SPECTRAL ANALYSIS OF THE DISTRIBUTION OF IMPACT MELT-RICH LITHOLOGIES IN LUNAR CRATER KEPLER USING M^3 DATA.

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Introduction: Complex impact crater Kepler (8.1ºN 322ºE, D=31 km, d=~2.7 km) is of Copernican age, overlying Imbrium basin ejecta [1] and the Upper Imbrian and Eratosthenian high-iron mare basalts of the Procellarum KREEP Terrane [2, 3]. The impact excavated high-Th and moderately high-Fe material from beneath the mare basalts [2]. Based on Clementine data, the composition of Kepler's rim is probably noritic [4].

Recently, we carried out a photogeologic analysis of Kepler with a focus on impact melt properties and distribution [5]. That study noted, among other things, an asymmetric distribution of both rays and melt-rich material, implying an impact trajectory from the SE sector (rays: ~ESE; melt ponds: ~SSE). Here, we further characterize impact melt distribution and composition in and around Kepler using high-resolution Moon Mineralogy Mapper (M^3) data.

Data and methods: M^3 visible (VIS) and near-infrared (NIR) spectrometer, onboard India's Chandrayaan-1 spacecraft, imaged the Kepler region in 85 channels with a spatial resolution of 140 m/pixel [6]. Our analysis used "U" calibrated radiance, converted to reflectance. We generated several spectral parameter maps, such as the band depth at 1900 nm (BD1900), and the slope of the continuum (VIS/NIR) to accentuate features of the reflectance spectrum and distinguish ferrous absorptions diagnostic of mineralogy and composition. In addition, we applied a principal component (PC) analysis to characterize the variability of the data [7]. Primary image datasets include the Kaguya Terrain Camera (TC, ~7.4 m/px) and Lunar Reconnaissance Orbiter (LRO) Narrow Angle Cameras (NAC, ~0.5–1.2 m/px; see [5] for further details of the datasets used). Identification of impact melt-rich lithologies was based on established morphological criteria [*e.g.*, 5, 8, and references therein].

Results: The spectra of the exposed wall of Kepler display narrow absorption bands and a relatively flat continuum, interpreted to represent a crystalline, low-Ca pyroxene-dominated (noritic) composition, in agreement with earlier studies [4]. The melt-bearing floor units [5], however, are different from the crater wall or the surroundings by having broad absorption bands and a positive continuum slope, interpreted to represent less-crystalline material with a high-Ca pyroxene-dominated (gabbroic) composition (dark in Fig. 1a). Similar spectral characteristics can also be seen in a newly identified dark splash-like feature on the SE crater wall and proximal ejecta blanket (Fig. 1a), with a minor splash on the W wall. The central uplift shows a variable Ca pyroxene signature, but compared to the crater wall or melt-rich floor these spectra have a much higher albedo and mafic absorptions are not as strong, which we attribute to higher modal plagioclase.

The BD1900 parameter map (Fig. 1a, which is not an albedo image) provides the best view of the unexpected splash-like presence of material on the SE wall and proximal ejecta blanket. In the BD1900 parameter map the floor and the splash appear dark, due to a relative depletion of low-Ca pyroxene (low-Ca pyroxene has a maximum absorption near 1900 nm). The SE splash is coincident with a region of Kepler's terrace zone with the highest concentration of narrow radial grooves, interpreted to be channels eroded by impact melt [5]. However, a smaller area with similar channels on the SW wall does not show up in the BD1900 parameter map, and a minor splash on the W wall, spectrally resembling the floor, roughly coincides with an area having a higher albedo, but no melt channels. On the SE rim flank and proximal ejecta blanket the splash feature seen in the BD1900 parameter map approximately corresponds to a poorly defined, but fairly large, area characterized by features indicative of some scouring and/or minor flows, small melt ponds with indistinct boundaries, and occasional patches of fractured melt veneer [5]. However, despite approximate spatial correlation, this distinct spectral feature does not have a clear-cut morphologic equivalent.

A map of the VIS/NIR slope of the continuum (accentuated in PC7 shown in Fig. 1b) shows a dark asymmetric halo of poorly crystalline material surrounding the crater. Only faint traces of it can be seen in high solar angle photographic imagery. This halo extends ~18–20 km from the rim in the W, N, and E, ~15 km in the NW, but only ~7–9 km in the S and SSE. Despite being slightly subdued in the NW, the asymmetry of the halo is generally compatible with the inferred impact trajectory, but the halo somewhat exceeds the area covered by the photogeologically defined exterior melt ponds and rim veneer [5] and, unlike the dispersed exterior ponds, the halo is a very uniform feature.

Implications: The SE splash in Fig. 1a represents only a very surficial feature, probably small melt particles or glassy rock coatings deposited on top of the ejecta blanket. This is indicated by the fact that despite some indications of impact melt flow and ponding, the most typical morphological features of impact melt [5, 8] are absent or only very poorly defined. Larger morphologically defined melt ponds N of Kepler are only poorly distinguished in M^3 data.

