MINERALOGY MORPHOLOGY AND TECTONIC SETTING OF GARDNER CRATER OF THE MOON.

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Introduction: Gardner crater is an 18 km diameter crater of late Imbrian age [1], located at 17.7° N, 33.8° E on the Gardner volcanic shield. This shield plateau is located in northern most part of the mare-highland boundary of Mare Tranquillitatis. Gardner crater is located at northern most part of the shield. The Gardner shield volcano is 70 km in diameter with 1.6 km of relief [2]. The Gardner shield is >3.8 Ga old, making it Nectarian to Pre Nectarian in age. Gardner crater, located at the northernmost part of the shield, is an important location to be studied, as it possibly exposes shield volcanic plateau material and the highland material from the subsurface.

Data set and Calibration: Data from the Moon Mineralogy Mapper (M3) instrument [3-4] on-board Chandrayaan-1 have been used to study the mineralogy of Gardner crater and its surrounding area. We used the M3 Level-2 data products from Chandrayaan-1 Optical Period 1A (OP1A) and Optical Period 1B (OP1B). These data products provide projected, thermally corrected, and photometrically corrected, reflectance [5-6]. M^3 operates in the VNIR spectral region, ranging from 540 nm to 3000 nm with 85 contiguous bands and 140 m/pix spatial resolution [7]. Data were acquired from PDS Geoscience Node, georeferenced and mosaicked.

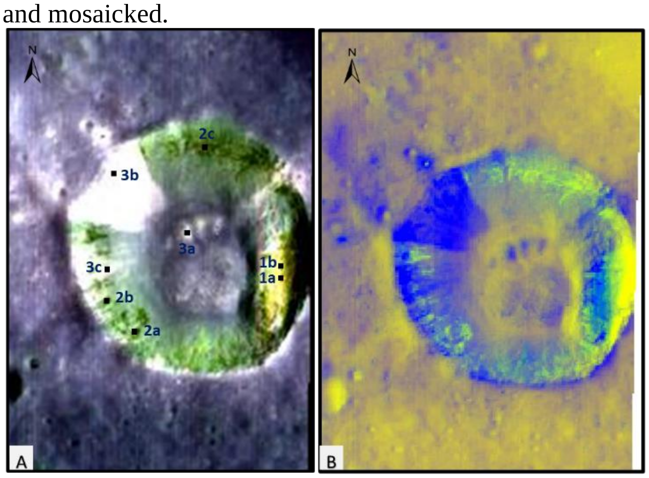

Figure 1. (A) M3 False color composite (FCC) and **(B)** Integrated Band Depth (IBD) FCC images. Marked area shows location of the reflectance spectra presented in Fig. 2.

Lunar Reconnaissance Orbiter (LRO) Lunar Orbiter Laser Altimeter (LOLA)-digital elevation model (DTM) data and Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC) data were used to study the topography and morphology of the crater.

Methodology: The mineralogical variation in the area was assessed using the integrated band depth (IBD) parameter technique from [8]. The IBD parameter is defined for characterizing the band depth for 1- and 2- μm absorption features in order to capture mineralogical variations. The IBD-1 and IBD-2 captures integrated band depth of crystal field absorption at 1 μm and 2 μm absorption band respectively. An IBD false colour composite (FCC) image was prepared by assigning a red channel to IBD-1, green to IBD-2 and blue to the 1578 nm M3 albedo channel (Fig. 1B). The IBD FCC image and spectral reflectance profiles (Fig. 2) collected from the locations marked in the Fig. 1A demonstrate the mineralogical variability of the crater.

A triangulated irregular network (TIN) model was generated from a contour map using the LOLA DEM data set to study shaded relief topography of the crater (Fig. 3).

