MAPPING THE 1.5 μm ILMENITE SPECTRAL FEATURE WITH CHANDRAYAAN-1 M^3 DATA.

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Introduction: Lunar mare basalts contain significant percent of titanium either in a dispersed phase in different minerals and agglutinate glasses, or in the mineral ilmenite ($FeTiO_3$). Comparisons show that for the grains of the same size fraction from the same soil, the abundance of the ^{3}He isotopes is significantly higher (up to 100 times) in ilmenites, than in other mineral [e.g., 1]. The isotope is considered to be a feasible fuel for the nuclear fusion. The isotope was implanted in the lunar surface from solar wind.

A number of different techniques to map the abundance of TiO_2 have been developed [e.g, 2-5]. The techniques use spectral data obtained by the Clementine and LRO as well as HST observations in the UV/Vis range of wavelengths [5]. However, these maps cannot be directly applied to ilmenite assessments. Ilmenite is a very dark material with a slightly broad absorption band centered at 1.5 μm [6]. We here suggest results of ilmenite determination with the 1.5 μm spectral feature using data from the Chandrayaan-1 Moon Mineralogy Mapper (M^3). The M^3 is a scanning spectrometer operated most effectively from 0.54 to 2.65 μm in 83 narrow spectral channels with a spatial resolution of approximately 80 m/pixel. An example of such a spectrum normalized by continuum is shown in Fig. 1.

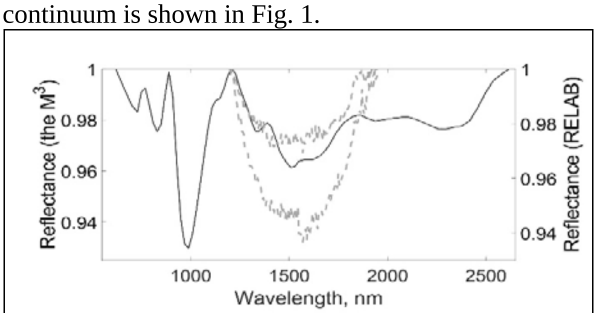

Figure 1. The spectra of ilmenite from REALB (dashed line) and several mare pixels from the M^3 data (solid line) divided by their convex hulls

Source data and processing: We here map the depth of the 1.5 μm spectral feature using M^3 data for the Plinius crater and its surroundings located in Mare Tranquillitatis. We search for relationships between the depth and TiO_2 distributions. The region in Mare Tranquillitatis is very attractive for such purposes due to its mineralogical diversity and the significant variations of TiO_2 abundance (Fig. 2). We use the M^3 image M3G20090731T092152_V01 [7]. A TiO_2 distribution from [8] is used in further analysis.

The raw data of the M^3 spectrometer needs addition processing because of the significant contamination by random and systematic instrumental noise, like, for instance, vertical strips having random intensity. These features can be suppressed using the Gaussian λ-convolution of spectra and Fourier filtration of images, which results in good quality M^3 data [9]. The presence of glass is confirmed for dark mantle areas on Aristarchus Plateau. We here use an improved Fourier filter that softly rejects frequencies responsible for the strips in the Fourier plane. This allows us to remove the Gibbs effect and some other problems. The Gibbs effect produces false brightness oscillation near sharp contrast edges on images. We multiply the spatial spectra of the scene by a Gauss multiplier $h(n)$ instead of total rejection of the frequencies containing this noise feature, where n is the position number of the coefficient in the rows of the discrete Fourier 2D spectra.

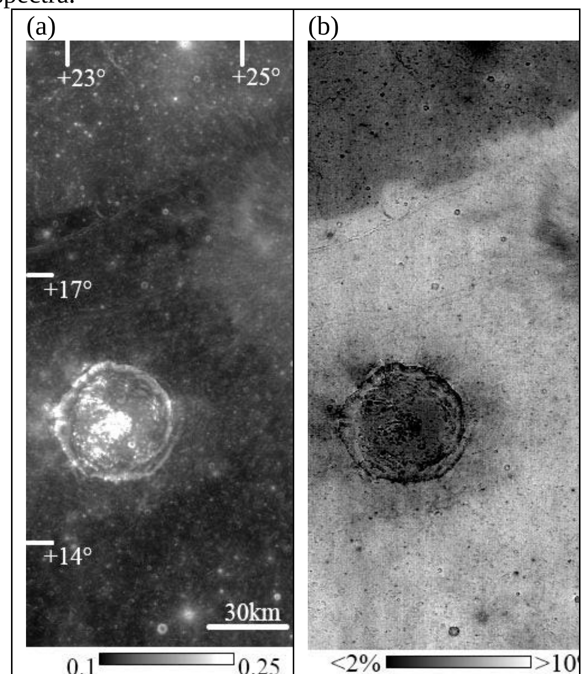

Figure 2. (a) The WAC image of the surroundings of Plinius [8] at λ=415nm; (b) the map of WAC TiO_2 abundance [8] calculated by the Lucey technique [10]

$$h(n) = \exp\left[-\left(\frac{n-b}{c}\right)^2\right] \qquad (1)$$

where b and c are constants.

This filter acts like a summability kernel (a family of functions proposed by L. Fejer) helping us to reduce significantly the Gibbs effect, although the function (1) is not exactly a summability kernel, since we violate wittingly the normalization requirement of such kernels though not disturbing the Fourier coefficient corresponding to zero frequency.

