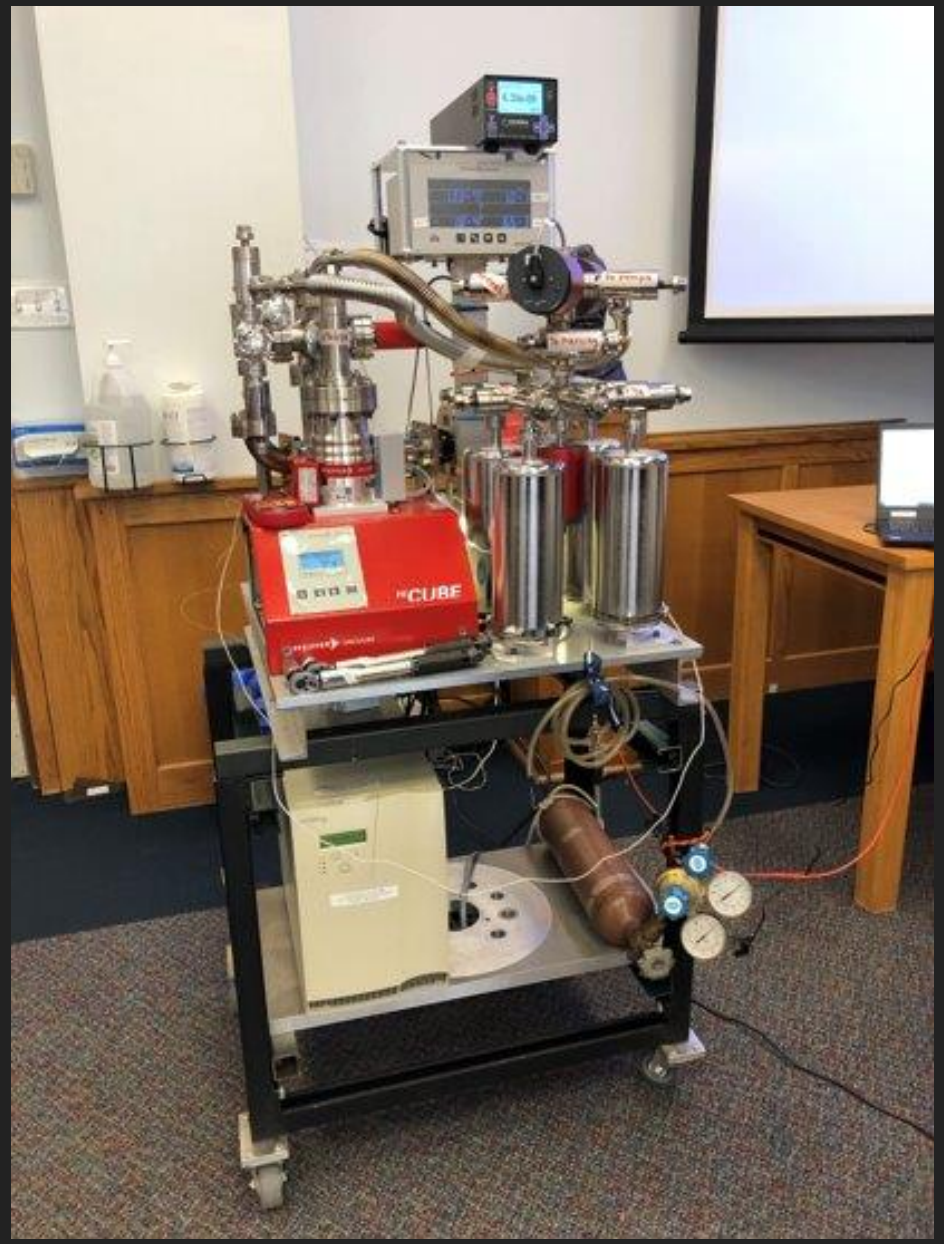
Sample Allocation 4

Lessons Learned

Imaging data such as XCT will enables science to be done during sample processing. However, the data must be disseminated in a timely and equitable manner.

Allocation of samples need to be better coordinated with preliminary examination documents. Therefore, the PE observations need to be done in a timely manner.

