MINERALOGICAL AND MORPHOLOGICAL INVESTIGATION OF BUTTERFLY-SHAPED UNNAMED CRATER USING DATASETS FROM RECENT LUNAR MISSIONS.

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Introduction: Chandrayaan-2 (Ch-2), India's second lunar probe delivers a wide range of information that can unravel many mysteries and enhance our knowledge regarding Moon. Among 8 payloads on-board Ch-2 orbiter, the Imaging InfraRed Spectrometer (IIRS) instrument plays a major role in identifying and mapping the mineralogy of the lunar surface. The wide spectral range of IIRS aids in detection of minerals, and detection as well as quantification of the hydration features more accurately than the Moon Mineralogy Mapper (M^3) aboard Chandrayaan-1. In this study, we report the compositionally bimodal impact melt and ejecta materials associated with the fresh impact crater centered at 18.6°N, 121.5°E with ~3 km diameter, situated on the western side of the heavily degraded Lomonosov-Fleming (LF) basin region that contains cryptomare deposits [1, 3]. The impact melt flow pattern inside the central part of the crater and the ejecta pattern is suggestive of an oblique impact [2]. High resolution data of Lunar Reconnaissance Orbiter-Narrow Angle Camera (LRO-NAC) distinctly shows the presence of impact melt deposits (within the crater) and ejecta blankets resembling the wings of a butterfly [4], hence we are refereeing it as butterfly-shaped crater.

Datasets and methodology: To identify the mineralogical diversity of the crater, Ch-2 IIRS dataset of 16th January, 2021 has been utilized, which covers an unknown fresh crater near Olcott crater. The IIRS instrument is presently mapping the lunar surface in the spectral range of ~800-5000 nm and has spectral (~20-25 nm) and spatial resolutions (~80 m/pixel) better than the previously flown imaging spectrometers [4-6]. Firstly, the level-1 radiance data of IIRS has been converted to reflectance by normalizing the measured spectral radiance with the incoming solar flux. Subsequently, a false colored composite (FCC) is generated to identify the spectrally anomalous locales. Red, green and blue channels are assigned to 998-, 1588- and 2127-nm bands of IIRS, respectively (Fig. 1b). Also, integrated band depth (IBD) image has been generated to depict the spectral variability of the area primarily based on the spectral absorption band strengths of 1000- and 2000-nm absorption features arising due to the electronic transition in Fe2+ residing inside the crystal lattice of major rock forming mafic silicates. IBD-FCC has been prepared by assigning red, green and blue channels to IBD-1000 nm, IBD-2000 nm and 1588-nm albedo channel (as this spectral region is free from any lunar mafic silicates absorption) of IIRS, respectively (Fig. 2(d, e)). The high-resolution NAC images and SELENE/LRO digital elevation model (SLDEM) co-registered with NAC-derived DEM have also been used in this study to analyze the morphological features present within the crater [8].

Results and discussions: The high-resolution image and the morphological analysis of the study area suggest it to be the result of two small impact events not much separated in time (Fig. 1d). The elevation profile of the crater suggests that the slope of the southern wall is steeper that the northern wall. Further, the profile also carries the signature of the second and relatively younger/smaller impact as manifested by a trough seen in the cross-section near 'B' in Figure 1d. At the base of

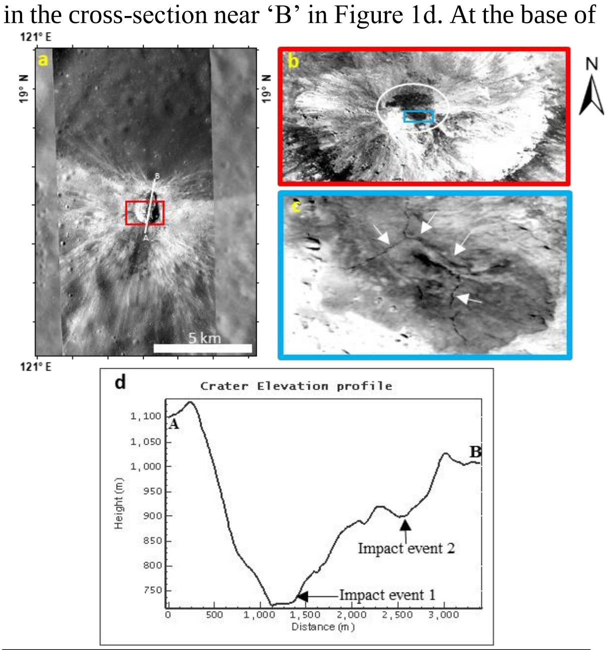

Figure-1: a) LRO-NAC image of study area overlaid on WAC mosaic. NAC image showing the distinct morphology features b) melt ponds c) polygonal cracks inside melt pond. d) Elevation profile of crater suggesting two impact events.

