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FT-IR/PAS Studies of Lunar Regolith Samples

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This paper describes investigations of the surface properties of lunar regolith powder samples from the Apollo 11, 12, and 16 missions, respectively. For this part of studies conducted at the Faculty of Chemistry, Maria Curie-Skłodowska University a Fourier transform infrared photoacoustic spectroscopy was applied.

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1. Introduction

The formation of regolith and soil on airless planetary bodies, such as Moon, asteroids, is the result of processes virtually nonexistent on Earth. The physical and chemical changes that occur to the materials at the surfaces of such airless bodies are collectively known as "space weathering" and are mainly caused by impacts of meteorites, micrometeorites, galactic and solar-wind particles, in the deep vacuum of space [1].

Between 1969 and 1972 six Apollo missions brought back 382 kilograms (the majority was delivered by Apollo 15, 16 and 17 missions) of lunar rocks, core samples, pebbles, sand, and dust from the lunar surface. The six space flights returned 2200 separate samples from six different exploration sites on the Moon [2]. The Apollo samples are handled and stored either under vacuum or in clean dry nitrogen gas (Fig. 1) at the lunar sample building of the National Aeronautics and Space Administration (NASA) Johnson Space Center.

Lunar soil and rock samples of the Apollo missions have been already examined in detail [2–4]. Planning new missions and the establishment of a manned

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Fig. 1. Sample 64501.228 delivered by the Apollo 16 mission in an original container.

station at the Moon require some additional information. The aim of broader investigation (including this one) is to obtain parameters relevant to the capability of the Moon surface to store water in relation to the environmental conditions.

2. Experimental

2.1. Samples

Below, in Tables I and II there are included data characterizing investigated Moon regolith samples.

TABLE I

Brief description of the investigated samples [3].

Mission	Duration of the mission	Geographical area	Type of area	Total amount of taken samples [kg]	Sample No.*
Apollo 11	16–24.07.1969	Mare Tranquillitatis	Mare	21.55	10084.2000
Apollo 12	14–24.11.1969	Oceanus Procellarum	Mare	34.35	12001.922
Apollo 16	16–27.04.1972	North of Crater Descartes	Terra	95.71	64501.228

*numbers according to NASA

2.2. Spectroscopic measurements

Fourier transform infrared photoacoustic spectroscopy (FT-IR/PAS) measurements were performed using Bio-Rad (Excalibur 3000MX) spectrometer and helium purged MTEC300 photoacoustic detector, over the 4000–400 cm^{-1}. Spectra were obtained at room temperature (RT) at 4 cm^{-1} resolution. The spectra were normalized by computing the ratio of a sample spectrum to the spectrum of a MTEC carbon black reference material. A stainless steel cup was filled with samples (thickness < 6 mm). Each phase of data collection was preceded by the

TABLE II

Chemical composition of the lunar samples (main components) [1].

Element	Apollo 11	Apollo 12	Apollo 16
Na	0.18%	0.29%	0.21%
Mg	4.40%	4.00%	2.00%
Al	9.51%	3.71%	15.13%
Si	19.12%	10.44%	19.10%
K	0.21%	0.13%	<787 ppm
Ca	9.85%	5.31%	11.84%
Ti	5.11%	1.26%	0.31%
Cr	0.21%	0.20%	731 ppm
Mn	0.14%	0.10%	445 ppm
Fe	10.55%	7.71%	2.83%

PA cell purging with dry helium for 5 min. Interferograms of 512 scans were averaged for each spectrum. Changes in absorption bands were investigated in the mid IR region.

3. Results and discussion

Figure 2 illustrates FT-IR/PA spectra of the investigated samples in the 4000–2600 cm^{-1} region. Strong, broad bands with the maxima around 3440 cm^{-1} are characteristic of the asymmetric H–O–H stretching vibrations. This is an indication of physically adsorbed water on the samples' surfaces.

In the range 3000–2800 cm^{-1} there are several low intensity bands and brief description is given below (Table III).

The presence of organic compounds containing carbon and hydrogen is an indication that all samples were slightly contaminated in the past. This is not an evidence that such compounds exist on the Moon. In the following figure (Fig. 3) there is spectral characteristic of the investigated samples in the 2000–400 cm^{-1} region. Bands with the maxima around 1640 cm^{-1} are connected with the symmetric H–O–H stretching vibrations. Weak bands located at about 1384 cm^{-1} and band at 1540 cm^{-1} (Apollo 12) can be attributed to C–H deformation stretching. Moreover, a weak band with the maximum at 1739 cm^{-1} can be an indication of the presence of carbon containing oxygen organic compounds. This is an additional evidence that examined samples were contaminated.

Based on the literature data and Raman spectroscopy studies [6] it is known that the majority of the minerals found on the Moon are of the same kind as those occurring on our Earth (Table IV).