There is a perception by members of the community that the distribution of samples may have caused friction in the community during both Apollo and ANGSA. Therefore, NASA needs to clearly define how samples will be analyzed starting with PE, and what/when opportunities will be available to the community in the years/decades to come. The allocation of samples need to occur in a fair and transparent manner. Previous, community allocation committees such as LESAP, CAPTEM had a record for fairness.



Enabling Science 1

ANGSA

Linking orbital and surface observations placed ANGSA within a well-defined science context and added value to the sample suite.

With ANGSA prohibited from applying to NASA for COVID-19 funding , graduate student and post-doc pay will run out before the PE and science investigations can be completed as 6-8 months of inactivity due to the pandemic still required these people to be paid.

Several types of measurements that are late in the analytical campaign (e.g., chronology) are highly dependent upon detailed PE and earlier science measurements. Therefore, the delay in these earlier observations resulted in a delay of these types of measurements.

There is a certain amount of uncertainty associated with the types of samples encountered in the core. For example, are the lithic fragments in the Station 3 core appropriate for chronology and associated science?

In many cases, sample analysis flow charts were constructed by analysis teams. This approach enables coordination among science team members and conserved samples. Examples are shown in Appendix 2. However, flow charts for sample allocations and analysis were not constructed by all teams and among teams.

Enabling Science 2

Lessons Learned

Funding flexibility must be found in anticipation of other unforeseen national-international events.

Local, regional, and planetary geologic context increases the science value of samples. Therefore, it is valuable to have science backroom teams for specific landing sites and missions. Further, defining sample context measurements through payload/in-situ measurements would enable/enhance the science value of the returned samples. It is important to understand the duration and complexity of surface context measurements and their influence on surface activities.

Identify pathways for accessing early documentation of samples to enable measurements late in the analytical campaign. For example, provide early XCT analyses of samples of interest to these types of measurements.

Sample science success for missions can be enabled through (a) defining science and appropriate samples prior to missions and (b) realizing that not all samples may be appropriate to answer mission objectives but still may reveal important unanticipated results. For (a) it is important to have sample scientists engaged in mission planning. For (b) not all future science objectives can be anticipated before the constituents of the sample cache are known and therefore flexibility in team measurements and objectives is required. Potentially add science members and analytical approaches through a participating scientist program.

Enabling Science 3

Lessons Learned

Coordination of sample allocation and analysis provides a more efficient use of samples and links team science activities. However, it must be recognized that not all samples are appropriate for coordinated teaming activities or that all science activities are linked.

For training and utilizing Apollo samples in a consortium fashion it is important to undertake a continuous series of ANGSA efforts to "return to the Moon" through Apollo. Such an approach could be continued using SSERVI nodes. However, this would put additional pressure on JSC lunar sample curation.

Make it easier for the exchange of students among participating analytical facilities.

Cross-generational teams helped to transfer knowledge in all directions.