A portion of the spectra between 1.2 and 1.75 μm was used to assess the depth of the 1.5 μm bands. We find the convex hull ($R_{CH}(\lambda)$) for each reflectance spectra ($R(\lambda)$) to exclude continuum (Fig. 1) [9]. The depth of the 1.5 μm band was calculated with the following formula for all wavelengths from the interval 1.2 and 1.75 μm:

$$depth = \max\left\{1 - \frac{R(\lambda)}{R_{CH}(\lambda)}\right\} \qquad (2)$$

Results and discussion: Figure 3a shows the processed M^3 albedo map. No long vertical strips can be observed, and there are no artifacts along the edges of the bright Plinius features or other craters on the image. Figure 3b depicts the map of the distribution of the parameter depth. The well-known border between two chemically different Mare Serenitatis and Mare Tranquillitatis on this image is clearly seen; that is, we do not find ilmenites in Mare Serenitatis.

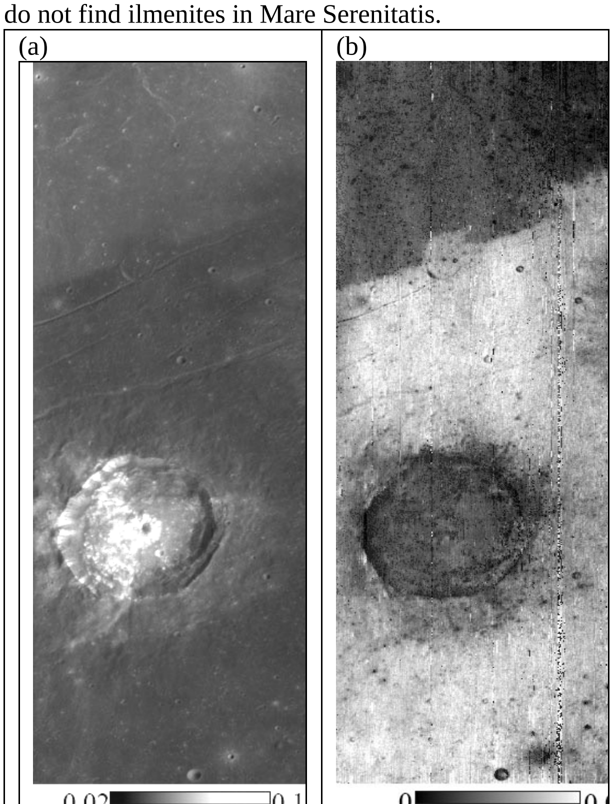

Figure 3. (a) The processed reflectance image obtained by the Chandrajaan-1 M^3 at λ = 1.5 μm; (b) The strength of the 1.5 μm band is calculated with Eq. (2)

Other formations that do not contain the 1.5 μm band in their spectra are Plinius, almost all fresh craters, and the ejecta of Dawes crater. The position of the 1.5 μm band has a narrow distribution; the average maximal depth is centered at 1.48 μm.

As can be seen, Fig. 2b and Fig. 3b that present the WAC TiO_2 map and distribution of the spectral band depth at 1.5 μm have great similarity, even in the pattern of the Dawes ejecta. The correlation diagram for these two maps is shown in Fig. 4. There are two clusters. It is easy to identify that lower cluster corresponds to the south part of Mare Serenitatis, walls of Plinius, ejecta of Dawes, and all bright craters; whereas, the upper cluster represents Ti-hosted rocks of Mare Tranquillitatis. The upper cluster has elongated shape; this is a consequence of the tiny differences in the pattern of the ilmenite and TiO_2 maps. No correlation inside the cluster can be observed. This can be caused by several factors: image and/or processing inaccuracies, as well as real effects related to the fact that TiO_2 can occur in not just ilmenite. An adequate interpretation of such a correlation demands further investigations.

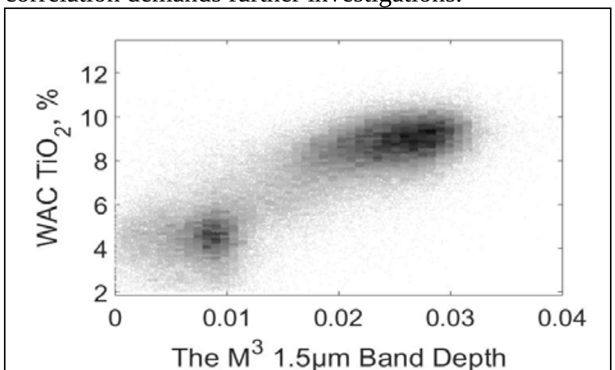

Figure 4. The correlation of the maps of WAC TiO_2 and the 1.5 μm band depth

References: [1] Fa Wenzhe and Jin Ya-Qiu (2007) *Icarus 190*, 15-23. [2] Adams J. et al. (1974) *JGR 79*, 1605-1813. [3] Sato H. et al. (2017) *Icarus 216*, 216-238. [4] Gillis-Davis J. (2006) *Geochim. Cosmochim. Acta 70*, 6079-6102. [5] Robinson M. et al. (2007) *GRL 34*, L13203, doi:10.1029/2007GL029754. [6] Isaacson P.J. et al. (2011) *LPSC-42*, 2130.pdf. [7] https://pds-imaging.jpl.nasa.gov/data/m3. [8] wms.lroc.asu.edu/lroc/view_rdr_product/WAC_TIO2_E350N0450. [9] Shkuratov Y. et al. (2019) *Icarus 321*, 34-49. [10] Lucey P.G. et al. (2000) *JGR 105*, 20,297-20,306.