

CONSTRAINING LUNAR SURFACE MINERALOGY WITH COMBINED THERMAL- AND NEAR-INFRARED SPECTRAL DATA. K. L. Donaldson Hanna¹, M. B. Wyatt¹, J. Helbert², A. Maturilli², and C. M. Pieters¹, ¹Department of Geological Sciences, Brown University, Providence, RI 02912, ²Institute for Planetary Research, German Aerospace Center DLR, Rutherfordstr. 2, Berlin-Adlershof, Germany.

Introduction: The current understanding of lunar surface mineralogy largely comes from two sources: samples (Apollo and meteorite [e.g. 1]) and remote near-infrared spectroscopic measurements (telescopic and Clementine [e.g. 2]). Samples provide detailed compositional analysis of a limited number of sites across the lunar surface and NIR measurements provide global, high-resolution coverage of Fe-bearing mineralogy. The upcoming Diviner Lunar Radiometer Experiment (DLRE) on the Lunar Reconnaissance Orbiter (LRO) will provide the first global coverage maps of thermal-infrared derived compositions and physical properties. Diviner has only three mineralogy spectral channels centered at 7.8, 8.2, and 8.6 μm so it is important to integrate Diviner with other compositional data sets.

We examine two approaches in this study. First, thermal infrared laboratory spectral measurements of mineral endmembers, a mineral mixture, Apollo 16 highlands, and Apollo 17 mare soil samples are convolved to Diviner spectral bands. With these laboratory spectra, we investigate how Diviner data can be applied to distinguish lunar surface materials. Second, the thermal infrared measurements of minerals and a mineral mixture are integrated with an adapted near-infrared spectral curvature parameter developed for mafic minerals and Clementine data [2]. Here, we examine the extent to which combined analyses can be used to constrain the mineralogy of immature lunar surface lithologies (i.e. small outcrops and crater central peaks).

Samples and Methods: Laboratory emissivity spectra of < 25 μm grain size fractions of plagioclase, low- and high-Ca pyroxenes, and olivine used in this work are from the Berlin emissivity database (BED). Emissivity measurements were made with a Fourier-transform infrared spectrometer Bruker VERTEX 80V [3]. A 50/50 wt% mineral mixture of end-members anorthite and olivine is also examined.

Lunar soil samples are characterized by the Lunar Soil Characterization Consortium (LSCC) [4-5]. Apollo 17 mare soil samples chosen for this study include 71061, 71501, 70181, and 79221 [4] and Apollo 16 highlands soil samples include 61141, 61221, 62331, 64801, 67471, and 67481 [5]. Apollo lunar soils are plotted in Figure 1 on a plagioclase-orthopyroxene-clinopyroxene ternary diagram [6].

Highland soil samples are classified as anorthosite and mare soil samples as gabbro.

Brown University's Reflectance Experiment Laboratory (RELAB) Nexus FTIR spectrometer was used to measure thermal infrared spectra of each lunar soil sample for the 10 – 20 μm grain size fraction. Thermal infrared RELAB spectra are converted to emissivity using the approximation to Kirchoff's relation $E=1-R$. All thermal infrared spectra are convolved to Diviner's three spectral bands using ENVI's spectral resampling tool.

The Diviner spectral bands were chosen specifically to measure the location of the Christiansen Feature (CF). The CF is an emission maximum, or reflectance minimum, first described as an indicator of compositions by [8]. The CF shift to shorter wavelengths for particulate materials in a vacuum environment is well constrained [9-10]. In this study, we calculate three band ratios (7.8/8.2, 7.8/8.6, and 8.2/8.6) for each spectrum, assume that the CF shift applied to each spectral band is the same, and apply the ratios to accurately identify lunar lithologies.

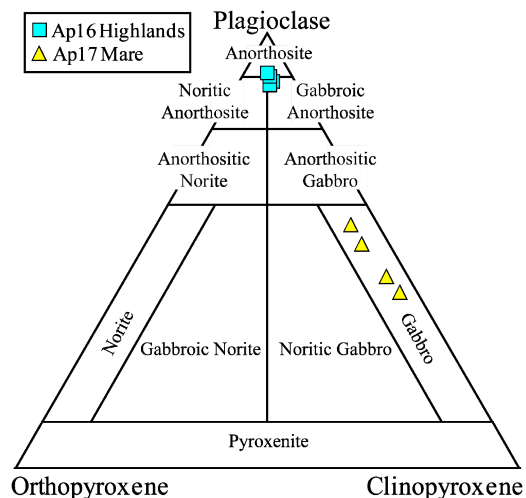


Figure 1. Ternary diagram of the lunar rock classification scheme [6].

Thermal-Infrared Data: We first explore how to use Diviner band ratios for distinguishing minerals, mineral mixtures and lunar soil samples. Band ratios in the near-infrared have been applied to accurately distinguish major mafic mineral groups in Clementine data [2]. Figure 2 shows the 7.8/8.6 versus 8.6/8.2 Diviner band ratios for individual minerals (plagioc-

lase, orthopyroxene, clinopyroxene, and olivine), the 50/50 wt% mineral mixture, and lunar soil spectra. Each mineral group is clearly distinguished using the 8.6/8.2 ratio with plagioclase plotting in the upper left (CF at shorter wavelengths) and olivine plotting in the lower right (CF at longer wavelengths). Mixture end-members anorthite and olivine plot within their respective mineral groups, however the 50/50 mixture is indistinguishable from orthopyroxene and clinopyroxene. Apollo 16 highlands spectra plot closer to the plagioclase mineral group compared to Apollo 17 mare spectra, consistent with its classification of anorthosite. However, the Apollo 17 mare spectra are not distinguishable from the clinopyroxene group or a mixture of plagioclase, orthopyroxene, clinopyroxene and olivine minerals. The highlands are thus easily distinguished from mare, however it is not possible to interpret specific mineral assemblages using only thermal-infrared band ratios.

