

LINK BETWEEN SPECTRA AND MATURITY DEGREE OF LUNAR SOILS: THE LSCC DATA AS APPLIED TO CHANDRAYAAN-1 M³ SPECTROMETER. V. Kaydash and Yu. Shkuratov, Astronomical Institute of Kharkov University, Sumskaya 35, Kharkov, 61022, Ukraine, vvkaydash@gmail.com

Introduction: Determination of lunar mineralogy and soil maturity (I_S/FeO) with multispectral data is a key technique in optical remote-sensing of the Moon. Lunar imaging spectrometers operate in the UV-VIS-NIR spectrum and cover few spectral bands as a compromise with imaging capabilities and data transmitting rates. Integrating spectrometers such as SIR-1,2 (SMART-1, Chandrayaan-1) or SP (Kaguya) capture continuous spectra (250+ narrow bands) in cost of averaging the signal in the field of view. The Moon Mineralogy Mapper (M³) onboard Chandrayaan-1 [1] provides an imaging of the lunar surface together with the high spectral resolution. The goal of the M³ imaging is mapping the mineralogy and maturity degree. In this study we analyze the effect of spectral resolution and selecting bands on the reliability and accuracy of I_S/FeO prediction with M³ data.

Determination of I_S/FeO in lunar soils with M³ data: The M³ spectrometer imaged the Moon in 40 km strips mainly in the global mode with 140 m/pixel resolution in 86 spectral channels in a spectral range from 0.43 to 3.00 μm . The width of spectral channel varies from 20 nm for 0.73-1.55 μm to 40 nm for the rest of spectrum [2]. Without the spectral range 2.6-3.0 μm affected by thermal radiation, totally 76 channels were used for global lunar imaging with M³.

The parameter I_S/FeO characterizes the amount of nano-phase reduced iron relatively to the total iron abundance in regolith particles [3]. Therefore it affects the main features of lunar spectra: smooth increase of reflectivity toward the greater wavelengths and two broad bands with the centers near 1 and 2 μm . Several approaches for remote determination of I_S/FeO using spectral data were developed after Clementine mission. However, they utilize 5-10 spectral bands used in UVVIS and/or NIR camera (e.g., [4,5]). To search for the best link between maturity degree and spectral parameters we use the Lunar Soil Characterization Consortium (LSCC) data to emulate the M³ observations.

LSCC data for lunar soils: Coordinated compositional and spectral measurements of a broad suite of lunar soils provided by the LSCC are appropriate for developing an algorithm for remote determination of I_S/FeO with full spectral resolution [6]. Particularly, the LSCC carried out I_S/FeO measurements of 18 lunar samples, each of 4 particle size separates: 1) <45 μm , 2) <10 μm , 3) 10–20 μm , and 4) 20–45 μm . The <45 μm samples are considered to present the bulk soils, since it has been demonstrated that the optical proper-

ties of bulk soils are dominated by small particle size fractions [7]. Bi-directional reflectance spectra over the spectral range 0.3–2.6 μm with constant 5 nm sampling resolution were acquired for each sample in the RELAB at Brown University [8].

Particle size separates: With the LSCC data we search for the best correlation between I_S/FeO and spectral parameters. First, we check which particle size separate is most optically sensitive to maturity variations. With this aim we are looking for the statistically best link in the following form:

$$\log[I_S/FeO] = \sum_{k=1}^K W_k \cdot R_k + A \quad (1)$$

where k is the spectral channel number, K is the total number of channels, R_k is the spectral reflectance in the k^{th} channel, W_k is the k^{th} weight coefficient, A is the additive coefficient. We note that the set of 18 LSCC samples allows searching for the link between I_S/FeO and reflectance only for spectra consisting of <18 spectral channels. This limitation follows the requirement of completeness of the linear equations system used for the statistical analysis. Thus for 3 size separates (w/o bulks) we start with decreasing the number of channels K twice, to 38, with reducing the spectral resolution $\delta\lambda$ to 40 nm (and 80 nm for the lowest and highest wavelengths). Similarly, when a set of spectra for one size separate is considered, we start with $K=15$ and reduce $\delta\lambda$ to 100 (200 for the rest of spectrum) nm.

Then we apply eq. (1) to LSCC soils spectra re-sampled to different spectral resolutions. Spectra are re-sampled evenly by averaging the reflectance for adjacent spectral channels. Thus we consider the $4 \leq K \leq 38$ range (for 3 size separates, 54 spectra) and $4 \leq K \leq 15$ range (for single size separate, 18 spectra). Width of spectral channel is increased from 40 (80) to 260 (520) nm (3 size separates) and from 100 (200) to 260 (520) nm (single size separate), respectively.

Figure 1 shows the results of the statistical analysis. We plot the number of spectral channels K versus the correlation coefficient r that characterize the similarity of I_S/FeO values calculated by eq. (1) and those for real samples. The best results in terms of r are achieved for the fraction 10-20 nm and bulks (<45 nm) for most K values, i.e. these fractions are spectrally sensitive to the I_S/FeO from the statistical point of view. Overall the size fractions reveal higher r values in comparison with 3 joined size fractions in most cases from the $4 \leq K \leq 15$ range. Thus we conclude that

there are specific intrinsic relationships between spectra and maturity degree inside each of size separate, and the closest relationship is for the fraction 10-20 nm and bulks.

