

AUTOMATIC SEGMENTATION OF PETROGRAPHIC GEOLOGIC UNITS BASED ON ELEMENTAL ABUNDANCE MAPS. A. Grumpe¹ and C. Wöhler¹, ¹Image Analysis Group, TU Dortmund University, D-44227 Dortmund, Germany; {arne.grumpe | christian.woehler}@tu-dortmund.de.

Introduction: Geological units on planetary bodies are commonly defined by lithostratigraphy or chemostratigraphy. The definitions are based on manually selected criteria. Thus, the geological units may vary depending on the human that defines them. In contrast, automatic algorithms, e.g. cluster algorithms, may be applied to “learn” the defining criteria based on so-called features, e.g. topographic slopes or surface reflectance.

Motivation: Recent development in hyperspectral remote sensing has enabled an advanced mineralogical analysis of the surface e.g. by spectral unmixing [1]. In [2] a nonlinear spectral unmixing method is proposed that automatically selects endmembers from a given catalogue. The runtime of that method, however, is too high to be applied at a global scale. The computational complexity, though, may be greatly reduced if homogeneous mineralogical units are known, such that the endmember selection needs to be executed only once per geological unit.

Related work: In a previous work [3], we have proposed a split-and-merge clustering algorithm which determines the geological units and compares the continuum-removed (CR) reflectance within each geological unit, respectively. If the spread within one geological unit is too large, the geological unit is split into several units. Afterwards, similar but independently found geological units are merged into single units. The proposed features therein were coefficients of a spectral decomposition based on the most distinct reflectance spectra.

Contribution: The obtained geological units are based on reflectance spectra and thus only contain indirect clues to the mineral composition of the surface. In order to produce geological units which are suitable for the unmixing approach, this work proposes a different feature set based on the petrographic properties of the surface.

Dataset: The proposed method is applied to our photometrically normalised global mosaic derived from hyperspectral data acquired by the Moon Mineralogy Mapper (M³) [4] instrument. All M³ images and the corresponding regions of the GLD100 digital elevation map [5] are resampled to 20 pixels per degree. The global mosaic covers a latitudinal range of $\pm 60^\circ$. The thermal emission component was estimated for each image and subtracted from the observed spectral radiances according to [6]. Afterwards, a channel-wise single-scattering albedo according to the Hapke model [7] was estimated for each pixel by minimising the mean-squared deviation between the modelled and the measured spectral reflectance over all overlapping images [8], where the GLD100 topo-

graphic data set was used to take into account the influence of surface topography. The remaining parameters of the Hapke model were adopted from [9]. The normalised reflectance was computed by inserting the estimated single-scattering albedo and a standard illumination geometry of 30° incidence angle, 0° emission angle and 30° phase angle [10] into the Hapke model. Here, we downscale the global mosaic to two pixels per degree to reduce runtime.

Automatic clustering algorithm: We adopt the clustering algorithm of [3] to determine homogenous geological units. The proposed feature set, however, is changed to a petrographically motivated feature set.

Split-and-merge algorithm: According to [3], the spectra are grouped into 12 initial clusters using a self-organizing map (SOM) [11]. Afterwards, the median and the quartiles (25% and 75% quantiles) of the member spectra are computed for each cluster, respectively. The CR reflectance of the median spectrum and the quartile spectra are then compared and the cluster is split into three subclusters using the SOM if the correlation exceeds a threshold. Once the spread of the CR reflectance is homogenous in each cluster, similar clusters that originate from different original clusters are merged based on the correlation of the cluster's median spectra.

Feature extraction: The features proposed in [3] are based on the most distinct spectra within the whole mosaic. To select features that are more directly related to the mineral composition of the surface, we estimate the elemental abundances according to [12]. At a spatial scale of 0.2 pixels per degree, a linear regression model was trained to map spectral parameters, i.e. the continuum slope, the depth and wavelength of the absorption minimum and the width of the ferrous absorption trough at ~ 1000 nm and the continuum slope and the depth of the absorption trough at ~ 2000 nm, onto the Lunar Prospector Gamma Ray Spectrometer elemental abundance maps of the elements Ca, Al, Fe, Mg and O [13,14]. In the case of the element Ti, a quadratic regression model based on the continuum slope at ~ 1000 nm and the logarithm of the band depth ratio between ~ 1000 nm and ~ 2000 nm was determined [15]. From the estimated elements the most uncorrelated elements, i.e. Fe, Mg and Ti, are chosen. The correspondingly estimated weight percentages are used as features for the clustering algorithm.

