Applied science investigations enabled by Artemis and a sustained human presence on the Moon

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Johns Hopkins Applied Physics Laboratory

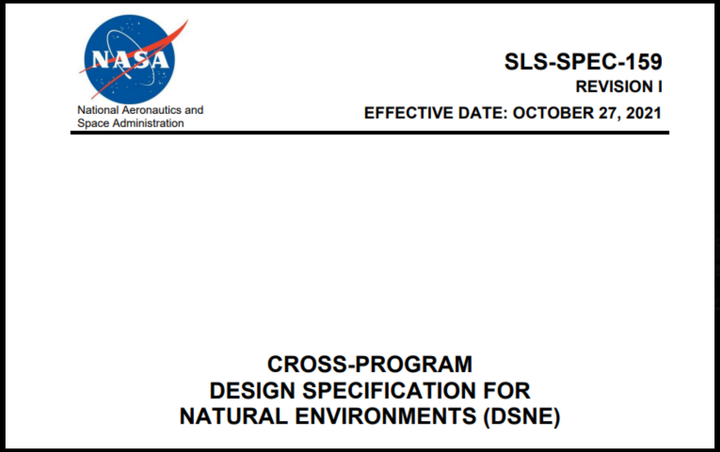
Applied Sciences panel, NASEM Study of non-polar destinations for human exploration

June 12, 2025

Context/background for this talk

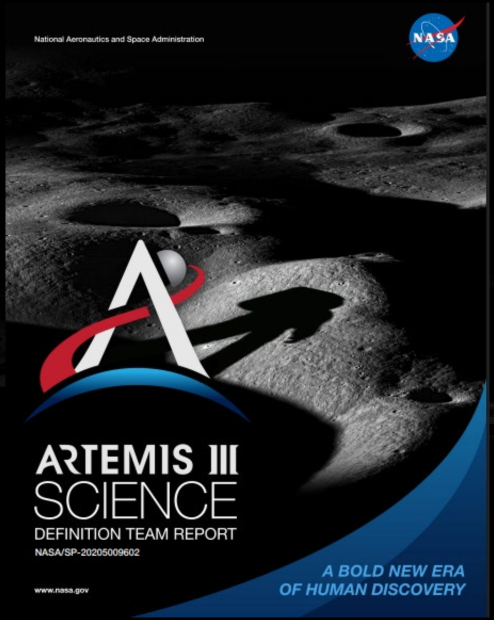
- ~2019-2022 @NASA MSFC, Design Specification for Natural Environments (DSNE)
  - Rapid effort to add lunar surface and orbital environments at the beginning of Artemis, first rev with Moon was 2019

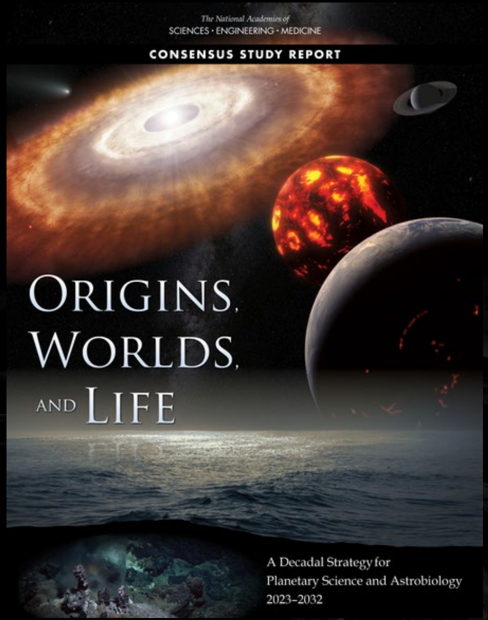
  - Incorporation of new LRO data on rock abundance, slope statistics
  - Collaborated on ‘ejecta environment’ model (lead: Anthony DiStefano, MSFC; underwent NASA NESC review)
  - Note that most regolith properties data in DSNE has Lunar Sourcebook heritage.
- 2020, A3-SDT; ~2022, Decadal survey; ~2023, A3GT

