Mapping lunar TiO2 and FeO with Chandrayaan-1 M3 data. W. Zhang[1] and N. E. Bowles[2], University of Oxford, Department of Physics, Clarendon Laboratory, Parks Road, Oxford, OX1 3PU, United Kingdom, [1]zhangw@physics.ox.ac.uk , [2] n.bowles1@physics.ox.ac.uk .

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 are 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. And surely M3 is a good opportunity. 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]. But there is little research on determining Fe and Ti abundance of the lunar surface using M3 data [3].

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. The mission ended partway through its nominal 2 year mapping period in late August 2009, after a loss of communications with the satellite. Despite an abbreviated mission, M3 was able to cover more than 95% of the Moon in its global mode of operations [8]. Additional details of the operation aspects of the M3 instrument during lunar mapping are given by Boardman et al. [8], and details of the M3 instrument design and capabilities are presented by ref [10].

Methods: After achieving the data, we then decide the mapping methods on the basis of previous models. FeO and TiO2 mapping methods were developed using Clementine and Galileo multispectral data. A series of empirical models have been developed to predict the FeO and TiO2 content from Clementine UVVIS images [4-5]. Among these models, Lucey's model has been one of the most popular and has undergone a series of refinements [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 TiO2 content retrieval while mapping Clementine UVVIS data. The method takes into account the parameters of the two spectral features, separated spectral features of FeO and TiO2 with the effect of maturity. The formula to calculate FeO content is therefore provided,

$$\theta_{Fe} = -\arctan\left(\frac{R_{950}/R_{750} - 1.26}{0.01}\right) \quad \ldots\ldots(1)$$

$$FeO\% = 17.83 \times \theta_{Fe} - 6.82 \quad \ldots\ldots(2)$$

The design and principle of the TiO2 inversion method is much more simple. For TiO2 content retrieval, Lucey's method introduces a simple relation between the UV/VIS ratio (415 nm/750 nm) and TiO2 content in soil of a mature mare to a titanium-sensitive parameter, an angular measure of the TiO2 content of soils taken from landing sites and sample stations in the plot of UV/VIS versus visible reflectance, to suppress the effect of maturity. 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–TiO2 for the lunar nearside, Shukuratov [9] have studied the relationship for FeO and TiO2. It shows the correlation to be rather high with the correlation coefficient 0.81. The regression equation is as follows:

log(TiO2[%])= 0.06 (FeO[%]) - 0.54……(3)

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 TiO2 content based on M3 data, and show that TiO2 content also varies from 0 wt.% to 7 wt.%. See Figure 3.

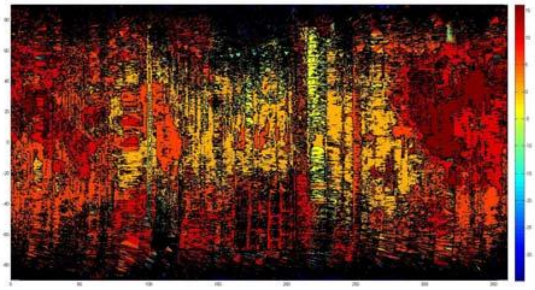

Figure 1: FeO content retrieval result from M3.

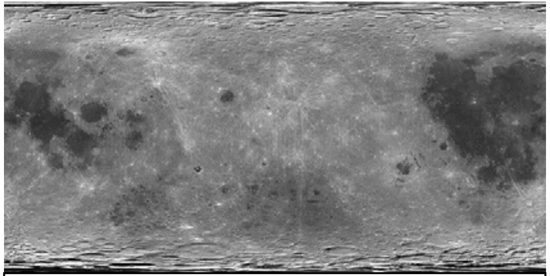

Figure 2: Lunar albedo map.

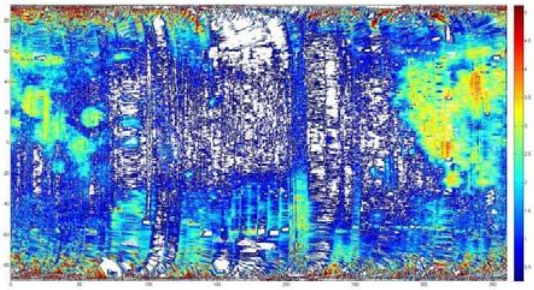

Figure 3. TiO2 content retrieval result from M3.

We may notice some strips here from the map. This is because the Chandrayaan-1 spacecraft experienced a diverse range of non-nominal thermaland field-of-view (largely pointing) conditions while M3 data were acquired (see discussions in [8,10]).

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

Landing site	Sample TiO_2 (%)	M3 TiO_2 (%)	Sample FeO (%)	M3 FeO (%)
Apollo 11	7.40	**2.23**	15.8	**14.8**
Apollo 12	2.68	**2.65**	15.7	**16.0**
Apollo 14	1.72	**1.70**	10.4	**12.8**
Apollo 15 (mare)	1.64	**2.32**	15.2	**15.1**
Apollo 16	0.55	**0.88**	5.0	**7.8**
Apollo 17(highland)	0.90	**0.95**	8.1	**8.6**
Luna 16	3.36	**2.71**	16.7	**14.8**
Luna 20	0.47	**0.74**	7.4	**6.9**
Surveyor 5	7.60	**2.01**	12.1	**13.8**
Surveyor 6	3.50	**2.41**	12.4	**13.2**
Surveyor 7	0.50	**0.75**	5.5	**6.9**
Luna 24	1.15	**2.52**	20.6	**17.8**

Except 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 TiO2 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).

Conclusion: M3 provides the FeO and TiO2 valid contents which fit with “ground truth” from returned samples. Owing to its high spatial resolution (140 m/pixel) and spectral resolution (85 channels), M3 data is applicable to determine the chemical and mineral composition of the lunar surface.

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