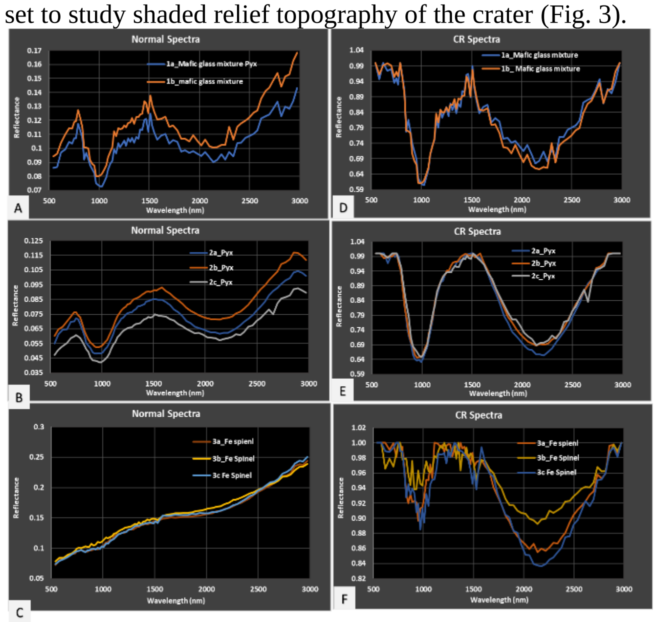

Figure 2: M3 normal (Graph: A, B, C) and Continuum removed (Graph: D, E, F) reflectance spectra**.**

Results and Discussions: The Gardner volcanic plateau formed in the Nectarian period which is nearly 3.90 Ga old [9]. Gardner crater formed in the late Imbrian age, so exposes fresh material from the shield plateau. The crater lies close to the nearby highlands, so exposes highland material that may have been very near to surface. The IBD FCC image (Fig. 1B) shows a yellowish part at crater floor and rim, which denotes the presence of high calcium pyroxene-bearing basaltic material. The blue pixels in Fig. 1b show the presence of highlands material. Location 1a and 1b show presence of a mafic glass mixture possibly composed of olivine and glass. Spectra collected from locations 2a and 2b display presence of high calcium pyroxene-bearing material from the shield area. Spectra from 3a, 3b, 3c expose Fe-spinel bearing material that may belongs to the Mg suite. These regions appear blue in Fig. 1b. The northern part of the crater floor shows three small mounds. The east, southeast, south, west, and southwest parts of the rim show landslides on the crater wall (Fig. 4). Many areas of the crater wall have prominent boulder tracks and trails that reach the crater floor, with clusters and linear tracks of boulders along the way. These observations indicate tectonic settlement of the crater after its formation. The crater also shows prominent finer debris flow features at the eastern wall and southern wall (Fig. 4). These granular debris flows, studied in detail by [2] are very fine in nature and also support the hypothesis of tectonic settlement of the area.

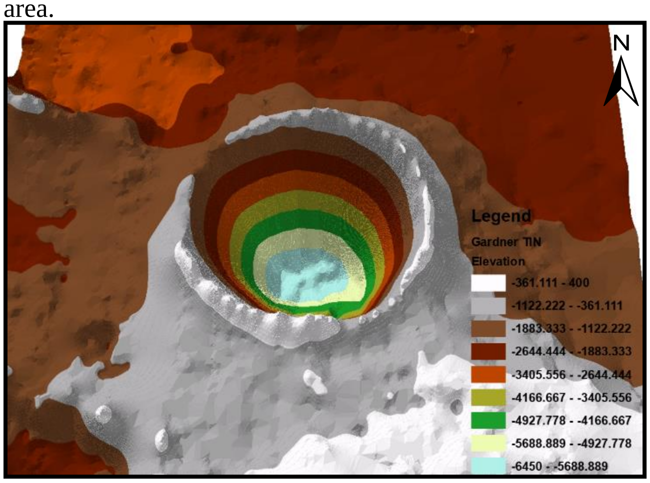

Figure 3. TIN image generated using LRO LOLA data 1024 pix/degree Gridded data record which represents topographic map from the top view of the Gardner crater with legends showing elevation in meters.

The elevation profile surrounding the crater gradually increases from north to south as the southern part of the crater is elevated towards the highest point of the shield (white shaded region in Fig. 3). The rim of the crater shows gaps at the upper most part, which indicates collapse of the ejecta material from the rim through crater wall to the floor. These observations confirm prominent debris flows in the wall and boulder run off (Fig. 4, 5). The northern part of the crater floor shows three mounds (pale green in Fig. 3) which correspond with the presence of Fe spinel bearing material.

