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Regolith thickness at the Chang'E-3 landing site from the Lunar Penetrating Radar and impact craters

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Abstract

The Chang'E-3 lunar penetrating radar (LPR) observations reveal a newly formed regolith layer (<1 m), an ejecta layer (~2-6 m), and a palaeoregolith layer (~4-9 m) from the surface to a depth of ~20 m. The thicknesses of the newly formed regolith layer and the palaeoregolith layer are consistent with the estimations based on the excavation depth and morphology of small fresh craters.

1. Introduction

Lunar regolith structure is critical to studying the geology and impact history of the Moon [1]. To date, direct study of the regolith structure was only available at a few landing sites through core tube experiments, where regolith was sampled to a maximum depth of 3 m [1]. On December 14, 2013, China's Chang'E-3 (CE-3) spacecraft successfully landed in the northern Mare Imbrium [2]. The CE-3 landing site is within a geologic unit (I22) consisting of high-titanium basalt, with a model-surface age of 2.96 Gyr [3]. The landing site is ~50 m away from the east rim of a 500 m diameter crater (unofficially named as CE-3 crater) [4]. The age of the CE-3 crater is estimated to be ~100 Myr according to its morphology prominence [5]. For the first time, a rover-deployed ground penetrating radar is used to characterize the structure and dielectric property of the regolith over the landing site. Here we report the LPR observations at the high-frequency channel (500 MHz).

2. Regolith stratigraphy from the LPR observations

The LPR started working on December 15, 2013, and its surface traverse is ~110 m during its effective observation time of ~8.3 hours (Fig. 1a). The collected raw data were processed through horizontal band removal, band-pass filtering, compensation of geometrical spreading and dielectric attenuation, and range migration. The processed LPR data are displayed in B-scan format as a function of horizontal distance and apparent depth (Fig. 1b) [4]. The real depth is the apparent depth divided by the square root of the dielectric permittivity (3 as in [4]).

The most prominent features within the first meter are the three to five bright irregular layers with typical thickness of 0.3-0.5 m. These layers are probably ejecta from small local craters that were later modified by micrometeorite bombardment and solar wind. This region is interpreted as the newly formed surface regolith.

At an apparent depth from ~1 to 10 m, is a region with bright radar echo. This region contains numerous, chaotic, irregular layers, and hyperbolic curves. These layers might result from irregular interface geometry, or densely distributed rocks smaller than the LPR wavelength [4]. We interpreted this region as the continuous ejecta from the CE-3 crater.

Below the ejecta layer is a region with weak radar echoes. The thickness of this layer decreases from ~9 m to 4 m with increasing distance from the CE-3 crater. This region is relatively homogeneous, and only few hyperbolic curves are visible. This region is probably the regolith layer produced on top of the mare basalt during 2.96 Gyr and was later buried by the ejecta of the CE-3 crater. Thus, this region can be regarded as a paleoregolith.

Beneath the palaeoregolith layer, at an apparent depth of ~20 m, the strength of the radar echoes increases and numerous irregular layers appear again. This should be the transition zone between the palaeoregolith layer and the underlying mare basalt.

3. Regolith thickness from impact craters

Images from the CE-3 landing camera show 9 craters with diameters ranging from 2 to 16 m (Fig.

1a). The excavation depths of these small fresh craters are <2 m, which are consistent with the LPR observed thickness of the newly formed regolith.

Crater counting results from high-resolution LROC image show that, within an area of 8.1 km × 12.2 km surrounding the landing site, there are 1688, 237, and 54 normal, flat-bottomed, and concentric craters, respectively. Using the relation between regolith thickness and crater morphology [6], cumulative distribution of regolith thickness is obtained (Fig. 1c). The median regolith thickness is estimated to be 6.5 m. Meanwhile, 867 small craters of distinctly blocky (type A), a few blocks (type B), and no blocks (type C) [7] were also counted, of which 7 are type A, 55 are type B, and 805 are type C. Fig. 1d shows the relative distribution of the counted A, B, and C type craters, and the threshold diameter between types A, B and type C is ~55 m. Therefore, the regolith thickness is ~5.5 m using a simple crater depth/diameter ratio of 1/10 [7]. These two estimations are consistent with the thickness of the palaeoregolith layer as observed by the CE-3 LPR.

4. Conclusions

The CE-3 LPR observations at 500 MHz show a surface regolith layer less than 1 m, an ejecta layer of ~2-6 m, and a palaeoregolith layer of ~4-9 m from the surface to a depth of ~20 m. The observed thicknesses of the surface regolith layer and the palaeoregolith layer are consistent with the estimations based on the morphology and excavation depth of small fresh craters. The revealed regolith stratigraphy, in combination with surface age from crater counting, indicates a complex regolith evolution at the CE-3 landing site.

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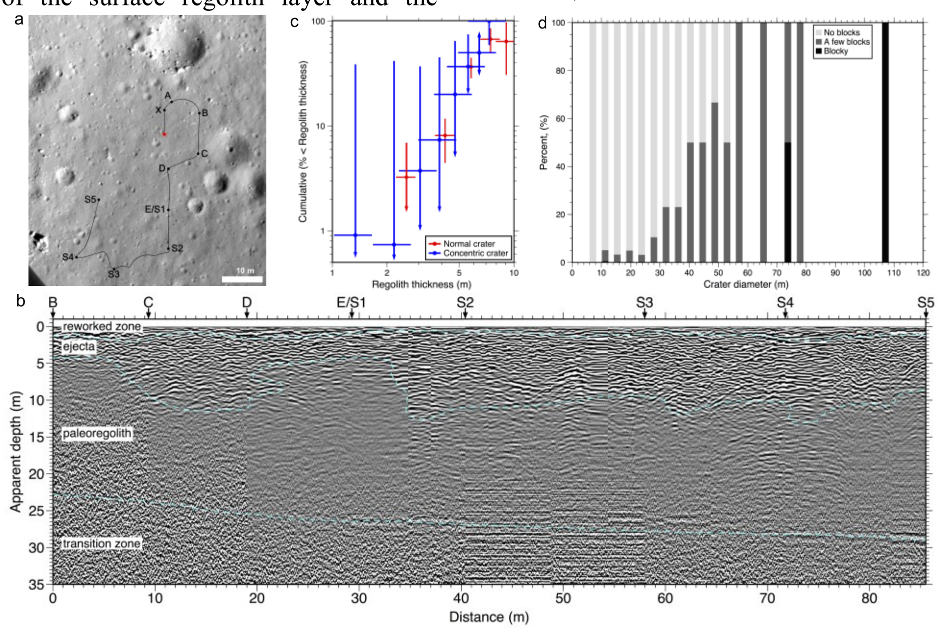

Figure 1. (a) An optical image from CE-3 landing camera showing the LPR survey line. (b) LPR image at 500 MHz from Point B to S5 along the survey line. (c) Cumulative distribution of regolith thickness estimated from normal (red) and concentric (blue) craters. (d) The distribution of blocky craters types A, B, and C as a function of diameter for the region surrounding the CE-3 crater.