National Aeronautics and Space Administration

Lunar Science

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Program: FY22 R&TD Strategic Initiative
Strategic Focus Area: Lunar Science - Strategic Initiative Leader: John D Baker

Background:
Lunar Volcanism: The Moon Diver 2019 Discovery proposal, which aimed to send a two-wheeled, extreme terrain Axel rover into a 125-m lunar pit to determine the eruption conditions and compositions of a sequence of lava layers, was rated "low risk" in technical/management/cost, but received several specific science and science implementation-related weaknesses. This initiative proposes to retire these weaknesses. Research into these scientific foundations will also be applicable to mission concepts such as the long-range Endurance A and Intrepid missions and future PRISM proposals.

Lunar Water: Following water is a major new focus of the lunar exploration program. Although upcoming orbital missions will be able to determine the areal distribution of water in the lunar polar regions and temporal variation of modern water (e.g., Lunar Trailblazer), future science-driven missions to the lunar polar regions will be focused on where the ice came from: delivery by comets/asteroids, creation over time by solar wind processes, or outgassing from the Moon's interior. This initiative examines the signatures that would be expected from these different water sources.

Lunar Geophysics: The Lunar Geophysical Network (LGN) is a high priority in the lunar science community. JPL has invested in seismometer technologies and is currently leading a PRISM seismology mission to the lunar farside. This initiative investigates new ways to use seismometers to better achieve the goals of the LGN.

Objectives:
The Lunar Science Strategic R&TD was designed to mature science cases for three near-term lunar mission opportunity types: a mission focused on lunar volcanism (Moon Diver), a mission focused on lunar water (a Permanently Shadowed Region Explorer), and a mission focused on lunar seismology (e.g., the Lunar Geophysical Network). The first year focused on lunar volcanism and lunar water. Specific tasks in support of lunar volcanism included: 1. Collection of images and hand samples from analog lava sites, representing the end-members of what might be encountered by Moon Diver. 2. Analysis of sample composition and mineralogy using traditional laboratory methods; 3. Creation and analysis of datasets analogous to what would be produced by Moon Diver's instruments (APXS, Multispectral Micro-Imager) of the same sample suites; 4. Comparison of the laboratory analysis and interpretations with what can be interpreted from Moon Diver data. For lunar water, measurements were taken of lunar volcanic beads to assess their volatile fingerprints so that a potential volcanic origin of lunar polar water could be assessed.

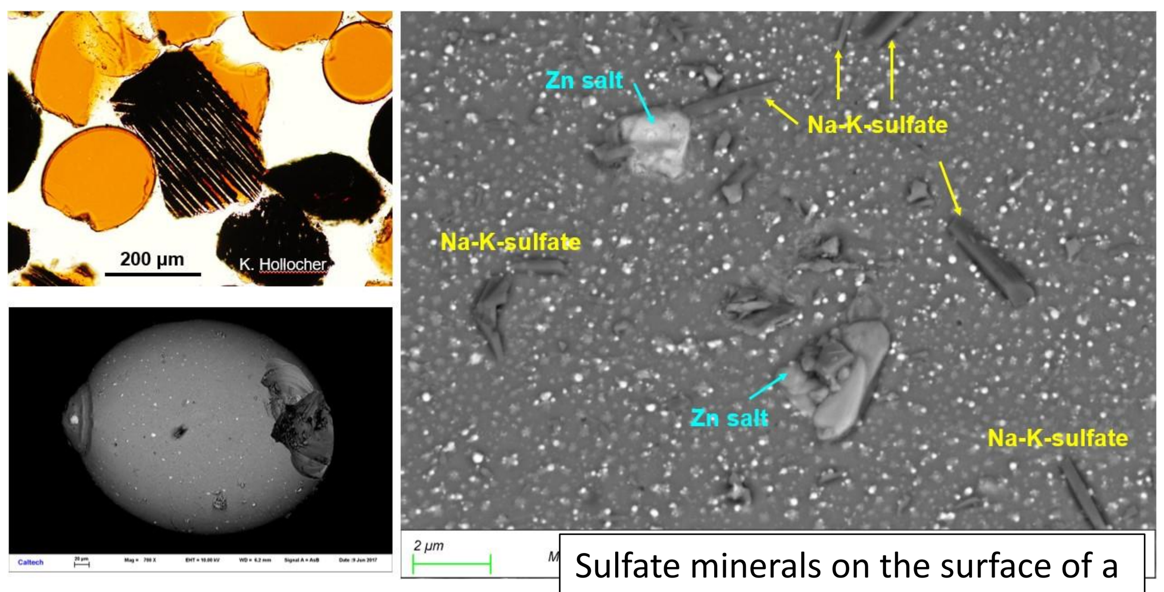
Approach and Results:
Lunar Volcanism: Two basalt end-member types are thin (<1 m) Hawaiian-type basalts (typical of low fluxes) and thick (>30 m) flood basalts (typical of high fluxes). This project studies these two lava types to determine whether Moon Diver's instruments are capable of reconstructing their end-member histories (including flux, effusion style, and petrologic origin). Samples and images from low-flux lava layers were already in hand from previous field work to a variety of volcanoes. New samples and images were collected from high-flux flood basalt lavas at Dry Falls, Washington, where ~60 m of flood basalts is exposed in accessible outcrops. The field team collected images, chemical analyses, and samples that mimic what Moon Diver would see during its descent.

