

**INVESTIGATING YOUNG (<100 MILLION YEARS) IRREGULAR MARE PATCHES ON THE MOON USING DIVINER OBSERVATIONS.** K. L. Donaldson Hanna<sup>1</sup>, R. Evans<sup>1</sup>, N. E. Bowles<sup>1</sup>, P. H. Schultz<sup>2</sup>, B. T. Greenhagen<sup>3</sup>, and K. A. Bennett<sup>4</sup>, <sup>1</sup>Atmospheric, Oceanic and Planetary Physics, University of Oxford, Clarendon Laboratory, Oxford, UK (Kerri.DonaldsonHanna@physics.ox.ac.uk), <sup>2</sup>Dept. of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI, USA, <sup>3</sup>Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA, and <sup>4</sup>School of Earth and Space Exploration, Arizona State University, Tempe, AZ, USA.

**Introduction:** The investigation and characterization of volcanism on a planetary surface provides the best insight into the composition, structure, and thermal history of its interior. The lunar maria, vast plains formed of basaltic flows, are limited to and cover 17% of the lunar near side [1]. Radiometric age dating of returned Apollo samples and crater counts from remote observations indicates that mare basaltic volcanism was active from ~4.2 to 0.8 Ga [e.g. 2-5].

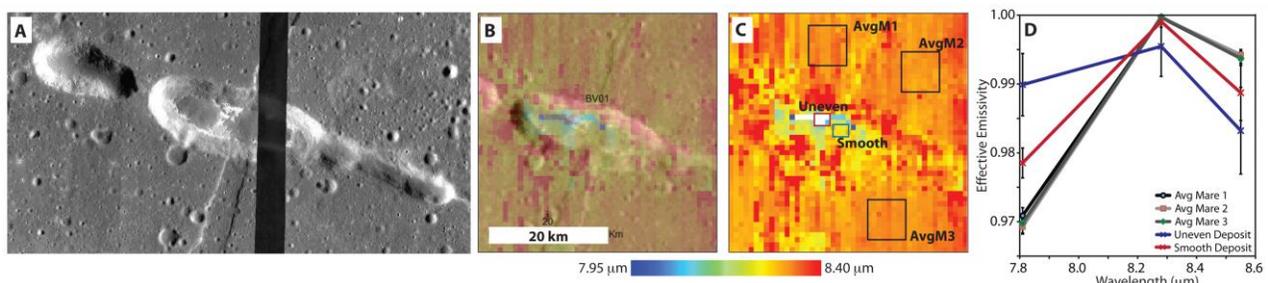
Lunar-Orbiter/Apollo images and Clementine UVVIS observations identified four regions, including Ina, of small-scale, low relief patches of rubble with a maximum age of ~10 Ma [6]. Recent observations by the Lunar Reconnaissance Orbiter Camera (LROC) onboard NASA's Lunar Reconnaissance Orbiter (LRO) have expanded this list of unusual morphologic features by identifying similar features termed meniscus hollows [7] or irregular-bounded mare patches (IMPs) on the lunar near side with ages < 100 Ma [8]. The IMPs have two morphologically distinct deposits, uneven and smooth deposits [6-8]. The uneven deposits have a rough surface texture and contain a range of block densities, whereas the smooth deposits have a fairly uniform surface texture and almost no blocks. Most importantly, the boundary scarps have very low relief indicating recent formation. Two hypotheses for the origin of the irregular mare patches (IMPs) have been suggested: (1) recent, episodic outgassing from deep within the lunar interior [6] and (2) small basaltic eruptions that occurred after mare volcanism had ended [8].

These young volcanic features have implications for the cooling and volatile content of the lunar interior and may provide insight into the compositional evolution of magmatic materials over time. In this study we investigate the composition of the irregular mare patches in an effort to better understand the origin of

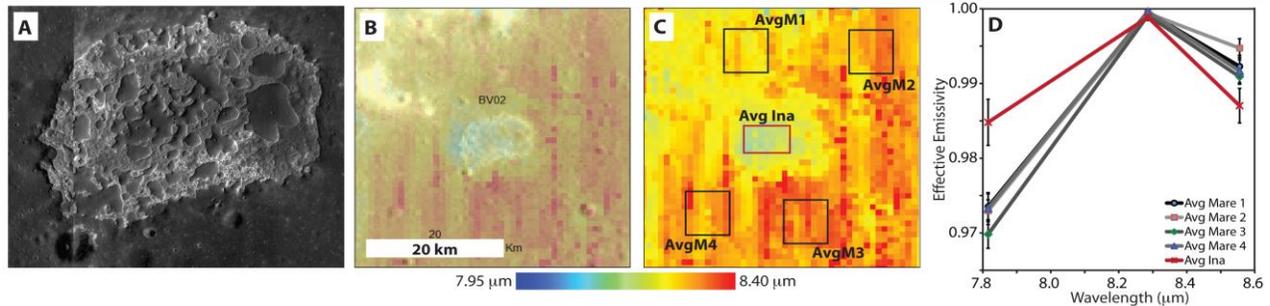
these features and the evolution of lunar basalts over time. Compositional differences across each IMP as well as differences with surrounding mare materials are investigated using thermal infrared observations from LRO's Diviner Lunar Radiometer Experiment (Diviner).