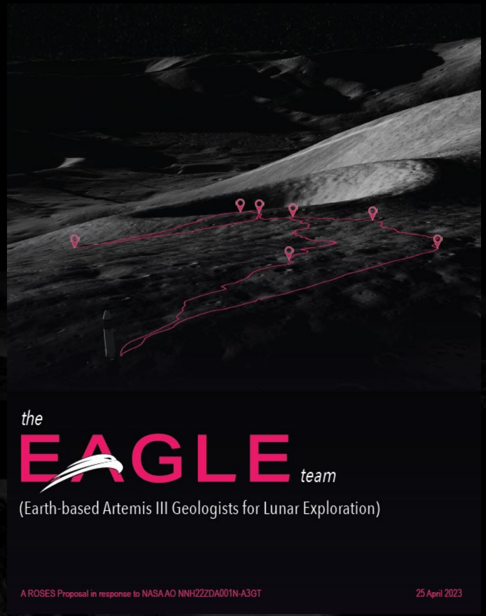

National Aeronautics and Space Administration

SLS-SPEC-159
REVISION I
EFFECTIVE DATE: OCTOBER 27, 2021

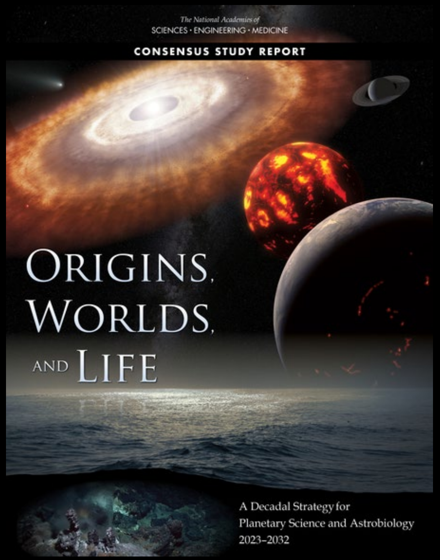
CROSS-PROGRAM
DESIGN SPECIFICATION FOR
NATURAL ENVIRONMENTS (DSNE)







ARTEMIS III GEOLOGY GOALS

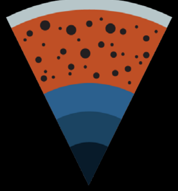


“The central goal of a science-driven program of lunar discovery and exploration is to reveal the history of major events and processes that have shaped the Earth–Moon system and the solar system.

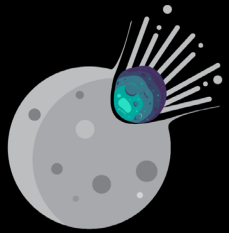
The committee prioritizes three overarching science themes that address (1) Solar System History, (2) Geologic Processes, and (3) Water and Volatiles.”

Solar System History

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

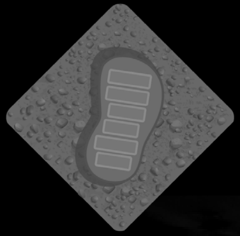


Goal B: Determine the Lunar Record of Inner Solar System Impact History



Geologic Process

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



Volatiles

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

Artemis III: Outcomes for Applied Science

Artemis III will be the first crewed flight to the lunar south pole.

- A3 will be a flight test of many critical systems: Suit, lander, tools.
- Science is an influence on mission planning, but not driving the mission.

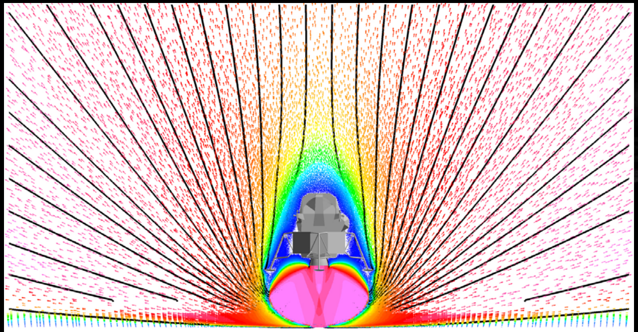
Artemis III will have implications for Applied Science

- Better understanding of plume-surface interaction (PSI) with implications for both science and future infrastructure
  - Disturbance of the landing point and a blast zone in the surroundings of lander
  - Volatile deposition
- Validating and revisiting the Apollo knowledge base for interacting with the regolith by suited crew and other equipment
  - Regolith variability and character in a polar highlands site
  - New information on trafficability, cohesion, grain size distribution, dust, geotechnical properties etc

Plume-Surface Interaction

- Models exist for effects of rocket exhaust.
  - Need tests to prove these apply to HLS-scale landers
- Primary concern is disturbance & transport of the regolith by the lander.
- Artemis-sponsored ground testing is ongoing with cold gas tests at NASA Langley (NASA MSFC POC Wesley Chambers)
- SCALPSS data from Blue Ghost descent.

https://www.youtube.com/watch?v=emebSgs1f2w



Apollo Lunar Module plume impingement at a distance of 5 m above the landing surface. (https://www.nasa.gov/directorates/stmd/plume-surface-interaction-psi/)

Visual Obscuration During Apollo 16 Landing (Metzger, 2010)

