

FE-RICH PYROXENE AND MG-RICH OLIVINE AT CHANG'E-4 LANDING SITE CONSTRAINED BY SPECTRAL CHARACTERISTICS OF LUNAR SOIL ANALOGS USING VNIS PROTOTYPE. Changqing Liu¹, Zongcheng Ling^{1*}, Li Liu¹, Jian Chen¹, Haijun Cao¹, Hongkun Qu¹, Le Qiao¹, Jiang Zhang¹, Xiaobin Qi¹, Rui Xu², Zhiping He², ¹Shandong Provincial Key Laboratory of Optical Astronomy and Solar-Terrestrial Environment, Institute of Space Sciences, Shandong University, Weihai, Shandong, 264209, China. (zcling@sdu.edu.cn). ²Shanghai Institute of Technical Physics, Chinese Academy of Sciences, Shanghai 200083, China.

Introduction: Chang'E-4 (CE-4) spacecraft successfully landed on the floor of Von Kármán crater (45.4°S, 177.6°E) in the South Pole-Aitken (SPA) basin [1-3], and made the first-ever *in-situ* investigations on lunar farside. Von Kármán crater floor is extensively covered by ejecta from Finsen crater, and exhibits obviously heterogeneous compositional distribution [4].

The mineralogy investigated by the Visible and Near-infrared Imaging Spectrometer (VNIS) onboard the “Yutu-2” rover remained controversial. The rock and soil at the CE-4 landing site are thought to be dominated by olivine (OL) and low-Ca pyroxene (LCP) utilizing the Modified Gaussian Model (MGM) [5, 6]. However, other studies showed that CE-4 materials are olivine-poor based on Hapke’s radiative transfer model [7, 8]. We conclude that laboratory spectroscopy studies on lunar soil analogs are necessary to better constrain the mineralogy at the CE-4 landing site.

Sample Preparation: Four terrestrial minerals including augite (representative of HCP), hypersthene (representative of LCP), OL, and plagioclase (PL) purchased from *ShuiyuanShanchang Co. LTD* were ground into grains smaller than 100 μm. Subsequently, powders were mixed in different volume fractions (Table 1) to obtain ~170 g mixtures with variable HCP/(HCP+LCP) (19.4~58.6%) and plagioclase proportion (34.1~59.5%). Besides, olivine (4.7~27.5%) was added in mixtures.

VNIS Prototype Measurements and Spectral Processing: VNIR spectra (450~2395 nm) were obtained using CE-4 VNIS prototype (a copy of in-flight VNIS) in Shanghai Institute of Technical Physics, Chinese Academy of Sciences. Incident, emission, and phase angles were fixed at 60°, 45°, and 90° (azimuth angle of 55°) based on actual measurements of in-flight VNIS. The spectrometer was calibrated by a highly Lambertian Spectralon® diffuse reflectance standard (SRT-99-100) before each measurement.

The VNIR channels (450~945 nm) were connected to SWIR channels (900~2395 nm) at 900 nm. A linear continuum in wavenumber space for VNIS prototype spectra and a two-part linear continuum for CE-4 VNIS spectra [9] were then removed (Fig. 1). Subsequently, the parameters (e.g., band strength (Str)) of HCP, LCP, and OL were derived by MGM

deconvolution to estimate the modal abundance of mineral endmembers.

Table 1. Mineral volume fractions of lunar soil analogs in this work.

No.	Mineral volume fractions (%)			
	LCP	HCP	PL	OL
1	19.1	27.1	41.5	12.3
2	19.7	22.8	47.3	10.2
3	20.5	19.9	50.4	9.2
4	21.2	16.0	55.5	7.3
5	22.0	12.1	59.5	6.4
6	15.0	12.2	54.4	18.4
7	22.6	33.6	39.0	4.7
8	10.6	7.5	54.4	27.5
9	40.7	9.8	34.1	15.4
10	13.4	25.7	44.1	16.7

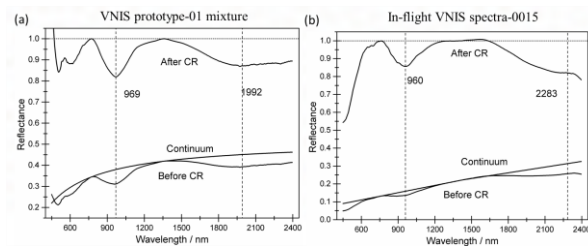


Fig. 1. Spectra acquired by VNIS prototype (a) and in-flight VNIS (b) before and after continuum removal.

Results for VINS Prototype spectra: The Str fractions of HCP in pyroxene appear to vary linearly with the volume fraction of HCP (Fig. 2a). Therefore, the HCP content in pyroxene can be quantified as follows:

$$\frac{HCP}{HCP + LCP} (\%) = 2.06 \times \left(\sum_{n=1}^{n=2} \frac{Str_HCP_n}{Str_HCP_n + Str_LCP_n} \right) (\%) - 51.40$$

where Str_HCP_1 and Str_HCP_2 respectively represent the Str of HCP in 1 μm and 2 μm regions. The predicted HCP/(HCP+LCP) using leave-one-out cross-validation (LOOCV) method and actual values are shown in Fig. 2b. All scattered plots lie along the 1:1 line within two dashed lines of ±7%, indicating a good correlation (RMSE = 4.08).