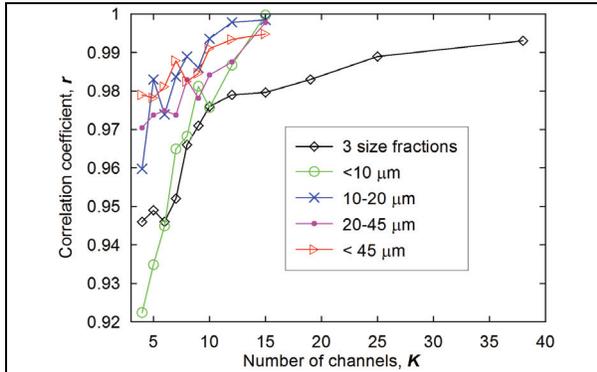


Figure 1. Correlation coefficient of I_S/FeO prediction for particle size separates at different spectral resolution.

Testing the quality of prediction with bulks: We established the link “spectra- I_S/FeO ” with eq. (1) using three particle size separates. Then we use the independent I_S/FeO values for the bulk samples to test the quality of our prediction. Figure 2 presents the dependence of the prediction quality on the number of spectral channels used, i.e. on the effective spectral resolution. Here the standard deviation σ describes the difference between prediction of I_S/FeO and sample data. Parameters (r, σ) are calculated in Fig. 2 using eq. (1) for bulk samples and set of (W_k, A) obtained from analysis of 3 size separates.

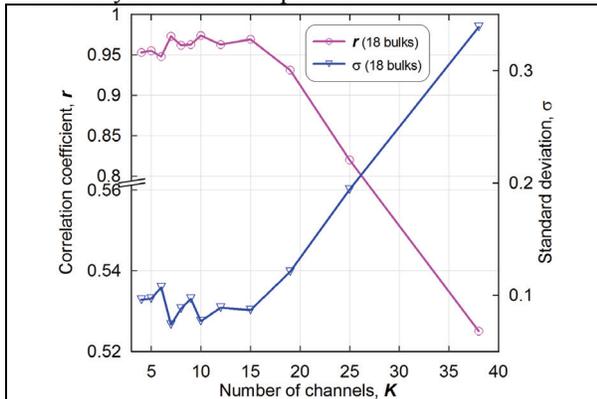


Figure 2. Quality of I_S/FeO prediction for bulks at different spectral resolution using weight coefficients obtained from size separates.

The best result for r and σ are achieved for 7-10 channels, the worst one is for the greatest $K=38$. We note high values of $r > 0.95$ for $K \leq 15$, i.e. reducing of the spectral data to ≤ 15 spectral bands generally leads to high correlation of spectral albedo with I_S/FeO .

Selected spectral channels: We verify the effect of selected channels on the I_S/FeO prediction for size separate 10-20 μm and bulks (which show closest rela-

tionships between spectra and maturity). We analyzed all possible combinations of spectral channels for $K \leq 15$. For all these combinations eq. (1) is solved, proper W_k are found, (r, σ) are calculated and finally the best in terms of r solution is retained for each K . Figure 3 presents a compilation of these results. The best combinations, being composed of non-evenly distributed bands, capture the overall spectrum slope from VIS to NIR. For $K \geq 5$ best solutions cover the center and wings of 1- μm band whereas the center of 2- μm depression usually avoids the best solutions (see Fig. 3). Bands in best solutions tend to the even distribution with increasing K .

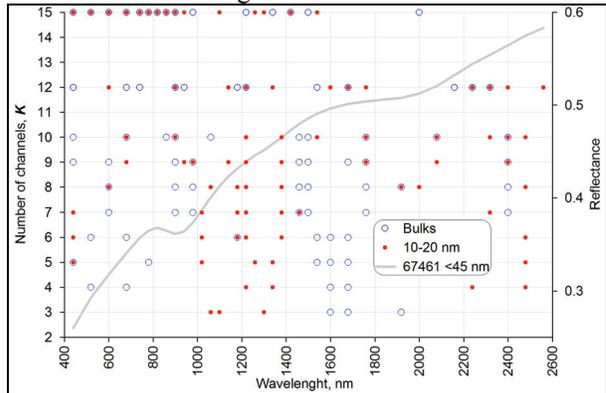


Figure 3. Combinations of reduced M^3 bands which give the best correlation with I_S/FeO data. Spectrum of LSCC bulk sample 67461 is shown.

Conclusions: We use the LSCC spectral and chemical data for lunar soils to study the reliability of the remote determination of maturity degree with M^3 multispectral data. We concluded that the most reliable determination is observed when spectra are re-sampled to 7-10 channels in the range 0.4 – 2.6 μm . The closest correlation between spectra and I_S/FeO is found for the fraction 10-20 μm and $<45 \mu m$. Preliminary study of the effect for selected channels on the reliability of the I_S/FeO prediction shows that the overall spectrum slope from VIS to NIR and shape and position of the 1- μm pyroxene band are more sensitive to estimate maturity degree variations.

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References: [1] Pieters, C., et al. (2009) *Lunar Planet. Sci.* 40 # 2052. [2] Green, R., et al. (2009) *Lunar Planet. Sci.* 40 # 2307. [3] Morris, R. (1978) *Proc. Lunar Sci. Conf.* 9, 2287–2297. [4] LeMoellic S., et al. (1999) *J. Geophys. Res.*, 104, 3833-3843. [5] Pieters, C., et al. (2002) *Icarus* 155, 285–298. [6] Taylor, L., et al. (2001) *J. Geophys. Res.* 106, 27,985–28,000. [7] Pieters, C., et al. (1993) *J. Geophys. Res.*, 98, 20,817– 20,824. [8] Pieters, C., Hiroi, T., (2004). *Lunar Planet. Sci.* 35 # 1720.