Activities during future pandemics 1

ANGSA

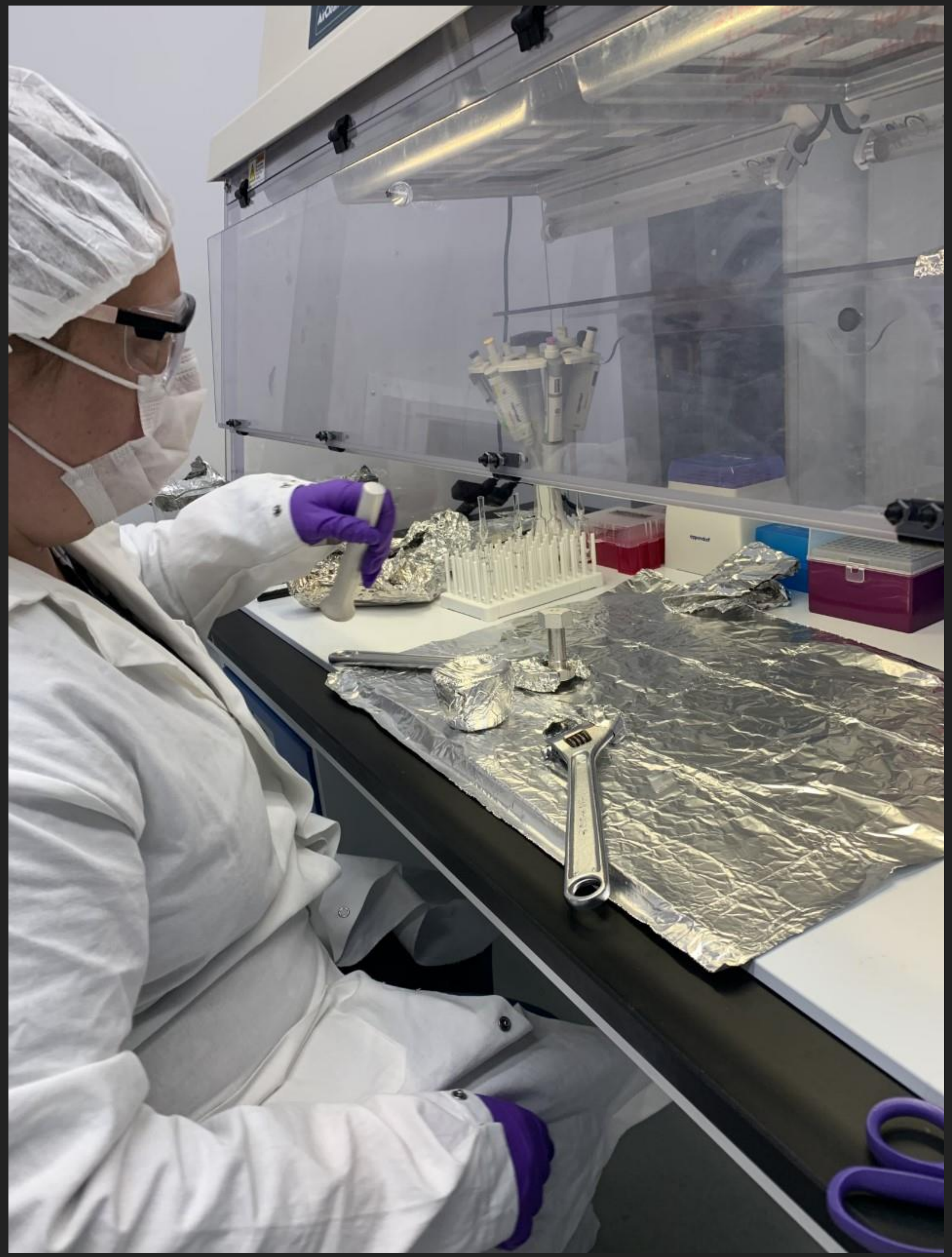
Science team engagement during a pandemic was maintained through appropriate, regular status meetings, discussion of data in hand (XCT data), and geologic context.

Due to institutional requirements or student-staff commitments, research funds were spent during early stages of ANGSA prior to samples being released.

ANGSA activities were given high priority during the pandemic at JSC and NASA HQ.

During the pandemic science team access to JSC curation for sample selection or secondary processing (e.g., selecting volcanic glasses) ranged from minimized to eliminated.

