Reflectance Imaging Spectroscopy Data (Hyperspectral) for Mineral Mapping in the Orientale Basin Region on the Moon Surface

V. Sivakumar, R. Neelakantan

***Abstract*—**Mineral mapping on the Moon surface provides the clue to understand the origin, evolution, stratigraphy and geological history of the Moon. Recently, reflectance imaging spectroscopy plays a significant role in identifying minerals on the planetary surface in the Visible to NIR region of the electromagnetic spectrum. The Moon Mineralogy Mapper (M^3) onboard Chandrayaan-1 provides unprecedented spectral data of lunar surface to study about the Moon surface. Here we used the M^3 sensor data (hyperspectral imaging spectroscopy) for analysing mineralogy of Orientale basin region on the Moon surface. Reflectance spectrums were sampled from different locations of the basin and continuum was removed using ENvironment for Visualizing Images (ENVI) software. Reflectance spectra of unknown mineral composition were compared with known Reflectance Experiment Laboratory (RELAB) spectra for discriminating mineralogy. Minerals like olivine, Low-Ca Pyroxene (LCP), High-Ca Pyroxene (HCP) and plagioclase were identified. In addition to these minerals, an unusual type of spectral signature was identified, which indicates the probable Fe-Mg-spinel lithology in the basin region.

***Keywords*—**Chandrayaan-1, moon mineralogy mapper, orientale basin, moon, spectroscopy, hyperspectral.

I. Introduction

HYPERSPECTRAL imaging spectrometer (spectroscopy) acquire images in many narrow and contiguous spectral bands. Imaging spectrometry has been widely used in geological / mineral mapping in the Earth and planetary surface. Hyperspectral data facilitate the discriminating various minerals across the spectrum. Reflectance spectroscopic data is helpful for identifying minerals on the planetary surface due to analytical absorption bands as a result of transitions of electrons in a crystal field [1]. The spectral (spectra) characteristics such as shape and absorption centers are very much useful for identifying various minerals. Mapping and analysing mineralogy of the lunar surface provides insights into the origin, evolution of crust, geological history and stratigraphy of the Moon. The M^3 instrument onboard Chandrayaan-1 provides reflectance spectral data of Moon surface. Many literatures are provides insight into detection of minerals on the lunar surface based on minerals absorption characteristics [2]-[7]. This present study aims to identifying minerals on the lunar surface using Chadrayaan-1 M^3 data.

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II. Study Area

The Orientale basin is located on the western limb of the Moon highland terrain and centered at 19º S, 95º W (Fig. 1). This basin is the youngest and most well-preserved large multi ring basin on the Moon and is sparsely filled by mare basalt [8]. The Orientale is a large impact structure basin and displays at least four concentric rings (multi-ring basin) [8], [9]. Scientists are curiosity to investigate on this basin due to its unique morphological setup. The study area elevation ranges from -4700 m to 9400 m (Fig. 2). Lower areas are shaded blue, with higher altitudes in red. The lowest areas are about -4700 m below the average height with the highest being about 9400 m above average (Fig. 2).

A. Geology

Orientale basin partly filled by mare basalt, therefore its original floor configuration can be clearly seen over most of the basin interior (Fig. 3). Recently, this basin has been remapped and named two new units namely mare and massif material by [10], utilizing the stratigraphic nomenclature of [11], which has been largely unchanged except that some formations have been subdivided into members on the basis of surface texture. Several geological formations collectively make up the Orientale Group; in the interior of the basin, formations are the Maunder, Montes Rook, and Hevelius formations. The Orientale basin interior displays a number of small melt ponds. The innermost center of the basin covers thinly basalt [10]. The basalts of Mare Orientale appear to be moderate in titanium content (~2.3 wt), which is relatively low Ti compared to the Apollo samples but higher than the Ti content of other typical farside maria [12]. The other informal rock unit is made up of the massifs of the inner basin rings. Some parts of the Inner ring are composed of massifs made up of pure anorthosite [13]-[15]. In some cases, these anorthosites are shocked to levels of at least 20 GPa, but less than 30 GPa, as evidenced by the presence of the 1250 nm plagioclase absorption feature [15].

III. Materials and Methods

M^3 data is used for collecting reflectance spectra for identifying the minerals in the Orientale basin area. The Indian Space Research Organisation's (ISRO) first mission to the Moon Chandrayaan-1 has M^3 instrument, as a guest instrument from NASA [16]. The M^3 records the reflected radiance from the Moon's surface in pushbroom mode between 0.46 and 2.97 µm in 85 contiguous spectral bands, between 20 – 40 nm spectral sampling with 140 m/pixel spatial resolution [17].