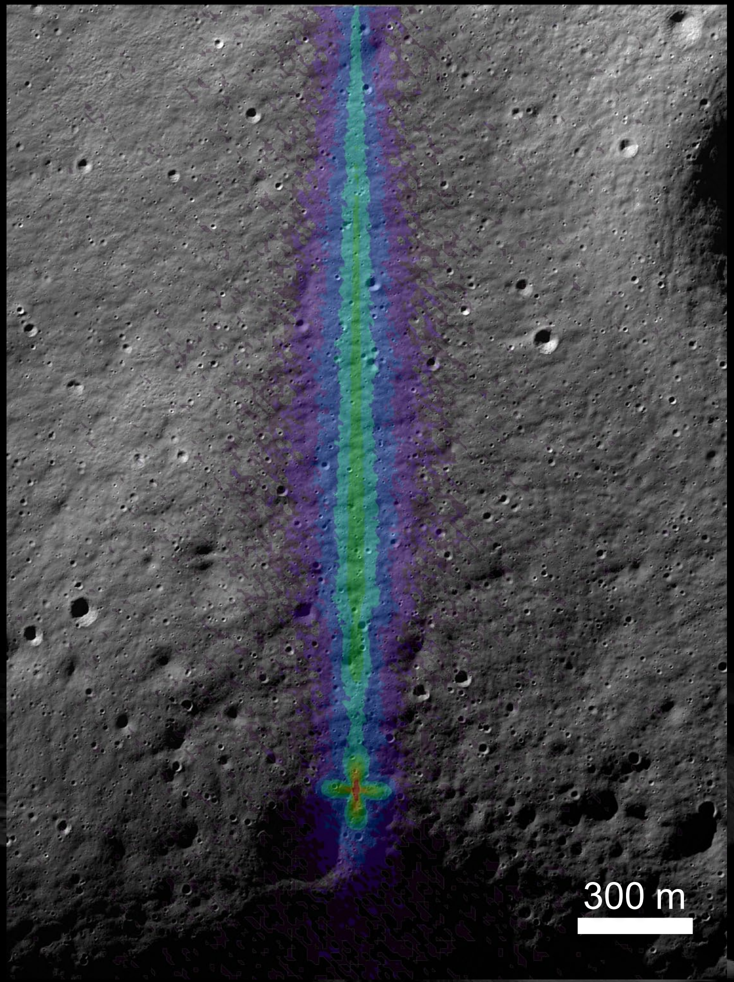
PSI and volatile deposition

- Specific concern for volatiles: expect exhaust can stick to surface in shadowed areas around lander, particularly along the approach vector
- Some may end up in the cold, permanently shadowed regions where we want to search for lunar volatiles and/or pursue ISRU.

Model of lander-deposited volatiles

Red (notional landing site): equivalent to 300 μm thick layer of water

Purple: equivalent to <0.3 μm thick layer of water



Farrell et al., 2024
https://iopscience.iop.org/article/10.3847/PSJ/ad37f5
Heldmann et al., 2025
https://ntrs.nasa.gov/api/citations/20250002111/downloads/LPSC2025-Artemis3Volatiles_V6.pdf

PSI and volatile deposition

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Notional samples to test this:

- Initial sealed surface skim sample soon after landing acquired in the shadow of the lander.
- Sealed surface skim from region that has been entirely in shadow since landing ~100 m away from the lander and away from the trail of expected exhaust impingement.
- Sealed surface skim during last EVA at same location as initial skim sample.
- Assess volatiles with respect to sample acquisition, thermal drivers between landing and collection, and the location relative to the expected impingement of the landing plume.

Farrell et al., 2024
https://iopscience.iop.org/article/10.3847/PSJ/ad37f5
Heldmann et al., 2025
https://ntrs.nasa.gov/api/citations/20250002111/downloads/LPSC2025-Artemis3Volatiles_V6.pdf

Collecting an analogue skim sample with government reference design scoop

Interactions with the regolith

- Artemis III science team plans to study interactions of regolith and hardware (e.g., cart tracks, boot prints, etc.)
  - Geotechnical data is of broad interest to both lunar scientists and engineers
  - Additional potential to learn something about the regolith from drive tube ops, trenches, etc.
  - Will (re)boost experiential understanding of crew & hardware interactions with dust.
- Returned samples from Artemis III will also provide some insight into regolith properties at surface of polar highlands (e.g., particle size distribution).
- <u>Opinion/Hypothesis</u>: I expect we will not see regolith properties substantially out of family with Apollo experience.
  - Apollo sites were approximately consistent with each other;
  - Impacts are primary factor influencing regolith evolution everywhere;
  - LRO remote sensing shows similar properties globally.
- Happy to be proven wrong though! ☺

Artemis III: Deployed Instruments

Instrument	Relationship of objectives to applied science
LEMS (Lunar Environment Monitoring Station) PI Mehdi Benna (GSFC/UMBC)	• New measurements of seismic and impact environments, relevant for future construction. • Regolith properties may prove useful for ISRU, deep subsurface exploration.
LDA (Lunar Dielectric Analyzer) PI Hideaki Miyamoto (University of Tokyo/JAXA)	• Probe dielectric properties of regolith (density/porosity) • Sensitive to any potential ice, frost. • Implications for ISRU, deep subsurface exploration.
LEAF (Lunar Effects on Agricultural Flora) PI Christine Escobar (Space Lab Tech., LLC)	• Study plant growth beyond Earth (radiation, gravity, etc). • Demonstration of closed system agriculture has potential feed-forward to future Moon and Mars exploration.

