Mapping lunar TiO_2 and FeO with Chandrayaan-1 M3 data.

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Introduction

Lunar Fe (Iron) and Ti (titanium) are two important elements distributed on the Moon. The study of lunar Fe and Ti characterization contributes to revealing the origin and development of the Moon and determining lunar surface chemistry and mineralogy. In the current study, visible to near-infrared reflectance data acquired by the Moon Mineralogy Mapper (M3) on Chandrayaan-1 was used to investigate the mineralogy of lunar surface. The motivation of this study is to apply previous methods derived from Clementine to new data set. The M3, a high resolution, high precision imaging spectrometer, flew on board India's Chandrayaan-1 Mission from October 2008 through August 2009. Compared with Clementine data, M3 data is new and contains wider spectral range, and is well calibrated too. At present some researchers use M3 data to detect OH/Water on the lunar surface [1–2].

M3 acquired visible to infrared reflectance data at spatial and spectral resolutions capable of measuring discrete basaltic flows within the lunar maria. Most of the M3 data were collected in a global mapping mode that covered the wavelength range of ~430 to 3000 nm in 85 spectral bands at 140 to 280 m/pixel spatial resolutions. Small amounts of data were also acquired over targeted regions at the full spectral and spatial capability of M3 (259 spectral bands and spatial resolutions of ~70 m). Reflectance data of several key sites in the western maria were also acquired at higher spatial and spectral resolutions using M3's target mode, prior to the end of the Chandrayaan-1 mission.

Methods

Calibrated M3 data are available from NASA PDS node: http://pds-imaging.jpl.nasa.gov/volumes/m3.html

After downloading the data, we then decide the mapping methods on the basis of previous models. A series of empirical models have been developed to predict the FeO and TiO_2 content from Clementine UVVIS images [4-5]. Lucey et al. [6,7] used the predictions of the Hapke model to quantify the spectral variations that accompany compositional changes. The effect of maturity on ferrous ion spectra of lunar soil, can be summarized in three points from the description of the spectral characteristics: First, at band 750nm, the reflectance R750nm decrease with the increase of lunar soil maturity; on the contrary, R950nm/R750nm just increase while the lunar soil maturity increases; when the iron ion increase, both R750nm and R950nm/R750nm decreases. Based on the above characteristics, Lucey et al developed the spectral characteristic angle parameters method [4-7] for FeO and TiO_2 content retrieval while mapping Clementine UVVIS data. The formula to calculate FeO content is therefore provided,

$$\theta_{Fe} = -\arctan\left(\frac{R_{950}/R_{750} - 1.26}{0.01}\right)$$

$$FeO\% = 17.83 \times \theta_{Fe} - 6.82$$

The design and principle of the TiO_2 inversion method is much more simple. For TiO_2 content retrieval, Lucey's method introduces a simple relation between the UV/VIS ratio (415 nm/750 nm) and TiO_2 content in soil of a mature mare to a titanium-sensitive parameter. In this paper, however, because M3 doesn't include the 415nm frequency (Clementine choose the different R415nm, while M3 data does not cover the band, also first few bands are noisy), we use Shukuratov [9] model instead. Using correlation diagram FeO–TiO_2 for the lunar nearside, Shukuratov [9] have studied the relationship for FeO and TiO_2. It shows the correlation to be rather high with the correlation coefficient 0.81. The regression equation is as follows:

$$\log(TiO_2\%) = 0.06(FeO\%) - 0.54$$

Results

According to formula (1-2), we analyzed the FeO content based on M3 data, and show that lunar FeO content varies from 0 wt.% to 20 wt.%. See Figure 1. We could notice from above that the iron distribution is much higher in mare regions than in highland. The iron content map indicates some similarity with geography. See Figure 2.According to formula (3), we analyzed the TiO_2 content based on M3 data, and show that TiO_2 content also varies from 0 wt.% to 7 wt.%. See Figure 3. Comparisons with Clementine and lunar prospector are presented.

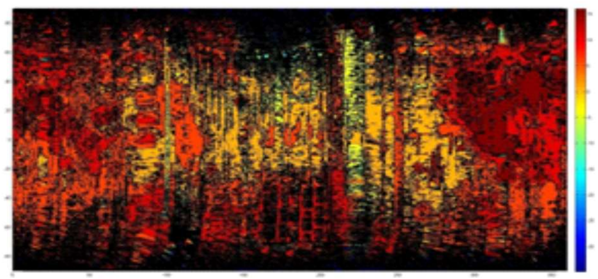
Figure 1. FeO content retrieval result from M3.

