MAPPING LUNAR SURFACE PETROLOGY USING THE MID-INFRARED EMISSIVITY MAXIMUM WITH THE LRO DIVINER RADIOMETER. B. T. Greenhagen and D. A. Paige, Dept. of Earth and Space Sciences, University of California, Los Angeles, CA, *greenhagen@ucla.edu*.

Introduction: The Diviner Lunar Radiometer Experiment is scheduled to launch in 2008 on the Lunar Reconnaissance Orbiter. Diviner is a nine channel infrared mapping radiometer. The primary goal of Diviner is to measure lunar surface temperatures and identify "cold traps" where ice is likely present. Additionally, Diviner will map petrologic variations in the lunar surface by determining the location of the mid-infrared emissivity maximum (Christiansen Feature), which is a good compositional identifier.

Most orbital remote sensing of the Moon has been preformed using visible and near-infrared instruments (e.g. Clementine, Lunar Prospector). While these instruments have proven capable of identifying an array of lunar minerals, they lack the ability to detect minerals without electronic transitions or other distinct spectral features in the $0.3 – 4$ μm region. In the early 1990s it was proposed to send a thermal emission spectrometer on the Lunar Observer spacecraft. Nash et al. (1993) wrote an extensive review article with regard to mapping the Moon in the thermal infrared [1]. They strongly endorsed the idea first proposed by Logan et al. (1973) and advanced by Salisbury and Walter (1989) of using the Christiansen Feature to make petrologic identifications of the lunar surface [1,2,3]. Although fundamentally different from the Lunar Observer instrument, Diviner will measure the Christiansen Feature using three narrow-band infrared channels. Here we will review the Christiansen Feature in the lunar environment, spectral data of lunar soils, and Diviner's planned observations.

The Christiansen Feature in the Lunar Environment: The lunar surface differs significantly from "typical" infrared remote sensing environments (i.e. Earth, Mars) and greatly reduces vibrational band, Restrahlen band, and transparency feature contrast while enhancing the Christiansen Feature. Therefore, the Christiansen Feature (CF) is the primary mid-infrared spectral feature in lunar soils (Fig. 1). The CF occurs near the Christiansen frequency (the location in frequency space where the refractive index of the material approaches the refractive index of its surrounding medium). It is a reflectance minimum and emission maximum.

Mineralogical Variations. The CF is a good compositional indicator. The location of the CF is correlated to the location of the fundamental vibrational bands. The fundamental vibrational bands and CF shift to longer wavelengths with increasing complexity of the silicate structure (e.g. feldspars have significantly shorter wavelength CFs than olivines). Petrologically, CFs are at shorter wavelengths for felsic rocks and shift to longer wavelengths for more mafic rocks (Fig. 2). [3,5]
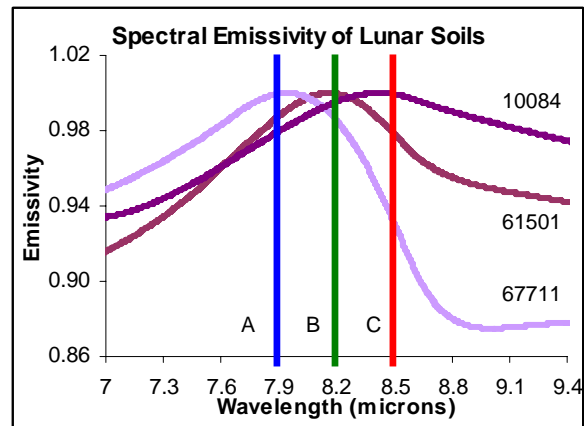

Figure 1: Spectral Emissivity of Lunar Soils Measured in a Vacuum. These three samples represent the range of expect CFs. Included are an extremely felsic highland soil (67711), a typical highland soil (61501), and a mafic mare soil (10084). The blue (A), green (B), and red (C) lines represent the locations of Diviner's narrow-band filters. Data digitized from Salisbury et al. (1973). [4]
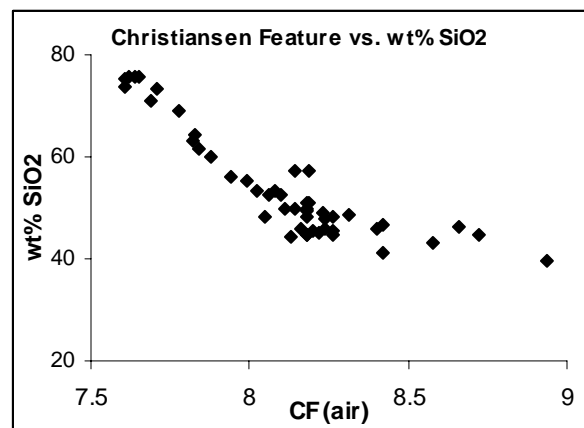