Samples were imaged with both a high-end hyperspectral imaging spectrometer and the MMI breadboard. They were also analyzed with the PIXL breadboard and compared with results from a traditional XRF and petrographic microscope.

Digital elevation models (DEM) were produced using a uncrewed aerial vehicle and Axel's own cameras and analyzed to characterize the navigation and instrument placement conditions on the wall. The photos and DEMs produced were analyzed to determine the effusion type for the lavas. Two petrologic models were used to derive normative mineral abundances predicted by the measured chemistry. These were compared with observed modal mineralogy from the multispectral data and benchmarked against laboratory data. These results will be incorporated into the Moon Diver science traceability matrix.

Lunar Water: Isotopic and compositional traits that could be used to constrain different sources for lunar water were studied. To characterize volcanically derived water, Task Lead Liu examined, described, and analyzed condensed volcanic vapor on the surface of volcanic beads. She and her collaborator, Dr. Ma, from Caltech made a second discovery of a never-before-reported mineral (Na-K-sulfate) from volcanically condensed Na-K-sulfide (Liu and Ma, 2022). With her previous discovery of condensed Na-Cl-S-bearing metallic Zn, her results shed light on the volcanic gas of lunar pyroclastic eruptions. These findings suggest that volcanic ice in lunar polar regions would contain high abundances of Na, Zn and S.

Significance/Benefits to JPL and NASA: At the current time, opportunities for JPL to participate in lunar science and exploration are growing rapidly. The next few years represent a critical time during which JPL can establish a reputation in the lunar science literature, and conduct analyses that will be critical for future lunar mission proposals. This proposal supports science case development for three mission types.

