

MID-INFRARED REFLECTANCE SPECTROSCOPY OF SOILS FROM APOLLO 14, 15 AND 16: SPECTRAL PARAMETERS AND SAMPLE MATURITY. A. Morlok¹, K.H. Joy², D. Martin², R. Wogelius², H. Hiesinger¹ ¹Institut für Planetologie, Wilhelm-Klemm-Strasse 10, 48149 Münster(morlokan@uni-muenster.de), ²Department of Earth and Environmental Sciences, The University of Manchester, Manchester, M13 9PL, UK.

Introduction The surface regolith of the Moon provides so far the only larger amount of samples of a differentiated planetary surface exposed to the space environment without any intervening atmosphere. Therefore, the study of the lunar soils is a way to obtain the ‘ground truth’ to be related to surfaces of other, similar, but more inaccessible primitive and differentiated bodies. The spectral study of lunar surface soils is also of key interest for the comparison to first data from the ESA/JAXA BepiColombo mission to Mercury [1,2]. A flyby of the Moon in 2020 by BepiColombo provided space-resolved spectra in the mid-infrared [3,4]. Here our aim is (a) to provide fundamental mid-infrared reflectance data for the Apollo soils, (b) compare broad spot and micro-FTIR techniques, and (c) investigate if mid-infrared spectra reflect the degree of soil space weathering ‘maturity’.

Samples Seven Apollo samples were selected to cover a wide range of maturity, quantified with the maturity index I_s/FeO (in brackets below): Apollo 14 samples: high-K highland soils 14163,135 (57) and 14259,672 (85). Apollo 15: High-Mg soils 15101,319 (70) and 15401,147 (high volcanic glass) [5,6]. Apollo 16: feldspathic soils 61220,41 (9.2), 62231,55 (91) and 67481,96 (31) [5,6].

Techniques The soil samples were sieved into 0–25 μm , 25–63 μm , 63–125 μm and 125–250 μm fractions. Also, an unsieved ‘bulk’ sample was used.

Broad Spot measurements of samples were performed using a Bruker 70v Vertex FTIR spectrometer at the Universität von Münster, Germany. A spot size of ~ 1 mm was used. Under vacuum conditions 512 scans per measurement from 3 to 25 μm [e.g., 7] were collected.

Micro-FTIR measurements were performed using a PerkinElmer Spotlight 400 spectrometer with attached microscope unit at the University of Manchester. Unconsolidated soil samples were analyzed using this instrument under ambient laboratory conditions. The spectra of each sieved size fraction were obtained by averaging all of the spectra in each FTIR map from 3 to 13 μm and 2 co-added scans per pixel [e.g., 8].

Results We present here the results for the 0–25 μm soil size fraction, since it contains all features of interest: the Transparency Feature (TF), indicative of the finest size fraction, the Christiansen Feature (CF), a characteristic reflectance low, and the Reststrahlenbands (RBs), vibration modes based on the molecular structure, the spectral ‘fingerprint’ [7]. For the < 25 μm

soil size fraction the spectra are quite similar for all three Apollo missions (Fig. 1). The characteristic intensity minimum, the CF is between 8.1 μm (67481,96) and 8.4 μm (15401,147). TF, indicative for the finest ($< 25\mu\text{m}$) size fractions, falls between 12.2 μm (14163,135) and 12.3 μm (15401,147).

Discussion

Mineralogical makeup The most prominent RBs are at 9.0 μm – 9.2 μm , 9.7 μm – 9.9 μm , 10.6 μm – 10.9 μm , and 11.2 μm – 11.6 μm . The latter features can be explained by the presence of pyroxene, while the former bands are indicative of the dominating feldspar mineral anorthite [9]. The generally weak RB are sitting on a broad continuum-like structure, typical for amorphous glassy materials, similar to synthetic glasses with lunar highland or mare compositions [7].

Comparison Techniques Spectral response results between the two techniques, e.g., for bulk Apollo 14163 (Fig. 2) are very similar, both regarding relative intensities, band shapes, and peak positions.

Maturity Soil maturity is the summary effects of space weathering and gardening of the regolith. Effects of maturity have to be taken into account when comparing soils with presumably similar starting composition, but different history due to increasing content of glassy, amorphous material in maturation

We used the spectral contrast between the CF and the emissivity of the feature near 10.5 μm to quantify maturity of the unsieved bulk samples [10]. The spectral contrast is calculated by subtracting the RB emissivity of the RB feature near 10.5 μm (Fig. 1) from the emissivity at the CF wavelength, and multiplying the difference by 100.

The broad spot analyses (Fig. 3) show a particular good correlation between maturity and spectral contrast ($R^2=0.59$), while Micro-FTIR (this study) and previously reported emission studies of the comparable < 1 mm grain size fraction [10] show much poorer relationships ($R^2<0.1$).

Conclusions A series of mid-infrared reflectance analyses of Apollo 14, 15, and 16 soils reveals rather homogeneous spectral features, mainly feldspar, glass and pyroxene bands, with similar results for broad spot and micro-FTIR analyses.

The spectral contrast between the CF and the 10.5 μm intensity correlates well with the maturity of the Apollo soils in the broad spot analyses of this study. This could serve as an easy, non-destructive technique for laboratory studies of maturity and remote sensing.

