LUNAR MARE BASALTS: INSIGHTS USING DIVINER THERMAL INFRARED DATA.

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Introduction: Lunar mare only covers 17% of the lunar surface [1]; however it provides the best insight into the composition of the lunar interior as well as its thermal history. Compositional variations in mare basalts have previously been identified with Earth-based telescopic and Galileo observations [e.g. 2, 3, 4, 5]. More recent analysis of higher-spatial resolution data from the Clementine UVVIS multispectral instrument [6] identified 86 spectrally homogeneous units across Oceanus Procellarum and related regions such as Mare Nubium, Mare Cognitum, and Mare Insularum. Each of these units is thought to have extruded over a short period of time and thus represents a single eruptive phase. Crater counting of the single eruptive phases indicates that mare basaltic volcanism was active from ~3.93 to 1.2 Ga. All of these previous analyses have focused on ultraviolet-visible to near infrared data sets as thermal infrared data had not been measured.

The Diviner Lunar Radiometer Experiment (DLRE) on NASA's Lunar Reconnaissance Orbiter (LRO) was launched on June 18, 2009 and has begun making the first global coverage maps of thermal infrared derived compositions and thermophysical properties. Diviner has nine channels: two broadband solar reflectance channels, three mineralogy channels, and four broad thermal channels [7]. The three mineralogy spectral channels are centered at 7.8, 8.2, and 8.6μm and were chosen to specifically measure the peak of the Christiansen Feature (CF) [8]. The CF is an emission maximum, or reflectance minimum, first described as an indicator of compositions by [9]. The CF shift to shorter wavelengths for particulate materials in a vacuum environment is also well constrained [10-11]. Thermal channels are intended to characterize the surface thermal emission over a wide range of temperatures and the minimum detectable temperature is less than 30K for two of its channels [7].

In this preliminary study we explore compositional and thermophysical characteristics of mare basalts using new DIVINER thermal infrared observations. Emissivity variations are mapped across lunar maria to determine compositional differences and for comparison with near-infrared spectrally homogeneous units identified by Hiesinger et al. [5,6]. Diviner day and nighttime temperature maps of lunar maria are also analyzed to determine physical properties of near-infrared spectrally homogeneous units. A goal of this work is to thus determine the extent to which thermal infrared data can provide new insights into previous near infrared measurements of lunar maria.

Data and Methods: Diviner image cubes including latitude, longitude, radiance, and brightness temperature were collected for Oceanus Procellarum and related regions such as Mare Nubium, Mare Cognitum, and Mare Insularum. Integrated radiance values ($Wm^{-2}Sr^{-1}\mu m^{-1}$) are converted to emissivity by finding the maximum measured brightness temperature in one of the mineralogical channels. A planck function is then calculated for the maximum brightness temperature and all pixel values in the mineralogical channels are divided by it. Daytime temperature maps were generated from the hottest part of the lunar day while the nighttime temperature maps were generated from the coldest.

Previous laboratory studies of minerals and lunar highland and mare soils indicate that ratios of Diviner's mineralogical spectral channels can be used to distinguish between: (1) mineral groups, (2) different compositions of the same mineral, and (3) lunar lithologies [12] (Figure 1). Therefore spectral ratios are taken to constrain compositional differences across the lunar maria as observed in the thermal infrared. In Figure 1, laboratory spectra were measured under ambient conditions and are thus not directly comparable to Diviner data for determining exact mineral or rock compositions. However, the observed trend of more feldspathic to more mafic compositions remains consistent. Once laboratory measurements are made under lunar-like conditions direct comparisons will be possible. Regions of the same composition (i.e. having the same emissivity value) are compared with the spectrally homogeneous units identified by Hiesinger et al. [6].

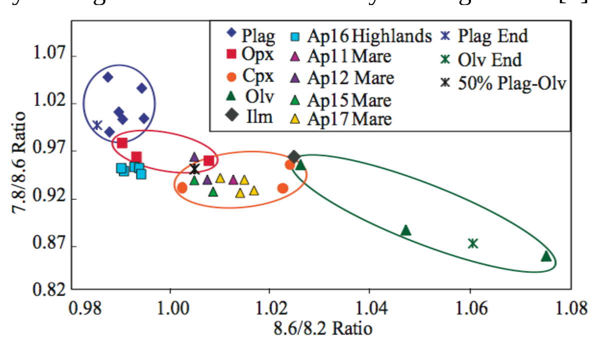

Figure 1. Diviner mineralogical band ratios 7.8/8.6 vs. 8.6/8.6 for individual minerals, a mixture of minerals, and lunar soils [12].

