

### SPECTROPHOTOMETRIC ANALYSIS OF THE LUNAR PLINIUS/APOLLO 17-REGION

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Spectrophotometric analysis (1,2) is a technique for estimating the chemical and mineralogical composition of the lunar surface from the spectral reflectance characteristics of lunar surface materials, taking into account the physical and structural state of the lunar surface. The geochemical composition of the lunar regolith as estimated using this spectrophotometric analysing technique is the basis for mapping the lunar surface in terms of geologic units. Besides the photogeologic interpretation of surface features lithologic surface units are now distinguishable in a quantitative way. In addition, the quantitative estimation of lithologic surface units enables the analyst to reconstruct the originally vertical sequence of rock units by analyzing the horizontal distribution of crater ejecta.

It can be shown that a functional relation exists between the spectral reflectance characteristic of lunar materials and the chemical composition of these materials (1,2). This relationship is given by linear combinations which connect spectral parameters with the concentrations of the chemical components of lunar surface samples. Quantitatively, the spectral parameters are described by the factors (principal components) of the variation of spectral signatures in lunar reflectance spectra. The reasons for these spectral variations are the different compositions of the surface materials. The spectral parameters are related to the chemical reasons for the spectral variations through the eigenvalues and the eigenvectors of a principal component analysis. The eigenvalues will define the variance in the direction of a principal axis and therefore define the number of interpretable principal components. The eigenvectors describe the signatures of a reflectance spectrum and therefore identify the primary chemical reasons for the spectral variations. Thus the variation of spectral features in dependence of variations of the chemical and mineralogical composition of lunar surface materials is defined by the spectral parameters. The analysis of lunar samples which have been examined in the laboratory both spectroscopically (3) and chemically (4,5), yields the following result: by assuming a constant viewing geometry the spectral reflectance characteristics of these samples are primarily dependent on the concentration of the chemical elements Fe, Ti, Si, Al, Mg, Ca, Mn (concentrations are expressed as wt.% of the typical oxides of these elements) and on the content of amorphous components (glass) in the lunar materials (1,2). Therefore the samples returned from the lunar surface define a spectral-geochemical model which can be used to derive spectrophotometric calibration coefficients. The spectrophotometric calibration coefficients are the result of a multiple regression analysis of the principal components and chemical components. The relationship between the spectral variations in the reflectance spectra of lunar surface materials and the geochemical composition of these materials is thus defined by the spectrophotometric calibration coefficients. The concentration of the chemical elements Fe, Ti, Si, Al, Mg, Ca and Mn and the content of amorphous components in the lunar soil can be derived directly by applying the spectrophotometric calibration coefficients to the measurable spectral reflectance characteristic within an error range of less than  $\pm 2.4$ wt.% of the oxides for the above chemical elements and less than  $\pm 4\%$  of the abundance of the amorphous components. The estimation errors of the concentrations are significantly smaller than the variation range of the concentration of chemical components in the lunar soil. Spectrophotometric measurements of the lunar surface can now be analysed within the limits of the spectral-chemical model by using the spectrophotometric calibration coefficients. Thus it is possible to estimate the geochemical content of a lunar surface element from remotely sensed spectrophotometric data.

The spectrophotometric analysis was carried out for a specific region of the lunar surface (Plinius/Apollo 17 region). Telescope-based spectrophotometric observations of the Plinius/Apollo 17 region at Mauna Kea Observatory (Hawaii) yields the required data base for this purpose. The spectrophotometric measurements were performed by using two different types of instruments: a CCD camera (spectral range:  $0.4\mu\text{m} \leq \lambda \leq 1.0\mu\text{m}$ ), sensitive in eight spectral channels and a spectrometer (spectral range:  $0.62\mu\text{m} \leq \lambda \leq 2.6\mu\text{m}$ ) with high spectral resolution. The spectrometer provides point measurements of the lunar surface with a high density of spectral information. The spectral point sources can be understood as spectral exposures which support the low spectral resolution but high spatial resolution areal CCD camera measurements. The spatial extension of a point of spectroscopic measurement is  $23.3\text{km}^2$ . A combination of the data from both instruments provides not only the possibility to investigate the spectral characteristics of the surface of the Plinius/Apollo 17 region in a broad spectral range ( $0.4\mu\text{m} \leq \lambda \leq 2.6\mu\text{m}$ ) but also allows to map (CCD camera) the most important geochemical trends in the regolith of the examined region with a spatial resolution of  $1.6\text{km}/\text{pixel}$  over a surface area of  $575\text{km} \times 575\text{km}$ . In this way, it is possible to make statements on the chemical composition even for such

