CHARACTERIZATION OF PROPOSED IMPACT MELT FACIES OF THE MOON'S CRISIUM BASIN.

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Introduction: Understanding the impact history of the Moon has important consequences for Earth's earliest history, including the time around the emergence of life ~4 Ga [e.g., 1], as well as for the overall bombardment history of the inner Solar System. The Nectaris and Crisium basins, particularly, are important anchor points in understanding this history. Spudis and Sliz [2] mapped 10 locations of putative impact melt outcrops (high-standing kipukas embayed by mare basalt flows) around the Mare Crisium's periphery. If these outcrops are impact melt from Crisium, they would provide sampling opportunities to radiometrically date and derive an absolute age for the Crisium forming impact event, allowing better calibration of crater-derived ages [3].

Here, we present high-resolution mapping (~1:50,000) of the proposed Crisium impact melt sites identified by Spudis and Sliz [2], identify lithologies, describe relevant regional geology, and further assess their likely origin(s). Specifically, we hypothesize that if these kipukas are outcrops of Crisium impact melt, their lithologies should reflect a more feldspathic composition than the embaying mare basalts since the target rock was likely highlands material.

Methods: Our data sets include global Lunar Reconnaissance Orbiter Camera (LROC) Wide Angle Camera (WAC) low- and high-incidence angle monochrome basemaps (100 m/px); low- and high-incidence angle LROC Narrow Angle Camera (NAC) images (~1 m/px); the combined 59 m/px global Digital Elevation Model (DEM) from the Lunar Orbiter Laser Altimeter (LOLA) and Kaguya Terrain Camera (TC) [4]; Moon Mineralogy Mapper (M^3) spectra; and Diviner Lunar Radiometer data. Using NAC images, the DEM, and the derived slope information, we mapped the boundaries of kipukas in Mare Crisium at a scale of 1:50,000 in ArcMap, with finer mapping (1:15,000) provided in places of low topographic contrast. We measured fracture dimensions using the LOLA/Kaguya DEM.

Results and Discussion: *Kipuka Mapping*. Examples of our kipuka mapping, refined from the work of Spudis and Sliz, are shown in Figure 1. As described by Spudis and Sliz [2], the kipukas display a range of morphologies, from domed and fractured to more subdued and hilly. Below, we focus on the Western Crisium Kipuka (WCK; box A, Figure 1) and northern Crisium kipukas (box B)..

Fracture Morphometry. The WCK exhibits fractures reminiscent of features in the Maunder Formation [2], the melt sheet of Orientale Basin [5]. However, fracturing is not unique to melt sheets, and floor fractured craters (FFCs) can display fractured morphologies [e.g., 6], hypothesized to originate in response to subcropping dikes, sills, and laccoliths [e.g., 7] that cause doming and fracturing of the crater floor. Morphometric measurements of the WCK fractures, and fractures in two FFCs showed identical slopes of around 15°. In contrast, the Orientale and Imbrium fractured melt sheets have higher slopes (~32-39°), and often beyond the ~33-34° angle of repose for many granular media. The higher fracture slopes in melt sheets may be consistent with formation in response to normal faulting [8,9], or could simply reflect fractures that are younger and less degraded than those observed at Crisium.

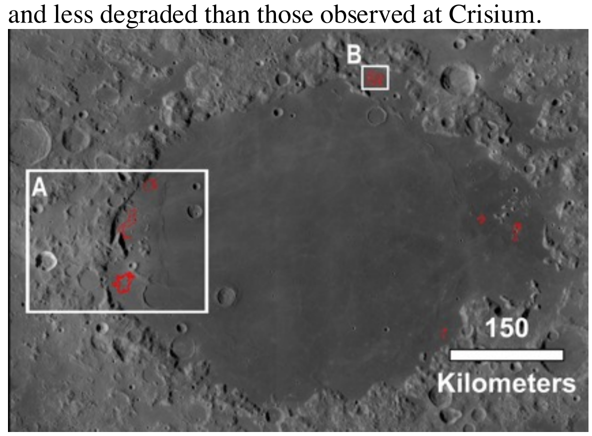

Figure 1. Refined mapping of the Crisium kipukas outlined in red. Part of Box A is shown in Figure 2.

Composition: Reflectance. We examined high-resolution NAC images with low incidence angles to evaluate the reflectance properties of the WCK and northern kipukas. Spudis and Sliz [2] report that the kipukas, especially the WCK, have a depressed FeO content relative to the rest of Mare Crisium basalts (~8.3 vs. >15 wt% for the WCK), interpreted as evidence favoring a Crisium impact melt interpretation. Photometrically normalized high-sun imaging shows the WCK to be overprinted by highland ejecta from Proclus Crater to the west, suggesting the depressed FeO values could be, at least in part, a result of Proclus contamination (Figure 3). Impact craters superposed on both the WCK and surroundings also have low-reflectance ejecta ("dark halo craters"; Box A in Figure 1; Figure 2), indicating a likely excavation of more mafic material from beneath Proclus ejecta and/or from below a thin surface unit native to the WCK (Figure 2). Reflectance values on the low-reflectance ejecta are 0.08, similar to surrounding mare, compared to > 0.1 for the rest of the WCK.

