The missing link: connecting remote observations to samples

White Paper submitted to: The Artemis Science Definition Team

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Introduction: Traditional field geology begins with large scale preliminary observations. In planetary science this remains true and in the case of the Moon, missions can be supported by meter-scale panchromatic and compositional imagery. These meter-scale data sets are used prior to arrival to assess potential areas of interest, landing sites, and hazards and form the basis of traverse planning. From orbit, however, it is not possible to have a local scale level of understanding of the site as these data can be affected by viewing geometry and/or atmospheric interference.

At a local scale, field geology is typically conducted using the unaided eye. However, to the unaided eye, many compositional variations are subtle or impossible to detect. For example, an astronaut may be trained to sample anorthosites by collecting white rocks, but if instead they are to collect a “wet rock”, they would be unable to identify one solely using their eyes. Remote sensing tools beyond the range of human vision are required.

During the Apollo missions, astronauts conducted experiments and geologic field work on the lunar surface. Of the twelve astronauts to set foot on the Moon, only one (Harrison Schmitt) had formal training in geology and field work. It was his keen-eye that spotted the orange soil that would later lead to revolutionary discoveries about the Moon [1-3]. The finding of the orange soil, however, relied upon a visual difference between the orange soil and the surrounding material and the expertly trained eyes of the crew. Unlike the orange soil, many compositionally interesting materials do not show unique colors in the visible or the variation with respect to its surroundings is so subtle that it cannot be detected by the unaided human eye [4].

Rover-based Reconnaissance: The addition of rover-based instruments aimed at acquiring compositional information of a scene prior to an astronaut setting foot onto the lunar surface will complement the human perception by providing information outside the human visual capabilities. Rover-based reconnaissance maps processed in real-time prior to astronauts performing an extra vehicular activity (EVA) can aid in planning a better and more efficient traverse path that will provide the highest sample return value. The maps will also provide information for inaccessible outcrops where in situ measurements and sampling are not possible, and they can be used to relate more accessible samples (such as displaced rocks) to intact stratigraphy [5] and allow for faster definition of units in a quantitative manor. Such a data set can also be used to connect meter-scale orbital and Earth-based remote sensing to collected samples.

There are three main advantages for implementing mineralogical and geochemical instruments into field work: 1) documentation of major compositional variations, 2) enhancement of visibly subtle or concealed variability in (sub) units, and 3) characterization of inaccessible outcrops [5]. Work conducted by Ito et al. (2018) [5] demonstrates ground-based spectral mapping of local terrain and its use during field analog work with the RIS^{4}E (Remote, In Situ and Synchrotron Studies for Science and Exploration) SSERVI (Solar System Exploration Research Virtual Institute) team. They conclude that spectral mapping of the local area from the surface of a planetary body provides a critical link between orbital imaging and in-situ measurements and samples. In addition, there has been a recent recognition that surface activities including landing can disturb the environment near the landing site. Up close remote sensing can characterize the undisturbed surface away from the landing site and detect fragile components such as volatiles that may be altered by sampling.

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Astronaut-based Instrument: Once on an EVA, astronauts should be provided with real time display or other feedback regarding the presence of decimeter sized compositional anomalies, including the ability to map large exposed breccias aimed at detecting key small clasts for sampling. This will allow the astronauts to see geologic features beyond the human visual capabilities and collect samples that are of high interest maximizing the sample return value. An astronaut-based instrument that provides compositional information can add additional sample context.

Scientific Context Example: Here we provide an example of how such a capability can be of use. Samples returned by the Apollo program contain volcanic glass beads (the orange soil collected by Harrison Schmitt) that originated from a pyroclastic eruption. After extensive studies, the pyroclastic glasses revealed hydrogen with abundances ranging from 4 to 46 ppm water equivalent hydrogen [3]. These glasses underwent diffusive degassing and numerical modeling estimates the pre-eruptive water content ranging from 260 to 745 ppm [3].

Following the discovery of water within pyroclastic glasses, three independent spacecraft observed a 3 μm hydration band across the lunar surface [6,7,8]. The Moon Minerology Mapper (M^3) onboard Chandraayn-1, provided global coverage of the Moon and has been used extensively to study the 3 μm hydration band. At pyroclastic deposits, M^3 measures hundreds of ppm of water [9], closer to the estimated pre-eruptive water contents [3,9]. The higher abundances measured by M^3 are explained by being adjacent to fissures and potential vents where the vapor cloud is likely the most dense or by the particle size not being accounted for in the estimate of abundance of water [9].

With the capability to identify water at local scales in real time from a rover- or astronaut-based instrument, this issue could be resolved. Orbital data provides the distribution of pyroclastic deposits and the general area of enhanced water. A mission to one of these locations for resource utilization is highly possible and an instrument capable of identifying water within a scene can provide astronauts with exact locations of the water and samples to collect. Once returned to Earth, these samples (under lunar like conditions and avoiding terrestrial contamination, or even on the lunar surface before contamination can occur) can be analyzed for their abundance of water present and their sizes measured. This three-part process would allow for better definition of an algorithm to estimate abundances of water from orbital and Earth-based remote sensing data sets.

Conclusion: Currently, there is a missing link in the scale between remote sensing of the Moon and samples collected. Selected samples, local-scale remote sensing, and global-scale remote sensing can all be linked provided a local-scale data set is collected. The samples provide the actual abundance present and an algorithm can be defined to calibrate the local- and global-scale remote sensing data to provide more accurate abundance measurements.

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