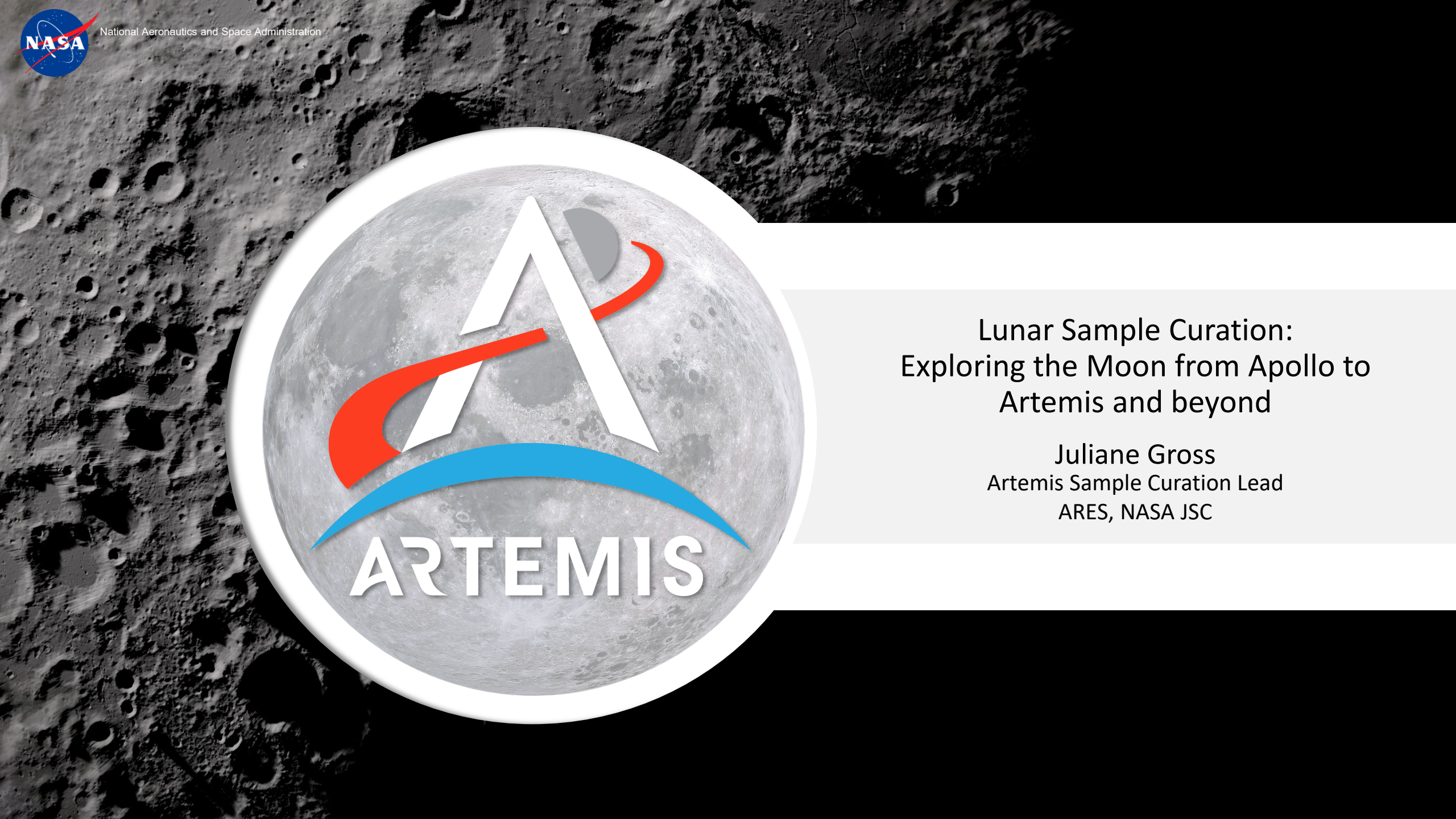
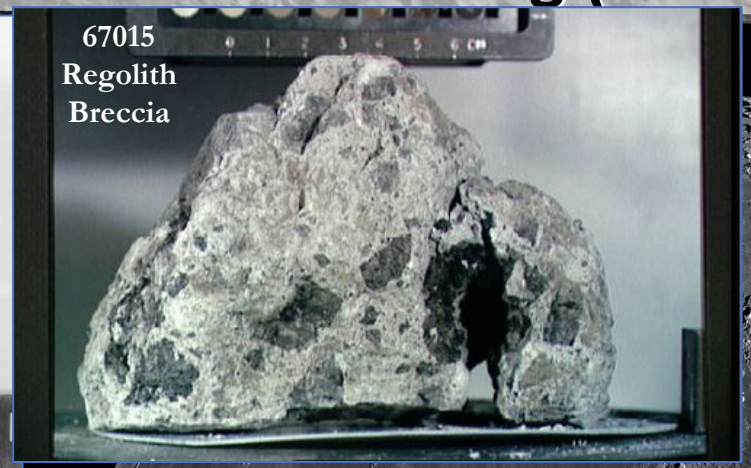
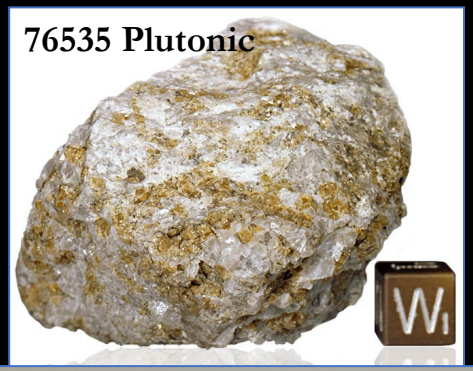


Lunar Sample Curation: Exploring the Moon from Apollo to Artemis and beyond

Juliane Gross
Artemis Sample Curation Lead
ARES, NASA JSC

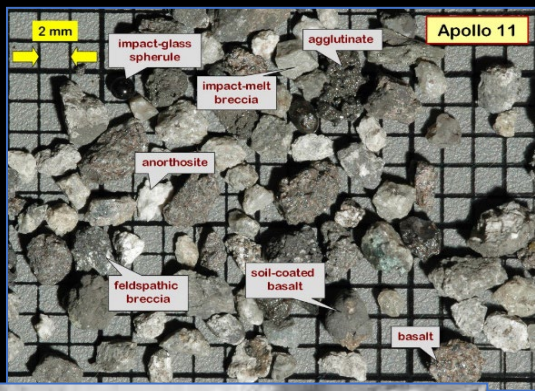
Apollo 11-17: returned 382 kg (between 1969-1972)





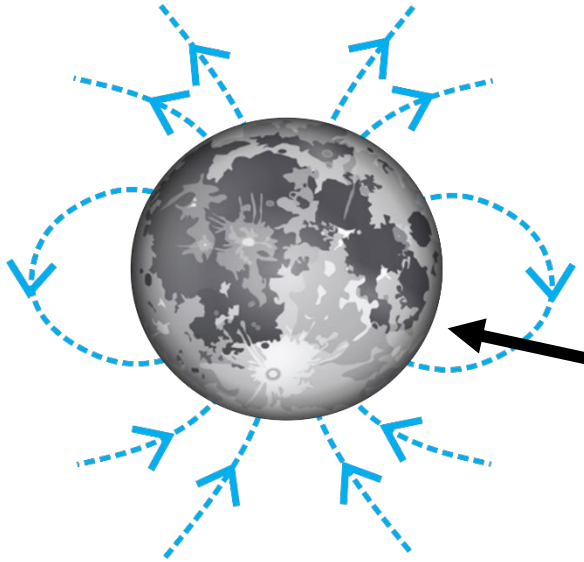
6 sample sites
382 kg total mass collected
2196 samples, 2191 examined
Wide variety rocks, soils, cores
Samples are "pristine"
Exquisite Geologic Context

LROC WAC Mosaic



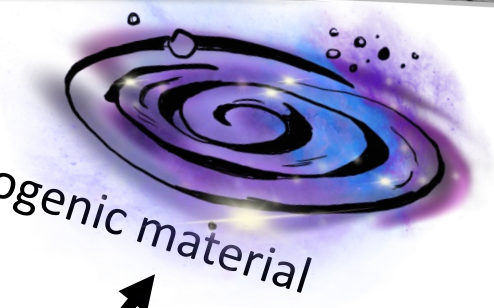
Soils,
Soil fragments
Core samples
Drive Tubes

