LARGE FLOW FEATURE AT COPERNICUS CRATER – IMPLICATIONS FOR IMPACT MELT EVOLUTION AND EMPLACEMENT CHRONOLOGY.
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Introduction: Impact cratering is known to be a very rapid and dynamic process [1] and is divided into three stages: contact & compression, excavation and modification. Impact melt formation and emplacement are important components of the excavation and modification stages of the cratering process [2], and there is abundant evidence that impact melt is mobile during the short-term modification stage of the transient cavity [3]. Here, we describe several aspects pertaining to impact melt evolution during the modification stage of the Copernicus cratering event on the Moon.

Geologic context: Copernicus is a 96 km diameter, young complex impact crater located on the lunar near-side, extensively studied using telescopic [e.g. 4] and spacecraft observations [e.g. 5]. The pre-impact stratigraphy (top to bottom) has been suggested [6] to be: i) Mare Basalts ii) Imbrium Ejecta (Fra Mauro Formation) and iii) upper crustal material. Later, detection of olivine-bearing lithology in the central peaks [4] led to the suggestion that the upper crust was probably thin here and the peak material might be representing lower crust or even mantle [7]. The crater also shows a north-south compositional heterogeneity [e.g. 8] interpreted to be an expression of the complex target. Recently, east-west differences [9] and identification of Mg-spinel [10] at Copernicus have expanded this diversity. The smooth north-western crater floor is believed to be an accumulation of a thick deposit of impact melt.

Large Flow Feature: The occurrence of a large flow feature at Copernicus has been recently suggested [11] based on M^3 data and further characterized using LRO-LOLA, NAC and Kaguya TC datasets. The large flow feature is >30 km long, sinuous unit, extending from the northern wall to the crater floor and terminating at the central peaks (Fig. 1). We suggest it to be a late stage impact melt flow perhaps triggered by a breach of pooled melt. The flow feature is a spectrally distinct unit, not easily discernible on albedo images and has low surface relief. M^3 spectral data analysis within and outside of the flow feature (Fig. 2) suggests that the flow feature lithology has absorption bands shortward of 1 and 2 µm and a different composition than the thick impact melt deposits, in the northwestern region of the floor, which have been excavated by two fresh craters. The feature can also be seen in independent Kaguya MI data [e.g. 9].

Several observations lead to the interpretation of the spectral feature as an impact melt flow unit: i) The feature extends from melt draped wall to the floor. Possible interpretation could be impact ejecta rays, impact melt, volcanic lava flow or swirls ii) Spectral detection of the feature suggests sampling of the topmost surface. The surface modification could be caused by any of the candidates listed above. iii) The feature is too isolated to be a lava flow and does not match with a basalt, which is the most common volcanic composition in the region. iv) The 'sinuous' shape of the feature, together with a lack of material of similar nature in the vicinity, would rule out an impact ejecta ray as a possibilty. v) Swirl origin can be ruled out due to lack of a magnetic anomaly [12, 13], no associated high albedo and different composition from surrounding. We, therefore interpret the feature as an impact melt flow.