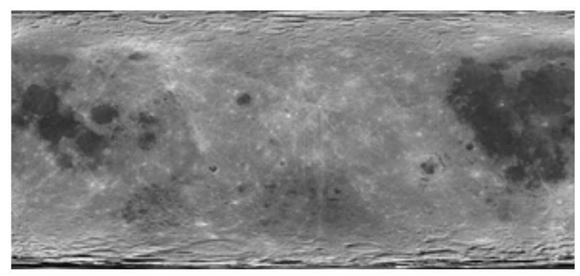
Figure 2. Lunar albedo map.

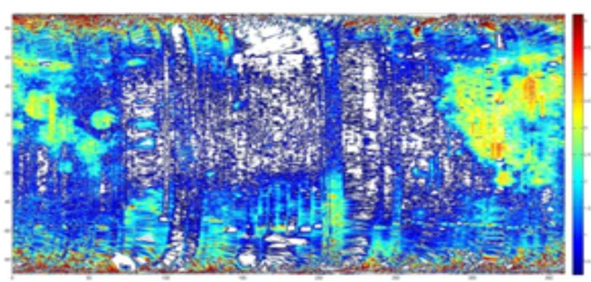
Figure 3. TiO_2 content retrieval result from M3.

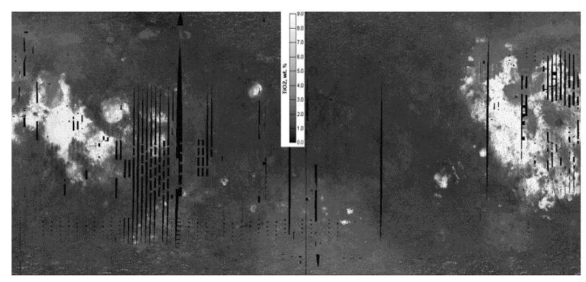
Figure 4. TiO_2 content distribution from Clementine.(Shukuratov [9])

Table 1. Comparison with Soils from the "Apollo," "Luna," and "Surveyor" Landing Sites. Ref from [9].

Landing site	Sample TiO2 (%)	M3 TiO2 (%)	Sample FeO (%)	M3 FeO (%)	References
Apollo 11	7.40	2.23	15.8	14.8	Nawa and Philpotts 1979, Heiken et al. 1991, King 1976, Florensky et al. 1981
Apollo 12	2.68	2.65	15.7	16.0	Nawa and Philpotts 1979, Heiken et al. 1991, King 1976, Florensky et al. 1981
Apollo 14	1.72	1.70	10.4	12.8	Nawa and Philpotts 1979, King 1976, Florensky et al. 1981
Apollo 15 (mare)	1.64	2.32	15.2	15.1	Nawa and Philpotts 1979, Heiken et al. 1991,
Apollo 16	0.55	0.88	5.0	7.8	Nawa and Philpotts 1979, Florensky et al. 1981, Heiken et al. 1991
Apollo 17(highland)	0.90	0.95	8.1	8.6	LSPET 1973
Luna 16	3.36	2.71	16.7	14.8	Florensky et al. 1981, Heiken et al. 1991
Luna 20	0.47	0.74	7.4	6.9	Nawa and Philpotts 1979, Florensky et al. 1981, Heiken et al. 1991
Surveyor 5	7.60	2.01	12.1	13.8	Mason and Melson 1970
Surveyor 6	3.50	2.41	12.4	13.2	Mason and Melson 1970
Surveyor 7	0.50	0.75	5.5	6.9	Mason and Melson 1970
Luna 24	1.15	2.52	20.6	17.8	Florensky et al. 1981, Heiken et al. 1991

Except for the titanium abundance from two extremely high samples (Surveyor 5 and Apollo 11), all the other landing sites' M3 data matches with return sample data with a deviation less than 15%. Our approach does well in the regions containing very low and low TiO_2 contents. For the high-Ti units, the predicted values of our approach are relatively low. The problem roots in the high-Ti samples being too few (only 4 samples).

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