Sample Importance: planetary science is anchored by lunar rocks

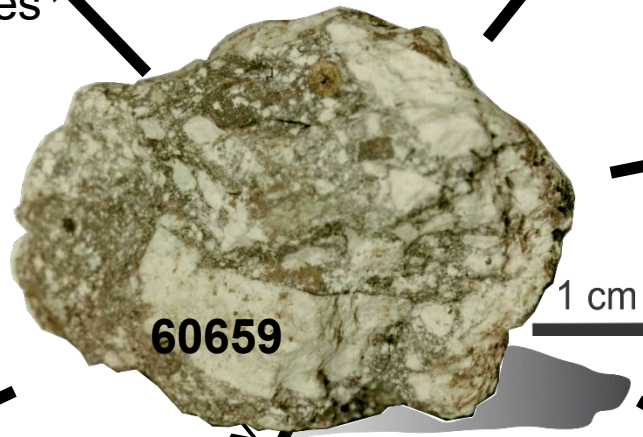


magnetism

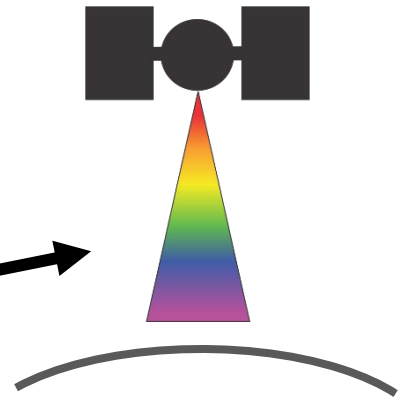
meteorites



exogenic material

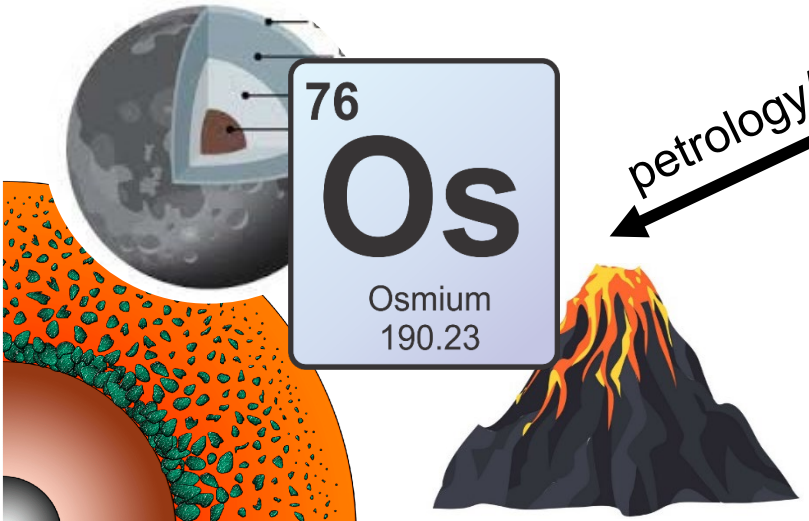


calibration



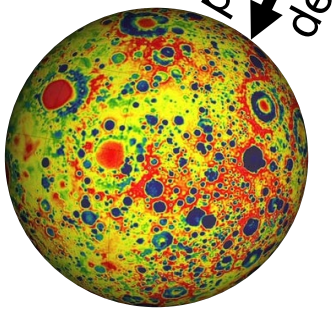
Remote sensing

petrology/ geochemistry



porosity

density



Missions (e.g., GRAIL)

absolute age

Crater counting

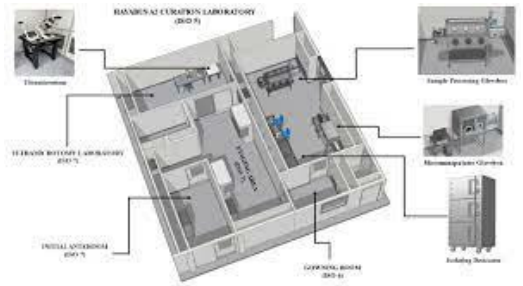
modified from Gross et al. (2025)

Goal and Importance of Lunar (Artemis & Apollo) Curation

- **Preserve** samples from collection on the lunar surface to their return to Earth
- **Provide** initial sample characterization and catalog development to enable scientific studies of samples
- **Curate** Artemis & Apollo samples for the long term, facilitating scientific investigations using technologies that will be developed in the future

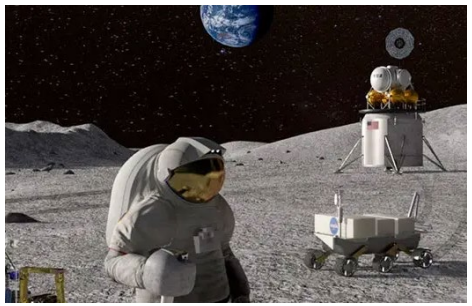
Curation starts pre-mission with the Curation Lead

Long term curation



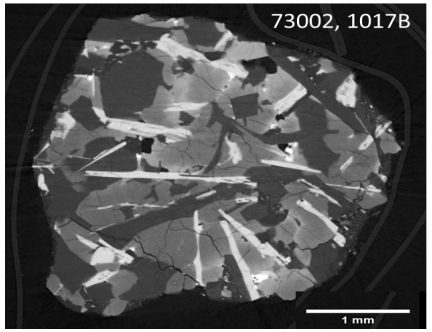
pre-mission planning

Curation Lead



During active mission

Collection Curator

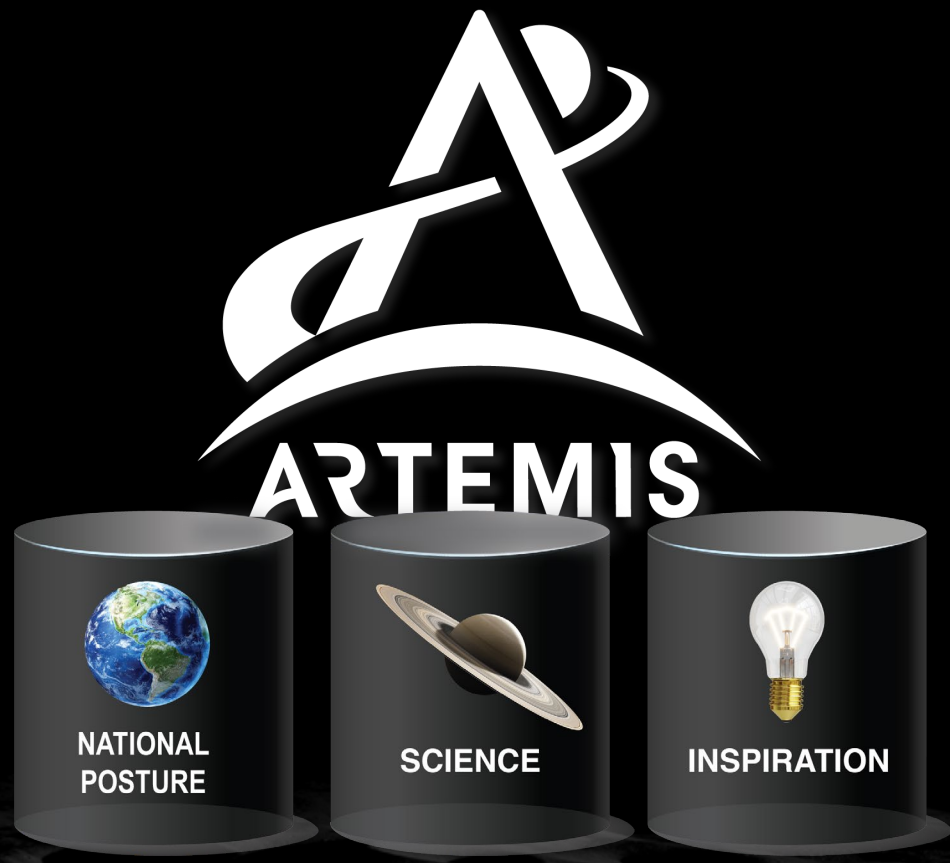


Preliminary Examination (PE)

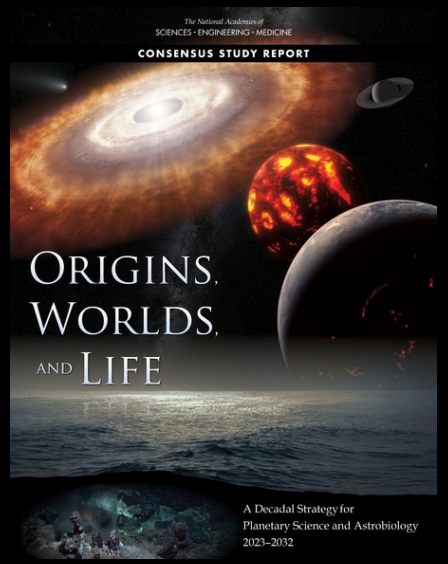
Recovery and Transport

A lot of science to do

- Time will be limited
  - ~6.5 days on surface
  - Exploration of landing during up to 4 surface EVAs
  - 2 crew members on foot, distance limited
  - Other mission priorities will also affect time available for geology
- Mass will be limited
- Must make sure we maximize the science accomplished during the mission
  - Make substantial progress toward decadal priorities
- Some tasks are complementary and support multiple objectives, some support only one objective
  - Many unknowns and exploration will mean on-the-fly adjustments
  - Need to prioritize among science objectives



ARTEMIS III GEOLOGY GOALS



"The central goal of a science-driven program of lunar discovery and exploration is to reveal the history of major events and processes that have shaped the Earth–Moon system and the solar system.