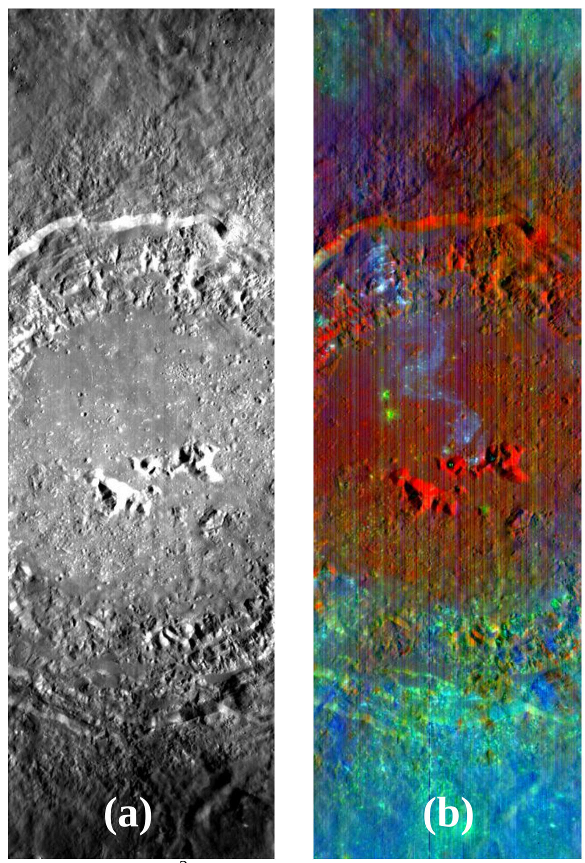

Fig. 1 (a) M^3 1489 nm albedo image of Copernicus crater. (b) RGB composite of the study area. The flow feature shows up in light blue tone on the crater floor and northern walls. (Red- Albedo at 1489 nm, Green- Integrated band strength at 2 µm, Blue- Band depth at

1.9 µm). Note that the flow feature is not clearly discernible by albedo alone.

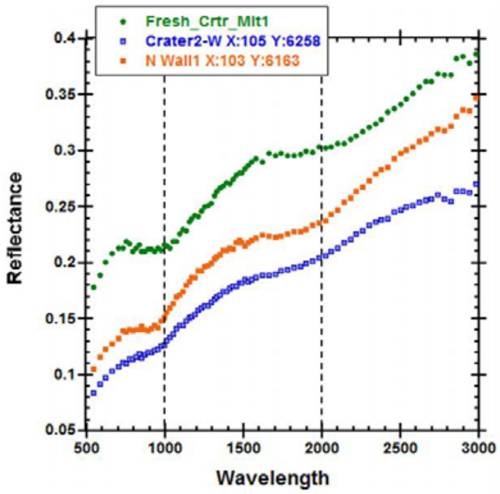

Fig. 2 Comparison of spectra from within the flow feature (blue-floor; orange-wall) to material from the deep pool of NW impact melt excavated by fresh craters (green spectrum). The shorter 1 and 2 µm absorption bands of the flow feature spectra not only indicates compositional heterogeneity for melt within Copernicus but a more Mg-rich pyroxene for the flow feature.

Implications for Melt Evolution: This observation of a new feature has provided insights into the formation, evolution and phases of emplacement of the impact melts.

Inefficient Mixing of Impact Melts: The notable difference in mineralogy of the flow feature compared to the surrounding impact melts on the crater floor (shown in Fig. 2) possibly suggests inefficient mixing across the melted target (which is known to be heterogeneous). It might be caused by insufficient time available for mixing or simply isolation of an impact melt unit during initial stages of melt movement. Terrestrial examples of inefficient mixing [14] support this possibility. Alternatively, potential melt differentiation and/or differences in clast mineralogy could also affect the compositional variation in impact melts. There may be multiple causes for such heterogeneity in impact melts and characterization of individual examples would require further investigations.

High Mobility of Melt : The great extent of the flow feature (>30 km) suggests that this last stage melt was sufficiently mobile and therefore had a relatively low viscosity and/or low clast fraction. The flow was perhaps aided by a relatively smooth crater floor as well. It remains to be explored whether it was the high heat budget of the melted material or a favorable composition that led to a highly mobile late stage impact melt flow.

Melt Emplacement Chronology: While there have been theories chronicling the sequence of events in an impact cratering process, there have been few field examples that document the relative chronology of formation of various crater units. In the present case, the flow feature termination at the central peaks nicely captures one such event, that of formation of the central peaks before the flow feature.

Extended Time Period for Melt Emplacement: The formation of this late stage ~30 km long flow feature on the floor strongly suggests that the floor was sufficiently solid to support the overburden of an additional volume of melted material that flowed over it. This would imply a time interval between melting of material and its final emplacement (in this case, the flow feature) suggesting that impact melts could be active for relatively long durations (perhaps ranging from days to weeks, if not months). Some of the recent studies [15] have arrived at similar conclusions, though at a smaller spatial scale.

Summary and Future work: The large flow feature at Copernicus has provided new insights into the formation, evolution and emplacement history of impact melts. It suggests that impact melts can be very heterogenous in their composition and they can remain active for extended durations. Future work would involve integrating multiple datasets to characterize the flow feature further and also to evaluate melt features elsewhere. This work is part of an ongoing effort to characterize the compositional diversity of impact melts.

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