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areas which lie outside the spatially limited points of spectroscopic measurements. The analysis of the spectrophotometric measurements results in the chemical characterization of the regolith exposed at the points of spectroscopic measurements as well as in the determination of the two-dimensional distribution of the concentration of the chemical components Fe, Ti, Al, Ca, and the content of amorphous components in the regolith of the lunar surface (geochemical map). It should be mentioned that due to the limited spectral range of the CCD camera ( $\lambda \leq 1.0\mu\text{m}$ ) the chemical elements Si, Mg and Mn are not detectable by using this instrument.

One of the basic requirements for quantitative spectrophotometric analysis is the determination of the absolute reflectance of a natural planetary surface. Thus it is necessary to take into account and to correct all effects which will influence spectral observations in order to provide remotely sensed measurements of high precision. Such effects are the extinction of the earth's atmosphere and those variations of the reflected light which are due to photometric effects induced by the physical and structural state of planetary surfaces. The estimation of chemical concentration will be influenced directly by the quality of the observational data. Remotely sensed measurements are of lesser quality than laboratory measurements. However, appropriate data reduction techniques will allow an estimation of remotely sensed reflectance values with an accuracy of typically less than  $\pm 3\%$  (2). Thus the concentrations of chemical elements and the content of amorphous components in lunar soils can be estimated from a spectrophotometric analysis within an error range of  $<\pm 2.0\text{wt.}\%$  of the oxides for Fe, Si and Mg,  $<\pm 3.0\text{wt.}\%$  of the oxides for Ti,  $<\pm 2.5\text{wt.}\%$  of the oxides for Al,  $<\pm 1.0\text{wt.}\%$  of the oxides for Ca,  $<\pm 0.05\text{wt.}\%$  of the oxides for Mn and  $<\pm 8.0\text{wt.}\%$  of the abundance of amorphous components. The precision of the spectrophotometric analysis and its application to remote sensing data was tested by comparing the spectrophotometrically estimated concentrations of the chemical elements Fe, Ti, Si, Al, Mg, Ca and Mn of the lunar landing sites Apollo 17 and Apollo 16 to the results of the chemical analysis of Apollo 17 and Apollo 16 samples in the laboratory (6,2). The deviations between both independently estimated data sets are less than 10%; these deviations are within the error of spectrophotometric measurements. The comparison of the spectrophotometric analysis with the results of a geochemical interpretation (Fe, Ti concentration and Al/Si, Mg/Si concentration ratio) of the Apollo X-ray and  $\gamma$ -ray measurements (7,8) yields the same result (6,2).

The estimates of the concentrations of chemical components in the regolith of the Plinius/Apollo 17 region as well as the estimation of the glass content by using spectrophotometric analysis are the basis for a geoscientific interpretation. The concentrations of the chemical components have also been used to calculate a normative mineralogical composition of the materials exposed on the surface of the Plinius/Apollo 17-Region at the points of spectrophotometric measurements. This results in six definable rock units in the area of the Plinius/Apollo 17 region: anorthositic rocks, noritic (gabbroic) rocks, intermediate rocks, titanium basalts, ilmenite basalts, mare basalts (2). In order to map the areal extension of these rock units, it was necessary to derive a lithologic model from the geochemical characteristics of lunar samples. This lithologic model describes surface rock units in terms of those geochemical parameters which can be detected by the CCD camera experiment. The basic geochemical parameters for distinguishing rock units in the lithologic model are the Ti/Fe ratio and Fe/Al ratio of surface composition. Finally, the overall geologic structure of the Plinius/Apollo 17 region can be evaluated from the common interpretation of all available geoscientific information: spectrophotometrically estimated chemical and mineralogical composition of the regolith; geomorphological and structural results of the photogeologic interpretation of the lunar surface; surface ages as estimated from crater statistics. Thus all informations are provided for mapping the geologic state of the lunar Plinius/Apollo 17-Region.

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