The committee prioritizes three overarching science themes that address (1) Solar System History, (2) Geologic Processes, and (3) Water and Volatiles."

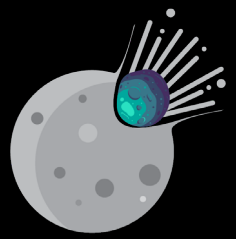
Solar System History

Geologic Process

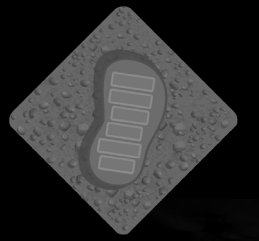
Volatiles

Goal A. Understand the Origin and Early Evolution of the Moon as a Model for Rocky Planets

Goal B: Determine the Lunar Record of Inner Solar System Impact History



Goal C: Determine How the Environment Controls Regolith Properties on Airless Bodies



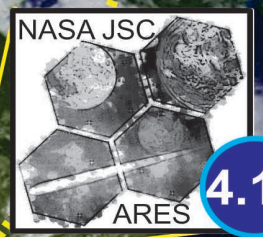
Goal D: Reveal the Age, Origin, and Evolution of Solar System Volatiles

Concept of Operations: *Artemis III Major ConOps Steps*

4.13 Initial Recovery

4.14 Transfer from Orion to Recovery Vessel

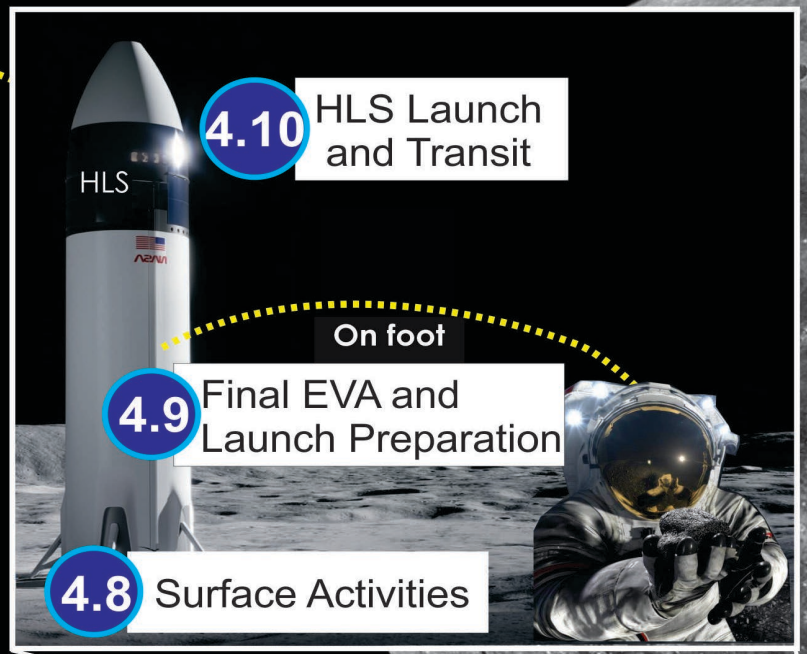
4.15 Recovery Vessel Activities



4.16 Transfer from Recovery Vessel to Curation

4.12 Orion Transit and Splashdown

4.11 HLS-Orion Rendezvous and Transfer



4.10 HLS Launch and Transit

4.9 Final EVA and Launch Preparation

4.8 Surface Activities

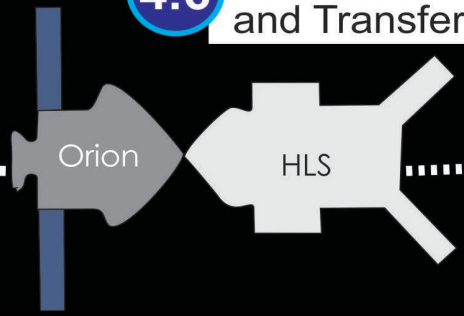
4.1 Planning, Development, Training, and Testing

