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Spectral mapping of morphological features on the moon with MGM and SAM

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ABSTRACT

Three types of morphological features observed in different lunar crustal terrains were studied and mapped using hyperspectral Moon mineralogy mapper (M^3) data onboard Chandrayaan 1 mission in order to assess the utility of cascaded MGM-SAM spectral mixture modeling approach to characterize the surface materials, which may occur as mineral mixtures, at different topography of the lunar surface. Selected morphological features include: the impact melts in Orientale basin, sinuous rilles in Procellarum KREEP Terrane (PKT) and a rayed crater in Feldspathic Highland Terrane (FHT). Methodology involves extraction of spectrally pure pixels (endmembers) of the area using Pixel Purity Index (PPI), identification of mineralogy of the selected endmember spectrum using the Modified Gaussian Method (MGM) and mapping of mineralogically identified endmembers using the Spectral Angle Mapper (SAM) method.

Mapping results demonstrate both the capabilities and the limitations of the MGM method of spectral deconvolution and the SAM method of spectral matching as effective tools for compositional characterizations of morphological features on the lunar surface. As a method of spectral deconvolution, MGM was able to identify and characterize both high- and low – Ca pyroxenes along with plagioclase feldspar. The Spectral Angle Mapper (SAM) was able to map identified mineral mixtures from MGM.

1. Introduction

Reflectance spectroscopy in the visible to near-infrared wavelength region has been proven to be an important tool for the qualitative and quantitative mapping of mineralogical and chemical composition of planetary surfaces based on their spectral characteristics (Goetz et al., 1985; Van der Meer, 1999; Bokun et al., 2010; Van der Meer et al., 2011). The compositional makeup of the morphological features of the lunar surface is a key to understanding the origin and geologic evolution as it has not been affected by plate tectonics, atmospheric effect, or surface erosion and denudation as observed on the Earth. Therefore, the lunar surface has preserved evidence of geologic and geomorphologic processes that were active over the last 4–4.5 billion years offering unique opportunity to study processes that were active in early geological time period for which evidence on the Earth's surface has long been erased (Hiesinger and Head, 2006). But, mapping surface materials through spectral remote sensing is quite challenging due to the complex nature of mineral mixing, degree of crystallinity, maturity variation, particle size distribution, illumination geometry and limited ground truth of the surface materials over different structural and morphological features of the lunar surface. Modified Gaussian Method (MGM) is successfully used in planetary science to characterize the spectra from Moon and Mars (Sunshine et al., 1990; Sunshine and Pieters, 1993; Schade et al., 2004; Noble et al., 2006; Kanner et al., 2007; Gallie et al., 2008), while Spectral Angle Mapping Method (SAM) widely used in spectral remote sensing to map the surface expressions in all application fields (Van der Meer and Jong, 2003). Therefore, the present study aims to assess the utility of cascaded MGM-SAM spectral mixture modeling approach to characterize the surface materials, which may occur as mineral mixtures, at different topography of the lunar surface.

1.1. Moon and the target features

The Moon, the Earth's only natural satellite, having 7.35×10^{25} g mass is thought to have formed approximately 4.5 billion years ago, not long after Earth. The Moon is in synchronous rotation with

