EARTH-BASED RADAR PERSPECTIVE OF MARE IMBRIUM: UNDERSTANDING VOLCANIC UNIT BOUNDARIES AND STRATIGRAPHY. G. A. Morgan[1] B. A. Campbell[1], B. R. Hawke[2], and D.B. Campbell[3] [1]Center for Earth and Planetary Studies, Smithsonian Institution, MRC 315, PO Box 37012, Washington, DC 20013-7012, morganga@si.edu, [2]HIGP, University of Hawaii, 1680 East-West Road, Honolulu, HI 96822, [3]Dept. of Astronomy, Cornell University, Ithaca, NY 14853

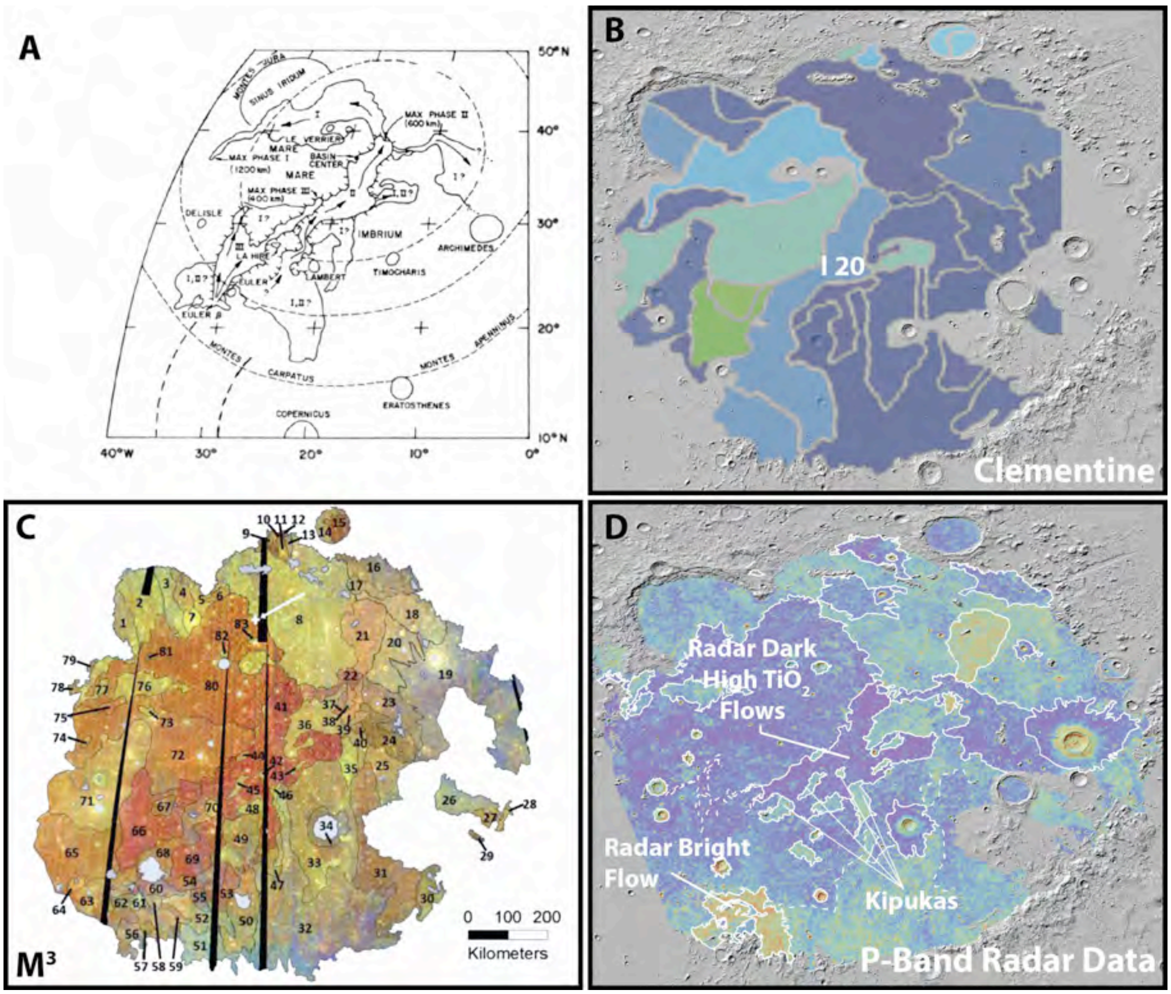

Fig. 1 *Comparison of Mare Imbrium Maps. A) Eratosthenian-period low TiO2 flows mapped by [Schaber, 1973]. B) Clementine derived spectral units mapped by [Hiesinger et al., 2000]. C) M3 derived spectral units mapped by [Thiessen et al., 2014]. D) Our P-Band radar map.*

Introduction: Lunar maria comprise 17% of the surface of the Moon and represent an important episode in the thermal evolution of the satellite. The low eruptive magma viscosity and the associated thin nature of lava units have resulted in the majority of individual flow morphologies being subdued and masked by impact regolith. In order to map the eruptive units that comprise the surface of the mare and investigate the associated stratigraphic relationships, multiple studies have exploited compositional variations derived from spectral data [Hiesinger et al., 2000; 2003; ; Bugiolacchi and Guest, 2008; Thiessen et al., 2014].