4.2 Transfer and Delivery of Sample Hardware

4.3 Inspection, Storage and Integration

4.4 HLS Launch and Orbit

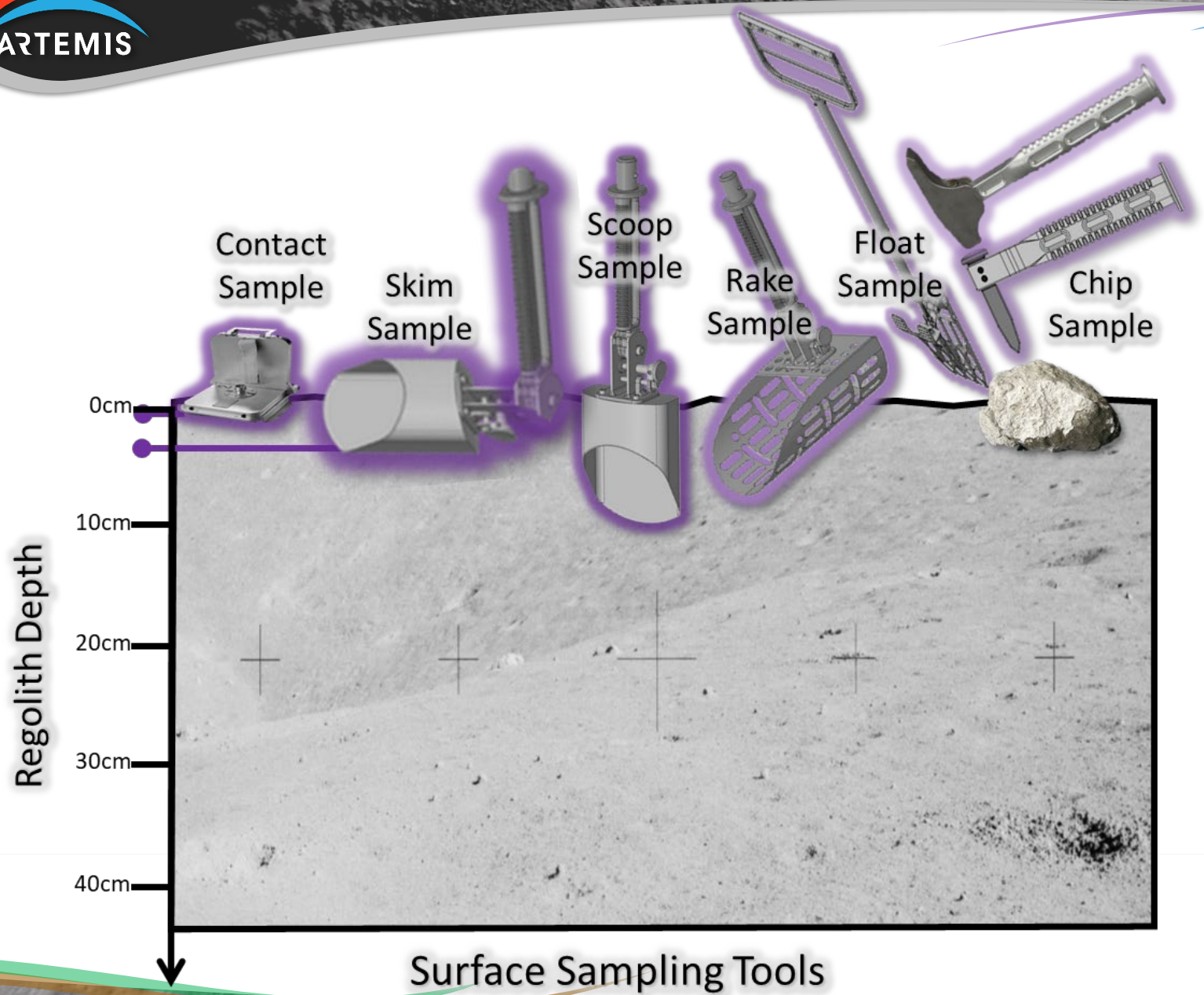
4.5 Orion Launch and Transit

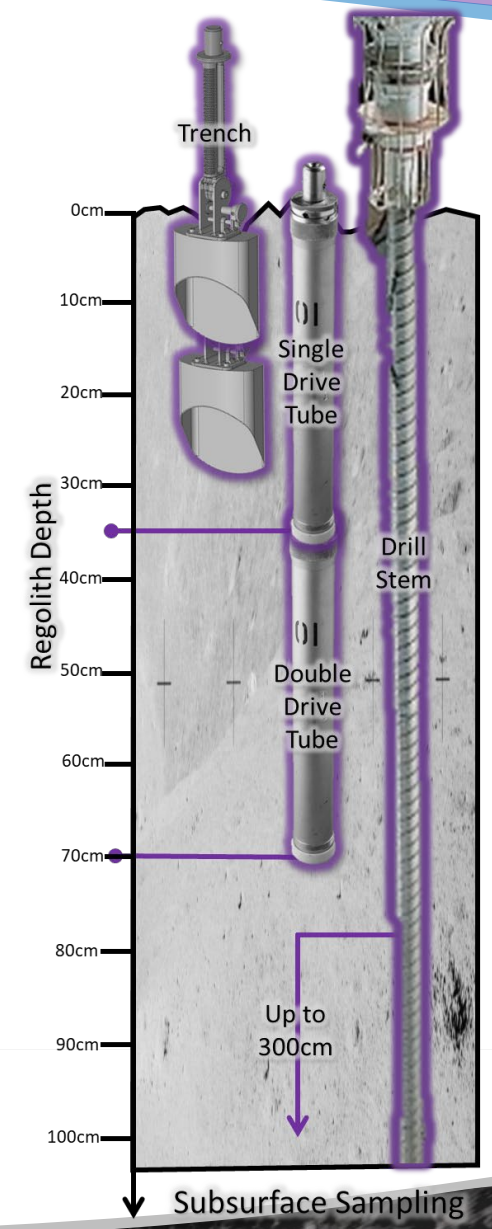


4.6 Orion-HLS Rendezvous and Transfer

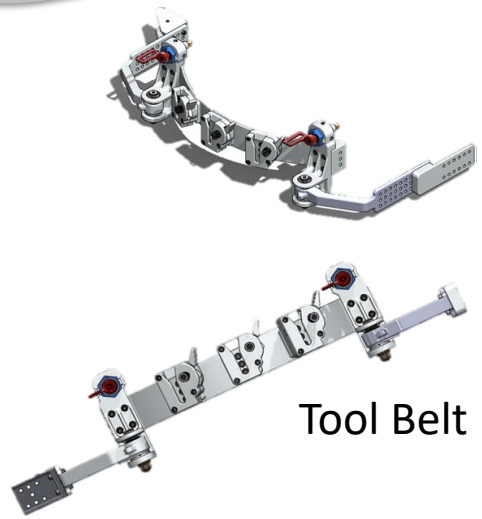
4.7 HLS Transit and Landing

Surface & Subsurface Sampling Types

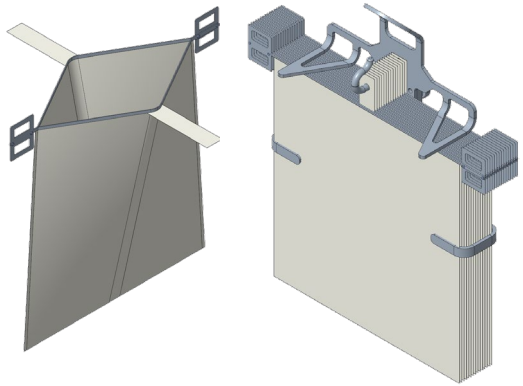




Sample collection Tools Overview: Government Reference Tools

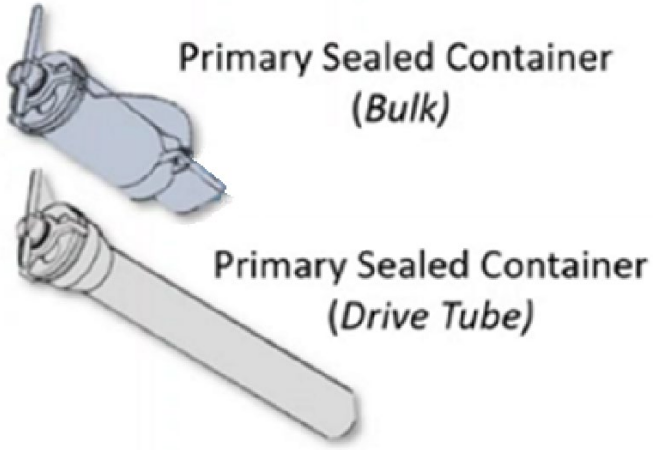


Tool Belt



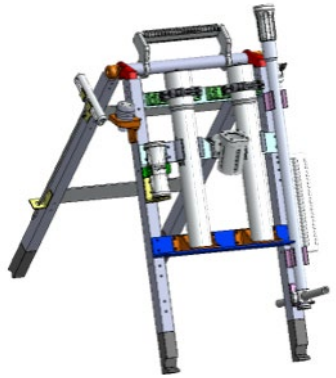
Sample Bag & Dispenser

Collection Pack

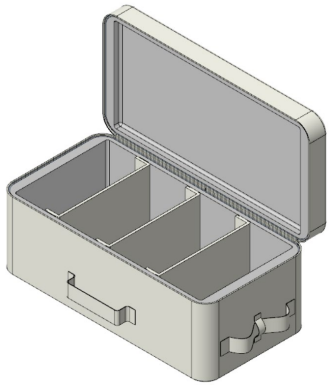


Not shown:

- Transport Liner
- Transport Pack
- Toolboggan/Tool Cart



Drive Tube Easel



Sample Return Pack
(conceptual)

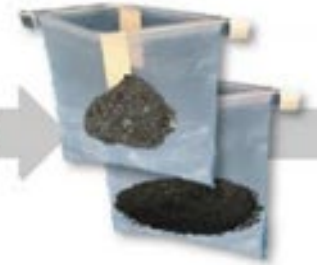
Sealed
Return Case (SRC)
(conceptual)

Scale

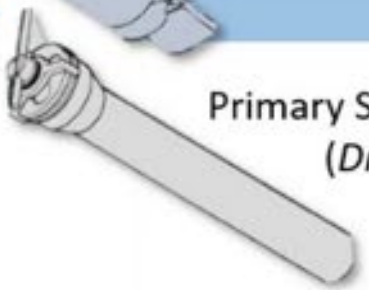
Artemis Sample Containment Flow

Sample Types	Volatiles?	Primary Containment	Samples Weighed	Return Container
Float, Chip or Rake Sample	Non-Volatiles	Sample Bags → Transport Liner		Sample Return Pack (unsealed)
Regolith Sample	Volatiles	Primary Sealed Container (*Bulk*)		Secondary Sealed Container
Drive Tube into Regolith	Volatiles	Primary Sealed Container (*Drive Tube*)		Secondary Sealed Container







Testing models of volatile deposition

Charlie Duke; AS16-116-18699

AS16-115-18557

Astronaut Zena Cardman, Iceland

SUPPORTING REAL-TIME OPERATIONS

Artemis 3: Ambient Sample Return

- South Polar Region lunar sample return with Astronauts
- Artemis 3 will return ambient temperature samples only
- Artemis 3 returned samples will be processed and curated under room temperature in the Apollo Labs under the direction of the Apollo Sample Curator
- Preliminary Examination: 6 months after arrival at JSC Curation

Apollo Curation Facility

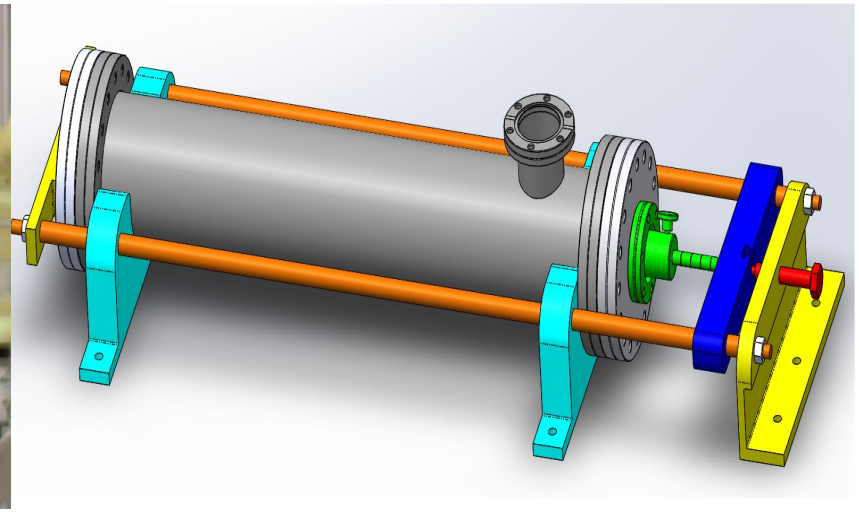
Current Lunar Facility (Apollo):