What Artemis III will not do for Applied Science

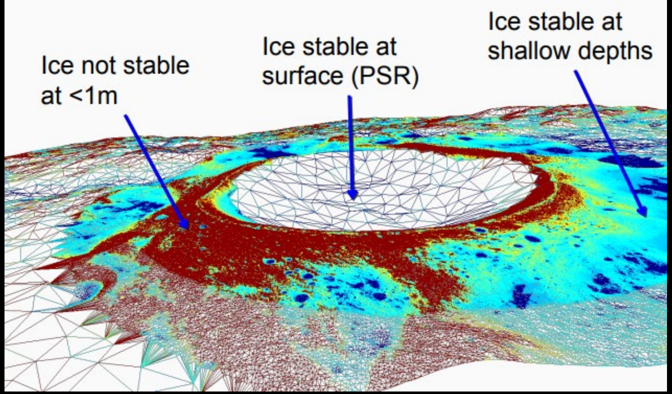
1. Artemis III will have limited mobility and range (walk-back).
   - LTV is slated for delivery prior to Artemis V for use in that mission.
   - LTV mobility radically extends exploration zone.
   - LTV performance itself will provide insight into trafficability and shear strength of the surface w/ slope, geology.
   - LTV instruments – solicited but not yet selected – will give additional context for exploration zones unavailable in A3.

What Artemis III will not do for Applied Science

2. Artemis III has a narrow set of instrumentation*:

*Caveat: As far as I know, perhaps subject to change

- No new thermal data (except modeling improvements enabled by higher resolution topography).
  - *VIPER would be very helpful for this.*
- Nothing on plasma or charging environment (natural or induced). Affects dust!
- Tools for subsurface access (drive tube, scoop) only allow access for tens of cm to ~1m.
- Crew navigation tools/aids may be limited and imprecise.
- Many conceivable handheld and deployed instruments relevant to Applied Science are not in the mission scope.



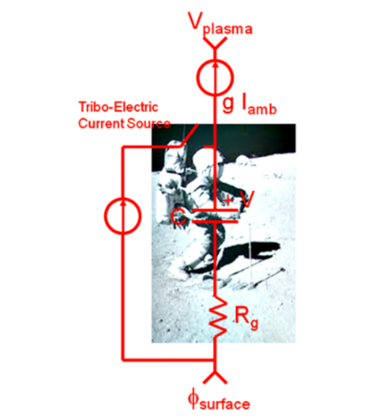
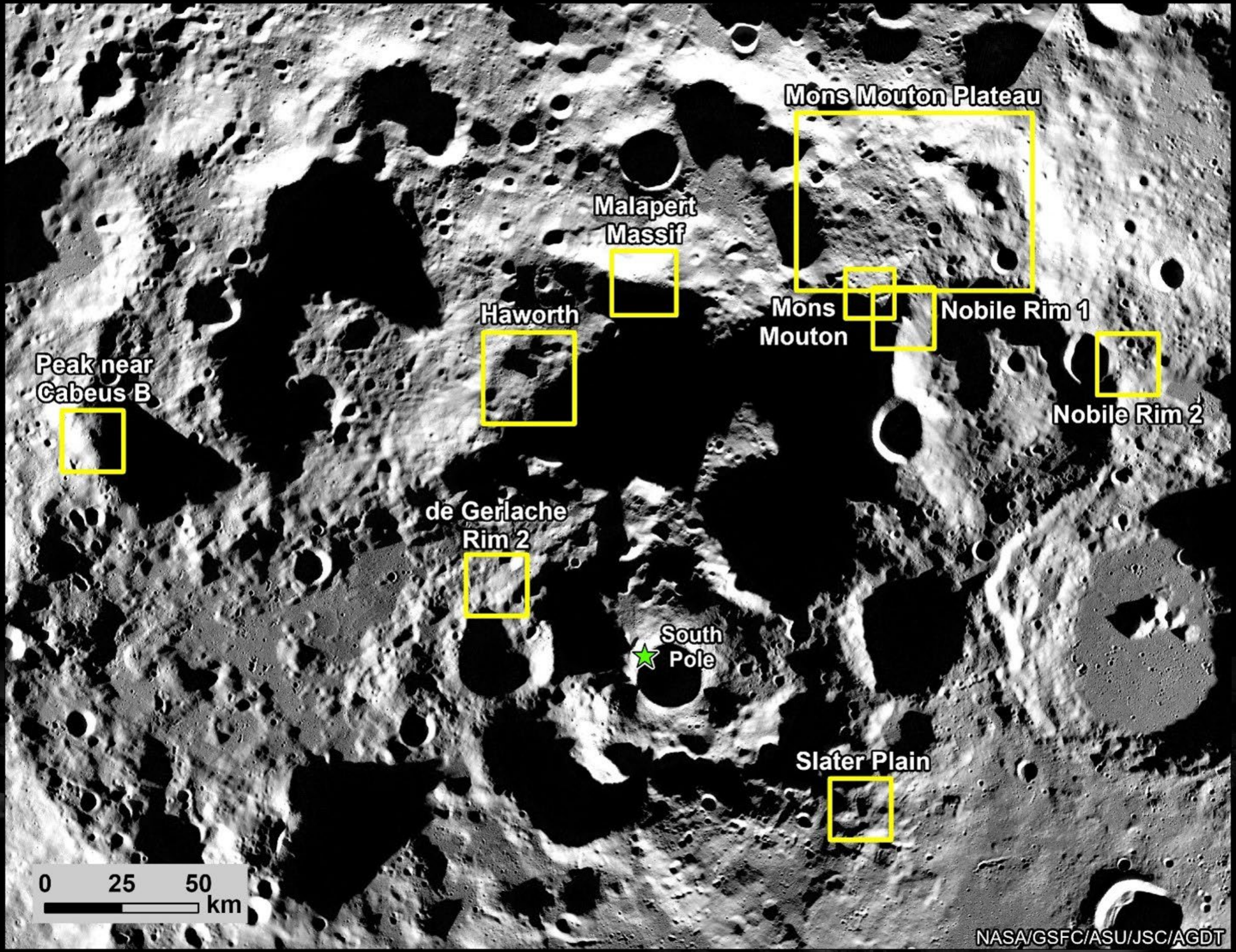