Composition: Spectra. The western and northern kipukas stands out from surrounding mare basalts [2] in terms of both the abundance of pyroxene and pyroxene composition as inferred from 1 and 2 μm absorption features observed in M^3 data. Both regions are more mafic than local massifs but more feldspathic than mare basalt with approximately a noritic anorthosite composition, which is consistent with what is expected for Crisium impact melt. In the case of the WCK, these spectra do not appear to show a large influence from Proclus ejecta. A ~3.5 km *D* diameter crater superposed on the WCK's northeast edge has a reflectance spectrum indicating a pyroxene composition similar to the noritic central peak of nearby Yerkes Crater, but is less mafic with a lower abundance of pyroxene. The most "pristine" WCK materials are probably those associated with the 3.5 km *D* crater: the ejecta are similar to non-mare materials observed in surrounding massifs and craters.

Composition: Thermal IR. We have begun to investigate Diviner Radiometer 8 μm data to locate the Christensen Feature position to further discriminate lithologies in the manner of Greenhagen et al. [10].

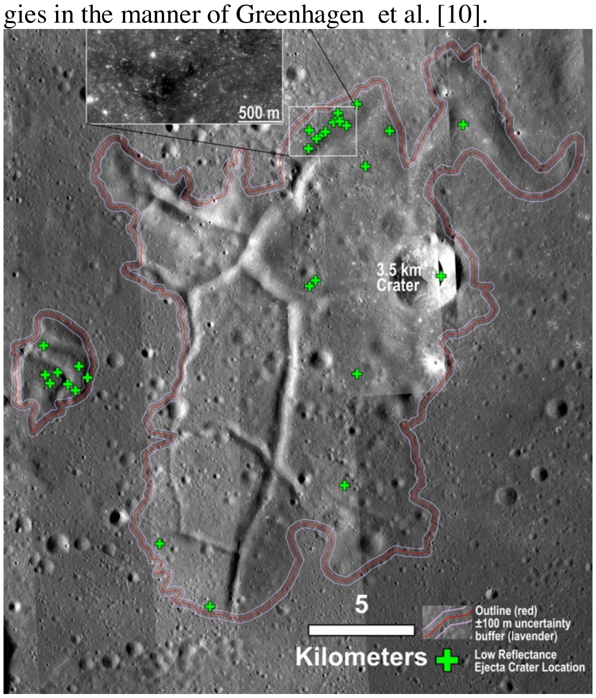

Figure 2. 1:50,000 mapping of the Western Crisium Kipuka (WCK; boxed as "A" in Fig. 1). Embayment and other topography contrast defines the mapped contact with a ±100 m uncertainty buffer. Low reflectance ejecta craters (LRECs, green +), possibly indicate excavated intrusive mafic material. INSET: Zoom of the northernmost LRECs shows a strong reflectance contrast between surface/subsurface material. Base image: NASA/GSFC/Arizona State University.

Discussion and Conclusions: The morphology and noritic anorthosite composition of the WCK and northern kipukas are consistent with an impact melt origin, concordant with the work of Spudis and Sliz [2]. At the WCK, we propose an impact melt origin followed by intrusive magmatic uplift in a manner similar to FFCs [6,7], embayment by mare basalt, overprinting by Proclus ejecta, and finally excavation of intrusive material by small impacts. The northern kipukas appear to also be Crisium impact melt but with only minor contamination via impact gardening.

It is unclear whether Luna or Apollo (A17) samples contain Crisium material [3]; therefore, sample return or in situ radiometric dating of kipuka material will be needed to definitively determine the basin's age. This underscores the need for a rigorous lunar surface exploration program to tightly constrain the impact history of the Moon, and, by extension, that of Earth. A future lander could be sent to the Crisium kipukas to perform in situ age dating [1] or return samples; geologic field and lab work could provide further context and understanding of their origin.

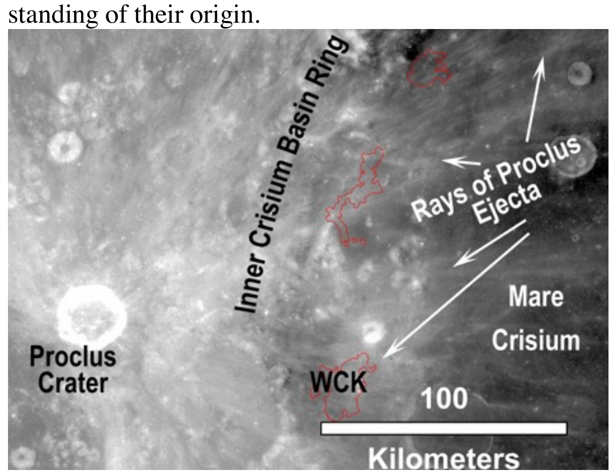

Figure 3. High-Sun photometrically normalized WAC mosaic showing highlands ejecta from Proclus Crater overprinting the WCK (centered at 15.0°N, 50.3°E) and other western kipukas, outlined in red. Base image: NASA/GSFC/Arizona State University.

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