INVESTIGATING THE MINERALOGY AND ORIGIN OF IRREGULAR MARE PATCHES WITH SPECTRA FROM MOON MINERALOGY MAPPER.

H. Vannier[1], B. Horgan[1] and J. Stopar[2], [1]Earth Atmospheric and Planetary Science, Purdue University (hvannier@purdue.edu), [2]Lunar Planetary Institute, USRA

Introduction: Irregular mare patches (IMPs) are morphologically distinct features on the surface of the Moon characterized by small and smooth topographically high regions that appear to overlie topographically lower blocky regions [4]. In addition, IMPs' small size (<5 km) and presence of fine scale surface textures (<5 m scale, not eroded) distinguish them from the surrounding mare, and the paucity of surface cratering within smooth regions imply ages of <100 Ma [4]. This suggests either very recent formation or unique compositional or structural properties that are not well suited for crater preservation [4,5,12].

Because they are commonly associated with volcanic vents and rilles, IMPs are expected to be the product of lunar volcanism [4,14]. If IMPs are young, they may represent the most recent volcanism on the Moon, having formed more than one billion years after than the most recent lava flows elsewhere on the Moon. This may imply that there was a long decline in lunar volcanism rather than an abrupt cessation ~1.5 Gyrs ago.

Various formation mechanisms for IMPs have been proposed, including explosive outgassing, pyroclastic eruptions, and magmatic foam [5,12,13]. Each of these processes have different implications for IMP composition, but the composition of IMPs is not well understood. We use VNIR spectra (0.35-3 μm) from the Moon Mineralogy Mapper (M^3) to constrain the mineralogy of the three large IMPs, Ina (18.65°N, 5.31°E), Sosigenes (8.34°N, 19.05°E), and Cauchy-5 (7.12°N, 37.65°E), in order to place constraints on their formation mechanism.

Methods: For each region containing the IMPs, we extracted spectra from three regions of interest (ROI): the IMP itself, nearby mare, and fresh craters (Figure 1). We used a band ratio combination based on [3] in conjunction with the Kaguya and Clementine spectral maps displayed in the LROC Quickmap tool [10,11] to identify spectrally homogenous regions. Future work will include more detailed parameter mapping to search for additional variability within and around the IMPs.

For the average spectra from each ROI (Figure 2), we used the continuum removal techniques described within Horgan et al. 2014 [8]. To estimate the continuum, two line segments are fitted to endpoints at 0.7-1.0, 1.2-1.7, and 2.0-2.6 μm. Computing the position, area, and shape of the 1 and 2 μm iron bands enables the identification of various iron bearing minerals [8] (Figure 3). These techniques have been used with M^3 data to successfully determine mineralogy of different units in and around Ina [1] as well as other volcanic features on the Moon [2,3,6].

Results: All regions have 1 μm band centers ranging from ~0.95-1.02 μm and 2 μm band centers from ~2.15-2.28 μm that are consistent with clinopyroxene (CPX) and typical of Apollo mare samples [9]. The consistently low asymmetry of the 1 μm band (<10%) implies there is not significant glass or olivine present at Ina, Sosigenes, Cauchy-5 or the surrounding mare.

Our results agree with [1] that the composition of Ina is similar to its surrounding mare, which is also the case for Cauchy-5. However, Sosigenes has a composition that more closely matches the fresh craters in the region rather than nearby mare. This may imply the surface composition at this location differs from the subsurface, and that Sosigenes is more similar to the subsurface.

Discussion: Our results show that both the IMPs and their surrounding mare tend to exhibit similar signatures, in these cases consistent with CPX. This implies that IMPs are either composed of mare material or different volcanic deposits sourced from a similar or the same magma source. This is likely inconsistent with emplacement of new magmatic material billions of years after the eruption as we would expect significant magma evolution over that time.

Both optical maturity measurements and crater age dating imply that the surfaces of IMPs are far younger than their surrounding mare [1,4,13]. However, our preliminary results suggest that at least these three IMPs do not include eruptive products from recent explosive or effusive eruptions. Recent explosive volcanic activity [4,5] has been proposed as formation hypothesis, but if glass is not present in and around these three IMPs, this would likely rule this out. One previous investigation suggested that glass may be present in a halo around Ina [7], and we will investigate this hypothesis with future mapping and spectral analysis.

Instead, our results so far suggest that the IMP's examined in this study may have formed due to recent modification of the mare. Recent explosive outgassing has been proposed to explain the youthful appearance, as the explosive removal of thick surface layers would expose optically young material [13]. This may explain the general similarity between the IMPs and surrounding mare. We suggest that other collapse processes could also produce the observed morphology and mineralogy, perhaps including collapse of lava tubes. The observation that Sosigenes is similar to mare units underlying the surface may support an outgassing or collapse origin.

Alternatively, it has been proposed IMPs formed contemporaneously with their surroundings and are composed of a magmatic foam poorly suited for crater preservation rather than formation by recent volcanism [12]. While the expected mineralogy for magma foam is unclear, if it is composed of crystalline eruptive products and not significant glass, this could also explain the discrepancy between surface age and similar mineralogy. However, more work on magma foam composition is needed, and the mechanisms for regolith drainage in the foam model have been challenged [5].

IMPs display substantial diversity in size and shape, though few have been studied in detail. We will analyze 17 other large IMPs in detail in order to better understand whether they share a similar formation mechanism or mineralogy. In addition, we will determine the optical maturity of this suite of IMPs and their surroundings.