Activities during future pandemics 2

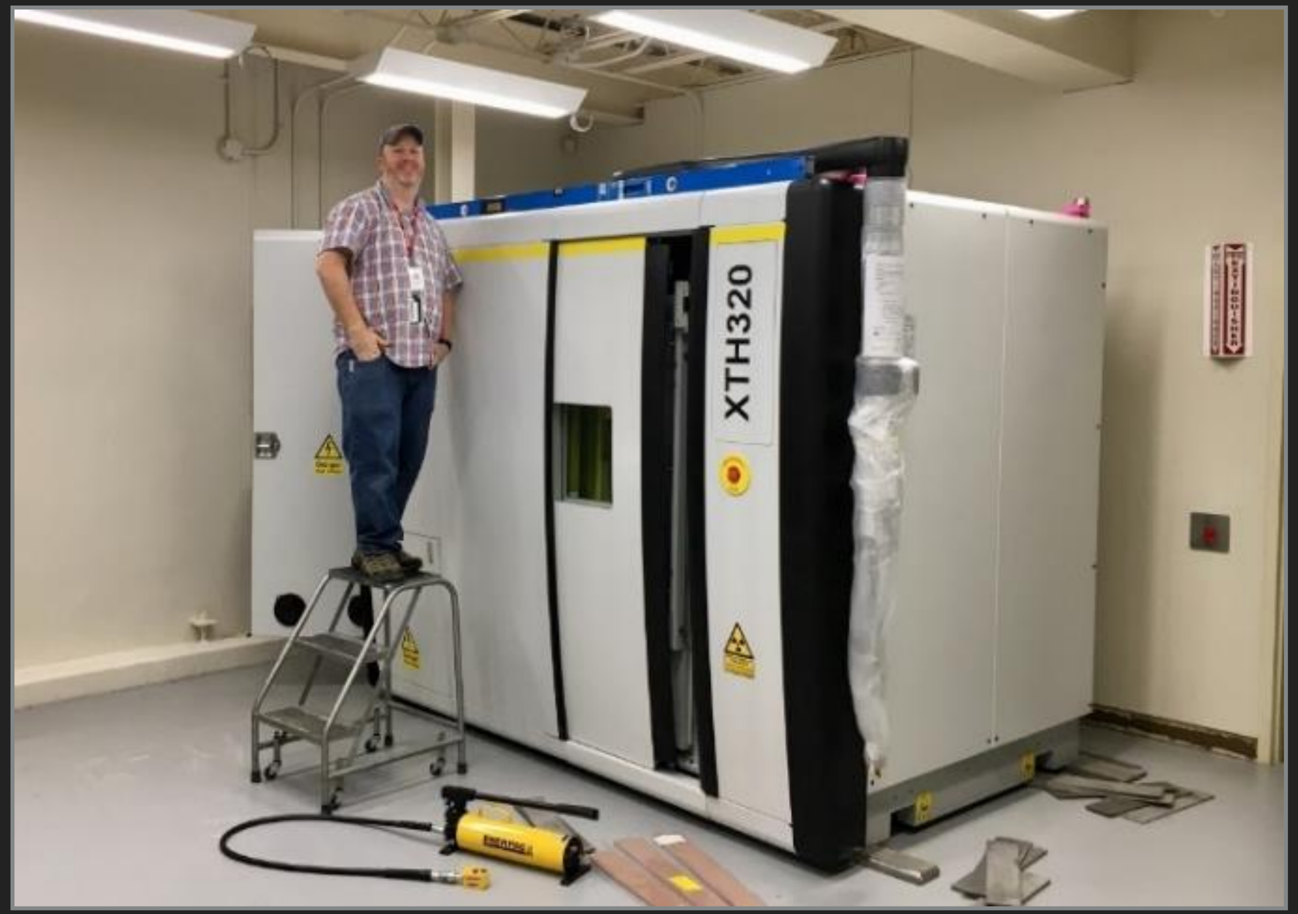


Lessons Learned

You can't prepare for the unknown, you don't know if Artemis samples will be returned during a pandemic or other events that will completely upend a plan. That said we could dig into what we do know about the context of the samples. For Artemis we'll have knowledge of the sample site, context, etc. Preliminary sample analysis can be augmented by an understanding of the geologic context of the sample sites.

Follow on funding for post-PE/ANGSA work needs to be identified. Over the course of PE/ANGSA new science questions emerge that are lunar-sample specific. Funding allocation for Apollo/Artemis sample science is CRITICAL.

Develop fall back plans for sample processing and allocation during future pandemics.



Other Possible Lessons Learned Themes for 2021-2022 1

ANGSA

The Apollo 17 CSVC was examined for its capability of preserving lunar samples.

The 73001/2 core was processed in a N glove box.

Gas extraction system was used to sample potential gases released from CSVC 73001 (Appendix 1). Dilemma was faced with strategy for opening CSVC.

Samples that were preserved at -20° C for 50 years were also curated at -20° C.

Other Possible Lessons Learned Themes for 2021-2022 2

Lessons Yet to be Learned

Did the N glove box processing compromise potential science? Does the glove box N need further conditioning (e.g., organics, water)? Do other processing environments need to be considered?

How successfully did the CSVC preserve the 73001 double drive tube sample? What are the implications for further sample collection on the Moon? Additional funding needed for new containment vessels?