- About 83 % of the Apollo samples (by mass) remain pristine.
- Pristine samples have been kept under nominal storage conditions since returned, which include:
  - Kept in ISO 6 (class 1000) clean rooms.
  - Stored and processed inside dry N_2-purged SS Cabinets in our vaults and labs.
  - Limited materials that have come in contact with the samples, Stainless Steel, Al-metal, Teflon.
- Handling histories are carefully recorded, both in transit, in the lab, and while with the PIs.
- Specialty facilities for core processing and band-sawing (under N_2 purge), as well as sectioning samples (not under N_2).
- Has space for Artemis III and IV returned samples

ANGSA: Preparing for Artemis sample return and modernized PE

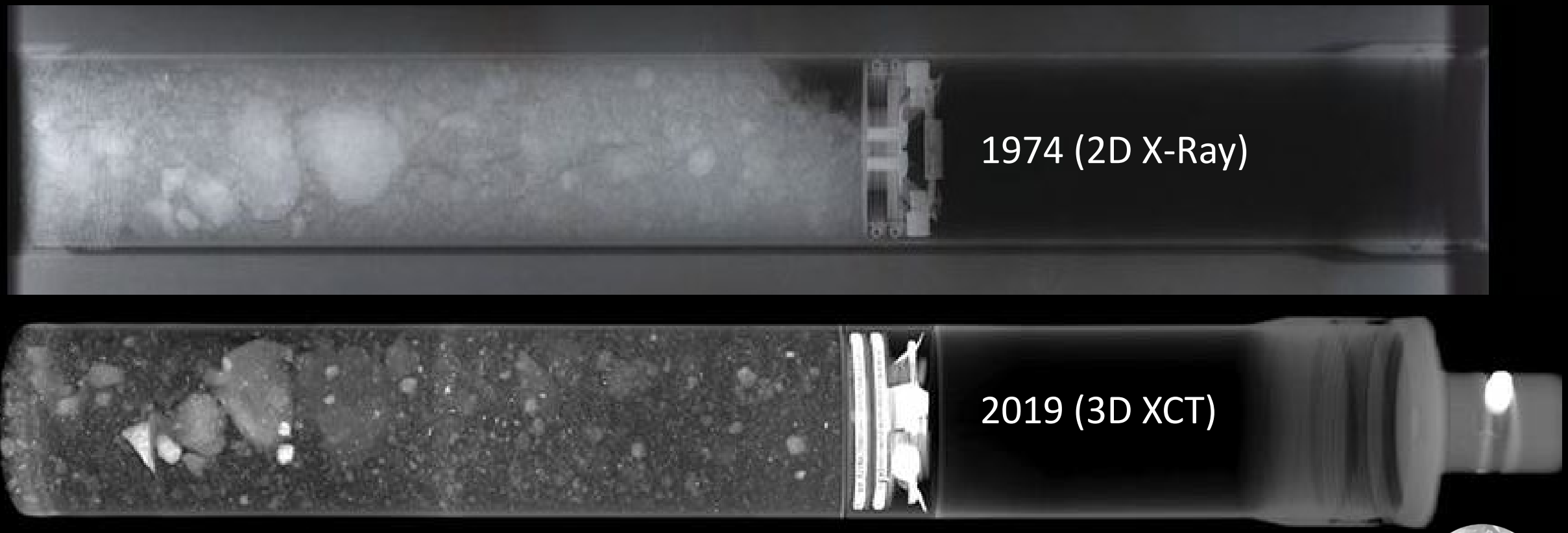
ANGSA (Apollo Next Generation Sample Analyses): A low-cost lunar “sample return mission”

- → Unopened and sealed double drive tube 73002/1
- → Consortia of 9 different competed teams
- → International collaboration to develop and test new tools and equipment for sampling and Preliminary Examination
- → Assess how well lunar material has been collected, stored, and preserved over time

