Thermal infrared emissivity measurements in a simulated lunar environment of the major silicate minerals on the Moon. K. L. Donaldson Hanna[1], M. B. Wyatt[1], I. R. Thomas[2], N. E. Bowles[2], B. T. Greenhagen[3], and D. A. Paige[4], [1]Department of Geological Sciences, Brown University, Providence, RI 02912, [2]Atmospheric, Oceanic, and Planetary Physics Department, University of Oxford, Oxford, UK, [3]Geophysics and Planetary Geosciences Group, Jet Propulsion Laboratory, Pasadena, CA, [4]Department of Earth and Space Sciences, University of California, Los Angeles, CA.

Introduction: Thermal infrared spectra of planetary surfaces have diagnostic features of rock and mineral compositions [1-7]. These include: (1) the Reststrahlen bands (RB), the fundamental molecular vibration bands due to Si-O stretching vibrations, (2) the Christiansen Feature (CF), an emissivity maximum resulting from a rapid change in the refractive index at wavelengths just short ward of the fundamental molecular vibrations, and (3) the Transparency Feature (TF), an emissivity minimum caused by volume scattering in a spectral region of relative transparency between the principal RB.

Compositional studies using thermal infrared data returned from Mars orbiting spacecraft and rovers have mainly utilized laboratory spectra of coarse-grained (> 100 μm) minerals and rocks measured under ambient conditions. However, determinations of surface compositions on airless bodies using thermal infrared data, including the Moon, Mercury, and asteroids, are complicated by fine-grained particle sizes and thermal gradients which affect the spectral character of surface materials. In this study, we characterize the thermal infrared spectral changes between ambient and lunar environmental conditions for major silicate minerals identified on the Moon as well as ilmenite. Our new measurements demonstrate the high sensitivity of minerals to environmental conditions under which they are measured and provide important constraints on interpreting new thermal infrared datasets of the Moon, including the NASA LRO Diviner Lunar Radiometer Experiment [8].

Background: Previous studies of thermal infrared spectra of a wide range of igneous rocks [4,5] and minerals [2] have demonstrated that as particle sizes decrease, spectral contrast in the RB decreases while TF form at wavelengths shorter than the CF as well as at wavelengths longer than the RB. Further work under simulated lunar vacuum conditions [3,4] demonstrate that near-surface thermal gradients form due to the absence of interstitial gases between regolith grains causing radiative transfer to dominate the upper microns of the planetary regolith [9]. As pressure decreases and thermal gradients are introduced, the CF shifts to shorter wavelengths, the overall spectral contrast increases, and the spectral contrast of the RB decreases. Determinations of surface compositions on airless bodies using thermal infrared spectra thus require accurate applications of lab measurements under realistic environmental conditions.

Samples and Experimental Setup: In this study, we build upon previous work [1-7] by making new thermal infrared measurements of major minerals identified on the Moon under a simulated lunar environment. We focus on a fine-grained mineral suite (0 – 25 μm) including well-characterized samples of the plagioclase solid solution series: albite, oligoclase, andesine, labradorite, and anorthite; clinopyroxene and orthopyroxene; the olivine endmember forsterite, and ilmenite [10] to evaluate their application for lunar remote sensing.

Each composition was measured in a new thermal emission chamber at Oxford University built to simulate the temperatures and pressures experienced on the lunar surface [11]. The chamber is attached to the emission port of a Bruker IFS 66v Fourier Transformer and spectral measurements are made under 2 conditions: ambient (sample cup is heated to ~500K and the chamber is filled with ~1 bar of nitrogen) and a simulated lunar environment (SLE) (sample cup is heated to ~500K, vacuum pressures equal to ~1e-6 mbar, and interior of the chamber is cooled to ~150K).

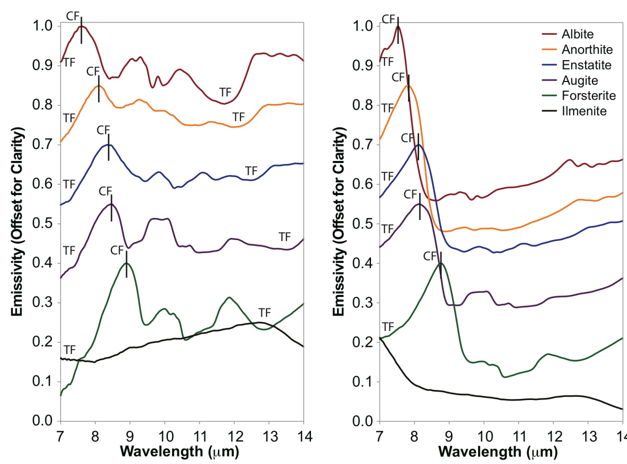

Figure 1. TIR emission spectra of fine grain minerals (0 – 25 μm) measured under ambient (left) and simulated lunar environmental conditions (right). Spectra are arranged from top-to-bottom with increasing CF position and are offset by 0.15 emissivity.