References: [1] Bennett et al. (2015) *LPSC, #2646.* [2] Bennett et al. (2016) *Icarus* 273, 296–314. [3] Besse et al. (2014) *JGRP* 119, 355–37. [4] Braden et al. (2014) *Nature Geo*. 7, 787-791. [5] Elder et al. (2016) *Icarus* 290, 224-237. [6] Gaddis et al. (2015) *LPSC, #2059*. [7] Glaspie et al. (2019) *LPSC, #2132.* [8] Horgan et al. (2014) *Icarus 234*, 132–154. [9] Huang et al. (2020) *Geology*, v. 49 [10] Lemelin et al. (2019) *Planet. & Space Science 165, 230-243* [11] Pieters et al. (1994) *Science* 266, 1844–1848. [12] Qiao et al. (2018) *M&PS 53, 778-812*. [13] Schultz et al. (2006) *Nature* 444, 184–186. [14] Strain & El-Baz (1980) *Proc. LPSC,* pp. 2437–2446.

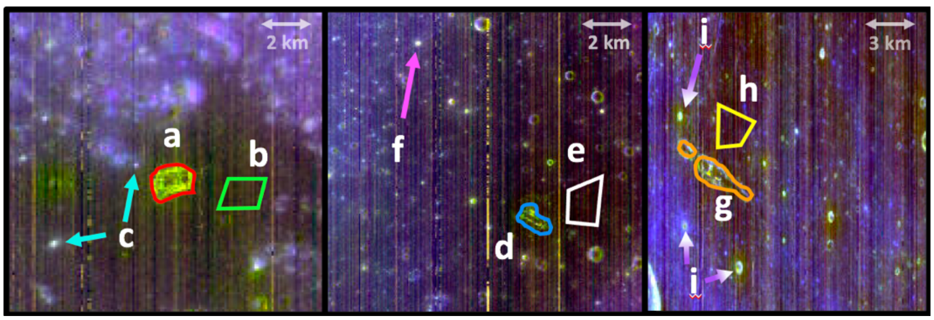


Figure 1: *From left to right, M^3 RGB combinations of the regions containing Ina, Cauchy-5, and Sosigenes, respectively. IMPS: letters a, d, and g. Nearby mare: b, e and h. Arrows point to fresh craters. Red is R(1580 nm)/R(1900 nm), green is R(1580 nm)/R(2300 nm), blue is R(1580 nm).*

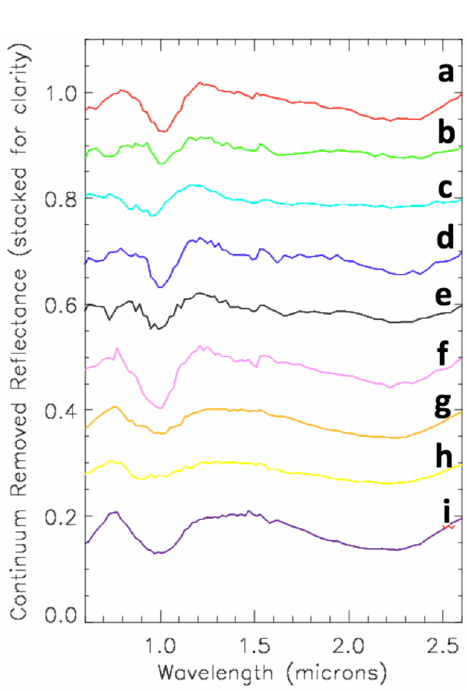
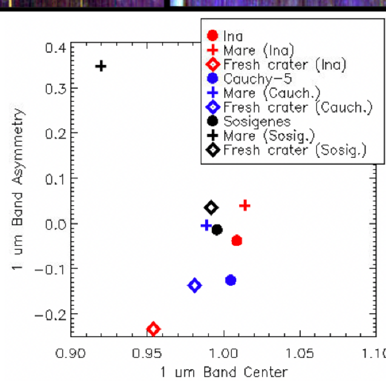


Figure 2*: M^3 reflectance spectra, continuum removed and vertically offset for clarity. Each letter corresponds to the regions in Figure 1.*



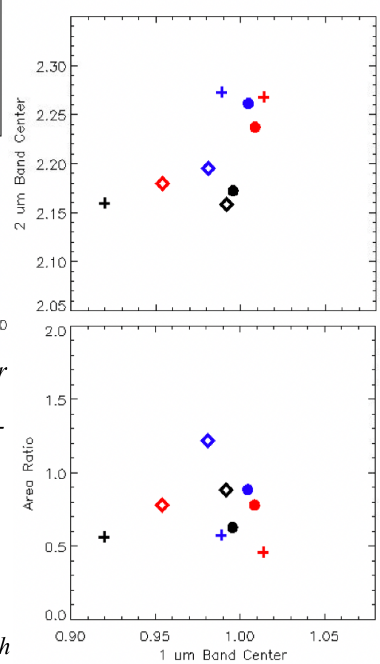


Figure 1: *1 and 2 µm band parameter calculations for the regions in Figure 1, where each point represents the average M^3 spectra for each ROI. The low asymmetry (<10%) in the first panel implies there is no significant glass or olivine present. The second panel shows that all regions have 1 µm band centers ranging from ~0.95-1.02 µm and 2 µm band centers from ~2.15-2.28 µm that are consistent with clinopyroxene (CPX). The relatively low band area ratio (panel 3) implies there is no significant contribution from olivine.*