MAPPING OF THE MINERALOGY OF THE MOON WITH CLEMENTINE UVVIS AND NIR DATA ANALYZED BY A MULTIPLE-ENDMEMBER LINEAR SPECTRAL UNMIXING MODEL (MELSUM)

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Introduction: In the context of the new interest for the Moon, preparation for future exploration and data analysis is possible by revisiting old datasets. A newly-calibrated global multispectral mosaic from the Clementine spacecraft has been released in May 2007 [1]. This paper presents results obtained from a UltraViolet-Visible and Near-Infrared (UVVIS-NIR) dataset calibrated by using the method described in [2] and using telescopic spectra as reference. The region of interest includes the Aristarchus crater and its surroundings. These data are analyzed by a Multiple-Endmember Linear Spectral Unmixing Model (MELSUM) [3]. The objective is to map the mineralogy while accounting for mixtures of materials and surface maturity. Due to the use of the very discriminative infrared bands, we expect to improve the accuracy of abundance estimates and composition identifications with respect to previous analyses that relied on the UVVIS only [e.g. 2, 5, 6]. The first results for the main minerals and surface maturity are in good agreement with previous maps [4].

Clementine UVVIS and NIR data: Two multispectral cameras on board the Clementine spacecraft imaged the Moon globally in 11 bands at 100 to 250 m/pixel [7]. The data have 5 channels in the UVVIS in the range 450-1000 nm and 6 channels in the NIR in the range 1100-2780 nm. The global mosaic released by [1] is resampled at 100 m/pixel, with a coregistration accuracy of 0.2 pixel. The NIR data have been released after resolving many calibration issues of the instrument [1, 8, 9, 10, 11]. These data were normalized using the phase function of the lunar surface [12] for all phase angles and converted into bidirectional reflectance. A normalization to the spectrum of the Apollo 16 reference sample 62231 has been performed in order to make Clementine spectra directly comparable to lunar sample measurements, so that actual composition can be derived [13]

Spectral mixing analysis: Retrieving spectral contributions in mixtures is done by a least square inversion of the system Y = AX, where Y is a vector containing the remote sensing spectrum, A is a N x M matrix filled with the endmembers spectra (the input library, with N the number of endmembers, and M the number of spectral channels), and X a vector containing the coefficients of each components of the input library [14, 15]. Negative coefficients may occur from the inversion equation, which is not physically acceptable [15, 16]. To avoid this, the MELSUM [3] explores unmixing results for all possible combinations of spectral endmembers and retains the best fit provided by positive coefficients only. In addition, a mixture deconvolution is significant only if it is explained by a limited number of components [17]. A maximum of four is permitted in the present study.

Two approaches are possible: 1) Use of a reference spectral library of minerals that are relevant for a region of interest, combined with a synthetic positive slope spectrum that represents surface maturity, and a positive constant across the spectrum that compensates for different grain sizes and illumination variations. 2) Building a reference library by collecting spectral endmembers from the image. In this way, the unmixing is constrained to provide a sum of image fractions equal to one, and thus retrieve image fractions close to actual proportions. In the present abstract, results are based on the first approach.

Lunar reference spectral library. Spectra of representative minerals of the Moon are shown in Figure 1.

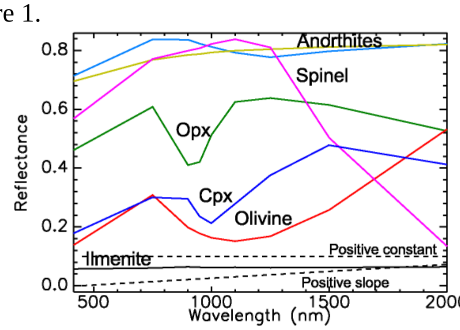

Figure 1. Spectral library of pure minerals (resampled at Clementine wavelengths) and synthetic spectra. The positive flat spectrum accounts for grain size variations and shade, and the positive slope is sensitive to surface maturity.

Anorthites are ubiquitous on the Moon, and make up the bulk of the lunar highlands. Mafic silicate minerals of the lunar crust include clinopyroxene (cpx), orthopyroxene (opx) and olivine (ol). Ilmenite is an opaque oxide in varying abundances in the lunar maria. Spinel is an oxide that contaminates most of lunar olivines and, despite weight fraction of about 1 %, it has strong spectral features that may dominate the signal near 2 µm.

