MULTI-WAVELENGTH BISTATIC INVESTIGATION OF COMPOSITIONAL VARIATIONS ACROSS MARE IMBRIUM USING MINI-RF.

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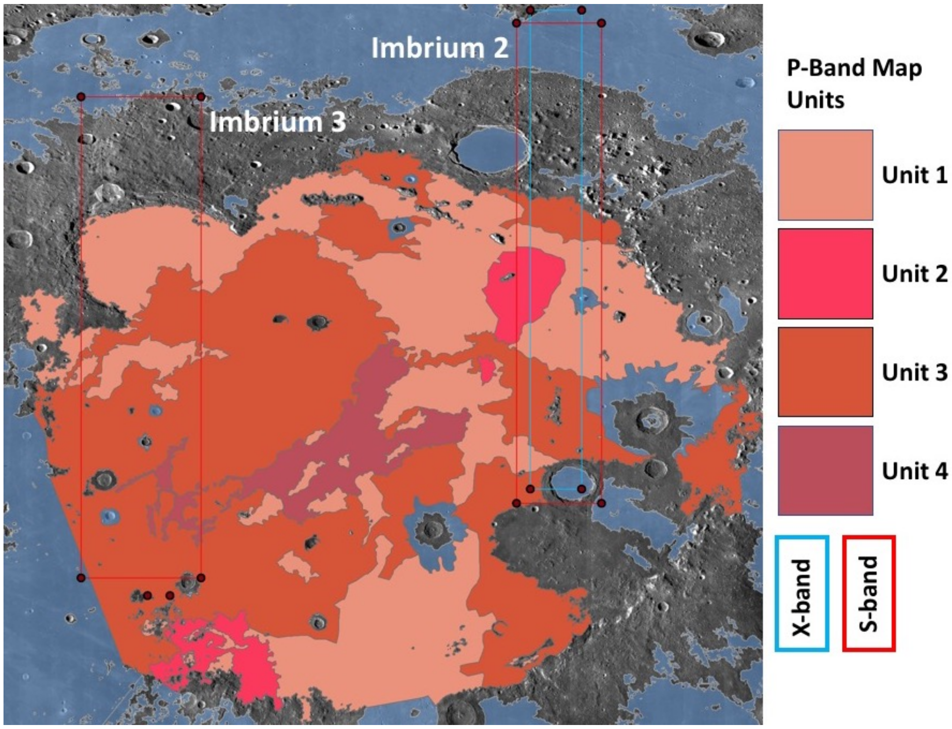

Figure 1. *Mare Imbrium Mini-RF targets for both S and X-band collects. The map units are from P-band radar mapping work conducted by Morgan et al. [1]. The four units represent a stratigraphic framework from oldest (Unit 1) to youngest (Unit 4) surfaces and form the bases for comparing the biostatic Mini-RF collects.*

Introduction: The Lunar Reconnaissance Orbiter (LRO) Cornerstone Extended Mission has seen the revival of the Mini-RF radar in order to conduct bistatic observations of the lunar surface. Working in conjunction with S-band (12.6 cm) and X-band (4.2 cm) signals transmitted by Arecibo (Puerto Rico) and Goldstone (southern California) observatories, respectively, enables dynamic viewing geometries through which bistatic angles from 0 - > 50º can be achieved. Studying the variations in the power returned over such bistatic angles can impart important information about the geology of the near surface including signatures diagnostic of the presence of ice [2]. During the 2018 LPSC meeting the Mini-RF team will present on multiple diverse studies that are currently being undertaken as part of the Cornerstone extended mission. Here we present on an our ongoing targeting campaign to investigate the composition of the lunar mare, the aim of which is to better constrain the titanium content of individual lava flows.

Previous Lunar Mare Compositional Variations: The lunar mare are the product of extensive flood volcanism which formed ~4.1 - 1.5 Ga [e.g., 3]. Despite the lack of distinct flow boundaries typical of flow fields on the Earth, Mars and Venus, variations in composition of the lunar eruptions have enabled the surface of the maria to be subdivided into individual units [4]. Such mapping work is vitally important to our understanding of the geologic history of the Moon as it enables the generation of a stratigraphic framework for lunar eruptions as well as constraining the evolution of magma chemistry. The majority of investigations into mare composition have used spectral investigations involving ultraviolet to near infrared (UV-NIR) data obtained from Earth and lunar orbit [e.g., 4 -6].

Radar Mapping: More recent studies comparing S- and P-band (70 cm) Earth based radar data have provided an additional and complementary means to map mare flows [1,7]. Based upon modeling work incorporating studies from Apollo sample returns, TiO_2 content was found to be the most dominant influence on the P-band return [7]. Tracking broad variations in the strength of the P-band backscatter across the surface of the lunar mare can therefore be used as a proxy for ilmenite ($FeTiO_3$) content.