the crater floor, impact melt pool has been identified. The melt pool has polygonal thermal cracks that could be attributed to the post-impact viscous relaxation of the crater floor (Fig. 1b and 1c). The butterfly-shaped crater ejecta can be easily identified in the LRO-NAC data sets as it stands out as a very high albedo feature relative to its immediate surroundings (Fig. 1a). The shape of distinctly asymmetric ejecta and the impact flow fronts suggests that this crater might be from the result of an oblique impact. In RGB-FCC, the mafic-rich exposures appear in the shades of yellow to dark maroon. The IBD-albedo based FCC clearly reveals mineralogically/ compositionally bimodal pattern in the distribution of the ejecta and/or impact melts around the crater. The ejecta distribution pattern has close resemblance with the wings of a butterfly and is spread on either side of the crater in more or less east-west direction. In the IBD-albedo based FCC, the wings of the ejecta appear in blue, possibly suggesting the occurrences of shocked plagioclase-bearing lithology. On the other hand, the mafic-rich melts/clasts appear in yellow and are found to cluster very close to the southern crater rim having an elongated spread in South South West (SSW) direction. Also, mafic melts are found encircling the southern inner as well as outer rim. The material scooped out by the small superposed crater in the north also reveals mafic signature and thus appear in the shades of yellow to orange. The spectral signatures of low Ca-pyroxenes (LCPs) dominate in and around the crater, which have been characterized by the strong dual absorption features around 930-950 nm and 2057-2100 nm (Fig. 2f). To avoid the effect of thermal emissive component, the reflectance spectra have been clipped at 2500 nm. LRO-NAC images indicate materials along the terraces have variable textures including blocky boulders and smooth deposits. The geological features of the studied site can be easily outlined even in the IIRS data due to its high spatial details (Fig. 2c).

Conclusions: From this study, it can be concluded that the examined crater is a fresh crater formed by the oblique impact with low incidence angle. The impact direction is possibly North North East- South South West (NNE-SSW). Bimodal ejecta/melt pattern is seen highlighting density-driven ejecta/impact melt segregation of the felsic and mafic materials. The spread of relatively denser mafic-rich material is restricted along the southern inner and outer rim and only shows an elliptical spread in the SSW direction immediately adjacent to the southern crater rim, whereas, the lighter felsic materials have a larger spread. During the oblique impact, a melt pool might have formed at the central crater floor and over the time cracks opened up as the melt pool cooled. Synergetic studies using IIRS and NAC provides an opportunity to decipher the rich morphology and mineralogical composition of this area. Due to its butterfly wing shaped ejecta pattern, we refer this crater as “Butterfly crater”.

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References: [1] B. Shankar et al. (2012) LPSC XXXXIII Abstract #1357. [2] Plescia, J. B., and M. J. Cintala (2012), J. Geophys. Res., 117, E00H12. [3] Giguere, T. A., et al. (2003). JGR. 108 (E11) 5118; [4] Herrick RR, Forsberg-Taylor NK (2003). Meteorite Planet Sci 38(11): 1551–1578 [5] Roy Chowdury A. et al. (2020)Curr. Sci. 118(3), 368-375. [6] Bhattacharya S. et al. (2020) LPSC XXXXXI, Abstract #1516. [7] Bhattacharya S. et al. (2021), LPSC XXXXXII, Abstract #1848. [8] Green et al. 2011, JGR, Vol. 116, E00G19.

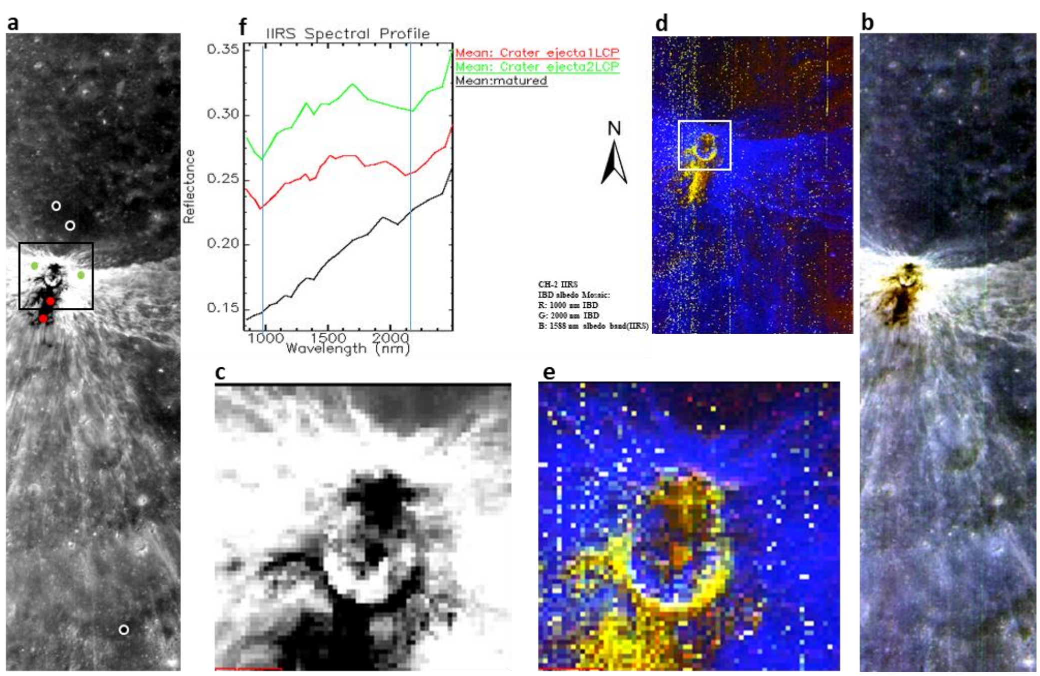

Figure-2: a. IIRS image showing the fresh crater (within black box), and spectra regions of interest (ROIs) (shown by white circles) are represented b. FCC mosaic of fresh crater using Ch-2 IIRS data. c. subset of study area showing the crater and impact melt features (d-e) IBD mosaic images of Crater have been prepared by using IIRS dataset. (f) Representative reflectance spectra of various minerals from IIRS.