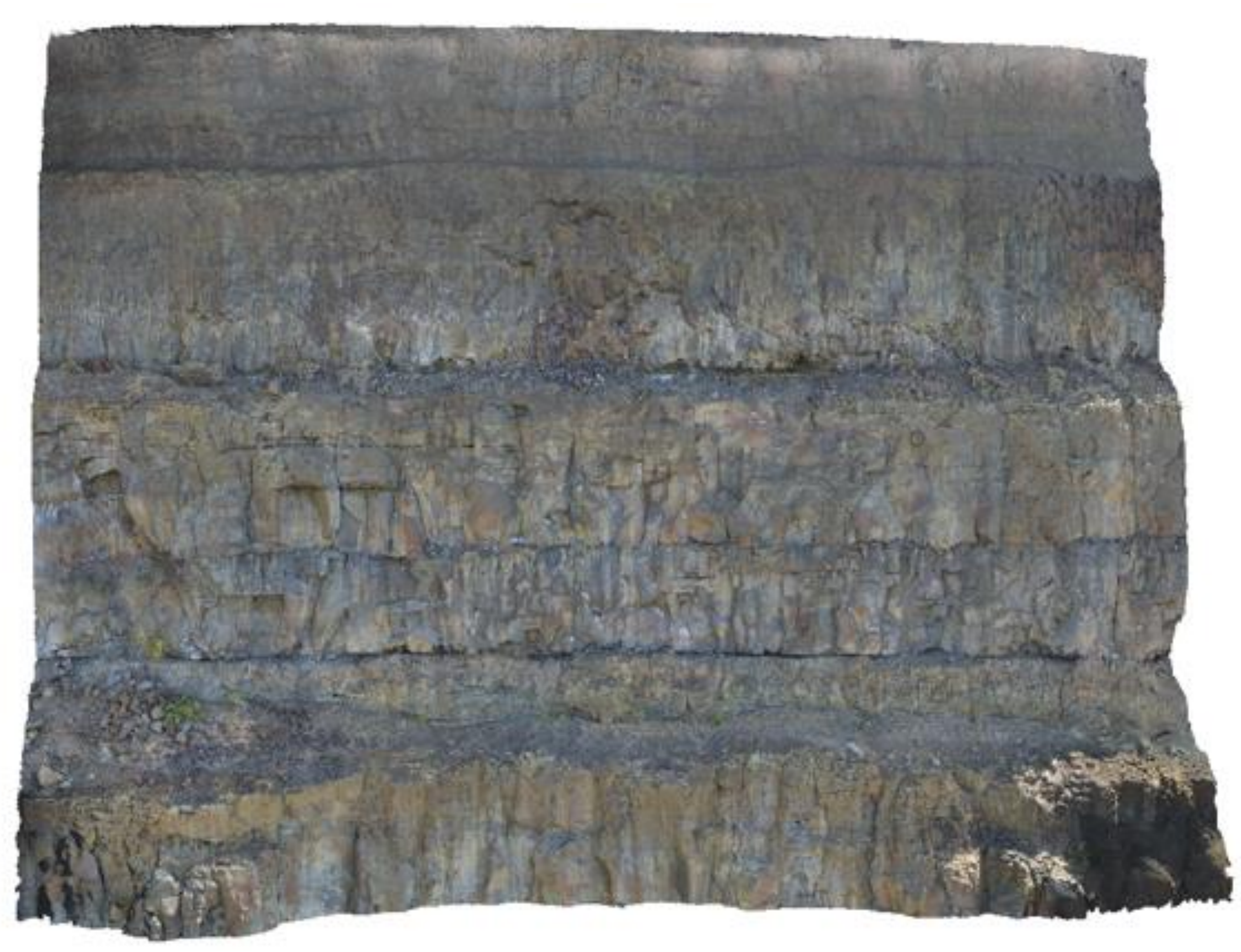


Sulfate minerals on the surface of a volcanic pyroclastic bead.

