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Mineralogical and Geomorphological Mapping of western central part of Mare Tranquillitatis using Hyperspectral Imager onboard Chandrayaan-1

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Abstract- Geological mapping of a part of Mare Tranquillitatis has been done using Chandrayaan-1 Hyper spectral imager data for the first time in the present study. Mare Tranquillitatis is well known for its high Titanium content on the Moon. Geology and topography of the western portion of the Mare is investigated, which is older, heavily cratered and covers most of the large crater of the Mare. Band parameter technique and reflectance spectroscopic method which has been established previously, is used to investigate mineralogy and rock type of the study area. Mostly High Calcium Pyroxene (HCP) rich material has been found in Mare area, while highland area shows signature of Low Calcium Pyroxene (LCP) as well as HCP in the northern highland. Using Band parameter technique we have identified three major lithological units – ancient mature Mare unit, highland contaminated Mare unit, HCP and LCP rich fresh crater within mature anorthositic highland crust. From the geological and geomorphological study, our new investigation confirms that Maclear is a pre-Mare crater which has been filled partially by Mare basaltic lava. Sabine crater shows crenulated floor which may have formed due to tectonic and/ volcanic activity at the floor. Topographically the northern half of the study area is low lying area with comparatively younger age, while southern Mare shows topographic highs with older age.

Index Terms- Lunar geology; Geomorphology; Remote Sensing; Mapping; Hyperspectral data; Chandrayaan-1; Mare Tranquillitatis.

1. INTRODUCTION

The Tranquillitatis basin is of Pre-Nectarian age [1], located at 7°N and 30°E on the eastern limb of near side of the Moon (Fig. 1). Mare Tranquillitatis is a nonmascon basin extending about 800 km in diameter at its longest dimension is from east to west [2]. The basin is divided in to two as eastern and western basins by subtle differences in topography and superposed features [3]. It is characteristically a blue Mare that demarcates a rough surface boundary and is well known for its highest Titanium content [4], [5], [6]. The Imbrian-age basalts in the south-western portion of this basin were the site of the first manned landing, Apollo 11 Tranquillity Base. Extensive areas of this Mare is within other parts of the basin and are similar to the region sampled by Apollo 11 in both spectral character [7] and crater age.

In present study, we have used Indian Space Research Organization's (ISRO) Hyper Spectral Imager (HySI) data operating in visible and near infrared spectral region, onboard Chandrayaan-1 for mineralogical study of the lunar surface. The total spectral range of 421 nm to 964 nm is resolved in 64 contiguous bands with spectral sampling better than 20 nm. The spatial sampling for all bands is 80 m and the pixel value is 12 bit quantized. The instrument maps the lunar surface in push broom mode with a swath of 20 km from the polar orbit of 100 km altitude [8]. For the topographic mapping of the area NASA's Lunar Reconnaissance Orbiter (LRO) - Lunar Orbiter Laser Altimeter (LOLA) data has been used.

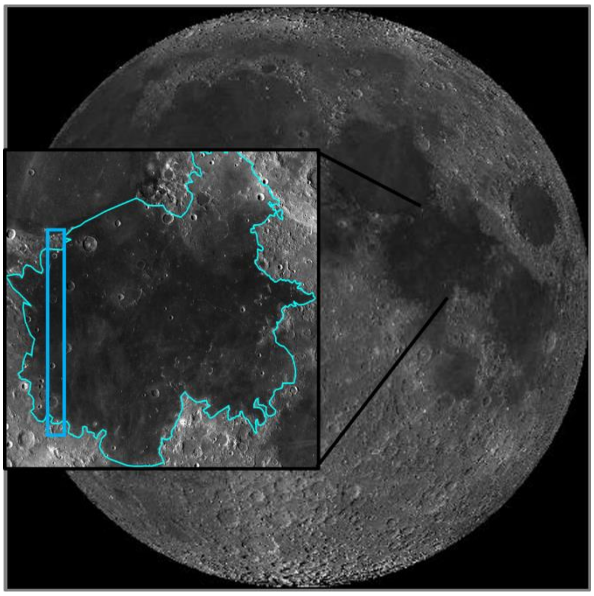

Fig. 1. LROC WAC map showing location of Mare Tranquillitatis basin on the Moon. Rectangle strip shows location of study area (HYS_NREF_20090731T181300758).