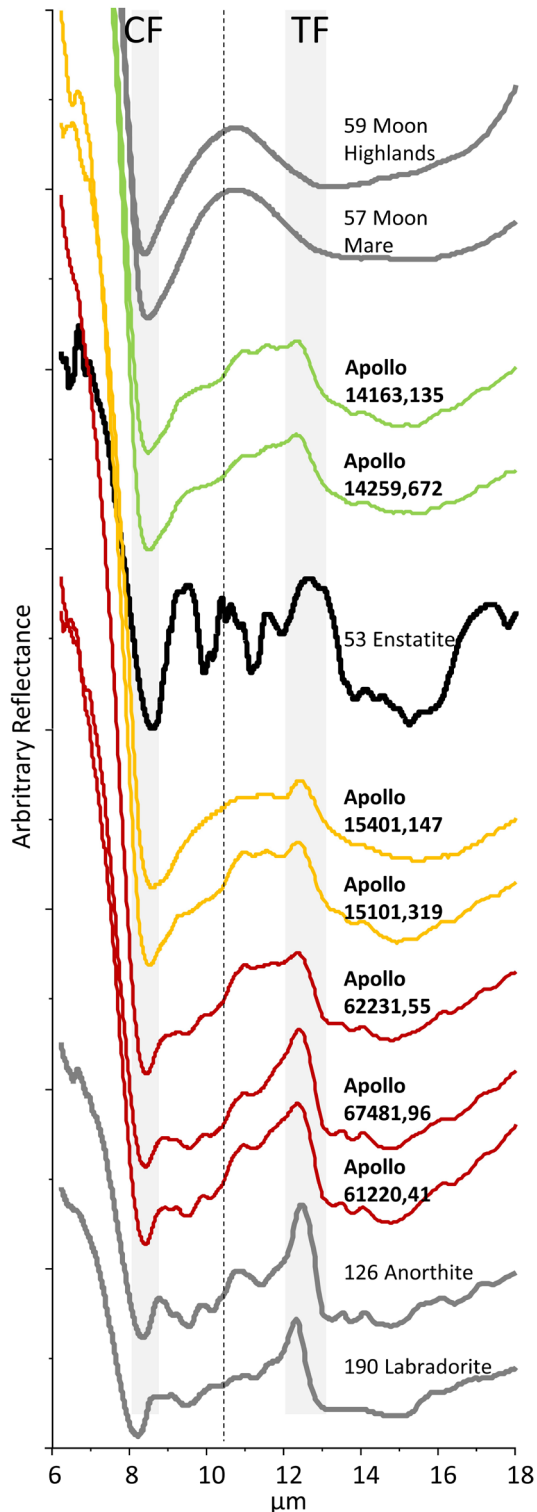


Figure 1: Comparison of the 0-25 μm size fractions (denoted as sub samples) with standard minerals (feldspars and pyroxene, [9]) and synthetic samples (lunar mare and highlands [7]). The black dashed line marks the point used for spectral contrast calculations with the CF [10].

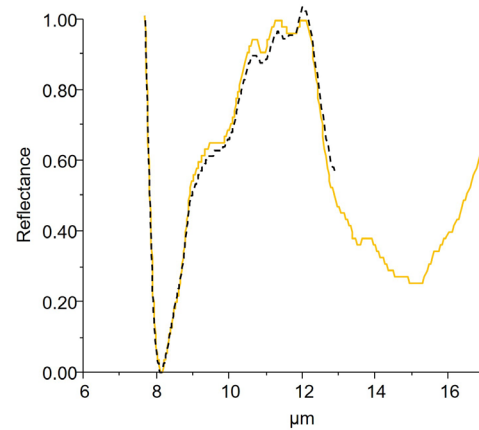


Figure 2: Comparison of spectra of the same sample (Apollo 14163 bulk): broad spot spectrum (yellow line) and micro-FTIR spectrum (dotted line), both normalized to unity.

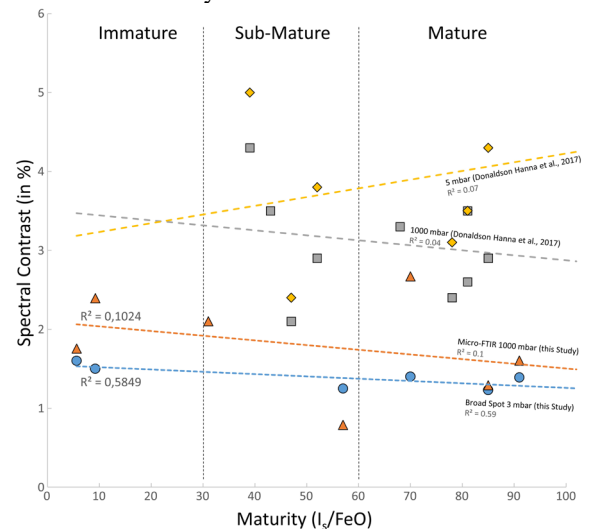


Figure 2: Correlation of the maturity with the spectral contrast. Yellow diamond, grey squares: < 1 mm grain size fraction in [10]. Triangles: micro-FTIR results (this study), Circles: Broad spot analyses bulk fraction (this study). R^2 =Coefficient of determination.

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