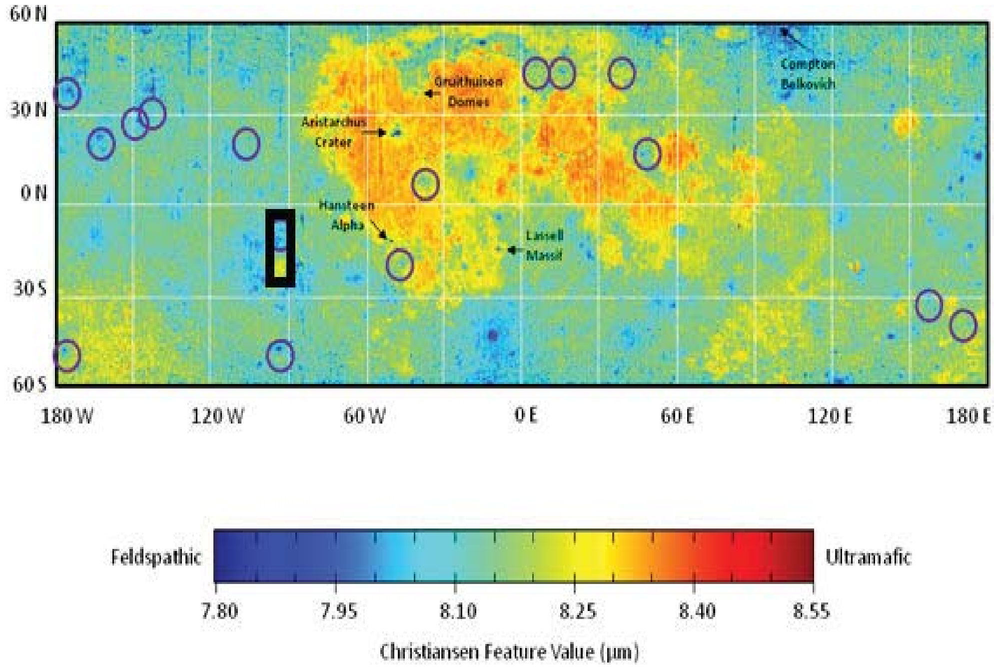


Fig. 1 Study area location (M^3 coverage) is highlighted with back color box on Diviner Global Composition map [18]

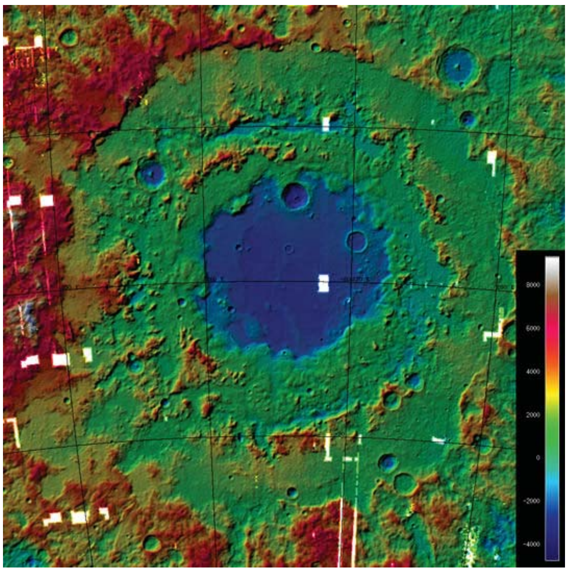


Fig. 2 LRO's Wide-Angle Camera Digital Terrain Model of the Orientale Basin (1,100 km diameter). Lower areas are shaded blue, with higher altitudes in red. The lowest areas are about -4700 and highest are about 9400 m. Image credit: NASA/Goddard/Arizona State University

Photometrically and thermally corrected Level-2 was downloaded from PDS geosciences node (Fig. 4 (a)). The spectral profiles from different locations were collected (fresh/bright exposures are considered as representative pixel) using ENVI image processing software and continuum was removed for better understanding of absorption parameters (Fig. 4 (c). The sample locations are show on M^3 image (Fig. 4 (a)). Reflectance spectral profiles (3*3 pixel average) were collected from different locations of the basin area and continuum has been removed for reflectance spectra for better understanding absorption spectra characteristic. Unknown sample reflectance spectras were matched with known RELAB spectra (Fig. 4 (b)) [19] for identifying minerals. The comparison was carried out based on pixel-by-pixel to express the similarity between the unknown and know spectra.