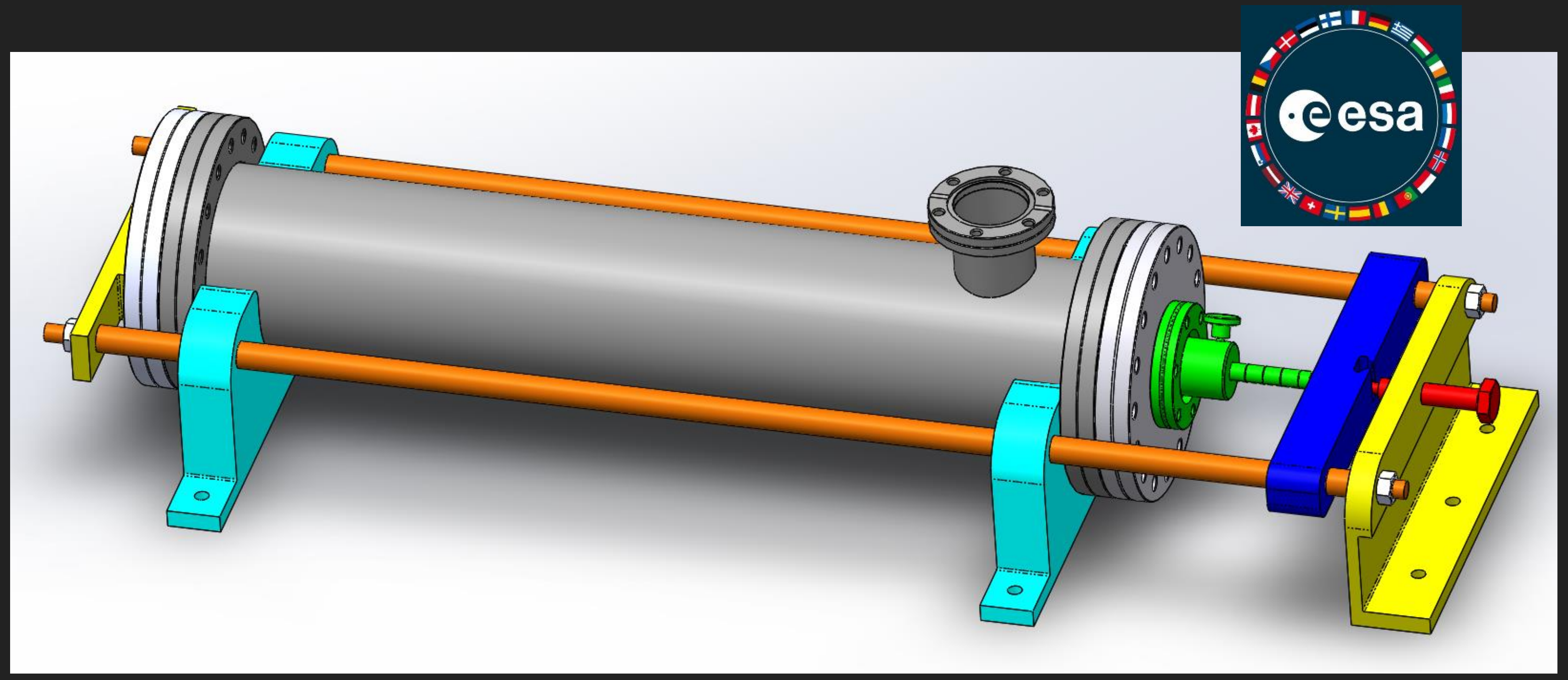
How successful was the gas extraction system for piercing and sampling gas components in sealed samples? Was the sampling strategies and protocols effective?

How effective was cold curation for preserving samples? How detrimental was cold curation and storage on samples? Is curation at lower temperatures required? What temperatures are required for storage, curation, and study of samples collected from cold traps? What are the budget, training, staffing, and preparation implications for curation and science?

Appendix 1. New tools developed by ANGSA Science and Engineering Team

A.

B.