Results: The clustering algorithm initially returned 143 geological units, but most returned clusters had only one member. Due to the split algorithm, each outlier is represented by its own cluster. Therefore, we removed all clusters with less than three

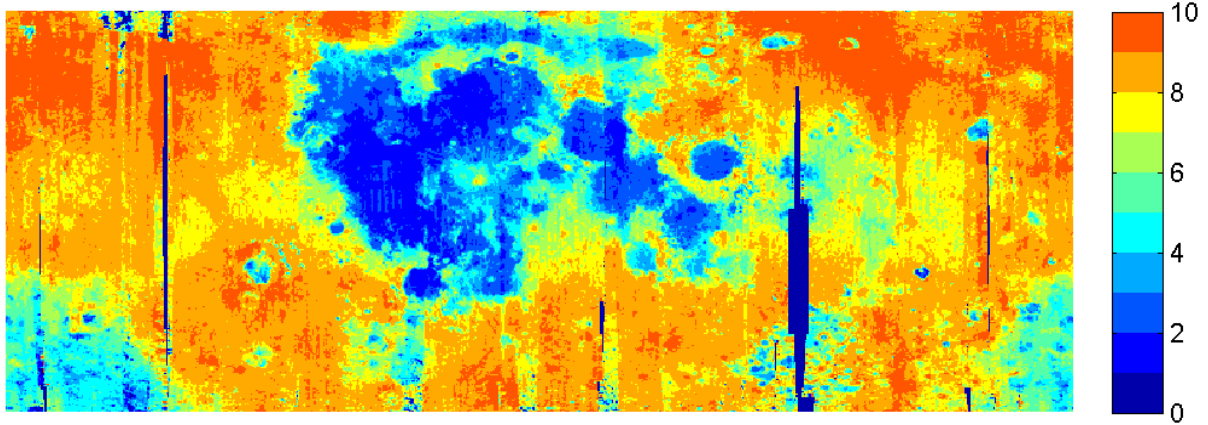


Figure 1: Result of the clustering algorithm for the M³ mosaic (selenographic latitude $\pm 60^\circ$). Colours denote cluster indices.

members and obtained a set of ten geological units that each contain several thousands of members.

Fig. 1 shows the global distribution of the clusters. The results are in good agreement with the basic types of lunar surface materials. The mare regions are clearly separated from highland areas. The corresponding prototype spectra show characteristic features for the corresponding region.

The mare prototypes (cf. upper graph of Fig. 2) exhibit deep absorptions near 1000 nm, indicating a high concentration of mafic minerals, while the highland prototypes (cf. lower graph of Fig. 2) show only weak absorptions. The minimum wavelengths of the mafic absorption troughs of the cluster 1-5 prototypes lie between 960 nm and 1000 nm and between about 1980 nm and 2200 nm, respectively. They reflect different pyroxene species containing different fractions of orthopyroxene vs. clinopyroxene (cf. e.g. [16]). The minimum wavelengths of the shallow absorption troughs near 1000 nm of the highland prototypes (clusters 6-10) are located between 970 nm and 1000 nm.

Notably, all prototypes show an absorption near 1300 nm which appears as an inflection feature for clusters 1-3. This absorption is usually attributed to the mineral plagioclase [17] but might also be a secondary absorption present in the spectra of some pyroxene species (cf. e.g. [18]). Since the clusters contain 5000-26000 members each and the prototypes are averaged spectra, this absorption feature is present all over the lunar surface.

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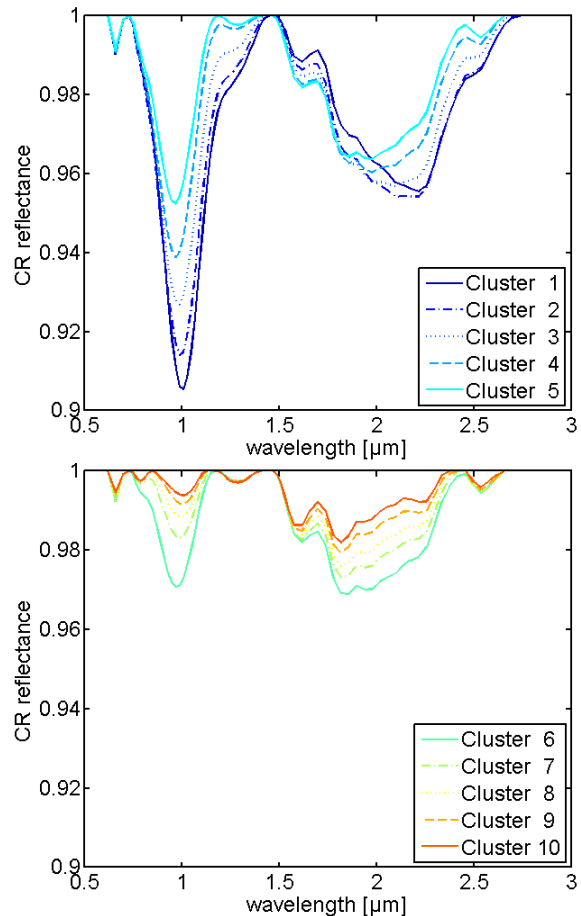


Figure 2: Continuum-removed prototype spectra. The spectra exhibit absorption troughs of variable depth near 1000 nm and 2000 nm. The position of the absorption band near 1000 nm varies across a wide range. Some prototype spectra show a shallow absorption band and others an inflection near 1300 nm.

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