FY24 Strategic Initiatives Research and Technology Development (SRTD)

Lunar Science

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Strategic Focus Area: Lunar Science/ Moon and Mars Extreme Cold, Steep Terrain Rover | **Strategic Initiative Leader:** John D Baker

Objectives and Significance to JPL: This task for FY24 included two subtasks, titled “Lunar Water” and “Lunar Geophysics”. The Lunar Water subtask focused on studying the volatiles that were outgassed from lunar volcanic eruptions by investigating the interior walls of vesicles in lunar basalts and the exteriors of lunar pyroclastic glass beads. This initiative positions JPL to be a leading expert in lunar sample analysis.

The Lunar Geophysics subtask focused on investigating whether deploying clusters of seismometers to locations on the Moon might mitigate the strong scattering of seismic signals that is characteristic of the Moon. This SRTD investment initiative allows us to quantify the potential advantages of the cluster approach over other current approaches. This work is motivated by the desire to be able to propose an improved version of the Lunar Geophysical Network mission as currently scoped-- potentially as a series of CLPS missions.

Approach and Results:

Lunar Water: Vapor deposits were characterized using a ZEISS 1550VP field-emission SEM for surface imaging and elemental analyses. Surfaces of samples were imaged using secondary electron (SE) and backscattered electron (BSE) modes in high vacuum. Compositions were determined using an Oxford X-Max SDD Energy Dispersive Spectrometer (EDS) system attached to the SEM and a JEOL JXA-iHP200F electron probe micro-analyzer (EPMA). Results: In recently opened Apollo samples, we discovered NaCl (halite) on black beads. The textural relationship suggests NaCl may have formed after the beads deposited on the surface by reacting Na2S with subsequent outgassed Cl. This work is now accepted by JGR- planet in the special volume for ANGSA (Apollo Next Generation Sample Analysis) (Liu et al., 2024a). Second, we made the first discovery of FeS/Fe condensate on Apollo 15 yellow beads. We presented results at LPSC 2024. The examination of vesicle walls of vesicular basalts has yielded many interesting discoveries. In this funding period, we reported the finding of apatite straw mats on vesicle walls suggesting the final melt/fluid at the end of mare basalts solidification is very low viscosity, the non-equilibrium growth of the apatite needles do not represent the bulk volatile budget.

Lunar Geophysics: We compared arrays of seismometers in 500 m and 5000 m rings. At these distances, we found that the signal-to-noise ratio does not improve by stacking (LG1; FY24). We based our seismic models on models calibrated with the artificial impacts. We created simulations of shallow moonquakes using a model of the Moon which includes a 50 km thick scattering layer. The 500 and 5000 m rings produced waveforms that were different enough that the waveforms did not correlate onto the start time of the arrival. The signals are emergent and so do not have a strong pulse on which to correlate on. Additionally, small variations meant that two random pulses often correlate. Therefore, the arrays do not improve results by stacking. We are still testing the hypothesis that by stacking signals from seismic stations different distances apart, we could remove the effects of random near-surface scatter and illuminate the core-mantle and crust-mantle boundaries (LG2; FY24). They are not visible by eye in the seismograms (we calculate phases of interest using TauP to help us). We are implementing further array processing techniques (including waveform polarization and vespagrams). We are writing a paper for Earth and Space Science on ‘Farside Seismic Suite: A Pathway to Implement a Lunar Seismic Network via Commercial Missions’ and we have submitted an abstract to LEAG. We are bringing together the results from the final seismometer tests and the lessons learned from the build. The paper will assess the science goals which can be achieved via the commercial route. We shared the LEAG submission with the FSS science team, who were very supportive of the idea. We also have the possibility of seismic network on the Moon in the next few years through international collaboration.

Figure 1: Ilmenite (titanium oxide) crystals in an SEM image of a lunar sample.