The reasons for the location and orientation of the SE splash feature are not easily understood. Rays and morphologic melt pond distribution clearly demonstrate an impact from the SE sector, whereas the splash feature seems to indicate the opposite. At the moment we do not understand this conundrum. More voluminous deposition of downrange ejecta might perhaps mask the subtle signature, and maybe there was a less turbulent deposition of quenched melt droplets in the uprange direction, resulting in a less dispersed accumulation of the droplets and therefore a stronger spectral signature. Or could late-stage collapse of the crater wall, which is best developed in the N (massive slumping) and W (more coherent terracing) [5] eject some of the melt on the SE wall and rim flank?

Because M^3 data represents only the uppermost surface, it alone cannot be used to estimate the distribution or volume of melt-rich lithologies. However, it can provide insights into near-surface processes related to impact melt deposition. The dark halo of less-crystalline material (Fig. 1b) probably represents a late-stage surficial deposit, possibly derived from the collapse of the impact plume which was slightly shifted due to an only moderately oblique [5] impact. Although the dark halo is more prominent on the N and NE sides rather than NW, the most narrow and faint part of it on the SE sector is consistent with the approximate trajectory inferred from photogeology.

The somewhat stronger plagioclase signature of the central uplift probably indicates an origin below the ~500 m of mare basalts and ~500 m of noritic Imbrium ejecta [5]. As the depth of melting likely reached ~3.5–4 km [9], the contribution from this deeper and more Ca-rich target material also explains the high-Ca dominated (gabbroic) signature of the impact melts, instead of a signature similar to the low-Ca dominated (noritic) wall material that would be expected if the wall material was the sole source of the melts. We also note that changing the probable Kepler impact melt composition from an average lunar norite to more gabbroic composition does not significantly alter their calculated and modeled rheologic properties [5].

Our results confirm studies of other craters (Gerasimovich D [7], Aristarchus [10]) showing that M^3 data can reveal subtle features that cannot be detected by photogeology alone, thus enabling a refined analysis of impact melt distribution and the cratering process.

Acknowledgments: Efforts of the science teams of the Chandrayaan-1, LRO and Kaguya missions, and M^3, NAC and TC instruments are gratefully acknowledged.

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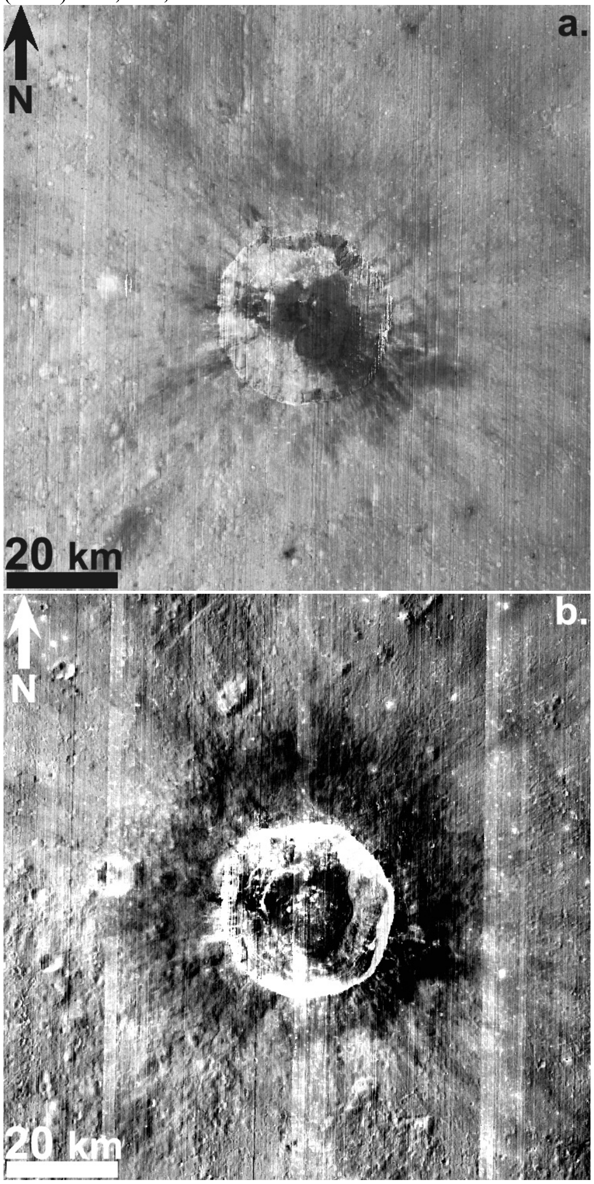

Fig. 1. a.) BD1900 spectral parameter map. Bright areas indicate a noritic, and dark areas a gabbroic composition. The dark splash on the SE wall and rim flank is similar to the floor melt material. b.) PCA axis 7 parameter map highlights an asymmetric halo (having a steeper continuum slope) on the continuous ejecta. We interpret this to show that the ejecta is overlain by less-crystalline material. The asymmetry roughly matches the impact trajectory from the SE sector as determined from photogeology [5], but the halo itself can only be seen in M^3 data.