The major mineralogy of various types of Mare basalt includes pyroxene, Mg-rich olivine, Ca-rich feldspar and ilmenite [9]. Low Calcium Pyroxene (LCP) is usually found in highland region, while High Calcium Pyroxene (HCP) is found within the Mare region [10]. Composition of the spatially distributed mineral and rock type present in a surface can be identified based on absorption feature in the reflectance spectra arises due to the Fe^{+2} electronic charge transition in the crystallographic site of the mineral [11].

2. METHODOLOGY

Geological mapping of a terrestrial surface using remote sensing and reflectance spectroscopy is being studied from last five decades. For this work**,** we have acquired HySI Level-4 Band to Band Registered (BBR) data sets of 200 km spacecraft altitude from the ISRO's Science Data Archive (ISDA). Hyperspectral data coverage from both 100 and 200 km orbital altitude of Mare Tranquillitatis region has been shown in Fig. 1. The data was converted from radiance to reflectance by dividing it with solar flux. HySI data was further cross calibrated with the Apollo 11 sample number 10084 of bulk soil sample data set, selected from the RELAB spectral library. To investigate compositional variations of the area using HySI data sets, we have used band parameter technique, which has been modified according to available HySI channel, which comprises three band parameters, namely, band strength (BS), band curvature (BC) and band tilt (BT) (originally derived for Clementine UVVIS data) have been applied on the HySI data [12]. These band parameters technique measures the shape, position and strength of the absorption feature near 1000 nm arising due to electronic transition of Fe^{2+} in crystallographic sites of major rock forming silicates. The band parameter expressions have been presented in the following equations:

$$BS = R_{947.7} / R_{748.3} \quad (1)$$
$$BC = (R_{748.3} + R_{947.7}) / R_{898.0} \quad (2)$$
$$BT = R_{898.0} / R_{947.7} \quad (3)$$

Where, R is the reflectance value of the corresponding band. Band parameter BC, BT and BS [i.e. Eq. (1), (2), (3)] have been assigned red, green and blue channel, respectively and Rock Type Color Composite (RCC) image has been generated for the study area. The RCC image has been presented in Fig. 2B. The average reflectance spectra of the marked area in Fig. 2 (1a-7a) have been calculated to study the nature of the material present in the area. Reflectance spectra of the all marked area has been shown in Fig. 2G.

Table 1: Measured Band Parameter (BP) characteristics and observations

BP	Characteristic	Observation
BS	Relates with depth of 1000 nm absorption depth	Anorthosite appears deep blue, highly mature soil shows significant component
BC	Variation in center of 1000 nm absorption feature	LCP bearing rock appear red
BT	Reflectance difference at 900 nm and 1000 nm	Abundance of HCP &/ olivine appear green

The diameter of craters, topography and the elevation profile of the area has been measured and studied using LOLA data.

3. RESULTS AND DISCUSSION

Fig. 2 shows major craters located at western central part of Mare Tranquillitatis. Upper and lower most part shows highland area and central part of the image shows Mare basaltic region. In Fig. 2, marked a1 is HCP rich small fresh crater within highland area, which separates Mare Tranquillitatis and Mare Serenitatis. Highland area shows bright green to yellow color, which represents feldspathic and HCP rich material respectively. Anorthositic crust, which is green in color composite image having HCP rich mafic craters, which gives yellow color and can be observed in Fig 2D and 2F. Al-Bakri crater located at 14.34° N, 20.25° E is of 12.21 km diameter. Crater rim shows HCP rich highland material and crater floor shows mature Mare material. Surrounding the Al-Bakri, there are small craters with pink to orange color that shows LCP rich material (marked 2a, Fig 2C). Purple to bluish part in the upper half area of the image shows highland contaminated region. Spectral signature of this region has been marked as 3a. South west part of the crater shows highland kipukas and southern part shows rimae Maclear, which appears as yellow color at some places that indicates presence of HCP rich material. Maclear and Ross B crater present at the central part has 20.32 and 5.72 km diameter respectively. Ross B crater shows presence of HCP rich material, which is marked as 4a in Fig. 2. Bell and Hawke have suggested that the large crater Maclear and Ross do not excavate any highland material or low titanium bearing material indicates possibly thicker high titanium basaltic layer in the area [13]. Impact crater excavates material from various depths within Mare depending on the size of the crater. Hence impact crater act as windows to study the basalt stratigraphy by applying approximate relationship of excavation depth of ~ 1/10 the crater diameter