Figure 2: Christiansen Feature of Earth and Lunar Rocks vs. wt% SiO$_2$. The location of the CF varies with mineralogy. Note: the location of the CF is also affected by hydration, which increases data spread for earth materials (like those above). Lunar materials that have not been contaminated by Earth's atmosphere should behave more ideally. Data from Cooper et al. (2002) and Salisbury et al. (1997). [5,6]
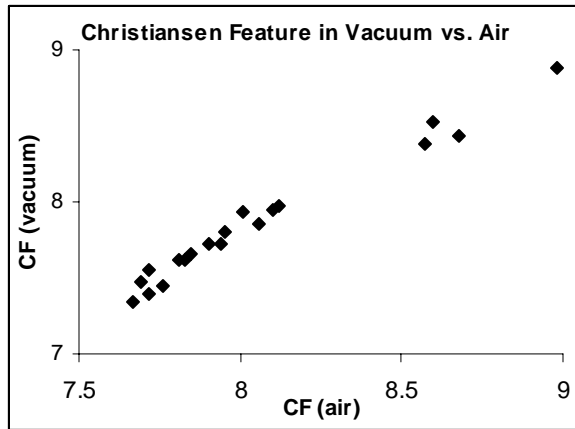
Figure 3: Comparison of Christiansen Feature measured in air and vacuum. The location of a CF measured in air correlates well with a CF measured in vacuum. Data from Salisbury and Walter (1989). [3]

Effect of Vacuum. The CF shifts to shorter wavelengths and has much higher spectral contrast when measured in vacuum. Lowing pressure introduces thermal gradients in the material that alter the emissivity of the material. As pressure decreases, interstitial gases that support convective transport of heat are lost. On the Moon, the surface soil is heated by absorption to a greater depth than the infrared emitting layer thickness. This large temperature gradient increases the spectral contrast of the CF. The CF shifts to shorter wavelength due to increased absorption in the Restrahlen Band region (longward of the CF). This shift in the CF location is well correlated (Fig. 3). [1,2,3,5]

Effect of Soil Maturing. The maturation of lunar soils has led to several distinct physical characteristics: small particle size, formation of agglutinates, vitrification, and mixing. The small particle size of lunar soils depresses Restrahlen Bands while enhancing overtone bands. Agglutinates are very porous and behave spectrally like fine particulates. Vitrification eliminates a regular lattice and thus lattice vibrations leaving only molecular vibrations (effectively removes fine spectral structure). The CF position is not affected by particle size, the presence of agglutinates, or vitrification. Mixing studies of many spectral features of fine soils typically result in non-linear mixing models due to volume scattering. However, mixing studies show the CF position has a linear mixing relationship. [1,3]

Effect of Temperature. The instantaneous sunlight-induced surface temperature depends on many factors including particle size, packing, rock abundance, and topographic slope. Several studies have shown that the overall intensity (emissivity or reflectivity) of the CF is affected by temperature but the location is not. [1,2]

Spectral Data of Lunar Soils: The most accessible collection of infrared spectral data of lunar soils available in the public domain was measured by Salisbury et al. (1997) in earth ambient conditions [6]. However, as discussed earlier, the lunar environment changes the spectral shape and contrast relative to earth ambient measurements. Salisbury et al. (1973) measured the thermal emission of lunar soils in a vacuum [3]. We digitized Salisbury et al. (1973) graphical data for use as our primary data set (some examples in Fig. 1). These data were sufficient to design the instrument. However, more complete infrared spectral data of lunar samples measured in a vacuum are needed for high confidence identifications. We plan to measure lunar samples in vacuum using a laboratory FTIR and the engineering model version of the Diviner instrument.

Diviner Observations: Diviner will employ continuous pushbroom nadir mapping to measure lunar surface temperatures, solar reflectance, and spectral emissivity in the CF region. Diviner's mapping resolution will be better than 500 meters with coverage greater than 50% at the equator for a LRO mapping orbit duration of one Earth year. Diviner has three narrow-band channels centered at 7.9, 8.2, and 8.5 µm (Fig. 1) to measure the spectral emissivity in the CF region. Since the spectral emission of the lunar surface at daytime temperatures peaks close to 8 µm region, Diviner will achieve very high signal-to-noise ratios (> 500). The location of the CF maximum for daytime measurements will be determined by fitting a 2nd order polynomial to the three data points for each pixel. It is expected that Diviner will be able to map the location of the CF maximum to latitudes as high as 80 degrees.

Diviner's determinations of CF variations will be used to map lunar petrologic variations. When correlated with existing spectral datasets and data acquired by future investigations, including Lunar Reconnaissance Orbiter Camera and Chandraayan-1 Moon Mineralogy Mapper, Diviner data will provide critical complementary information regarding the types and abundance of important non-iron bearing minerals. Anorthite (plagioclase feldspar) is the most common lunar mineral but not detectable in the visible and near infrared region. The ability to distinguish lunar petrology will add to a growing body of mineralogical information used for future landing site selection and lunar resource utilization.

References: [1] Nash D. B. et al. (1993) *JGR., 98,* 23535-23552. [2] Logan L. M. et al. (1973) *JGR, 78,* 4983-5003. [3] Salisbury J. W. and Walter L. S. (1989) *JGR, 94,* 9192-9202. [4] Salisbury J. W. et al. (1973) *LPS IV,* 3191-3196. [5] Cooper B. L. et al. (2002) *JGR., 107,* E4. [6] Salisbury J. W. et al. (1997) *Icarus, 130,* 125-139.