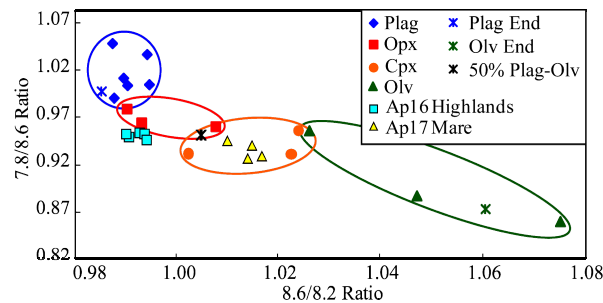


Figure 2. Simple band ratios 7.8/8.6 and 8.6/8.6 plotted against one another for individual minerals, a mixture of minerals, and lunar soils.

Integrated Thermal- and Near-Infrared Data:

We now examine the extent to which combined thermal- and near-infrared analyses can be used to constrain the mineralogy of immature lunar surface lithologies. Thermal infrared measurements of minerals and a mineral mixture are the same as Figure 2 and are integrated with a near-infrared spectral curvature parameter that has been used to map small outcrops, craters, and mountains with Clementine spectral bands [2].

The spectral curvature parameter is calculated as the angle between 0.75, 0.90, and 0.95 μm and can be applied to distinguish between Fe-bearing minerals. It is not intended to be used with mature lunar soils since the 1 μm ferrous band and continuum are strongly coupled and affected by space weathering effects. Since continuum removal is not possible with Clementine data, we do not examine the spectral curvature parameter for Apollo 16 and Apollo 17 soils which range from immature ($I_s/\text{FeO} < 30$) to mature ($I_s/\text{FeO} >$

60) [11]. Spectral curvature values are only adapted for individual minerals and a mineral mixture.

Figure 3 shows NIR spectral curvature plotted against thermal infrared 8.6/8.2 μm for each mineral end-member and a mineral mixture. As in Figure 2, the 8.6/8.2 ratio distinguishes each mineral group. With the addition of spectral curvature, the 50/50 mixture of plagioclase and olivine is now easily distinguished from orthopyroxene and clinopyroxene. This result suggests that immature lunar surface lithologies with varying abundances of mafic minerals can be separated using this diagram.

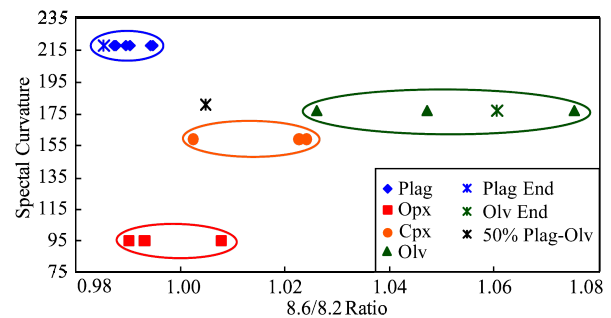


Figure 3. Near-IR parameter, spectral curvature, plotted against thermal-IR band ratios 8.6/8.2 for individual minerals and a mineral mixture.

Future Work: Additional thermal infrared spectra of highlands and mare lunar soil samples of varying compositions and particle sizes will be analyzed in an effort to make Diviner analysis techniques more robust for mineral identifications. Spectral emissivity measurements of minerals, mineral mixtures, and lunar lithologies will also be measured in vacuum conditions at Brown University and the Planetary Emissivity Laboratory at DLR. We will integrate these new thermal infrared data sets with upcoming high-spatial and spectral resolution M3 data to further investigate the extent to which combined analyses can be used to constrain the mineralogy of lunar surface materials.

References: [1] Jolliff B. et al. (2006) *Rev. Min. Geochem.*, 60, Min. Soc. Am. [2] Tompkins S. and Pieters C. (1999) *Met. & Planet. Sci.*, 34, 25–41. [3] Maturilli A. et al. (2008) *Planet. & Space Sci.*, 56, 420–425. [4] Taylor L. et al. (2001) *Met. & Planet. Sci.*, 36, 285–299. [5] Taylor L. et al. (2003) *LPSC XXXIV*, Abstract #1774. [6] Stöffler D. et al. (1980) In *Proc. Conf. Lunar High. Crust*, 51–70. [7] Pieters C. and Hiroi T. (2004) *LPS XXXV*, Abstract #1720. [8] Conel J. (1969) *JGR*, 74, 1614–1634. [9] Logan L. M. et al. (1973) *JGR*, 78, 4983–5003. [10] Salisbury J. and Walter L. (1989) *JGR*, 94, 9192–9202. [11] Lucey P. et al (2006) *Rev. Min. Geochem.*, 60, Min. Soc. Am.