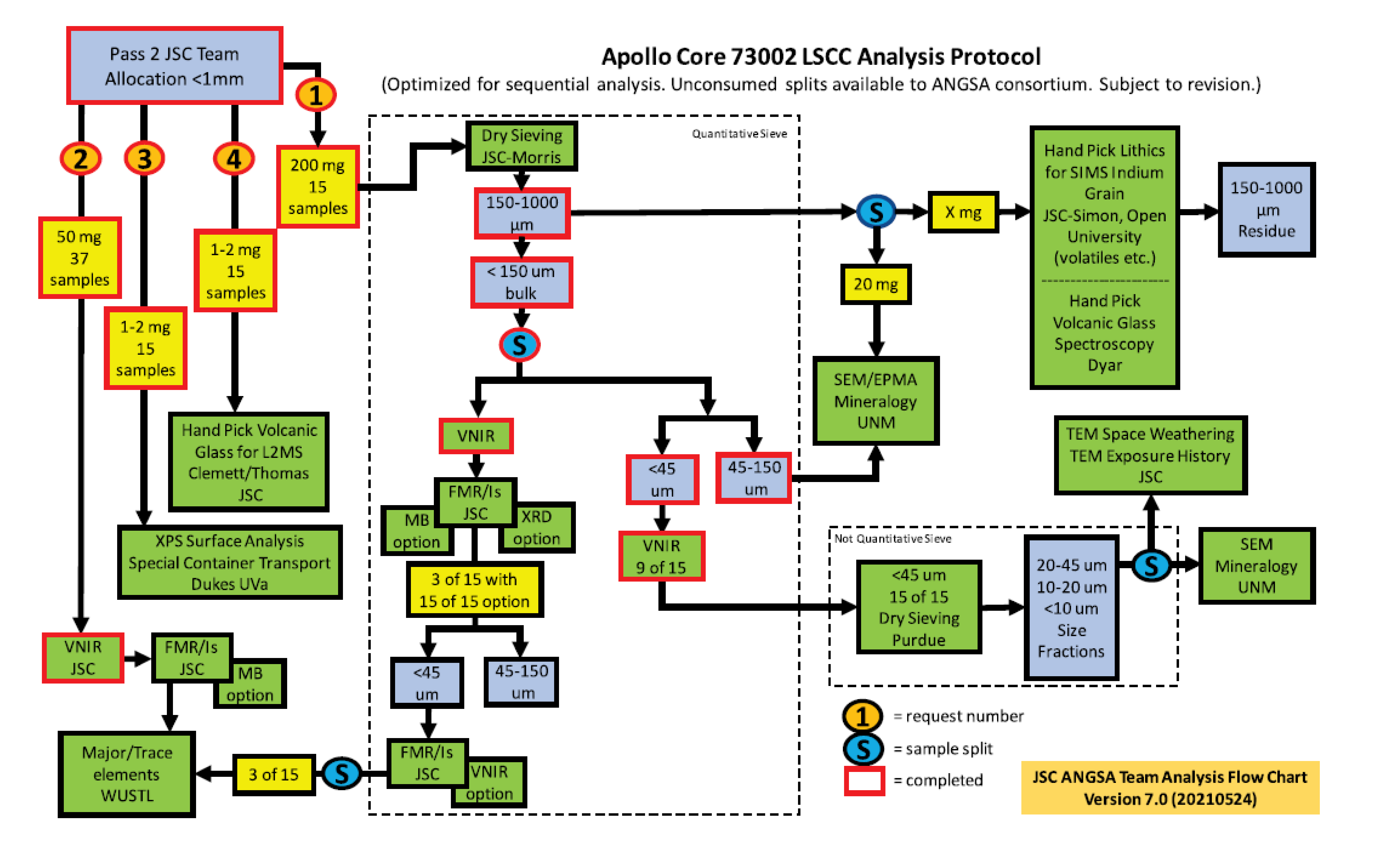


Tool for opening CSVC and sampling gas phases consists of 2 components (A) manifold and (B) piercing tool. The manifold and piercing tool were conceived by the ANGSA gas extraction sub-committee. The Manifold was designed and constructed by the ANGSA team from WUStL. The Piercing tool was designed and constructed by the ANGSA team from ESA.

C.