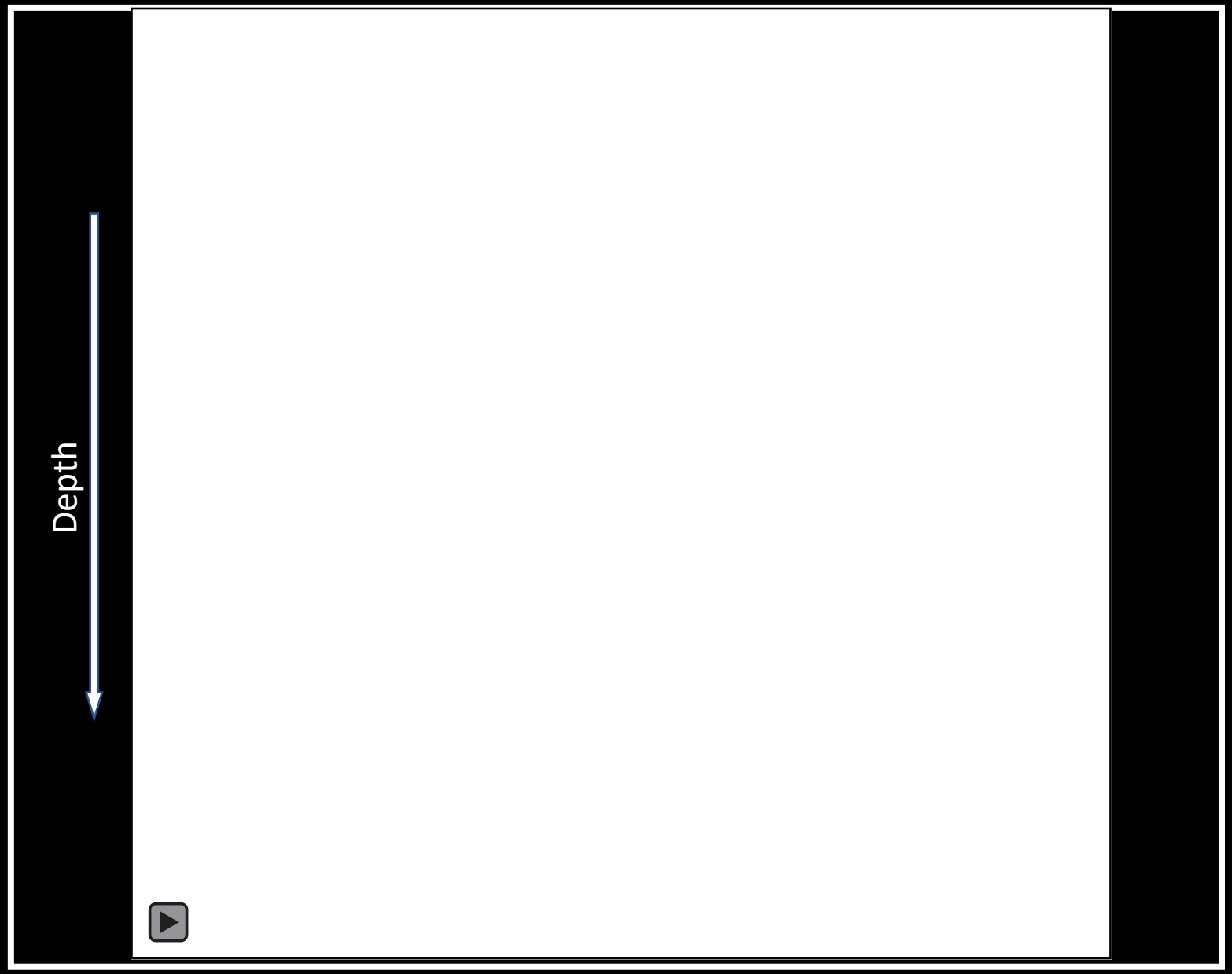


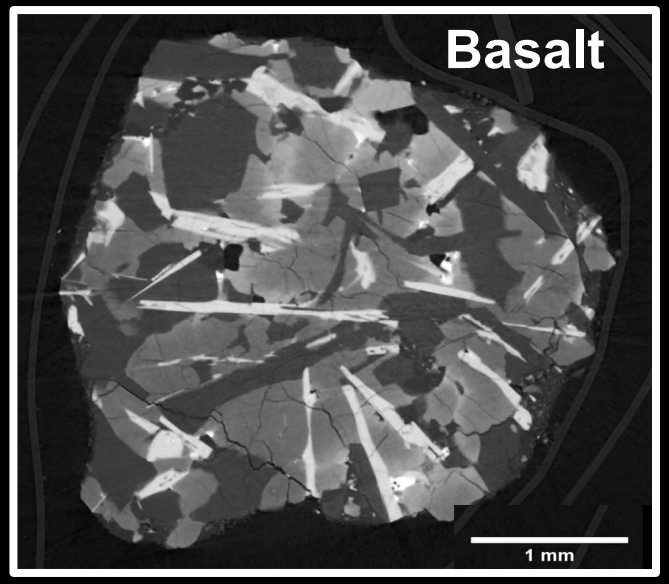
Preservation example: ANGSA

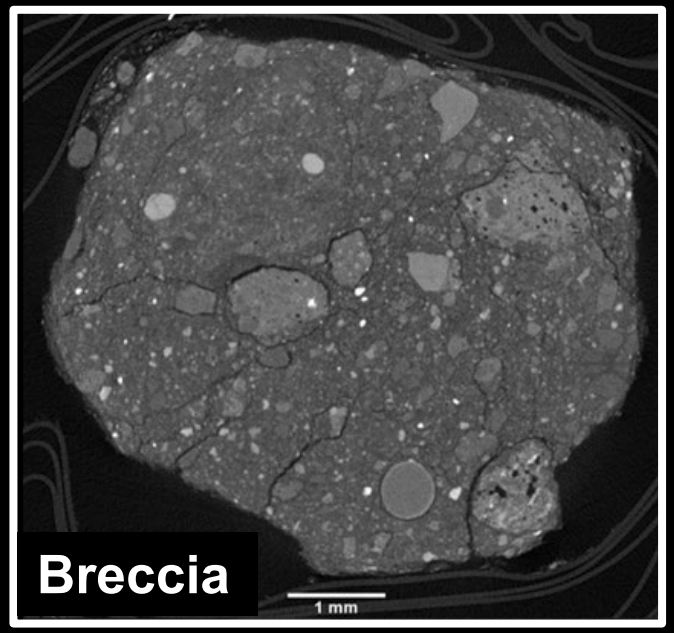
73002



ANGSA: critical new curation tool = X-ray computed tomography



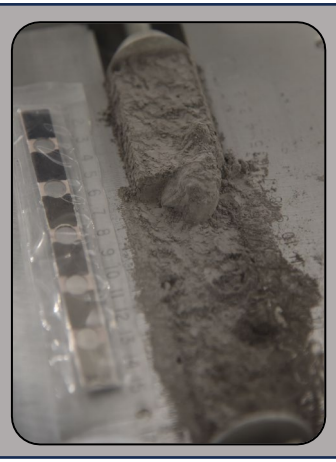


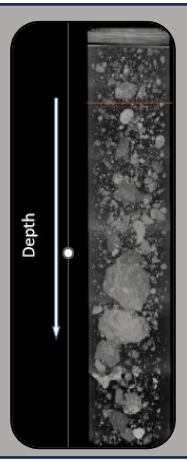


What does Artemis PE include? Lessons from Apollo and ANGSA

ANGSA

- One sample (double drive tube)
- PI led “mission” with competed scientific studies
- PE took 3 years to complete (COVID, boo)
- Detailed, beautiful catalog, published after 3 years





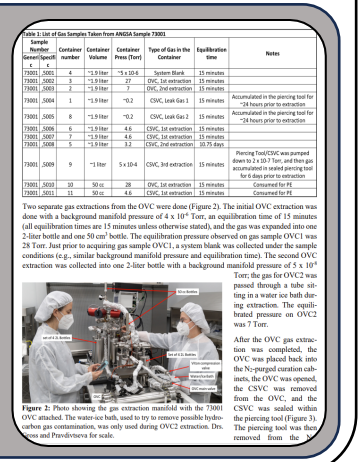


Table 1: List of Gas Samples Taken from ANGSA Sample 73001

Sample Number Geoserv	Specifi c	Container number	Container Volume	Container Press (Torr)	Type of Gas in the Container	Equilibration time	Notes
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

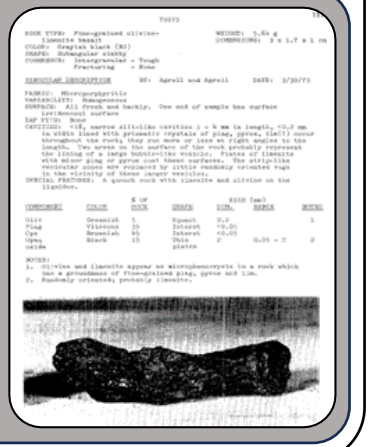
Two separate gas extractions from the OVC were done (Figure 2). The initial OVC extraction was done with a background manifold pressure of 4 x 10^{-6} Torr, an equilibration time of 15 minutes (all equilibration times are 15 minutes unless otherwise stated), and the gas was expanded into one 2-liter 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^{-4} 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.

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

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. Ross and Pravdivtseva for scale.

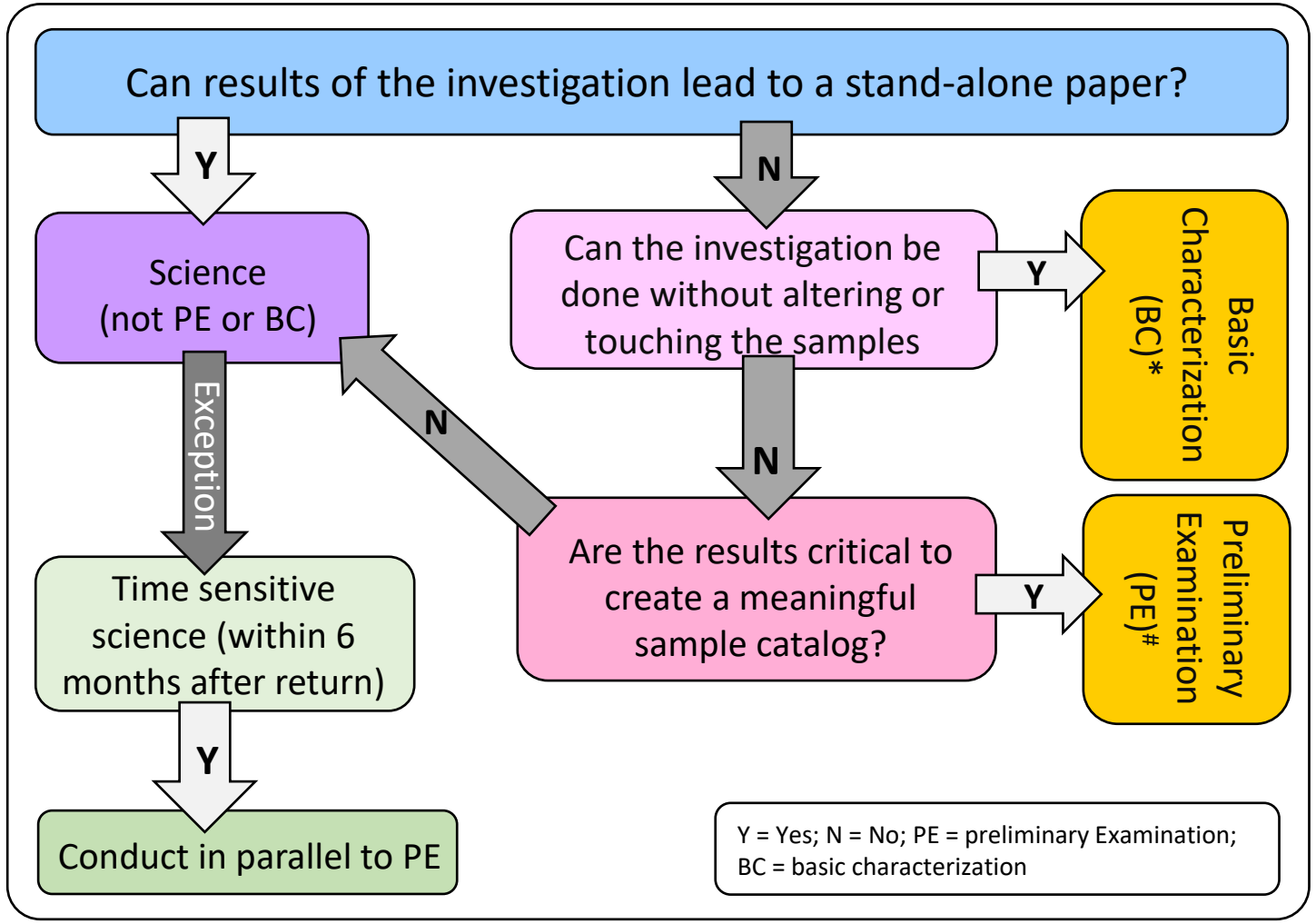
Artemis

- Lots of samples (~100 kg up-mass)
- NASA led mission; community carries out scientific studies via sample request
- PE complete within 6 month after delivery
- Basic catalog with enough information to request samples, publish within 6 months



What does Artemis PE include? Lessons from Apollo and ANGSA

- **Curation and PE plan under development taking lessons learned and differences into account**



*Basic Characterization (BC)

Documentation of sample containers & seals upon arrival via different methods (e.g., XCT, photos, videos, notes)

#Preliminary Examination (PE)

Documentation (e.g., photos, videos) of opened sample states (e.g., crumbled, broken, intact) and character (e.g., mass, size, texture).

