

USING MINERAL MIXTURES ACROSS THE LUNAR MINERALOGY TERNARY TO INTERPRET LRO DIVINER AND FUTURE THERMAL INFRARED DATASETS B.T. Greenhagen¹, C.M. Wagoner¹, C.N. Yasanayake¹, K.L. Donaldson Hanna², N.E. Bowles³, and P.G. Lucey⁴; ¹Johns Hopkins Applied Physics Laboratory, ²University of Central Florida, ³University of Oxford, ⁴University of Hawaii. Email: benjamin.greenhagen@jhuapl.edu

Introduction: On airless bodies, the uppermost portion of regolith, the “epiregolith”, represents the boundary layer between the surface and space that dominates spectral observations from far-ultraviolet reflectance to far-infrared emission. On the Moon, this layer is typically less than 2 mm in thickness and is estimated to be characterized by significant thermal gradients ($\sim 60\text{K} / 100 \mu\text{m}$) [1]. These thermal gradients make spectral emission from the Moon wholly different from Earth and Mars (where the epiregolith is essentially isothermal) and complicate the interpretation of spectral emission remote sensing data. Therefore, thermal infrared (TIR) spectroscopy experiments and spectral libraries measured in ambient laboratory conditions are not comparable to remote sensing datasets of airless bodies that contain significant emission components.

We work to overcome this challenge by measuring TIR emission spectra in a chamber that illuminates and heats particulate samples under vacuum to generate a thermal gradient akin to that found in the epiregolith of airless bodies. Simulating the lunar environment allows us to measure TIR spectra that are directly comparable to remotely sensed TIR observations from the Diviner Lunar Radiometer (Diviner) instrument aboard the Lunar Reconnaissance Orbiter (LRO).

Here we characterize the TIR emission spectra of two- and three-component silicate mineral mixtures with the endmembers plagioclase, pyroxene, and olivine. These uniform composition and particle-size endmembers bound the typical mineral compositions of the lunar surface (*Figure 1*). By understanding the TIR characteristics of these mixtures, we can better interpret Diviner and future TIR datasets and their implications for surface compositions on the Moon and other airless bodies.

Simulated Lunar Environment: In nearly 50 years of laboratory experiments, it has been established that thermal emission spectra measured in a simulated lunar environment (SLE) are significantly altered from spectra measured under terrestrial conditions [e.g. 1-4]. The data for this study were collected in the Simulated Airless Body Emission Laboratory (SABEL) chamber at the Johns Hopkins Applied Physics Laboratory. The lunar environment is simulated by (1) pumping the chamber to vacuum pressures ($<10^{-4}$ mbar), which is sufficient to simulate lunar heat transport processes within the sample, (2) cooling the chamber with liquid nitrogen to simulate a surface radiating into a cold space environment, and (3) simultaneously heating the sample

with cup heaters and illuminating the surface with a lamp to set up thermal gradients similar to those experienced in the top 100s of microns of the lunar regolith. This study used the environmental conditions described in [5], which through groundtruthing of Diviner observations and laboratory experiments on Apollo soils found the best consistency by matching the illumination to the expected flux for the given chamber incidence angle (~ 50 degrees).

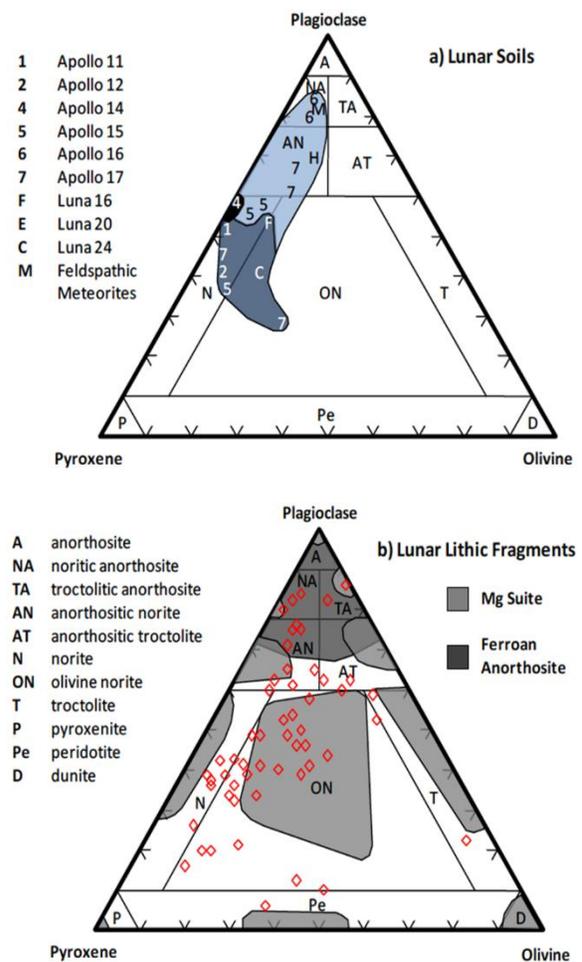


Figure 1: Lunar mineralogy is well-represented with a ternary of three silicate minerals (plagioclase, pyroxene, and olivine). Lunar soils are generally found to have noritic compositions (top; modified after [6]). However, lithic fragments and observations of crater central peaks (red diamonds) span the full range of compositions (bottom; modified after [7]).