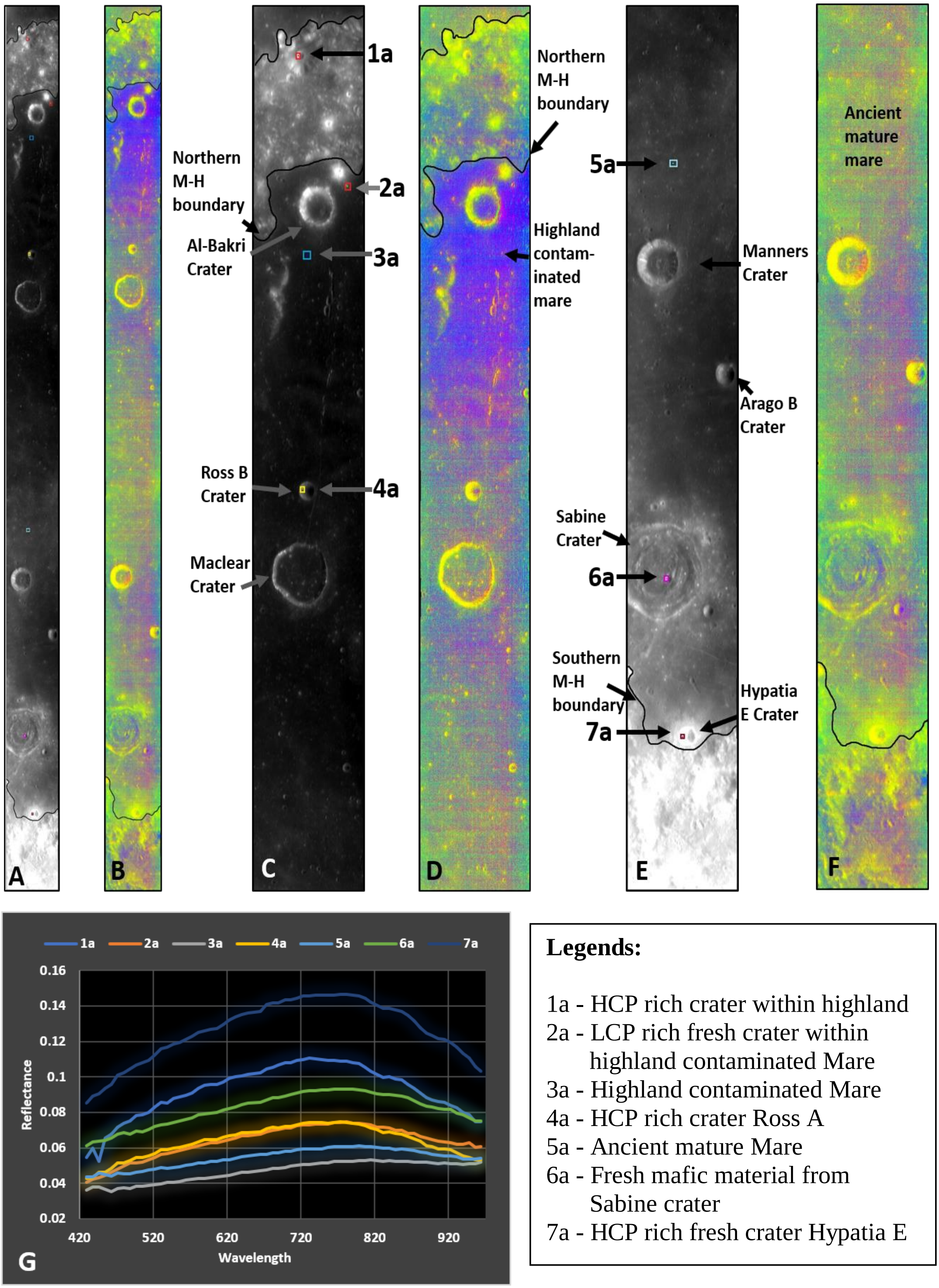

Fig. 2. A. HySI (HYS_NREF_20090731T181300758) reflectance image; B. HySI RCC image; C. Upper half of image 2A; D. Lower Half of image 2A; E. Upper half of image 2B; F. Lower half of Image 2B; G. Average reflectance spectra of marked area (1a-7a).

[14], [15], [16]. This fact indicates that Maclear crater is partially buried by Mare basalts as it does not fulfill the crater depth-diameter ratio. It also shows a clear long flat smooth floor with steep crater wall confirms that Mare basalts have poured in to the large crater Maclear. It also indicated that the Maclear crater is possibly older than the formation of Mare basalt within Mare Tranquillitatis. Elevation profile of the crater has been carried out using LRO LOLA data which has been shown in Fig. 3.

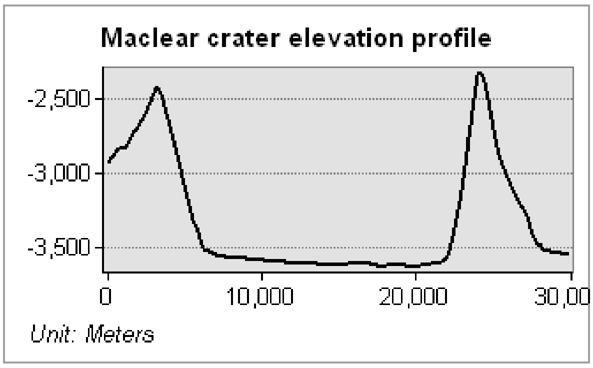

Fig. 3. Elevation profile of Maclear crater.

Central to southern Mare area is ancient mature Mare unit that gives purple to diffuse green color in rock type color composite image. Reflectance spectra of ancient mature Mare unit has been shown in figure 2G marked as 5a. Manners crater of 15.05 km diameter mostly shows the presence of HCP rich material, which exposes Mare material on the crater wall and rim.

Hiesinger has investigated age of the Mare Tranquillitatis using crater size frequency distribution method [17]. He has delineated total of 27 units of this Mare region on the basis of model age. According to them age determination