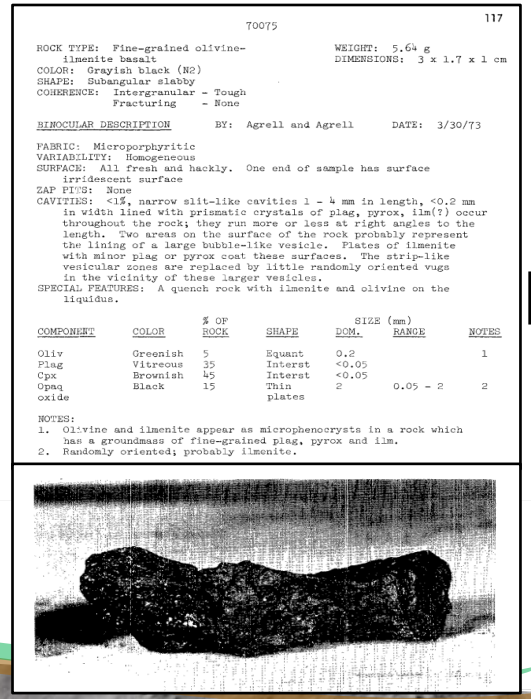
Extended Examination
(carried out on small subset of samples during PE time permitting; carried out during long term curation)

Documentation of physical sample properties via different methods such as sieving, XCT scanning, thin-sectioning, grain mounts, grain size distribution, maturity, core dissection.

Conclusion

- Apollo: PE catalog ≠ Apollo catalogs and Compendium (draws on results from community)

Lunar Sample Information Catalog (PE catalog)



70075 117

ROCK TYPE: Fine-grained olivine-ilmenite basalt
WEIGHT: 5.64 g
DIMENSIONS: 3 x 1.7 x 1 cm
COLOR: Grayish black (N2)
SHAPE: Subangular slabby
COHERENCE: Intergranular - Tough
Fracturing - None

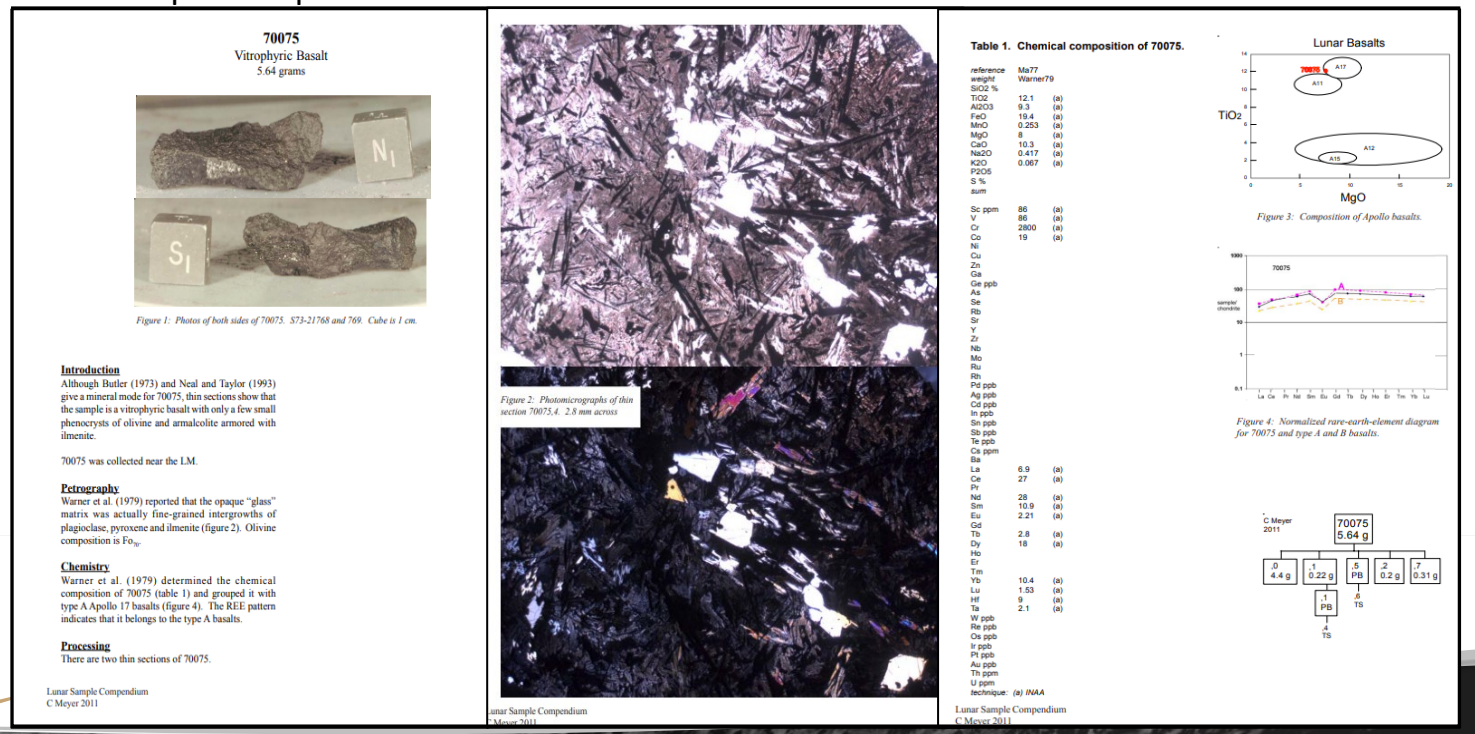
BINOCULAR DESCRIPTION BY: Agrell and Agrell DATE: 3/30/73

FABRIC: Microporphyritic
VARIABILITY: Homogeneous
SURFACE: All fresh and hackly. One end of sample has surface iridescent surface
ZAP PITS: None
CAVITIES: <1%, narrow slit-like cavities 1 - 4 mm in length, <0.2 mm in width lined with prismatic crystals of plag, pyrox, ilm(?) occur throughout the rock; they run more or less at right angles to the length. Two areas on the surface of the rock probably represent the lining of a large bubble-like vesicle. Plates of ilmenite with minor plag or pyrox coat these surfaces. The strip-like vesicular zones are replaced by little randomly oriented vugs in the vicinity of these larger vesicles.
SPECIAL FEATURES: A quench rock with ilmenite and olivine on the liquidus.

COMPONENT	COLOR	% OF ROCK	SHAPE	SIZE (mm) DOM.	RANGE	NOTES
Oliv	Greenish	5	Equant	0.2		1
Plag	Vitreous	35	Interst	<0.05		
Cpx	Brownish	45	Interst	<0.05		
Opaq oxide	Black	15	Thin plates	2	0.05 - 2	2

NOTES:
1. Olivine and ilmenite appear as microphenocrysts in a rock which has a groundmass of fine-grained plag, pyrox and ilm.
2. Randomly oriented; probably ilmenite.

Lunar Sample Compendium



70075
Vitrophyric Basalt
5.64 grams

Figure 1: Photos of both sides of 70075. S73-21768 and 769. Cube is 1 cm.

Introduction
Although Butler (1973) and Neal and Taylor (1993) give a mineral mode for 70075, thin sections show that the sample is a vitrophyric basalt with only a few small phenocrysts of olivine and armalcolite armored with ilmenite.

70075 was collected near the LM.

Petrography
Warner et al. (1979) reported that the opaque "glass" matrix was actually fine-grained intergrowths of plagioclase, pyroxene and ilmenite (figure 2). Olivine composition is Fo_{70}.

Chemistry
Warner et al. (1979) determined the chemical composition of 70075 (table 1) and grouped it with type A Apollo 17 basalts (figure 4). The REE pattern indicates that it belongs to the type A basalts.

