RAMAN SPECTROSCOPIC CHARACTERIZATION OF CHANG'E-5 DRILLED SUBSURFACE SOIL CE5Z0107.

Zongcheng Ling[1], Haijun Cao[1], Bradley L. Jolliff[2], Alian Wang[2], Jian Chen[1], Changqing Liu[1], Xuejin Lu[1], Xiaohui Fu[1], Jianzhong Liu[3] [1]Shandong Key Laboratory of Optical Astronomy and Solar-Terrestrial Environment, School of Space Science and Physics, Institute of Space Sciences, Shandong University, Weihai, Shandong, 264209, China; [2]Dept. Earth & Planetary Sciences and McDonnell Center for the Space Sciences, Washington University in St. Louis; [3]Institute of Geochemistry, Chinese Academy of Sciences, Guiyang 550002, China (zcling@sdu.edu.cn).

Introduction: As the newest lunar sample return mission, China's Chang'e-5 (CE-5) program collected ~1.731 kg of rock and soil samples from the northern Oceanus Procellarum of the Moon. With these new samples, we gleaned new insights about the age of young lunar volcanism (as young as ~2.0 Ga [1-2]) and its bulk chemistry and mineralogy, water content, petrogenesis, and space weathering effects[e.g., 3-6].

Raman spectroscopy is a powerful tool for mineral identification and characterization of planetary materials [7-12]. We have previously studied the scooped surface CE-5 soil sample CE5C0600 using Raman methods [13]. In this study, we investigate the mineral modes and geochemistry of the drilled subsurface sample CE5Z0107, which has been allocated to Shandong University by the China National Space Administration, mainly for Raman spectroscopic analysis. In addition, a Raman spectrometer has been selected as a rover payload for the Chang'e-7 mission. Data acquired for these samples is critical for the evaluation of this science payload for future surface exploration in the lunar south polar region.

Sample descriptions and Raman measurements: CE-5 lunar soil sample CE5Z0107 was collected by the drill core, which is from ~1 m depth of the CE-5 landing-site surface [14], assumed to be the least contaminated sample by the rocket exhaust. We took micro-images of the sample using a Leica microscope. Raman point-counting measurements of this CE5Z0107 soil are performed using a Renishaw inVia Raman spectrometer at Shandong University at Weihai. A 532 nm green laser with ~2.5 μm diameter and ⩽8.9 mW power was irradiated onto the sample through a 50× long-working distance objective. A Si wafer is used to conduct the wavelength calibration, which ensures peak position accuracy of ±0.2 cm^{-1}. The spectral resolution is ~ 1 cm^{-1} in the spectral range of 100-4000 cm^{-1}.

Micro-image analysis: With the micro-image acquired with the Leica microscope, we could identify the mineral grain size distribution of the soil. We counted ~3688 grains in total and found they ranged from ~4 to 780 μm in diameter and have an average soil grain size as ~27 μm, which is greater than that of CE5C0600 soil (~20 μm) collected at the surface [12]. This difference can be understood as less impact and gardening effects in the subsurface soil.

Mineral Modes: We acquired 801 Raman spectra during a point-counting measurement on the ~36 mm^2 flattened soil surface (step size > 400 μm). Mineral phases were identified using their typical "fingerprint" Raman spectra. The mineral modes were obtained using their appearing frequency in 801 spectra. The typical spectra of mineral endmembers are given in Fig.1a. We found nearly 20 mineral species including the major minerals pyroxene, plagioclase, and olivine as well as accessory minerals ilmenite, apatite, spinel, silica polymorphs, K-feldspar, baddeleyite, and tranquillityite. In addition, we discovered three types of glass, i.e., basaltic glass, feldspathic glass, and silica glass, and the last one has not been observed in surface soil CE5C0600.

The CE5Z0107 soil exhibits a similar mineral mode to the surface lunar soil CE5C0600 as shown in Table 1. Both show high mafic silicate mineral proportions consistent with the basaltic nature of the returned CE-5 sample. Clinopyroxene abundance can reach 31.2% of CE5Z0107 soil and plagioclase abundance is very similar (~32%). The major difference is that the subsurface soil CE5Z0107 has much more olivine (15.1%) and much less basaltic glass (7.1%) than the surface soil CE5C0600. The higher olivine proportion may be interpreted by the endogenous igneous process. The basaltic glass difference may be due to the evolution of the different-depth soils. The subsurface may have undergone less impact gardening and thus produced fewer proportions of impacted basaltic glass.

Table 1. Mineral modes (%) of Chang'e-5 subsurface soil CE5Z0107 and surface soil CE5C0600[13]

Mineral	CE5Z0107	CE5C0600
Plagioclase	32.1	31.6
Clinopyroxene	31.2	24.4
Orthopyroxene	2.4	2
Olivine	15.1	8.9
Ilmenite	3.2	4.6
Apatite	0.6	1.1
K-feldspar	1.4	0.3
Spinel	1.5	0.7
Quartz	1.3	1.1
Cristobalite	0.6	0.7
Baddeleyite	0.1	0.3
Tranquillityite	0.1	n.d.
Basaltic glass	7.1	21.9
Feldspathic glass	3.2	2.5
Silica glass	0.1	n.d.