Figure 2. The equivalent electric circuit of an astronaut moving on the lunar surface. The astronaut can be modeled as a capacitor that collects charge during each step via contact electrification (or tribo-charging). As a consequence, the plate on the capacitor charges to +Q with a voltage $+V = +Q/C$. The capacitor electric field tries to draw an equal but opposite charge $-Q$ through the highly resistive ground, R_g, in order to make the object (astronaut) charge neutral. However, ambient plasma currents react faster than the ground currents (plasma on time scales τ^+ in equation (1)), providing a neutralizing electron current to the +V plate in direct proportion to the voltage on the plate (gain, g, is eV/kT_e).

Farrell et al., 2008
https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2008GL034785

How Site-Specific will Artemis Learning be?

In my opinion, the most important learning for applied science requires mission cadence and ‘reps’, rather than being deeply site specific.



Reminder: These NASA-defined regions are A3 specific.

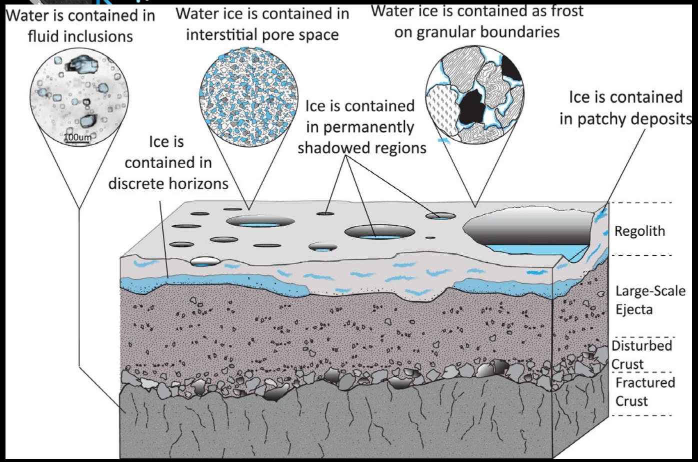
Gaps to fill later in Artemis for a sustained lunar presence (and onwards to Mars)

- Gap: Characterization of the ISRU resource.
  - Probably already know enough if the resource is just ‘regolith’. Challenge will be ability to process the needed volumes of material.
  - For an ISRU path reliant on water in PSRs, this requires knowledge of what usable resource is actually there.
    - Abundance / purity / contamination etc. (See next slide about VIPER)
  - Access and ability to work in very cold environments.
    - Knowledge of regolith properties in PSRs. Large PSRs might be outliers in porosity, roughness, geotechnical properties, rad/charging/plasma, etc.
- Gap: Plasma & charging environment, natural and induced, both in polar and non-polar environments. To a lesser extent, rad environment.
- Gap: Measurements to anchor seismic and impact environment.

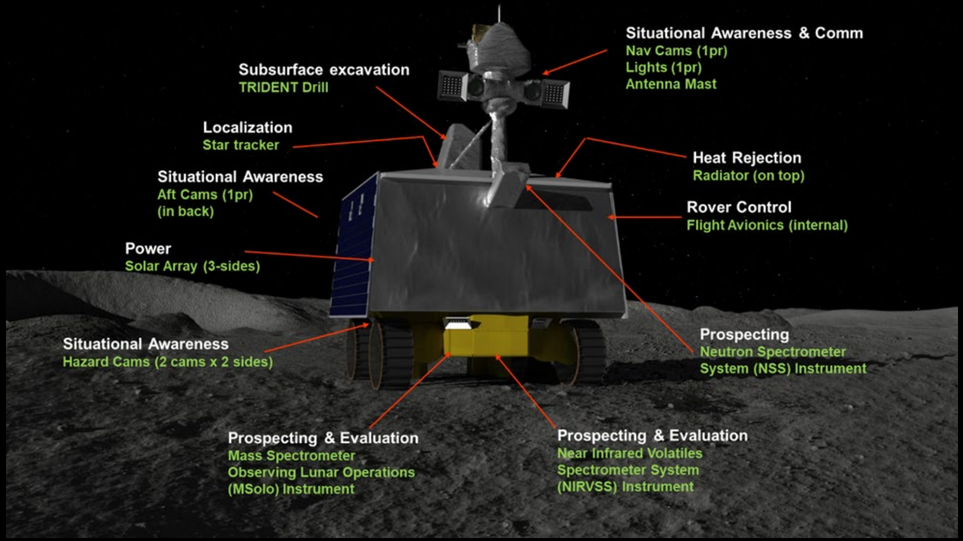
Long-term sustained exploration will require some degree of infrastructure, power, operations, logistics, autonomy...