Major phases are composed mainly with silica materials. Observed vibrations in the recorded spectra (Fig. 3) should be connected with the various Si–O

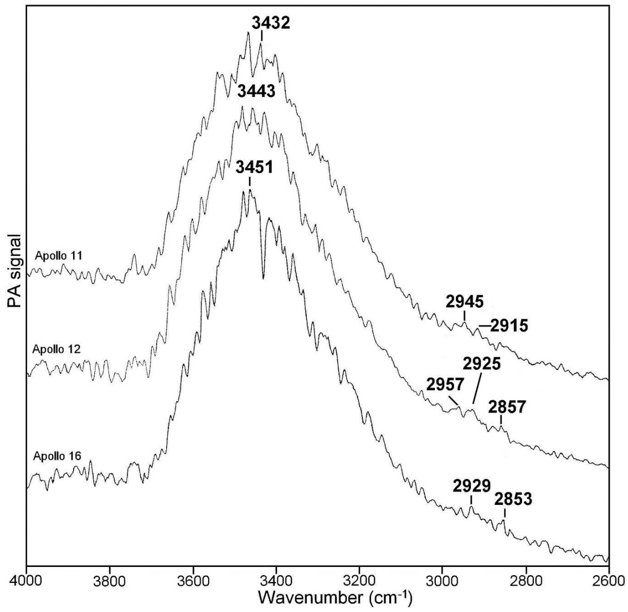

Fig. 2. FT-IR/PA spectra of Lunar regolith samples in the 4000–2600 cm^{-1} region.

TABLE III

Valence vibrations of C–H in the 3000–2800 cm^{-1} range [5].

Mission	Vibration [cm^{-1}]	Comment*
Apollo 11	2945	ν_{as}–CH_3
	2915	ν_{as}– CH_2
Apollo 12	2957	ν_{as}–CH_3
	2925	ν_{as}–CH_2
	2857	ν_s–CH_2
Apollo 16	2929	ν_{as}–CH_2
	2853	ν_s–CH_2

*ν_{as} and ν_s — asymmetric and symmetric stretching vibrations, respectively

stretching. In the recorded spectra maxima located in the range 1100–900 cm^{-1} can be attributed to ν_{as}(Si–O–Si) and Si–O stretching. The vibration with the maximum at about 730 cm^{-1} can be described as ν_s(Si–O–Si) stretching. A weak band at 628 cm^{-1} can be described as δ(Si–O–Si) or could be an indication of the magnetite presence [7].

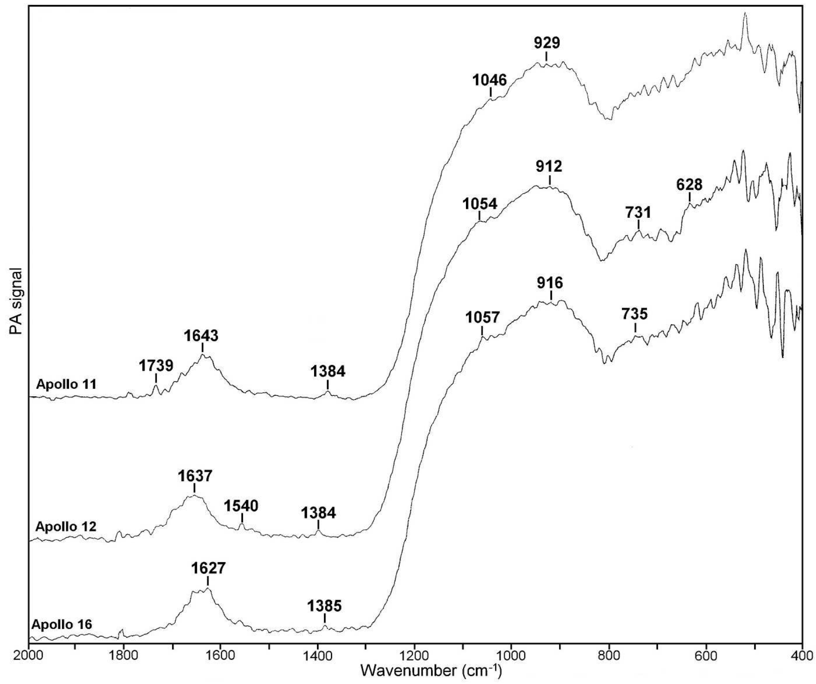

Fig. 3. FT-IR/PA spectra of Lunar regolith samples in the 2000–400 cm^{-1} region.

TABLE IV

Main minerals detected in the investigated samples [5].

Mission	Minerals and their chemical formula
Apollo 11	ilmenite ($FeTiO_3$), pyroxene ($(Ca,Mg,Fe)_2Si_2O_6$), anorthite ($CaAlSi_2O_8$), traces of Olivine ($(Mg,Fe)_2SiO_4$)
Apollo 12	olivine, magnetite (Fe_3O_4), pyroxene, anorthite
Apollo 16	anorthite, olivine, pyroxene

4. Conclusions

FT-IR/PAS technique in the studies conducted was a supplementary one. The presence of adsorbed water and silica materials was confirmed. Moreover, the analysis of very specific and rare samples verified the importance and the unique character of the spectroscopic method used [8]. Spectroscopic measurements conducted allow to detect the presence of contaminants.

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