Results: Spectral changes are observed for all minerals measured under a simulated lunar environment compared to ambient conditions (Figure 1). The CF shifts to shorter wavelengths, the overall spectral contrast between the CF and RB region increases by a factor of two, the spectral contrast of the RB decreases, TF are reduced in all of the SLE mineral spectra, and ilmenite has a distinctive slope change (Figure 1). The observed CF shifts range from 0.1 to 0.3 μm depending on the mineral (Table 1).

Table 1. The CF position for laboratory mineral spectra measured under ambient and SLE conditions.

Mineral	CF Position (μm) Ambient	CF Position (μm) SLE
Albite	7.62	7.53
Oligoclase	7.63	7.54
Andesine	7.97	7.59
Labradorite	7.98	7.61
Anorthite	8.10	7.82
Augite	8.46	8.13
Enstatite	8.34	8.12
Forsterite	8.89	8.76

Discussion: Our new thermal infrared spectral measurements generally agree with earlier measurements made under a simulated lunar environment by Logan et al. [4] and Salisbury and Walter [5]. Salisbury and Walter [5] found a linear trend between the CF position measured under ambient and vacuum conditions with a $R^2 = 0.9773$ (Figure 2). Our linear trend is displaced from the Salisbury and Walter trend (Figure 2), has a higher slope value, and a lower R^2 value ($R^2 = 0.8516$). The differences between the two trend lines could result from several factors: (1) the previous studies made ambient and vacuum measurements of rocks using different laboratory set-ups [4,5], (2) powdered rock data [4,5] versus powdered mineral data in this study, (3) laboratory reflectance spectra [4,5] versus laboratory emissivity spectra in this study, and (4) variable simulated lunar environmental conditions between studies.

Our emissivity spectral measurements of the plagioclase solid solution series corroborate previous reflectance spectral measurements by Nash and Salisbury [12] that varying compositions of the plagioclase solid solution series can be distinguished using their CF position. The Na-rich endmember albite has the shortest CF position while the Ca-rich endmember anorthite has the longest CF position. Our new measurements also demonstrate that this relationship holds under SLE. A linear trend is observed between the CF position measured under SLE and the anorthite content (An #) of the plagioclase sample. This linear trend may be used to approximate the CF position for other unknown plagioclase compositions.

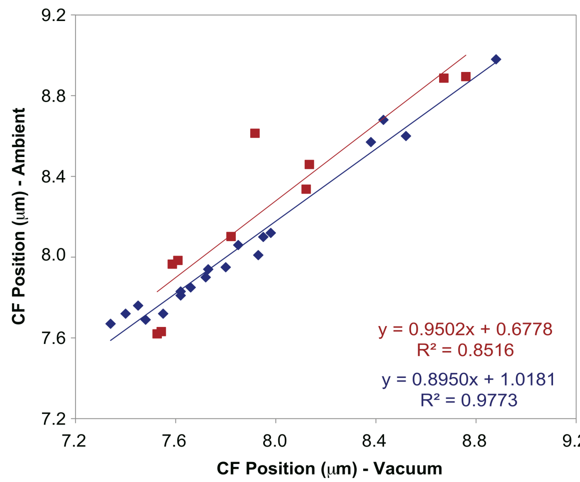

Figure 2. CF position measured under vacuum/SLE and ambient conditions for rock and mineral spectra. Blue data points are taken from Salisbury and Walter [3] and include a range of rock compositions (felsic to mafic). Red data points are taken from the mineral spectra measured under ambient and SLE conditions in Table 1.

Conclusions and Ongoing Work: Results from this study demonstrate the importance of developing new thermal emission spectral libraries of lunar-relevant materials measured under simulated lunar environmental conditions. Spectral changes are observed for all minerals measured under a simulated lunar environment compared to ambient conditions. Our new measurements generally agree with previous studies [4,5], however important differences exist. It is thus imperative that thermal infrared spectral measurements be made under realistic lunar environmental conditions for comparisons with new spectral data from the Diviner Lunar Radiometer Experiment and future missions to the Moon, Mercury, and asteroids.

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