Some of these are major gaps, even if they aren’t primarily technical.

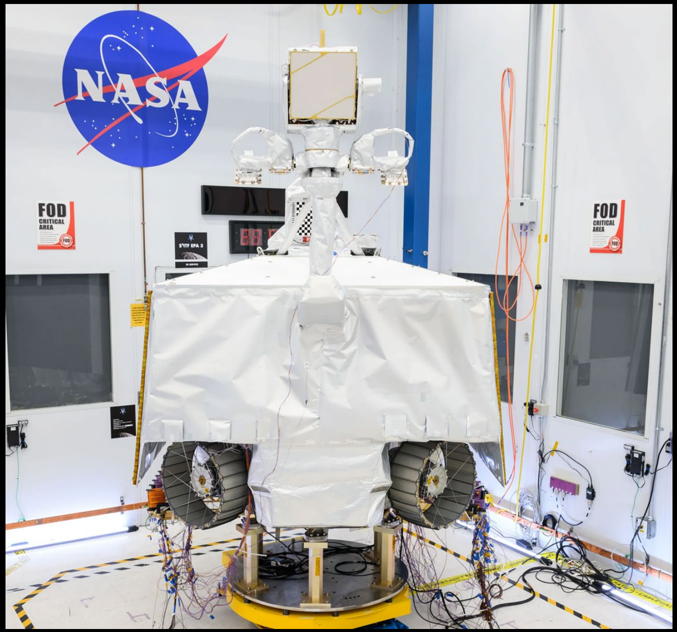
Benefits of a VIPER-like mission for resource evaluation



Coyan et al., 2025
https://iopscience.iop.org/article/10.3847/PSJ/adbc6c



Colaprete, 2021
https://ntrs.nasa.gov/citations/20210015009



(1) Surface temperatures at smaller scales than achievable from orbit, and relationship of environment to potential environments.

(2) Subsurface temperatures, regolith densities, and potential volatile stratigraphy in both lit regions and PSRs;

(3) Polar volatile sources, sinks, retention and distribution: required to identify regions with maximum potential for future resource utilization.

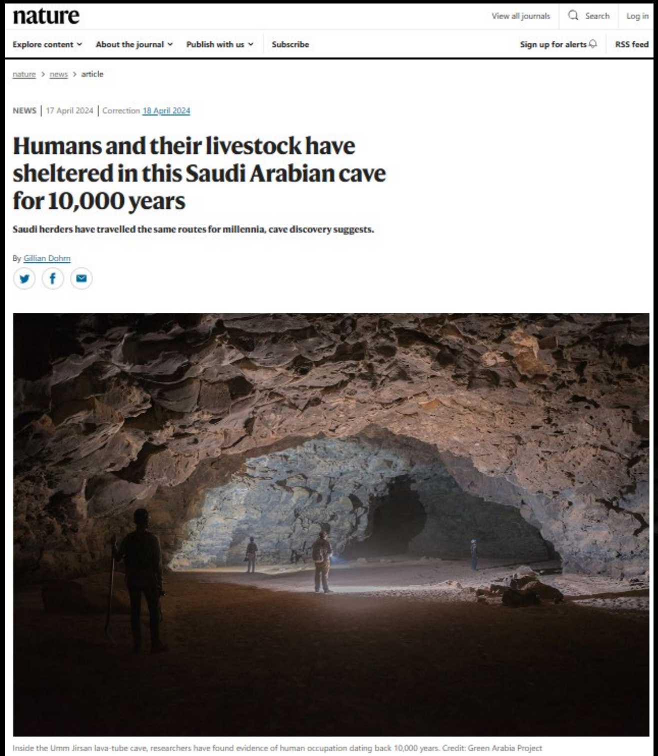
CLPS* contributions to Applied Science Knowledge

*Caveat: Skipping failures and investigations not currently manifested. Suggest talking to CLPS office/ESSIO about capabilities and outcomes from these experiments.