*n.d. denotes no detection.

Mineral chemistries: We calculated the pyroxene and olivine mineral chemistries (Fig. 1b, c) using their characteristic Raman spectral peak positions [8-12]. High-Ca pyroxene and Fe-rich olivine are two major characteristics of this soil. Compared with surface soil CE5C0600, the subsurface soil CE5Z0107 shows a relatively Mg-rich and Fe-poor nature in the pyroxene quadrilateral and olivine chemistry. This distribution is consistent with the observation of the mineral modes that the surface soil has more abundant glass and late crystallized mesostasis mineral phases. This may suggest a divergent temperature and geochemical gradient for mineral crystallization during lava flow cooling. A similar lava flow differentiation event has also been observed at Chang'e-3 landing site [15].

Exogenous materials related to Mg-suite rocks could also be evaluated by the statistics of Mg# distributions of pyroxene and olivine. We found that 0.1% of exotic materials exist in subsurface soil CE5Z0107, compared to 5-7% of surface soil CE5C0600 [13].

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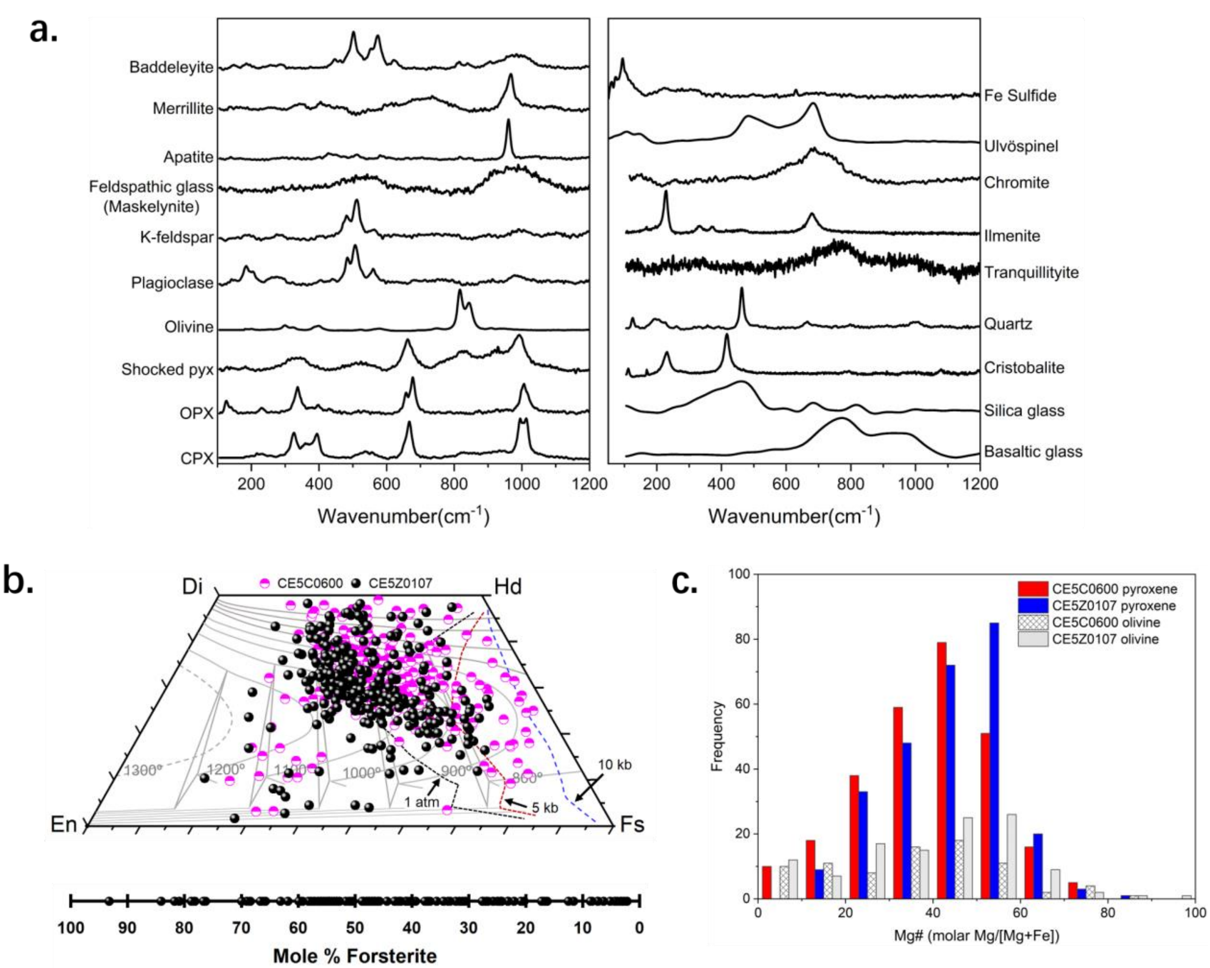

Figure 1. Raman spectroscopic characterizations of the subsurface soil sample CE5Z0107. (a) Raman spectra (b) Pyroxene and olivine chemistries; (c) Statistic of Mg# (Molar Mg/(Mg+Fe)) distribution of pyroxene and olivine.