**Data and Methods:** Diviner is a nine channel infrared filter radiometer with three narrow bands near 8  $\mu\text{m}$  used for mapping mineralogy (composition) [9,10]. Radiance data for Diviner bands 3, 4 and 5 are binned and averaged at 128 pixels per degree and then converted to three point emissivity spectra as described by Greenhagen et al. [10]. Diviner radiance data of the IMPs have been limited to lunar midday (10:00 to 14:00 local time) and emission angles < 5°. Diviner emissivity values are then corrected for local lunar time, latitude and topography to account for the effects of anisothermality [11]. The Christiansen feature (CF), an emissivity maximum indicative of composition [e.g. 12], is estimated by fitting a polynomial to each three point emissivity spectrum and identifying the wavelength of the maximum polynomial value. CF maps are made of each IMP region and 3-point emissivity spectra are extracted from the IMPs and surrounding mare materials.

**Results:** The Diviner observations of Sosigenes and Ina (CF map and spectra) are shown in Figures 1 and 2 along with Lunar Reconnaissance Orbiter Camera (LROC) mosaics. The uneven deposits (the higher albedo regions) within Sosigenes have (1) a shorter average CF position ( $7.97 \pm 0.31 \mu\text{m}$ ) than the smooth deposits ( $8.27 \pm 0.03 \mu\text{m}$ ) and surrounding mare ( $8.33 \pm 0.01 \mu\text{m}$ ) and (2) a flatter spectral slope between Diviner bands 3 and 4 than the smooth deposits and surrounding mare. The smooth deposits within Sosigenes have a slightly shorter average CF position than the surrounding and a similar spectral shape to average



**Figure 1.** (A) LROC WAC and NAC mosaic of Sosigenes. (B) Diviner CF map overlain on LROC WAC. (C) Diviner CF map indicating regions where spectra were extracted. (D) Average emissivity spectra for smooth and uneven deposits as well as surrounding mare. The standard deviation is expressed as the y-error bars.



**Figure 2.** (A) LROC WAC and NAC mosaic of Ina. (B) Diviner CF map overlain on LROC WAC. (C) Diviner CF map indicating regions where spectra were extracted. (D) Average emissivity spectra for Ina as well as surrounding mare. The standard deviation is expressed as the y-error bars.

surrounding mare spectra.

Since the uneven and smooth deposits on Ina are difficult to uniquely distinguish from one another in the Diviner TIR observations, an average Ina spectrum (including both uneven and smooth deposits) is compared to average spectra of the surrounding mare. Ina (uneven and smooth deposits combined) has a shorter CF position ( $8.20 \pm 0.03 \mu\text{m}$ ) than the surrounding mare ( $8.31 \pm 0.02 \mu\text{m}$ ) and has a flatter spectral slope between Diviner bands 3 and 4. In addition, the average CF position of Ina is longer than CF position of the Sosigenes uneven deposits, but shorter than average CF position of the smooth deposits.

**Discussion and Future Work:** The smooth and uneven deposits in both IMPs analyzed in this initial study indicate that both units in each IMP have CF positions at shorter wavelengths than the surrounding mare materials. This difference in CF position could be related to a change in composition [10,12], the degree of space weathering [13,14] and/or surface roughness effects. TIR laboratory measurements of augite (a high-Ca pyroxene found in basalts) under simulated lunar conditions found that the CF position was  $8.46 \pm 0.02 \mu\text{m}$ , which is longer than the  $7.84 \pm 0.02 \mu\text{m}$  CF position for anorthite (a high-Ca plagioclase feldspar found in several lunar rock types) [15]. Thus the addition of more feldspathic material would shift the CF position to shorter wavelengths. Lucey et al. [13,14] has demonstrated that the Diviner TIR observations of immature locations like crater ejecta rays have CF positions at shorter wavelengths (by as much as  $0.2 \mu\text{m}$ ) than the more mature surface locations the ejecta deposits are emplaced on. Thus, immature surface materials are expected to have CF positions at shorter wavelengths than mature surface materials of the same composition. The effects of large- and small-scale surface roughness on the CF position have yet to be quantified.

The observed differences in CF position ( $0.3 \mu\text{m}$ ) and spectral shape between the uneven and smooth deposits in Sosigenes is larger than what is expected

for differences due solely to space weathering effects. Thus, the TIR measurements suggest a compositional difference between the uneven and smooth deposits in Sosigenes. Due to the spatial resolution of the Diviner footprint, it is difficult in this initial analysis to constrain differences in the uneven and smooth deposits in Ina. However, the standard deviation of the CF position for the average Ina spectrum is only  $0.03 \mu\text{m}$  suggesting the differences between the uneven and smooth deposits within Ina is not as great as those in Sosigenes.

Future work will include more detailed spectral analyses on IMPs large enough to spatially resolve within the Diviner dataset. This will allow us to better characterize the TIR compositional trends within these features and constrain any compositional differences between the IMPs and their surrounding mare units. In addition, visible to near infrared (VNIR) observations of the IMPs from the Moon Mineralogy Mapper ( $M^3$ ) on board Chandrayaan-1 are also being analysed to investigate the compositional differences seen in a different wavelength regime. Combining VNIR and TIR data analyses will enable use to better constrain the origin and evolution of these lunar materials.

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