The band centers (BC) of olivine move linearly to longer wavelength with decreasing Fo values due to substitution of Mg^{2+} with larger Fe^{2+} [10]. The BCs of olivine M1 bands occur at 831~852 nm and 1185~1222 nm, suggesting a Mg-rich composition (averaged $Fo_{89.17}$, Fig. 2c). Olivine volume fraction in mafic minerals is predicted using partial least squares algorithm (PLS) based on $Str_{OL}/(Str_{OL}+Str_{HCP_1}+Str_{LCP_1})$ using 1 feature (~1250 nm), 2 features (~850 nm and ~1250 nm), and 3 features (~850 nm, ~1050 nm, and ~1250 nm) of OL, respectively. The scattered points of actual and predicted values using LOOCV method lie along the 1:1 line (Fig. 2d), and the model based on 1 feature of OL exhibits the best performance (RMSE = 9.50). This method could be used to estimate the olivine volume fraction in mafic minerals.

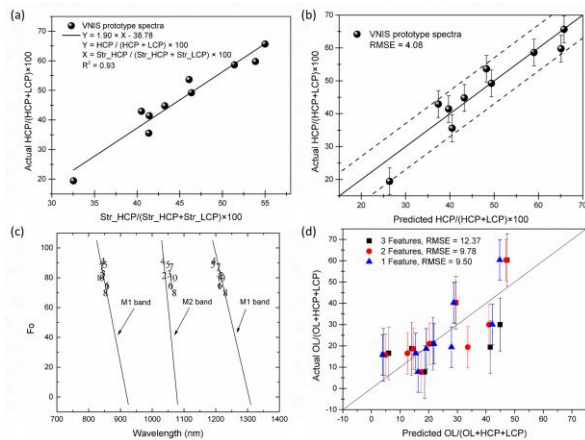


Fig. 2. (a) Comparison of HCP volume ratios in pyroxene and corresponding Str ratios derived from MGM using VNIS prototype spectra. (b) Scattered plots of actual and predicted HCP/(HCP+LCP) values. (c) Band centers of three primary 1 μm features of olivine. (d) Comparison of predicted and actual olivine fractions in mafic minerals derived from MGM.

Results for CE-4 spectra: The BCs of LCP and HCP are plotted in Fig. 3a and compared with data from Ref. [11, 12]. The compositions of HCP and LCP are determined based on the BCs derived from MGM using the method mentioned in Fig. 13 of Ref. [14]. The LCP and HCP are Fe-rich with slightly lower Ca content compared with the pyroxene in Ref. [11-14]. For OL, the Fo values and BCs derived from MGM are given in Fig. 3b, indicating a Mg-rich OL composition ($Fo_{61.1-79.7}$) at the CE-4 landing site. The Fe-rich pyroxene and Mg-rich olivine may come from rapid-cooling magmatic systems and be excavated by Finsen crater.

Conclusion: The spectra of a series of lunar soil analogs acquired by the VNIS prototype were analyzed to better constrain the geochemistry and mineral

derived from CE-4 spectra. The mineralogy at CE-4 landing site is dominated by Fe-rich pyroxene and Mg-rich olivine, which may come from rapid-cooling magmatic systems and be excavated by Finsen crater.

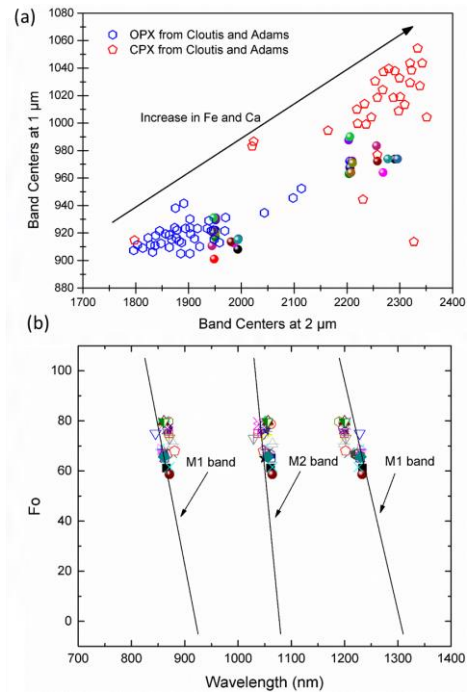


Fig. 3. Band centers of the pyroxene (solid points) and olivine derived from MGM based on CE-4 spectra.

Acknowledgments: This work is supported by the fundings from the National Natural Science Foundation (41972322, 11941001, U1931211), the Pre-research project on Civil Aerospace Technologies No. D020102 funded by China National Space Administration (CNSA). We also thank the Natural Science Foundation of Shandong Province (ZR2019MD008), Qilu (Tang) Young Scholars Program of Shandong University, Weihai (2015WHWLJH14), and China Postdoctoral Science Foundation (Grant No. 2020M682164).

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