From mineral mapping to Moon bases: ISRU-oriented hyperspectral analysis of lunar terrains

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From an in situ resource utilization (ISRU) perspective, the selection of landing sites characterized by high mineralogical resource potential is a critical prerequisite for the development of a sustainable lunar infrastructure. This study presents a comparative mineralogical analysis of four geologically diverse regions – Aristarchus, Malapert, Mare Tranquillitatis, and the Leibnitz crater – using hyperspectral data acquired by the Moon Mineralogy Mapper (M^3) instrument onboard the Chandrayaan-1 mission (Pieters et al., 2009). These sites were selected based on geological diversity and relevance to future crewed missions, as well as operational constraints such as terrain slope, communication feasibility, and environmental stability. Representative reflectance spectra were extracted from spatially subset M^3 data cubes and compared to laboratory spectra from the RELAB database (NASA PDS, 2020) using a suite of established spectral similarity algorithms including Spectral Angle Mapper (SAM), Spectral Information Divergence (SID), and Adaptive Coherence Estimator (ACE), implemented in the ENVI software. Prior to spectral analysis, data underwent standard preprocessing including radiometric, thermal, and photometric correction, followed by spectral denoising. A spatial and spectral subsetting was also performed to isolate the regions of interest and eliminate data anomalies at image edges. The operational hyperspectral workflow followed the established Spectral Hourglass approach, including Minimum Noise Fraction (MNF) transformation, Pixel Purity Index (PPI), N-Dimensional Visualizer clustering, and Linear Spectral Unmixing (LSU). These methods enabled the identification and mapping of key mineralogical units such as plagioclase, low- and high-Ca pyroxenes, ilmenite, and spinel. Notably, the Malapert region showed strong plagioclase signatures consistent with anorthositic highlands, while Mare Tranquillitatis revealed spectral features of high-Ca pyroxenes and ilmenite, indicating basaltic compositions with significant ISRU potential. Through the integration of mineralogical remote sensing data with principles of sustainable design and resource-based site assessment, this work provides a multidisciplinary framework to support the strategic selection of sites for long-duration lunar habitation and development.

NASA PDS (2020) - RELAB Spectral Library Bundle. NASA Planetary Data System, https://doi.org/10.17189/1519032.
Pieters C.M. et al. (2009) - The Moon Mineralogy Mapper (M^3) on Chandrayaan-1. Curr. Sci., 96(4), 500-505.