In contrast to UV-NIR spectral datasets, which are sensitive to the upper nanometers to microns of the surface, the P-band radar is able to 'sample' the entire regolith column that sits on top of the blocky remains of the uppermost basaltic flow surface (~10 m deep). As a result the radar data is less effected by surface contamination from thin ejecta deposits and distal rays and thus permits flow unit boundaries to be mapped more continuously relative to UV-NIR datasets.

Use of the P-band mapping technique has provided a stratigraphic framework for Mare Imbrium (Figure 1) [1], which is consistent with previous studies of embayment relationships between individual flows that are present within central Imbrium [8]. The mapping work also places important constraints on the interpretation of the Chang'e-3 Lunar Penetrating Radar measurements [9].

Mini-RF Study of Mare Composition: In principle, radar mapping may be leveraged to derive a value for TiO_2 content that is comparable to spectral based techniques [e.g. 10]. Such a dataset would be value to our understanding of lunar petrology, especially due to the advantages associated with radar imaging discussed above. To investigate the influence of titanium content on radar attenuation we have been collecting data with Mini-RF to measure the bistatic response across mare surfaces. Using the Morgan *et al.* [1] P-band map of Mare Imbrium as a basis for identifying mare units of relatively uniform ilmenite content, our aim is to establish whether individual units exhibit unique bistatic signatures in S- and/or X-band.

Previous work has indicated latitude (i.e. incidence angle) exhibits the dominant influence on the bistatic response, displaying an inversely proportional relationship to CPR (over all bistatic angles) [11]. This study however only considered entire mare deposits and did not differentiate between internal units that display varying compositions. Through the use of the Morgan *et al.* [1] map units we have tailored our targeting strategy to specifically consider the influence of variations in TiO_2 content. Through this we hope to isolate the various parameters which contribute to CPR values measured over a large range of bistatic angles, including mare surface age, regional slopes and emission angle.

Initial Results: To date we have collected data within three regions of Mare Imbrium, two of which (Imbrium 2 and 3) are displayed in Figure 1 and considered further below. For each target, we isolated the data returned exclusively from the surface of Mare Imbrium - excluding all highland terrain or large craters (D > 10 km) and associated ejecta – and plotted the region's CPR as a function of bistatic angle (Figure 2).

None of the targets in either S or X-band display an opposition effect (an increase in backscatter near zero phase angle), though there are distinct differences between each plot. As was observed by [11], the two S-band plots display a relatively flat CPR response across all bistatic angles. However, the response is different for each target area, despite the relatively similar latitudinal ranges. This suggests other parameters are possibly influencing the responses. The X-band CPR values for Imbrium 2 are also much higher than the corresponding S-band data, likely due to an abundance of surface rocks.

At LPSC we will present a complete analysis of all available Imbrium coverage in order to fully interrogate the parameters responsible for the variations in CPR.

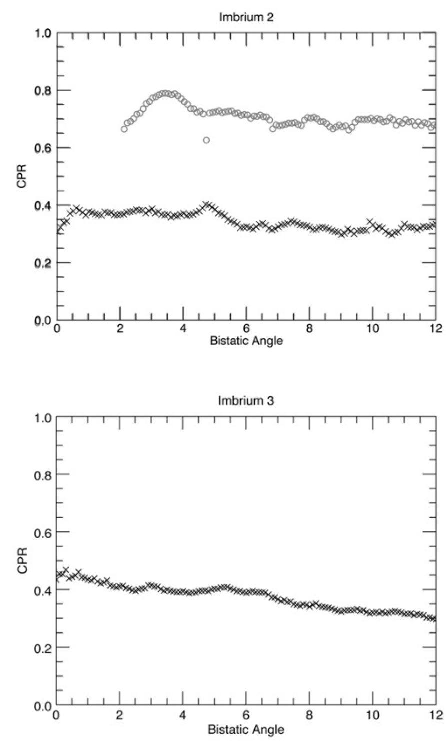

Figure 2. *CPR as a function of bistatic angle for two targets within Mare Imbrium. S-band data is denoted with an X and X-band with circles.*

References: [1] Morgan et al., 2016. JGR, 121, 1498–1513 [2] Hapke et al. 1998, *Icarus*, 133, 89-97. [3] Taylor (1982), Planetary Science: A Lunar Perspective, LPSC, TX. [4] Hiesinger, et al., 2000, JGR, 105, 29,239–29,275. [5] Soderblom, et al., 1977, Proc. Lunar Sci. Conf., 8th, 1191–1199. [6] Pieters, 1978, Proc. Lunar Planet. Sci. Conf., 9th, 2825–2849. [7] Campbell et al., 2014, JGR, 119, 313–330. [8] Schaber, 1973, Proc. Lunar. Planet. Sci. Conf., 4(1), 73–92. [9] Xiao, et al., 2015, Science, 347(6227), 1226–1229. [10] Lucey, 2000, JGR, 105, 20,297–20,306. [11] Patterson, et al. 2017, *Icarus*, 283, 2-19.