Relative amplitudes of the diurnal temperature curve across lunar maria are determined by taking differences of Diviner day and nighttime brightness temperature maps. These relative amplitudes are used to approximate thermophysical properties of surface materials. Surface units with similar thermophysical properties are compared with spectrally homogeneous units to provide insight into the evolution of lunar volcanism.

Results: Diviner emissivity and temperature data for the greater Oceanus Procellarum region (79.6° - 4.6° W longitude and 29.8° S – 58° N latitude) are binned into latitude and longitude at 32 pixel per degree and overlain with Clementine UVVIS data for analysis. A spectral band ratio of the 8.6 μm and 8.2 μm mineralogical bands indicates compositional differences across the region. As an example, Figure 2 shows surface compositions in and around Copernicus crater having values from 0.94 – 0.96 and the surrounding mare units having values from 0.99 – 1.01. Two inferences can thus be made: (1) Copernicus has excavated more feldspathic material and (2) compositional differences in purely mare regions exist. Since this mapped area has yet to been fully covered by Diviner it is not currently possible to assess how the differences in thermal infrared compositions correspond to near infrared spectrally homogeneous units identified by [5,6].

Diviner daytime temperature maps of the region have a range between ~300 – 400K with the hottest temperatures at the equator and the coolest temperatures in the northern latitudes. Diviner nighttime temperature maps have a range of 90 – 98 K with the same latitude dependence as the daytime temperature. However, small-scale variations in the daytime temperature are different than small-scale variations in the nighttime temperature as seen around Copernicus crater in Figure 2. These temperature differences reflect the thermophysical properties of this region. As an example, Copernicus' crater walls and peaks have a similar daytime temperature to its surrounding area, however its nighttime temperature is hotter than the surrounding area. Thus, as Diviner maps the same regions in the lunar maria at maximum and minimum temperatures it will be possible to map thermophysical properties of the different age and composition volcanic flows.

Ongoing Work: Currently ~60% of the Oceanus Procellarum, Mare Nubium, Mare Cognitum, and Mare Insularum regions are covered with Diviner data strips. More insightful comparisons with previous work will be made as Diviner coverage of the area increases and measurements are made at the same time of day. Future laboratory spectral measurements of minerals, rocks and lunar soils under lunar-like conditions at thermal infrared wavelengths, in particular wavelengths covering the CF region, will provide direct comparisons for measured Diviner spectra. Furthermore, analysis of new high-spatial and spectral resolution near infrared data from M^3 and SELENE's Multiband Imager (MI) and Spectral Profiler (SP) may further constrain spectrally homogeneous units in lunar mare regions. The integration of thermal and near infrared data sets for lunar mare will provide the best insight into the composition of the lunar interior as well as its thermal history.

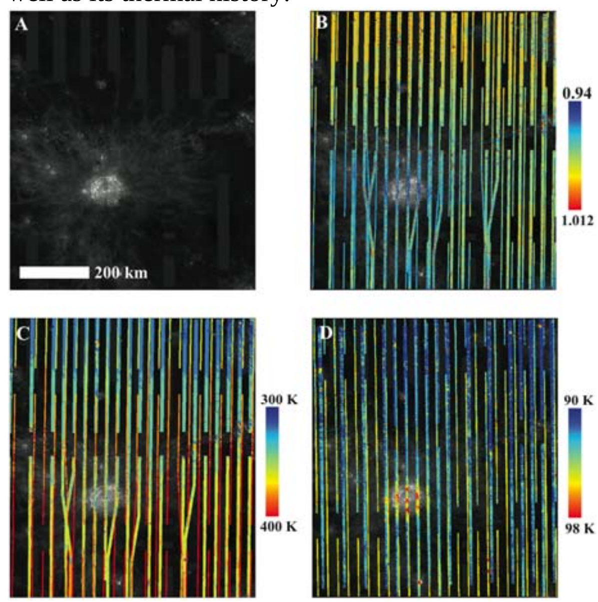

Figure 2. **(A)** Clementine 750 nm reflectance image for the region of 29.6° - 4.6° W longitude and 0.54° S – 28.73° N latitude which includes Copernicus crater. The Clementine image has been overlain with **(B)** Diviner 8.6/8.2 spectral band ratio indicating the range of compositions in the scene **(C)** Diviner daytime temperature **(D)** Diviner nighttime temperature.

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