for the area covered by Fig. 2A is divided in four parts. First part shown in Fig. 2C covers Al-Bakri crater to Lower part of Maclear crater, which shows 3.50 b. y. age. This is the youngest Mare basalt unit covered by the image. Though the upper part shows deep blue to purple color due to highland contamination and lower part shows diffuse green to purple color, which confirms the area as ancient mature Mare. Second part as shown in Fig. 2F covers the area surrounding the Arago B crater gives 3.54 b.y. age and can be delineated with diffuse purple color in the rock type color composite image. From the uppermost part to Manners crater in the Fig. 2F gives diffuse green color, which has been formed at 3.70 b. y. age according to [17]. From Sabine crater to the southern Mare highland boundary area shows 3.80 b. y. age. This is the oldest unit of the Mare Tranquillitatis or it can be said that first area within Mare Tranquillitatis which have obsereved volcanic activity. De Hon has identified the Sabine crater as volcanic caldera from its morphological analysis [18]. Staid had concluded it as crater from the multispectral analysis in which he found presence of highland material at the crater rim and its interior [19]. Our morphological investigation confirms the Sabine is a crater with structurally disturbed floor. The elevation profile derived from LOLA data (Fig. 4) shows steep wall with linear floor of crenulated margin that formed due to tectonic and/ volcanic activity.