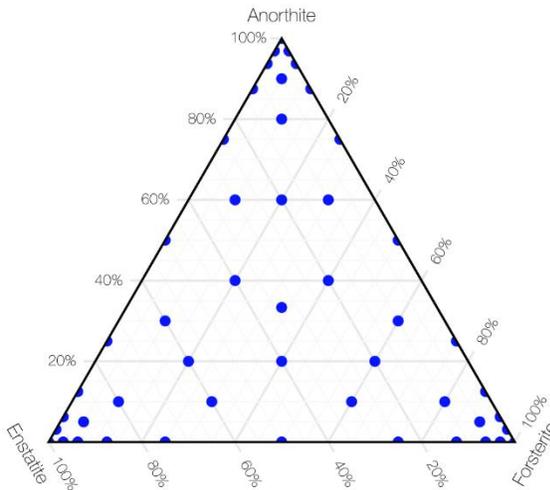


Figure 2: This study includes 49 total samples: 3 endmembers, 27 two-component mixtures, and 19 three-component mixtures (blue dots). All mixtures are shown in vol% of the endmembers.

Samples: Our sample suite is composed of terrestrial minerals with reasonably similar chemistries to lunar minerals. For plagioclase, we use Miyake Jima anorthite (~An95) that was manually picked and magnetically purified to remove basaltic coatings. For pyroxene, we use gem-quality Tanzanian enstatite (~Mg90). And for olivine, we use gem-quality San Carlos olivine (~Fo90). All minerals were crushed and sieved to particle size fractions less than 32 microns. A CAMSIZER was used to verify similar particle size distributions for each mineral endmember. Mixtures with 49 unique compositions were produced (*Figure 2*) and measured using SABEL.

Results: We found that the position of the Christensen feature (CF), a TIR emissivity maximum, in the two- and three- component mixtures followed smooth, generally linear trends across most compositions (*Figure 3*). The trends became non-linear at the highest olivine compositions. Additionally, the slope across the ternary was significantly different between endmember interpolations and mixture interpolations. An incomplete understanding of these factors could lead to an underestimate of olivine abundances, especially in olivine-rich lithologies. Importantly, the uniformity of these measurements lead confidence that mineral compositional constraints can be enhanced when both near-infrared and TIR data are included.

References: [1] Henderson B.G. et al. (1996) *JGR*, 101. [2] Logan L.M. et al. (1973) *JGR*, 78, 4983. [3] Thomas I.R. et al. (2012) *Rev.Sci.Inst.*, 83 (12), 124502. [4] Donaldson Hanna K.L. et al. (2017) *Icarus*, 283, 326-342. [5] Greenhagen B.T. et al. (2019) *LPSC 50*, Abstract

#2751. [6] Lucey P.G. et al. (2004) *GRL*, 31, L08701. [7] Cahill J.T.S. et al. (2009) *JGR*, 114, E09001.

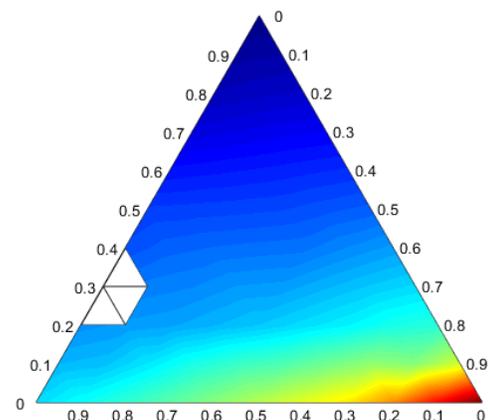
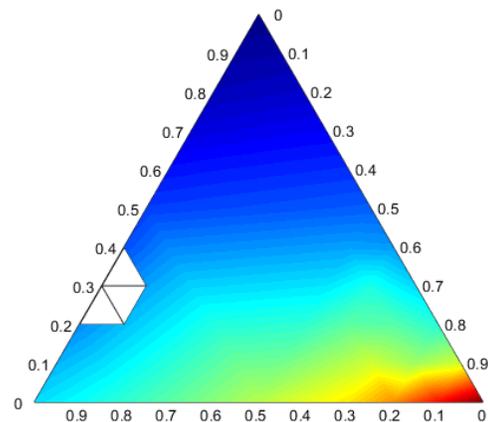
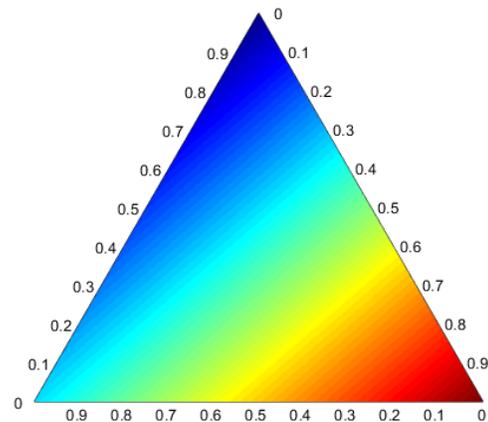


Figure 3: Top panel shows a linear interpolation of endmember CF positions. Middle panel shows a linear interpolation of all two-component mixtures (i.e. edges of the ternary). Bottom panel shows a linear interpolation including two- and three-component mixtures (i.e. edges and interior of the ternary). Endmembers and axes match *Figure 2*.