Investigations	Relationship of objectives to applied science
Blue Ghost payloads from March 2025 (Success!)	• Example: New measurements of plume-surface interaction during Blue Ghost descent, March 2, 2025. • Other data LEMS, RAC, LMS, LuSEE, etc…
FSS (Farside Seismic Suite) PI Mark Panning (JPL)	• New measurements of seismic and impact environments, relevant for future construction. • Regolith properties may prove useful for ISRU, deep subsurface exploration.
LITMS (Lunar Interior Temperature & Materials Suite) PI Bob Grimm (SWRI)	• Heat flow and electrical conductivity of crust • Deeper subsurface properties
Lunar Vertex PI Dave Blewett (APL)	• Investigation of unusual lunar swirls (surface changes caused (?) by magnetic anomalies)
Lunar-VISE (Vulkan Imaging and Spectroscopy Explorer) PI Kerri Donaldson-Hanna (UCF)	• Investigation of silicic domes
Venturi Astrolab's FLIP rover on Astrobotic Griffin	• Replaces VIPER, tests new mobility platform

Unique Non-Polar Applied Science

- Lunar Lava Tubes
  - Scientifically compelling (bedrock!!!) and potential as excellent natural shelters.
  - JPL’s Moon Diver concept is still a good idea!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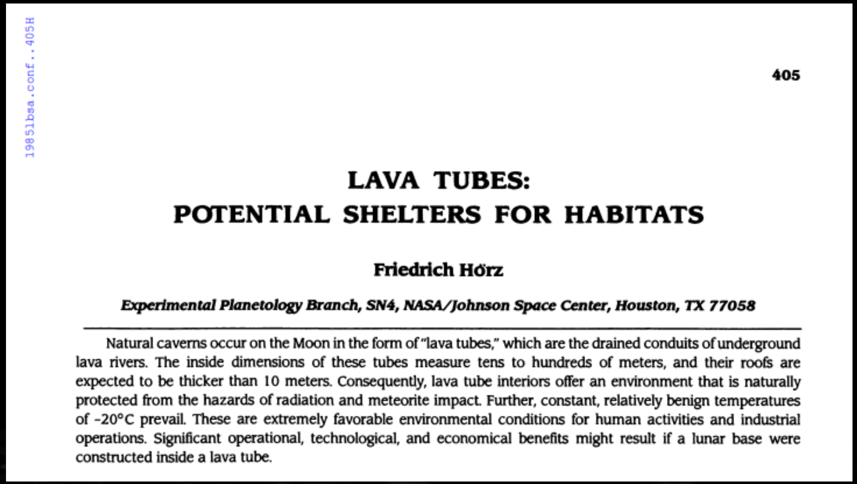
NEWS | 17 April 2024 | Correction 18 April 2024

Humans and their livestock have sheltered in this Saudi Arabian cave for 10,000 years

Saudi herders have travelled the same routes for millennia, cave discovery suggests.

By Gillian Dohm

Inside the Umm Jirsan lava-tube cave, researchers have found evidence of human occupation dating back 10,000 years. Credit: Green Arabia Project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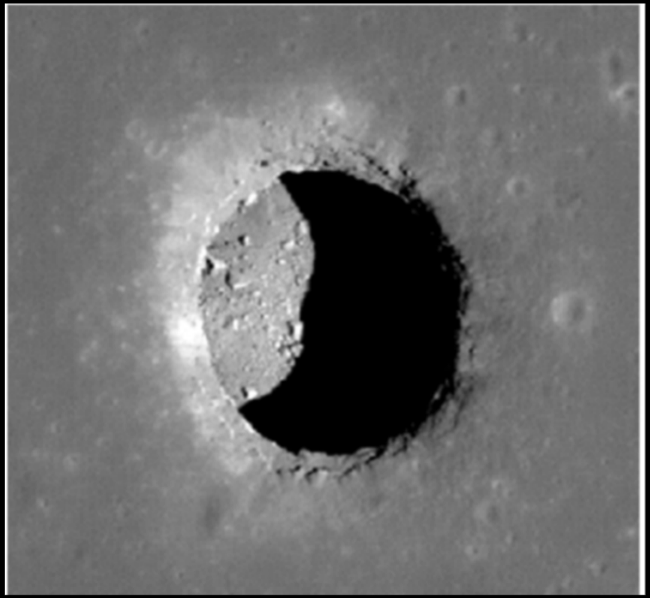
LAVA TUBES:
POTENTIAL SHELTERS FOR HABITATS

Friedrich Hörz

Experimental Planetology Branch, SN4, NASA/Johnson Space Center, Houston, TX 77058