Processing
There are two thin sections of 70075.

Lunar Sample Compendium
C Meyer 2011

Figure 2: Photomicrographs of thin section 70075,4. 2.8 mm across

Lunar Sample Compendium
C Meyer 2011

Table 1. Chemical composition of 70075.

reference	Ma77	Warner79
weight		
SiO2 %		
TiO2	12.1	(a)
Al2O3	9.3	(a)
FeO	19.4	(a)
MnO	0.253	(a)
MgO	8	(a)
CaO	10.3	(a)
Na2O	0.417	(a)
K2O	0.067	(a)
P2O5		
S %		
sum		
Sc ppm	86	(a)
V	86	(a)
Cr	2800	(a)
Co	19	(a)
Ni		
Cu		
Zn		
Ga		
Ge ppb		
As		
Se		
Rb		
Sr		
Y		
Zr		
Nb		
Mo		
Ru		
Rh		
Pd ppb		
Ag ppb		
Cd ppb		
In ppb		
Sn ppb		
Sb ppb		
Te ppb		
Cs ppm		
Ba		
La	6.9	(a)
Ce	27	(a)
Pr		
Nd	28	(a)
Sm	10.9	(a)
Eu	2.21	(a)
Gd		
Tb	2.8	(a)
Dy	18	(a)
Ho		
Er		
Tm		
Yb	10.4	(a)
Lu	1.53	(a)
Hf	9	(a)
Ta	2.1	(a)
W ppb		
Re ppb		
Os ppb		
Ir ppb		
Pt ppb		
Au ppb		
Th ppm		
U ppm		

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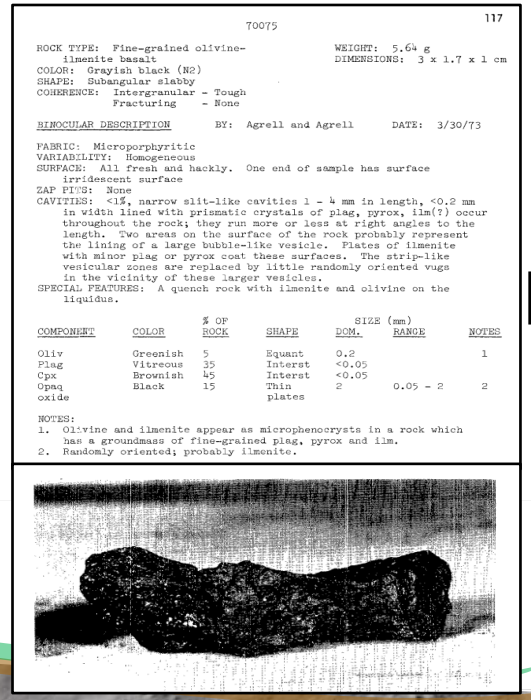
Figure 3: Composition of Apollo basalts.

Figure 4: Normalized rare-earth-element diagram for 70075 and type A and B basalts.

Conclusion

- Apollo: PE catalog ≠ Apollo catalogs and Compendium (draws on results from community)
- ANGSA: unique opportunity to learn and feed lessons forward to Artemis
- Analysis of the Artemis III samples and data will be a community-wide endeavor (including people that are still students now)
- It is all of our jobs to make sure the science foundation of Artemis is strong

Lunar Sample Information Catalog (PE catalog)



70075 117

ROCK TYPE: Fine-grained olivine-ilmenite basalt
WEIGHT: 5.64 g
DIMENSIONS: 3 x 1.7 x 1 cm
COLOR: Grayish black (N2)
SHAPE: Subangular slabby
COHERENCE: Intergranular - Tough
Fracturing - None

BINOCULAR DESCRIPTION BY: Agrell and Agrell DATE: 3/30/73

FABRIC: Microporphyritic
VARIABILITY: Homogeneous
SURFACE: All fresh and hackly. One end of sample has surface irridescent surface
ZAP PITS: None
CAVITIES: <1%, narrow slit-like cavities 1 - 4 mm in length, <0.2 mm in width lined with prismatic crystals of plag, pyrox, ilm(?) occur throughout the rock; they run more or less at right angles to the length. Two areas on the surface of the rock probably represent the lining of a large bubble-like vesicle. Plates of ilmenite with minor plag or pyrox coat these surfaces. The strip-like vesicular zones are replaced by little randomly oriented vugs in the vicinity of these larger vesicles.
SPECIAL FEATURES: A quench rock with ilmenite and olivine on the liquidus.

COMPONENT	COLOR	% OF ROCK	SHAPE	SIZE (mm) DOM.	RANGE	NOTES
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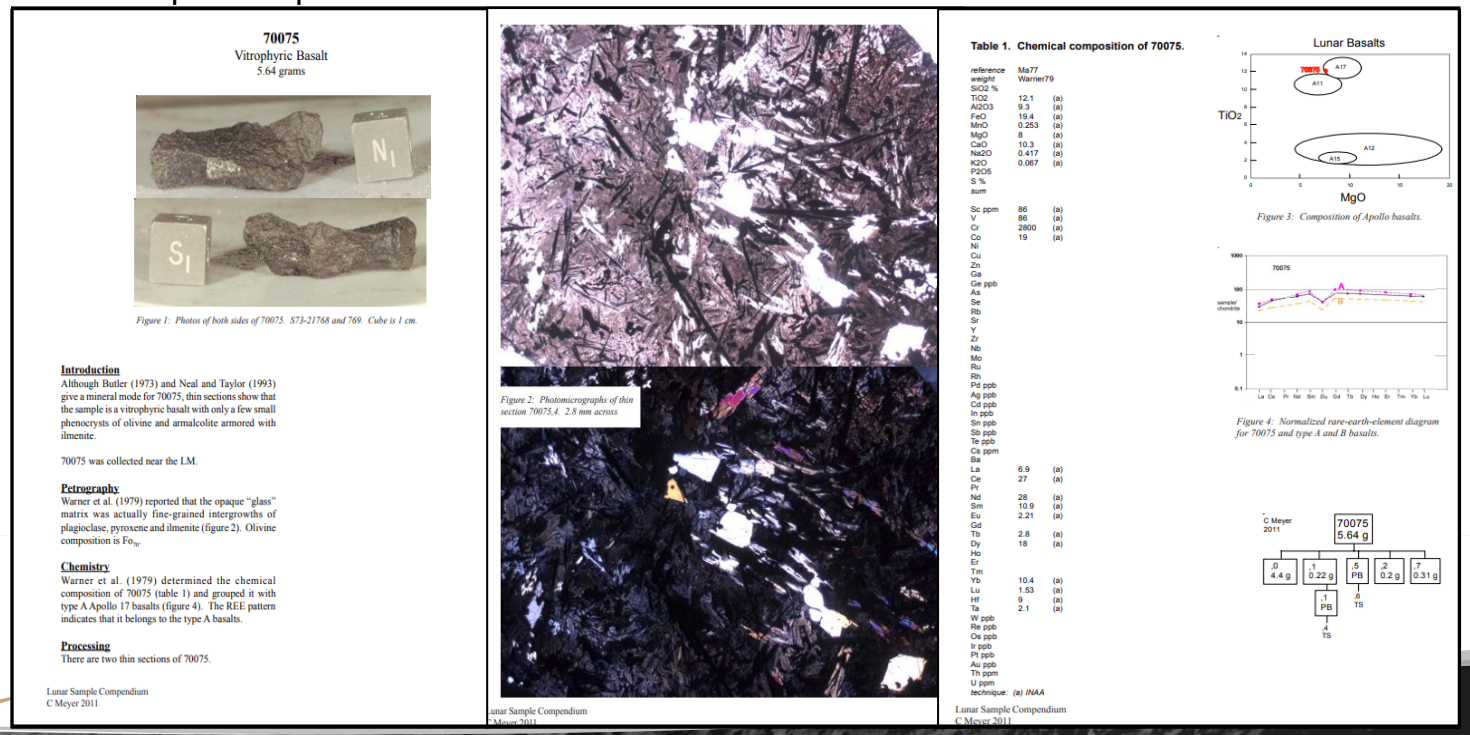

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Lunar Sample Compendium
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technique: (a) INAA

Lunar Basalts

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70075 5.64 g
,0 4.4 g
,1 0.22 g
,5 PB
,2 0.2 g
,7 0.31 g
,1 PB
,6 TS
,4 TS

Lunar Sample Compendium
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National Aeronautics and Space Administration

ARTEMIS

Thank you for your attention

Questions?

Artemis curation: juliane.gross@nasa.gov