SPACE WEATHERING VIEWED FROM THE CHANG’E-3 IN SITU SPECTRA. Y. Z. Wu¹, Z. C. Wang², X. M. Zhang³, W. Cai³, Y. Lu³, ¹Key Laboratory of Planetary Sciences, Purple Mountain Observatory, Chinese Academy of Sciences, Nanjing 210008, China (wu@pmo.ac.cn). ²Department of Earth Sciences, Nanjing University, Nanjing 210023, China, ³School of Geographic and Oceanographic Sciences, Nanjing University, Nanjing 210023, China.

Introduction: Space weathering is an important surface process occurring on the Moon and airless bodies. Understanding the effects of space weathering on reflectance spectra is crucial for the interpretation of elements and minerals using remote sensing data. The optical effects of the Moon’s space weathering have been largely investigated in the laboratory for lunar samples [1-3], simulants [4-6] and physical modelling [7,8]. However, duplication of the pristine regolith here on Earth is not possible. The in situ spectra measured by the Visible-Near Infrared Spectrometer (VNIS) onboard the Chang’E-3 (CE-3) “Yutu” rover provide the unique opportunity of investigating space weathering by measuring the regolith in its pristine, virtually undisturbed state, as well as comparison to the regolith naturally disturbed by rocket exhaust from the spacecraft. In this paper we report on space weathering as measured by the CE-3 in situ spectra.

![Figure 1](attachment://image.png)

**Fig. 1.** Before (a; NAC image M1127248516R) and after (b; NAC image M1147290066R) images of the CE-3 landing site.

**Table 1.** Spectral parameters and optical maturity.

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<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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<tbody>
<tr>
<td>Band Center (µm)</td>
<td>1.000</td>
<td>1.017</td>
<td>1.028</td>
<td>1.024</td>
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<tr>
<td>Band Depth (µm)</td>
<td>0.24</td>
<td>0.17</td>
<td>0.16</td>
<td>0.15</td>
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<tr>
<td>VNCS (µm⁻¹)</td>
<td>0.037</td>
<td>0.046</td>
<td>0.036</td>
<td>0.036</td>
</tr>
<tr>
<td>Visible Slope (µm⁻¹)</td>
<td>0.085</td>
<td>0.084</td>
<td>0.073</td>
<td>0.051</td>
</tr>
<tr>
<td>OMAT</td>
<td>0.34</td>
<td>0.24</td>
<td>0.26</td>
<td>0.18</td>
</tr>
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</table>

**The VNIS and in situ observations:** The VNIS uses acousto-optic tunable filters (AOTFs) as dispersive components and consists of a VIS/NIR imaging spectrometer (0.45-0.95 µm, 256 × 256 pixels, field of view: 8.5° × 8.5°) and a shortwave IR (SWIR) spectrometer (0.9-2.4 µm, 1 pixel, field of view: 3.6°). The default spectral sampling interval is 5 nm, and the total number of sampling bands is 400. The VNIS is mounted on the front of the rover and detects lunar surface objects from a height of 0.69 m above the lunar surface at a 45° emission angle.

![Figure 2](attachment://image.png)

**Fig. 2.** The VNIS reflectance spectra of 4 sites.

**Space weathering revealed by in situ spectra:** During the 114 m distance traveled by the Yutu rover, four measurements of the regolith (sites 5, 6, 7 and 8; Fig. 1) were made by the VNIS. Figure 1 shows that reflectance increased after CE-3 landed. Smoothing of surface roughness has been suggested as the main cause of the observed increase in reflectance [9-11]. Exposure of less mature soil was rejected because the maturity of core samples within the first tens of centimeters of regolith depth do not change significantly [11]. The four spectra (Fig. 2) and the spectral parameters (Table 1) show that the reflectance, absorption strength, visible slope, and optical maturity (OMAT) all increase for sites closer to the lander, indicating that the maturity of regolith becomes less for sites closer to the lander. Therefore, brightness increases after the spacecraft landed are due to removal of the finest, highly weathered particles by the lander’s rocket exhaust, not smoothing of the surface. Considering that the disturbance depth was very shallow and only the finest fraction of the regolith was disturbed, it suggests that:

1) the uppermost surficial regolith is much more weathered than the regolith immediately below, and
2) the finest fraction is much more mature than the coarser fraction.
The spectral slope and space weathering: In this paper, the spectral slope was divided into two types: the visible and near-infrared continuum slope (VNCS) and the visible slope. (note that mathematically a slope is the difference of two bands rather than a ratio of two bands). The VNCS is calculated as the slope of a line covering the 1000 nm absorption that connects two local spectra maxima at visible and near infrared wavelength and the visible slope describes the spectral slope in the visible bands. Canonical opinion thought that space weathering increases the spectral slope in the visible and near-infrared [7,12,13], such that the 415/750 nm ratio of Clementine data becomes smaller with increasing maturity. The in situ spectra show the effects on the spectral slope caused by space weathering are wavelength-dependent: space weathering increases the VNCS while decreasing the visible slope. That is, the in situ spectra reveal an opposite trend in the visible slope with respect to space weathering to the previously known trend. It is consistent with the ultraviolet observations for the Moon [14] and asteroids [15] and extends to the visible bands. Although [14] found that highland samples and craters exhibit more variation in the 321/415 nm ratio, when viewed in terms of the difference of two bands (i.e., the mathematically true slope), the spectral trends related to space weathering are identical for highlands and maria.

We further analyzed the visible slope using both M^3 and Clementine data for the whole Moon. The results show that immature regolith exhibits a larger visible slope than more mature materials, consistent with the finding from the VNIS data. For example, bright halos in Fig.3b & d indicate that the visible slope of young craters is larger than surrounding regolith. Correspondingly, the 415/750 ratio of fresh craters is smaller than the surrounding regolith (e.g., dark halo in Fig. 3a & c). This paper also demonstrates that the spectral slope should be calculated using the difference of two bands rather than represented as the ratio of two bands.

Since the lunar TiO_2 abundance algorithm is usually based on the traditional opinion that the 415/750 nm ratio becomes smaller with increasing maturity, developing a new TiO_2 abundance algorithm is needed. More complexity for the inversion of TiO_2 abundance is that the optical effects of TiO_2 and space weathering are identical, i.e., reducing albedo and causing the regolith bluer. Moreover, TiO_2 also reduces OMAT since it has the same trend on the optical effects as the influence of space weathering. Therefore, using OMAT to represent maturity should be used with care and a new OMAT is needed, taking into account the Ti content of the surface regolith.

Fig. 3. Images showing that space weathering reduces visible slope. (a) Ratio image (540-nm/730-nm) of M^3 data. (b) Difference image (730-nm—540-nm) of M3 data. (c) Ratio image (415 nm/750 nm) of Clementine data. (d) Difference image (750 nm—415 nm) of Clementine data.

Summary: The CE-3 in situ spectra provided the unique opportunity to investigate space weathering on the lunar surface. The CE-3 spectra revealed a spectral slope effects contrary to traditional opinion. This paper indicates that 1) the returned soils could not represent pristine regolith; 2) developing a new TiO_2 abundance algorithm and OMAT is needed. We propose specific sampling technologies such as electrostatically manipulating fine dust to sample the uppermost dust in the future missions.

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