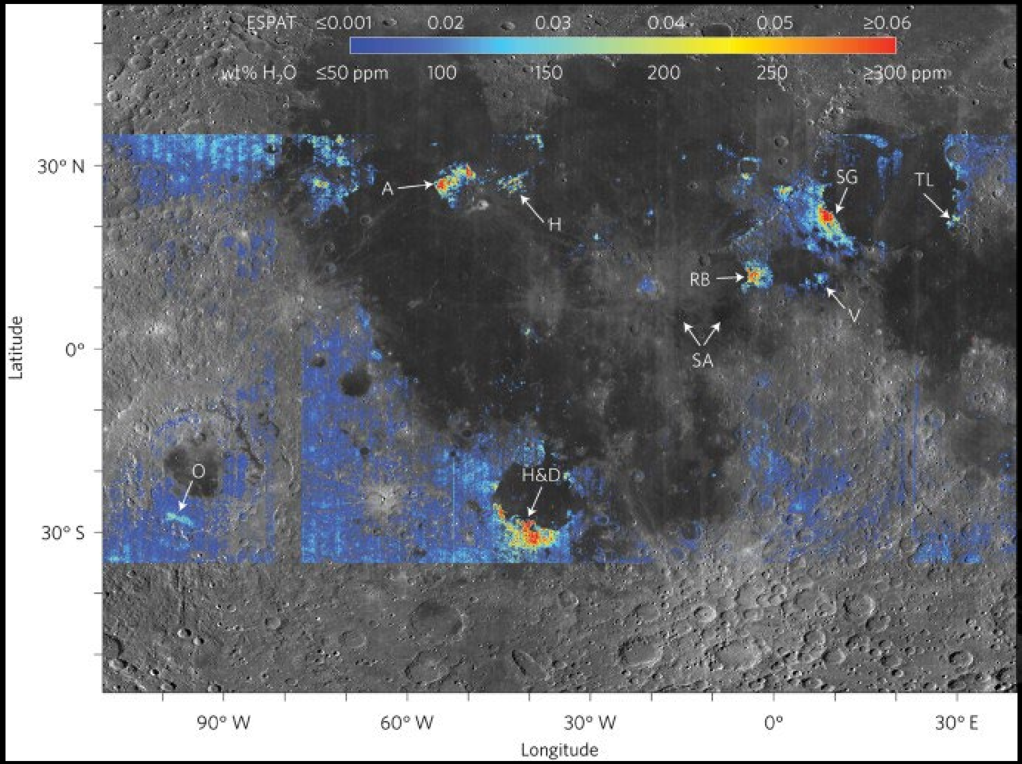
Natural caverns occur on the Moon in the form of "lava tubes," which are the drained conduits of underground lava rivers. The inside dimensions of these tubes measure tens to hundreds of meters, and their roofs are expected to be thicker than 10 meters. Consequently, lava tube interiors offer an environment that is naturally protected from the hazards of radiation and meteorite impact. Further, constant, relatively benign temperatures of -20°C prevail. These are extremely favorable environmental conditions for human activities and industrial operations. Significant operational, technological, and economical benefits might result if a lunar base were constructed inside a lava tube.



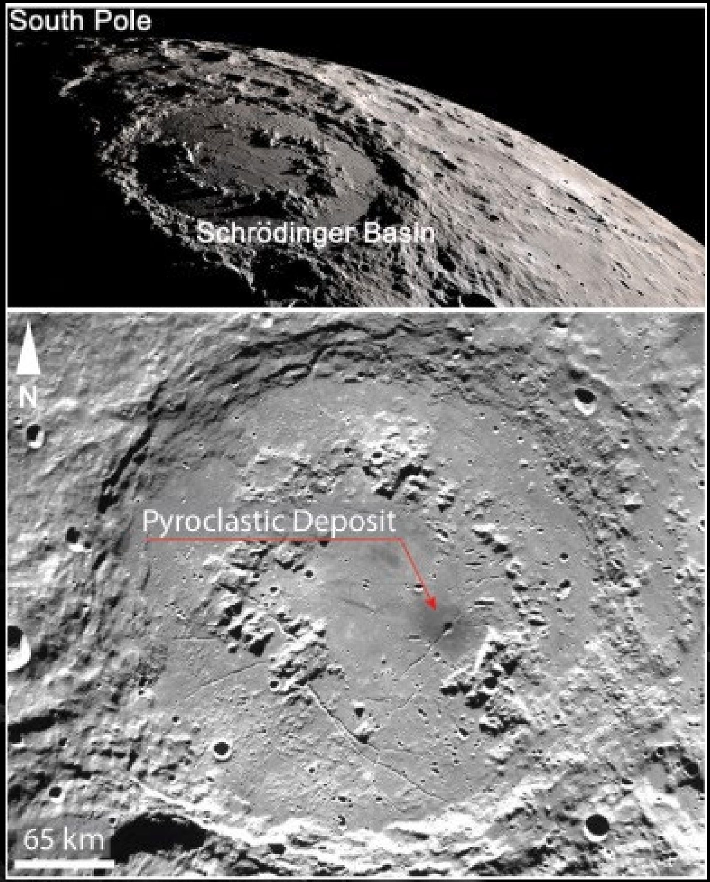
Mare Tranquililitatis Pit: M126710873R, M144395745L

Unique Non-Polar Applied Science

- Pyroclastic Deposits
  - ISRU that uses areas with abundant pyroclastic glass beads as feed stock…
  - No obvious pyroclastic vents are immediately near either pole. Schrödinger vent is likely the closest.



Milliken and Li, 2017
https://www.nature.com/articles/ngeo2993



Kring et al., 2025
https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2008GL034785

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