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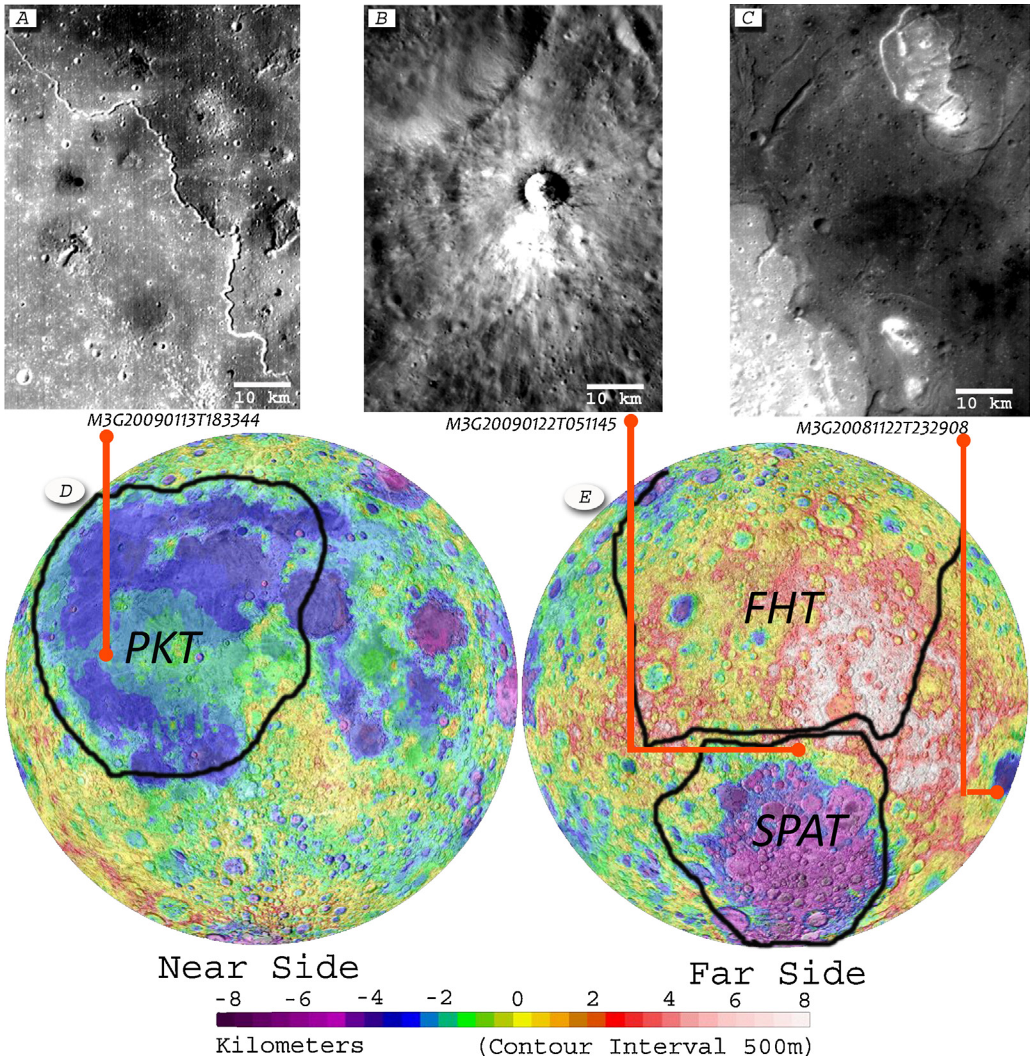

Fig. 1. Locations of the selected study areas of the Moon. A. Sinuous rille at the Procellarum KREEP Terrane (PKT), B. Simple Impact Crater at the South Pole-Aitken Terrane (SPAT), C. Impact Melt at Mare Orientale Basin, D. Near Side and E. Far Side of the Moon with the major crustal terrane as demarcated by Jolliff et al., 2000, on the clementine topographic map of the Moon (image courtesy: Lunar and Planetary Institute and Jolliff et al., 2000).

Earth, always showing the same face with its near side marked by dark volcanic maria that fill between the bright crustal highlands and the prominent impact craters (Taylor and McLennan, 2009). A gross subdivision of the Moon's surface is based on albedo; the bright highlands that account for over 80% of the Moon's surface has a high density of impact craters and have an albedo of 11–18 %, and the dark maria with an albedo of 7–10 % that covers 16% of the lunar surface (McSween and Huss, 2010; Pater and Lissauer, 2010). Jolliff et al. (2000) classified lunar terrain into three subdivisions based on their geochemical characteristics (Fig. 1). The Feldspathic Highland Terrane (FHT) is the most extensive terrain (over 60% of the Moon surface) concentrated on the lunar far side having 4.2% of FeO and around 53.6% of Th from the total amount at Moon Crust. The Procellarum KREEP Terrane (PKT) occupies a large oval shaped terrain (about 16% of the Moon Surface) of the near side of the Moon. It consists of a combination of highlands and mare basalts, with the materials characterized by high contents of potassium, rare earth elements, and phosphorus (KREEP). The South Pole-Aitken Terrane (SPAT) represents a gigantic basin having higher FeO (around 10%) contents than typical anorthositic crust (Jolliff et al., 2000).

Ninety-nine percent of the lunar surface is older than 3 Gyr and more than 80% is older than 4 Gyr. The absence of plate tectonics, water, life and an atmosphere, means that the present lunar surface is unaffected by the main agents that shape the surface of the Earth. The major process which responsible for modifing the lunar surface is the impact of objects ranging from micron-sized grains to tens to hundreds of kilometers in diameter bodies (Taylor and McLennan, 2009). Other than the Impact catering events, tectonics and volcanisms also shape the Moon surface to the present form.

Three geomorphological features in different terrains were selected to sample the maximum compositional variability, topography, illumination, maturity, texture with their unique characteristics (Fig. 1). These include: (1) Impact melts are a mixture of lithologies that can be distinguished from the conventional igneous rocks based on their compositional and textural characteristics (Hiesinger and Head, 2006). Identification and proper assignment of impact melts to a specific basin forming event is crucial for dating these events in order to derive a coherent, absolute lunar stratigraphy (Hiesinger and Head, 2006; Pieters et al., 2009). (2) Ray craters are relatively youth impact structures formed during a cratering event due to target materials ejecting from the crater in the form of narrow linear features, generally of high albedo, extending outward from the crater (Pieters et al., 1985). It provides an opportunity to study the litho-stratigraphic sequence at a particular location and information about the distribution of pre-impact target lithologies and the processes by which these materials were