Surface maturity. The space weathering processes (micrometeoritic impacts and solar wind particles) powdered lunar rocks in fine particles, and formed agglutinates. This process of surface maturation causes a reddening of the surface spectra (increase of a positive slope), and in a decrease of the spectral contrast of the absorption bands. Two synthetic components are included in the reference library to account for these effects.

Unmixed spectral data: Figure 2 shows an example of model fitting, where each reference spectrum is weighted by the mixing coefficient calculated by the MELSUM.

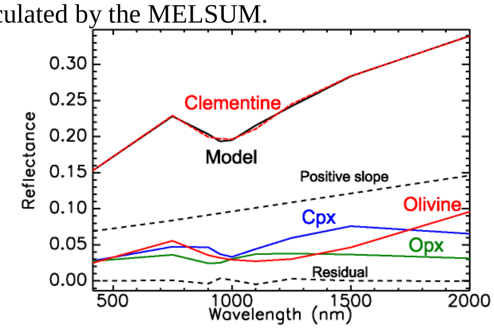

Figure 2. Example of a Clementine spectrum fitted by the MELSUM using pure mineral spectra from laboratory measurements.

Resulting maps (Figure 3) display mixing coefficients for each endmember. Most of the variations occur in and nearby the Aristarchus crater. A visible grayscale image (750 nm) is given as a reference in Figure 3a. Figure 3b summarizes the results for mafic minerals in a Red-Green-Blue color composite. The olivine-rich region south-east of the external rim of Aristarchus is consistent with its previous detections [18, 4]. The northern inner part of the rim was described as pyroxene-rich in [4], and it appears here to be a mixture of both cpx and opx. The central peak has been previously interpreted to be enriched in anorthite [18, 4], which is in good first order agreement with Figure 3c. Our results suggest that the anorthite-rich area extends towards the south-west of the internal rim. Because of spectral signatures of anorthite are weak in the considered wavelength range, these results need further investigation. Figure 3d (spectral slope component) shows patterns similar to surface maturity parameters in previous studies. Figure 3 e indicates that all the spectra can be fitted with low Root-Mean Squares residuals (RMS).

Perspectives: The MELSUM applied on combined UVVIS-NIR Clementine data provides a new method for mineral identification and mixture appraisal. The next objective is to perform the analysis at the global scale in order to prepare the analysis of the future Moon Mineralogical Mapper imaging spectrometer.

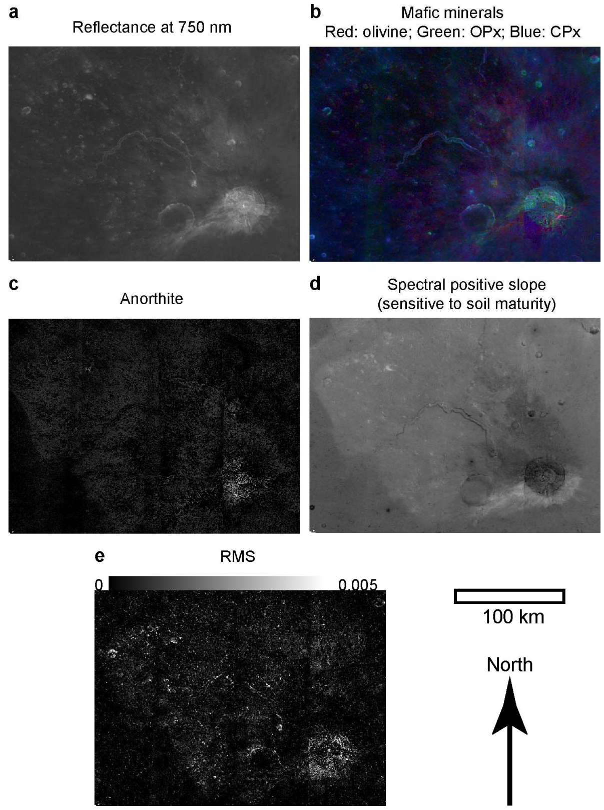

Figure 3. Maps of the Aristarchus area – a. Reference image at 750 nm – b-e. mixing coefficient images – b. Color composite for mafic minerals – c. Anorthite – d. Positive spectral slope (sensitive to soil maturity) – e. RMS.

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