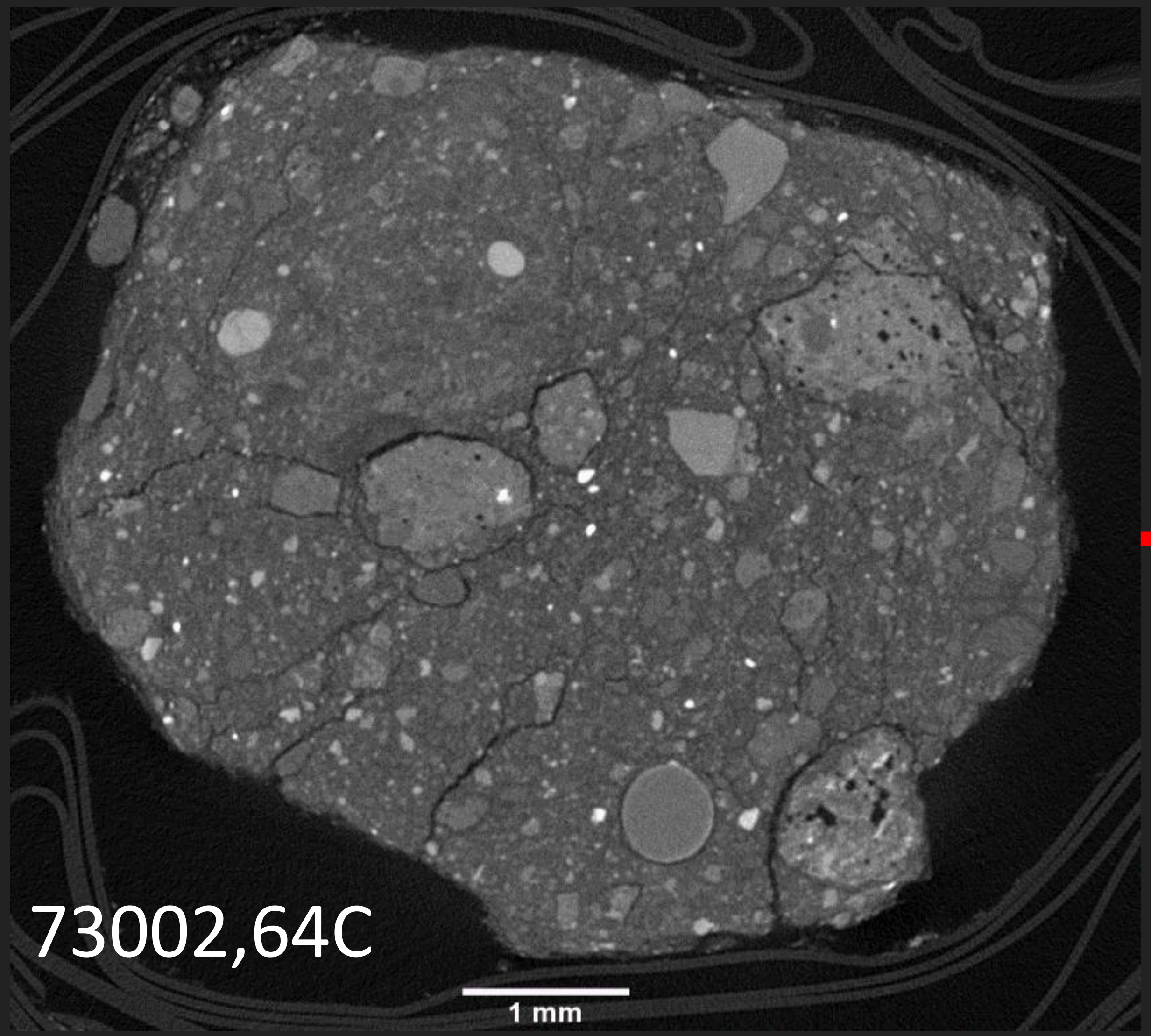
Tool for transporting samples from JSC curation N glove box to vacuum of instrumentation without interacting with the terrestrial atmosphere and modifying mineral surfaces.. Designed by the ANGSA team from the University of Virginia

Appendix 2A. Example of ANGSA sample processing plan.



Appendix 2B. Example of ANGSA sample processing plan for lithic fragments..

An example of a flow diagram for a coordinated team analysis of a lithic fragment. This approach will be instituted in 2021-2022.



From the XCT imaging classify sample and geologic context, identify total mass of lithology available for analysis, Identify potential science, measurements, and team members involved in carrying out study.

Follow-on documentation	Measurements (examples)	Mass/analysis (examples)	Members and Labs (examples)
Thin section documentation of textures and mineralogy	Geochemistry	100 mg	WUStL, UND
	Stable isotopes	50 mg	CSI
	Ar-Ar	20 mg	GSFC
	Nd-Sm, Rb-Sr	50 mg	LLNL
	Noble gases	Noble gases 100 mg	WUStL