IV. Result

Fig. 4 (c) shows the continuum removed reflectance spectra of olivine, LCP, HCP, plagioclase and Fe-Mg-spinel minerals. Olivine shows strong absorption band near 1000 nm and weak absorption band near 2000 nm [20]. Near 2000 nm weak absorption band of olivine may be presence of spinel in the olivine. LCP shows absorption bands near 1000 nm and 2000 nm [7], [21]. HCP shows absorption band near 1000 nm and also beyond >2000 nm, the band shift of longer wavelength (>2000 nm) may be due to Ca+ contribution [7], [20]. Plagioclase shows absorption band near 1250 nm [22], [23]. An atypical strong absorption band have been identified near 2000 nm and relatively weaker band 1000 nm, probably this signature indicates Fe-Mg-spinel minerals present on the surface [e.g., 24, 25].

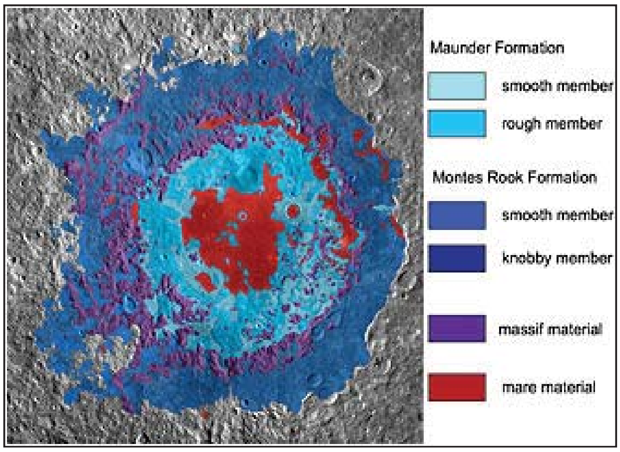
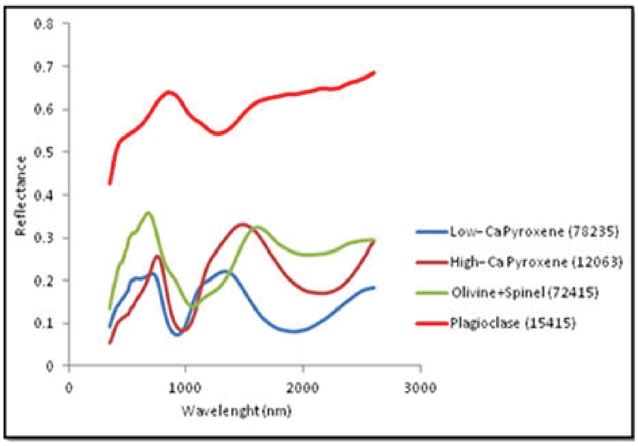
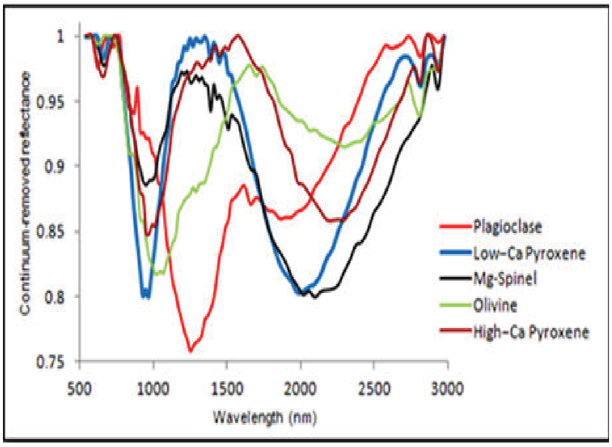


Fig. 3 Geological map of the Orientale Basin (Basin Interior) [10]

(a)



(b)



(c)

Fig. 4 (a) M³ coverage of the study area. Reflectance sample locations are plotted on the M³ image. 1-Plagoclase, 2-Low-Ca pyroxene (LCP), 3-Fe-Mg-Spinel, 4-Olivine and 5-High-Ca pyroxene (LCP), (b) RELAB reflectance spectral data, and (c) Continuum removed reflectance spectra of 1-Plagoclase, 2-Low-Ca pyroxene (LCP), 3-Fe-Mg-Spinel, 4-Olivine and 5-High-Ca pyroxene (LCP) minerals

V. Conclusion

Reflectance imaging spectroscopy data has allowed mapping/identifying minerals in the Orientale basin region on the Moon surface. Olivine, Low-Ca pyroxene (LCP), High-Ca pyroxene (LCP), plagioclase and Fe-Mg-spinel minerals were identified. This study put forward that Reflectance imaging spectroscopy (Hyperspectral imaging) is suitable for the mineral mapping on the lunar surface.

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