Conclusions: Gardner crater exposes high calcium pyroxene and mafic glass mixture-bearing material from the volcanic shield plateau. The NW part of the crater excavates Fe spinel-bearing material that may belong to the highlands Mg suite. The crater shows very prominent morphological features and structures such as debris flows on the crater wall, landslides on the rim, prominent boulder tracks, and boulder clusters and linearly tracked boulders. These features indicate tectonic activity in this area may have occurred due to tectonic settlement of the crater after its formation or due to subsurface activity of the shield plateau. Huang et al. [9] suggested that the Gardner plateau have stayed volcanically active for a long period (~3.90 Ga to 2.96 Ga) with multiple eruption episodes. The presence of such a prominent structure strengthens the possibility that major tectonic activity in this area may have happened due to volcanic shield plateau activity prolonged up to the Eratosthenian period.

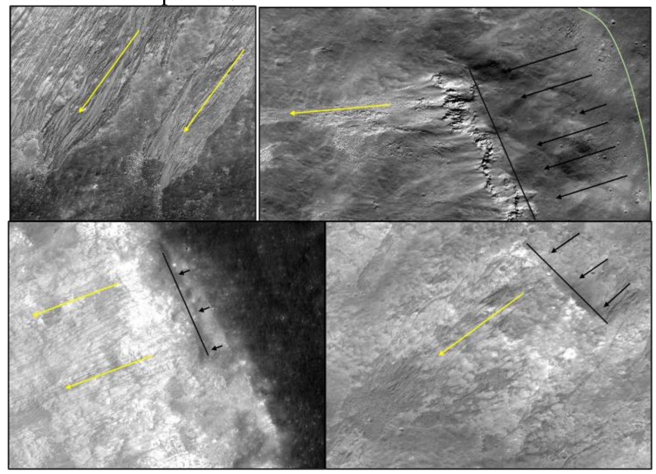

Figure 4. displays prominent debris flow and land sliding from the crater wall.

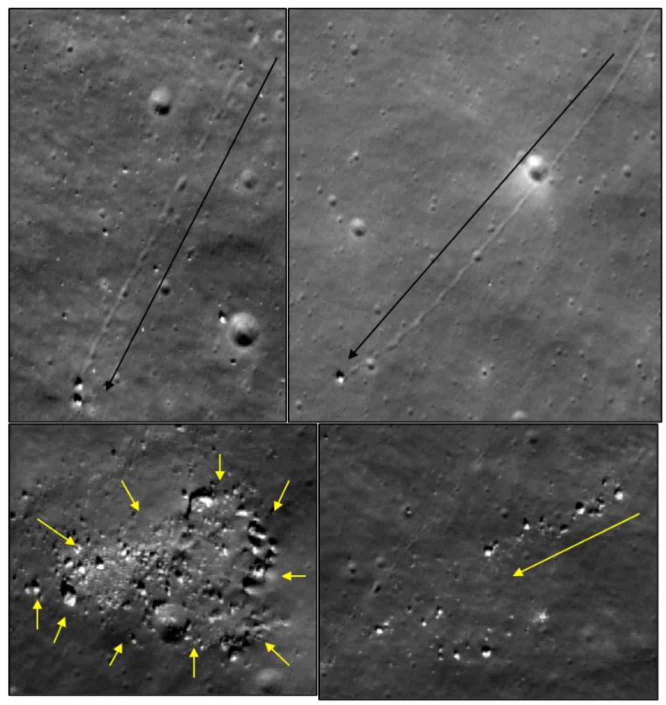

Figure 5. NAC image shows prominent tracks of boulder run off from the crater rim and wall to the floor.

References: [1] Scott D. H. & Phon H. A. (1972), *U.S. Geol. Survey Misc. Geol. Inv. Map I-799*, scale 1:1,000,000. [2] Spudis et al. (2013). JGR: Planets, 118, 2016-2029. [3] Goswami J. N. and Annadurai M. (2009) *Curr. Sci*., 96, 486-491. [4] Boardman J. W. et al. (2011) *JGR*, 116(E6). [5] Clark R. N. et al. (2011) *JGR*, 116(E6). [6] Besse S. et al (2013) *Icarus*, 222(1), 229-242. [7] Pieters C. M. et al., (2009). *Current Science*, 96, 500–505. [8] Mustard J. F. et al (2011), *JGR*, 116, E00G12. [9] Huang et al. (2020) Earth & Pl. Sci. Lt., 542, 116301.