Central Mare Imbrium (Fig. 1a) provides a distinct exception to the rest of the maria in that a series of 50 – 100 m thick, Eratosthenian-period flow lobes are clearly discernable within image and topographic data [Schaber, 1973]. Mare Imbrium therefore represents an excellent test site to compare mapping of volcanic units from multiple remote sensing datasets.

Utilizing Clementine data, Hiesinger et al. [2000; 2011] subdivided Mare Imbrium into 30 units (Fig. 1b), though recently the availability of higher spectral resolution M^3 data (Fig. 1c) has permitted a further reclassification of Imbrium into 83 units [Thiessen et al., 2014]. Visible – near infrared spectroscopy is sensitive to the upper few microns of the surface, and thus mapping is made problematic by rays and ejecta blankets comprised of highland or basaltic material of a different composition to that of the local area. Several large impact structures, younger than the most recent mare eruptions, have thrown extensive ejecta blankets across the surface of Mare Imbrium, the most prominent being Copernicus to the south.

Earth based 70 cm (P-band) radar signals can probe well beneath the mare regolith surface to provide information on the rocky transition zone situated just above the intact bedrock, which comprises the remains of the most recent basaltic flows (Fig. 1d). An investigation of Mare Serenitatis by Campbell et al. [2014] using 70-cm radar images identified a host of previously unseen volcanic features. These included flow-unit boundaries, and channels interpreted to be the collapsed remnants of plumbing systems similar to those of terrestrial basaltic volcanic fields. Another important result was the improved delineation of units, which helped to reconcile inconsistencies between regional stratigraphic relationships [Weider et al., 2010] and crater-count age dating [Hiesinger et al., 2000]. Here we use the methodology of Campbell et al. [2014] to focus on Mare Imbrium. We will present a radar map of all identifiable volcanic units (Fig. 1) and discuss their associated stratigraphic relationships.

Radar Dataset & Methodology: We used P-band radar images of the lunar nearside obtained by transmitting a circular-polarized signal from the Arecibo Observatory and receiving echoes from the Moon in both senses of circular polarization at the Green Bank Telescope [Campbell et al., 2007; 2014]. Radar returns in the same sense of circular polarization (SC) as that transmitted are attributed to diffuse scattering by rocks >10 cm in diameter, at the surface and buried within the probing depth of the radar signal (10-15 m in the lowest-loss mare regolith).

The Campbell et al. [2014] Serenitatis study was the first to utilize the highest spatial resolution, 200 m/pixel P-band data for the nearside. This study contrasted the shallower-penetrating 12.6-cm radar images with the new 70-cm data to identify volcanic features differentiated by very subtle differences in TiO_2 content. Applying the same techniques, we present new mapping of Mare Imbrium flow boundaries, particularly where TiO_2 changes are subtle or masked by debris from large craters like Copernicus.

Imbrium Map: The P-band coverage of Imbrium reveals a complex distribution of radar backscatter signatures (Fig. 1d). From this we have been able to map the surface into multiple facies, which display evidence of embayment between the different units. The topographically distinct flows mapped by [Schaber, 1973] are located in the central part of the basin and extend toward the NE (fig. 1a). These flows are well correlated with a radar dark unit in the Earth-based data, which is expected, as the high TiO_2 content strongly attenuates the radar signal. Our map unit for this feature is roughly correlated with unit I20 of [Hiesinger et al., 2000] but strongly matches unit 41 derived from M3 data by [Thiessen et al., 2014] (Fig. 1). Smaller radar bright units that match the backscatter of the surface directly to the north are found within and along the edges of the radar dark unit. Some of these match [Thiessen et al., 2014] units 42 – 45. Based on the morphology of these units and the similarity in strength of return with the unit that borders the high TiO_2 flows to the north, we argue that these smaller units represent kipukas formed by the emplacement of the high TiO_2 flows within an extensive region of earlier, lower-TiO_2 basaltic flows.

The presence of Copernicus ejecta across southern Mare Imbrium (Fig. 1, 2) hampers studies in both visible (Fig. 1, 2) and near-IR spectroscopic data due to contamination of the mare surface by highland material. The ability of the P-band signals to probe beneath the thin Copernicus rays permits unobstructed mapping of this quadrant of Imbrium. A lobate feature of enhanced radar backscatter is present north of Monte Carpathus (Figs. 1d). This feature represents the strongest 70-cm echoes returned from any non-impact landform within Mare Imbrium. The feature is ~100 km long and ~200 km wide (Fig. 1d), and its lobate morphology is suggestive of a lava flow complex. The feature is centered ~200 km southeast of the identified source of the >600 km long Eratosthenian lava flow units [Schaber, 1973]. Continued work will refine these unit outlines, and improve the overall definition of flow-complex boundaries for morphologic analysis and crater age dating.

References: Bugiolacchi and Guest (2008), Icarus, 197, 1. Campbell et al (2007) IEEE Trans. Geosci. Rem. Sensing, 45, 4032. Campbell et al., (2014) JGR, 119, 313. Hiesinger et al (2000) JGR, 105, 29239. Hiesinger et al (2003) JGR, 108, doi:1029/2002JE001985. Schaber, (1973), Proc. Lun. Plan. Sci. Conf. 4, 1, 73-92. Thiessen et al (2014) Planet. Space Sci. 104, 244. Weider et al., (2010) Icarus, 209, 323 – 336.