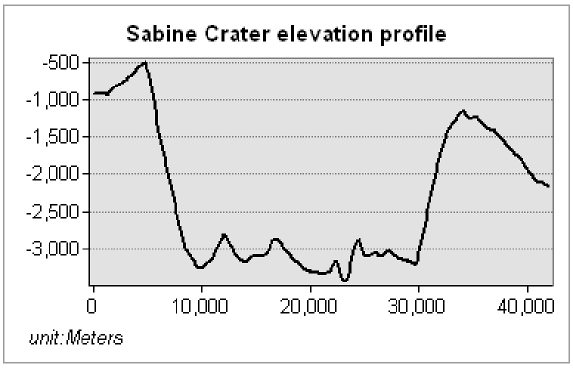

Fig. 4: Elevation profile of Sabine crater.

Spectral parameter analysis as well as spectral reflectance profile confirms the presence of HCP rich material at crater rim and at some part of the crater floor. Highland material is present in very less amount at the rim area that indicates a possible thicker Mare basalt in the area. Reflectance spectra calculated from fresh area within the crater has been presented in Fig 2G, Spectra 7a. Hypatia E is a fresh crater (6 km diameter), located at south west part of Mare Tranquillitatis at Mare highland boundary. Reflectance spectra (Fig. 2G, spectra 7a) and spectral parameter analysis confirms the presence of HCP rich material in the crater. The crater has excavated highland material as it is situated on Mare highland boundary. The elevation profile of whole image strip has been drawn from north to south as presented in Fig. 5. The profile shows that northern to central part of the Mare area is low lying while central to southern part is comparatively elevated.

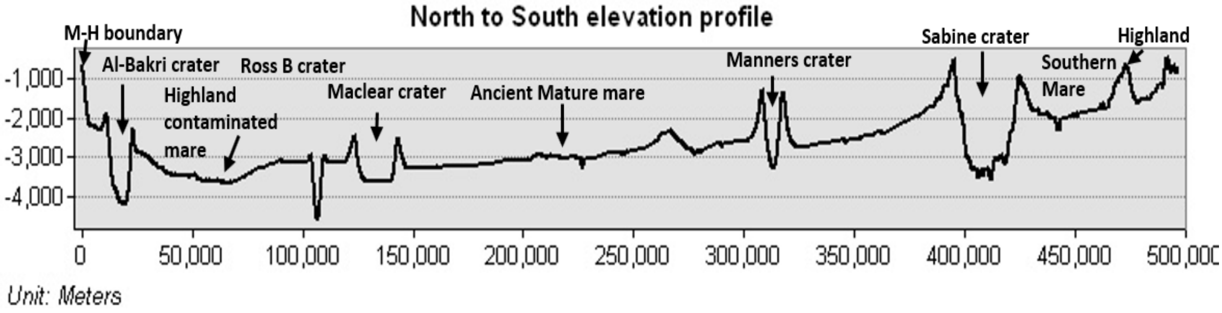

Fig. 5: Elevation profile of Mare area covered by HySI image in Fig. 2A. Left to right in the elevation profile is presenting north to south part of the Mare Tranquillitatis.

4. CONCLUSION

Three lithologic units have been identified based on the spectral band parameter and spectral reflectance profile, which are ancient mature Mare unit, highland contaminated Mare unit and HCP and LCP-rich fresh crater within mature highland area. HCP rich material within the highland area indicates presence of gabbro or gabbroic anorthosite rock type, which belongs to Mg-suit of highland rock type. LCP-rich material at the northern highland area indicates the presence of norite or noritic anorthosite rock type. Fresh HCP-rich material excavated by craters within Mare represents HCP-rich basalt rock type. It indicates that Maclear is a buried crater filled by lava. Sabine crater is situated at the oldest part of Mare Tranquillitatis which shows elevated and depressed part at its floor which may have formed due to tectonic and/ volcanic activity. The elevation profile from northern to southern Mare area covered by the HySI image indicates comparatively younger Mare unit (Fig. 2C) shows low elevation in northern part in relation to ancient mature southern Mare unit. Sabine crater and surrounding area also shows most elevated portion of the mare area.

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