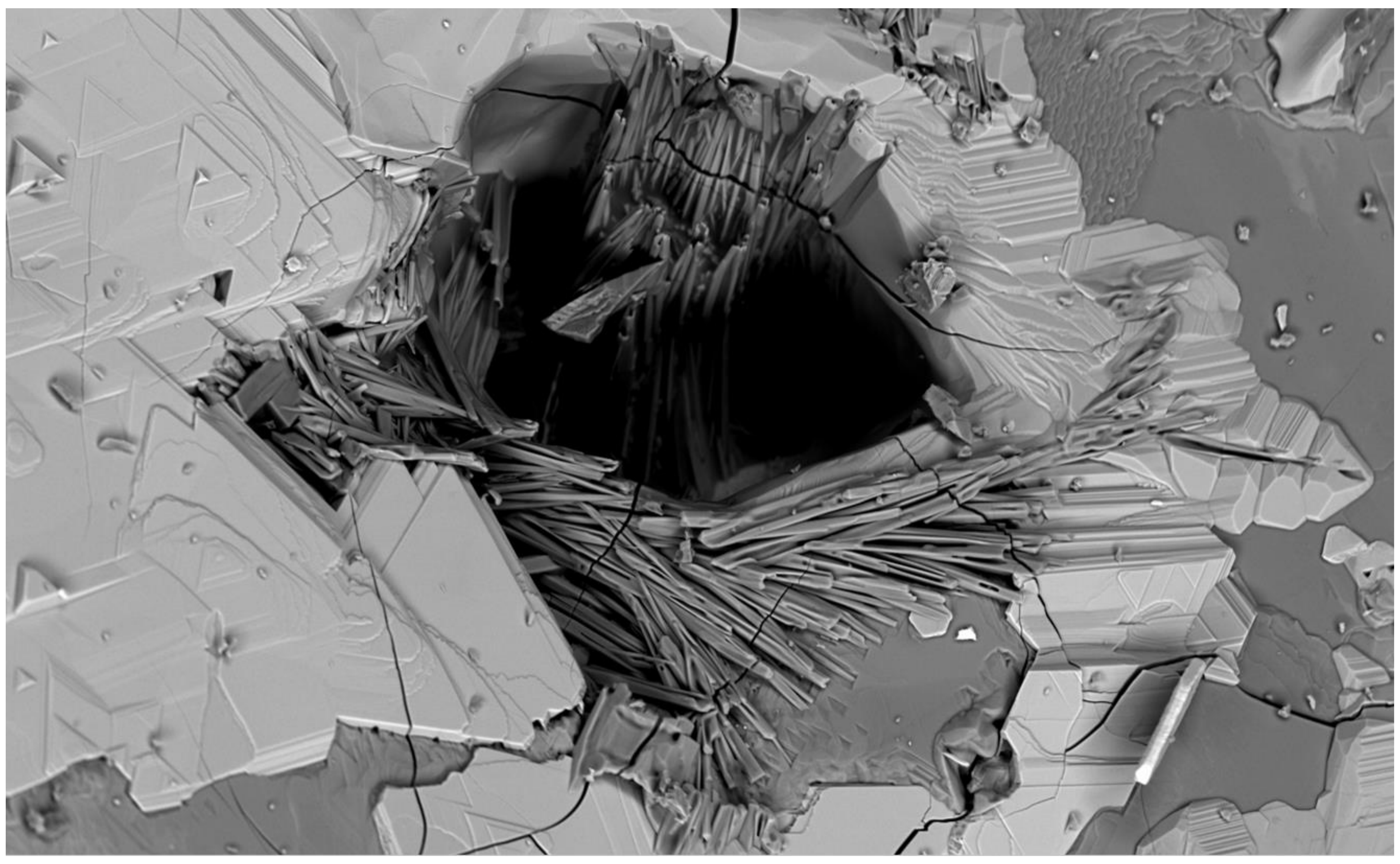

Figure 2: A “straw mat” of fluorapatite (phosphate) in the vesicle of a lunar sample (SEM image).

Publications:

[A] Farside Seismic Suite: A Pathway to Implement a Lunar Seismic Network via Commercial Missions; C. Nunn, M. P. Panning, S. Kedar, N. Bowles, S. Calcutt, M. Drilleau, R. Garcia, A. Horleston, T. Kawamura, P. Lognonné, E. Miller, D. Mimoun, W. T. Pike, S. de Raucourt, R. Weber, LEAG 2024, Abstract #5027 [B] Liu, Y., Ma, C. (2024a). Vapor condensates on the most pristine black beads from a clod in Apollo drive tube 73001: Discovery of lunar NaCl nanocrystals. Journal of Geophysical Research (accepted). [C] Y. Liu, C. Ma (2024b). Fluorapatite Needle Mats on Vesicle Walls in Apollo 15556 from Final-Stage Water-Rich Liquids. – GRL paper under revision, plan to resubmit by the end of September 2024 [D] Y. Liu, C. Ma, S. Eckley (2024c). Copper sulfide on Vesicle Walls in Apollo 15556 – Nature Geoscience, paper under revision

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