RECONAISSANCE USING NIR SPECTROSCOPY: LESSONS LEARNED FROM THE MOON.

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Introduction: From telescopic through orbital spacecraft measurements, near-infrared (NIR) data have provided critical data for understanding the composition of our Moon. Hyperspectral near-infrared data of the Moon from several missions in the last decade, including Chandrayaan-1 and SELENE have provided an unprecedented high-spatial resolution view of the mineralogy of the lunar surface. Coupled with laboratory measurements of samples returned from the Apollo missions, these observations have advanced our understanding of the compositional diversity and petrogenetic history of the lunar surface.

Synergy Between NIR Remote Measurements and Sample Return: Telescopic NIR color observations of the Moon were used to evaluate differences between potential Apollo landing sites, although minerals could not be explicitly identified [1]. The quality and spectral resolution of NIR spectroscopic measurements evolved rapidly in parallel with the collection and analysis of Apollo and Luna samples [e.g., 2,3], as laboratory spectroscopic measurements of the Apollo samples provided ground-truth measurements that could be used to enable or improve instrument calibrations. Today, NIR measurements provide the highest spatial-resolution compositional information that can be detected from orbit, and extensive laboratory measurements of extraterrestrial (meteorite and returned) and terrestrial samples have dramatically increased our understanding of the fundamental reflectance properties of minerals and planetary regoliths.

Key Lessons Learned from the Moon: Though there have been many lessons learned over the almost 50 years since samples were returned from the Moon, three topics stand out as being critically important to relating telescopic or orbital measurements to mineralogy: (1) mineral physics – understanding how small differences in the crystal lattice or mineral composition affect spectral properties; (2) space weathering – understanding how exposure to the space environment may affect the uppermost surface of the minerals in a planetary regolith; (3) photometry – understanding how regolith texture, porosity, and viewing geometry affects the reflectance measured by a sensor. The lunar experience has led to advances in each of these sub-disciplines, enabling remote interpretation of surfaces throughout the solar system. However, each is still rich with unanswered questions.

Mineral Physics: At near-infrared wavelengths, transition metal-bearing minerals exhibit strong, distinctive absorption bands that allow mineral composition to be evaluated [e.g., 4-5]. Depending on the mineral structure and the cations substituting into that structure, NIR data can be used to quantify mineral compositions to different levels of uncertainty. Transition elements such as Fe, Cr and Ti can be identified by absorption bands at visible and infrared wavelengths, while elements such as Mg, Al and Na can only be inferred based on the way their presence affects the structure of the crystals, and thus the positions of the major iron absorption bands. Understanding how mineral substitutions and oxidation state affect mineral spectral properties is critical to evaluating the origin and evolution of solid bodies in the solar system.

Space Weathering: Microscopic analysis of lunar samples led to the discovery that exposure to the space environment, in particular the solar wind and a constant barrage of micrometeorites, results in the formation of glassy agglutinate particles and nanophase iron coatings on mineral grains in the regolith [e.g., 6]. Because NIR spectroscopy is sensitive to the uppermost surfaces of regolith grains, space weathering can drastically alter the regolith spectral properties. Lunar samples have been critical for understanding this process, but many questions about how space weathering evolves the optical properties of other bodies in the solar system remain. Laboratory studies are used to simulate solar-wind or micrometeorite bombardment to provide insight to extrapolate the lunar understanding to other airless bodies, but only returned regolith samples can directly test our understanding of these processes.

Photometry: Though the fundamental physics of radiative transfer and scattering have long been studied, models for the photometric response of complicated surfaces with varying degrees of roughness, porosity, and weathering [e.g., 7]. Returned samples and resolved orbital data of planets and asteroids enable photometric response to be studied at a range of scales, improving photometric models.

Conclusions: Missions such as Hayabusa-2 and OSIRIS-REx will provide critical data for understanding the mineral composition, space weathering, and photometric properties of C-type asteroid regoliths. NIR data will both assess the diversity of materials on each asteroid and place landing sites into their geological context. Coupled with the laboratory studies of the returned samples, the value of these NIR data increases drastically, building our foundation for interpreting telescopic and orbital spectral data of the entire solar system.

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