FarCam Imagery

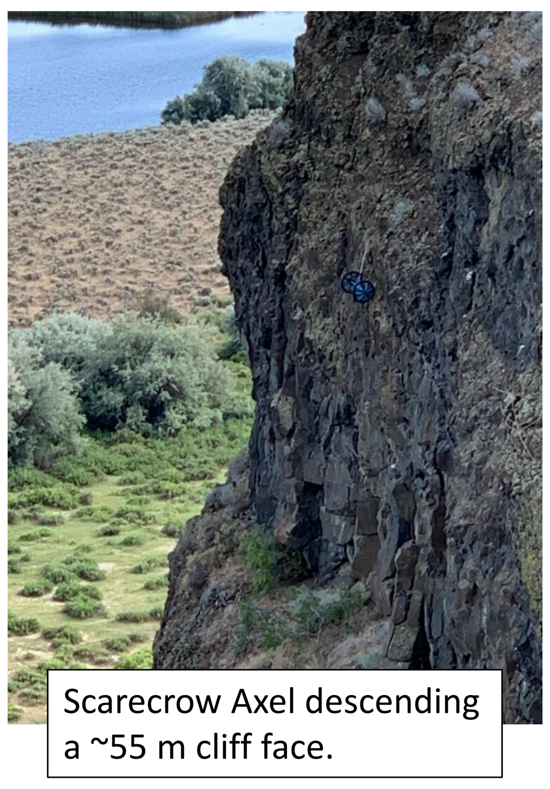
Low Flux Basalts

3-D models of high and low-flux basaltic cliffs



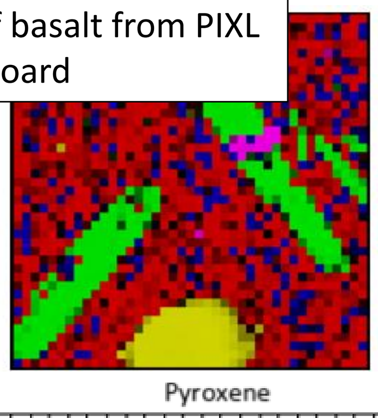
High Flux Basalts

CloseCam Imagery



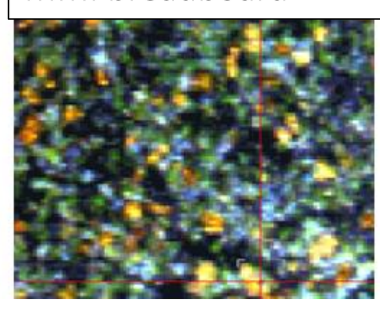
Scarecrow Axel descending a ~55 m cliff face.

APXS

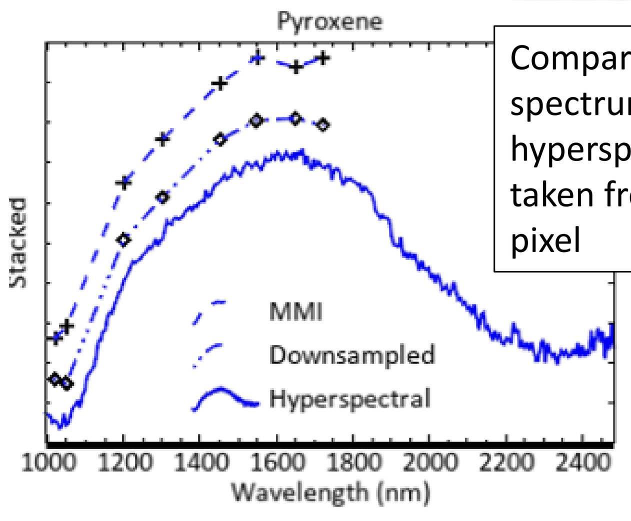


Elemental Chemistry Map of basalt from PIXL breadboard

MMI



False-color mineral map of coarse-grained from MMI breadboard



MMI

Comparison of MMI spectrum and hyperspectral spectrum taken from the same pixel

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Publications:

[A] Liu, Y., & Ma, C. "Direct evidence of volcanic outgassing of Na and K on the Moon from Apollo orange beads". *Icarus* **382** (2022), 115044.

[B] Kerber, L., Uckert, K., Hockman, B.J., Sellar, R.G., Nesnas, I., Denevi, B., Brosky, M., Wire, N., Hooker, A., Agner, R., Kestay, L., Grove, T., Prissel, T., Hannahs, C., Moore, N., Brockers, R., Khuller, A., Balint, T. "Moon Diver: Descending into the Geological History of Lunar Volcanism" 73rd International Astronautical Congress (2022), IAC-22-IAC-22/A3/2B-72741

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