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The Lunar Regolith Thickness and Stratigraphy of the Chang'E-6 Landing Site

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Abstract: The Chang'E-6 (CE-6) mission successfully returned 1935.3 g of lunar soil samples from the Apollo basin within the South Pole–Aitken basin. One of its scientific objectives is to investigate the subsurface structure and regolith thickness at the landing site. Using remote sensing datasets, we estimated the regolith and basalt thicknesses at the landing site by employing the crater morphology method and crater excavation technique. A total of 53 concentric craters and 108 fresh craters with varying excavation depths were identified. Our results indicate that the regolith thickness at the CE-6 landing site ranges from 1.1 to 7.0 m, with an average thickness of 3.5 m. Beneath the regolith, the basalt layer consists of high-Ti basalt overlaying low-Ti basalt, with a total thickness of approximately 64 to 82 m, of which the high-Ti basalt layer accounts for about 22 to 30 m. Based on the local geological history, we proposed a stratigraphy at the CE-6 landing site. These findings provide valuable geological context for interpreting the Lunar Penetrating Radar data and analyzing the returned samples.

Keywords: Chang'E-6 landing site; Moon; regolith thickness; mare basalt thickness



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1. Introduction

On 2 June 2024, the Chang'E-6 (CE-6) spacecraft successfully landed on the southern mare basalt unit of the Apollo basin within the South Pole–Aitken (SPA) basin on the lunar farside (41.64°S, 153.99°W) [1], collecting 1935.3 g of lunar soil samples. After the Chang'E-5 (CE-5) mission, which successfully returned lunar soil samples from the Oceanus Procellarum, China once again accomplished lunar sample return. Notably, CE-6 is the first mission that collected samples from the farside of the Moon and the SPA basin. These samples are expected to resolve some key scientific questions, such as the dichotomy between the nearside and farside of the Moon, and to expand our understanding of lunar farside volcanism [2]. Except for the sample return, the CE-6 lander also carries scientific payloads including a Landing Camera, a Panoramic Camera, a Lunar Mineral Spectral Analyzer, and a Lunar Penetrating Radar (LPR). Among them, the LPR was designed to detect the lunar subsurface structure and assist with the drilling and sampling processes [3–5].

The 490 km Apollo basin, located on the northeastern edge of the SPA basin on the lunar farside (Figure 1a), is one of the largest peak-ring basins within the SPA and was formed approximately 3.9 to 4.1 billion years ago (Ga) [6]. Extensive areas of mare basalt are exposed in the central, western, southern, southeastern, and northwestern basin floor (Figure 1b). The southern mare, where the CE-6 landed, was filled with two Imbrian-aged basalt lava flows that are characterized by a distinct difference in TiO₂ content. Previous studies suggested that although low-Ti basalt is observed only in the eastern part of the southern mare, it likely initially filled the entire low-topography area between the peak

ring and the rim crest. Subsequently, relatively younger high-Ti basalt erupted and flowed from west to east, solidifying and covering the western part of pre-existing low-Ti basalt due to blocking by wrinkle ridges [2,7].

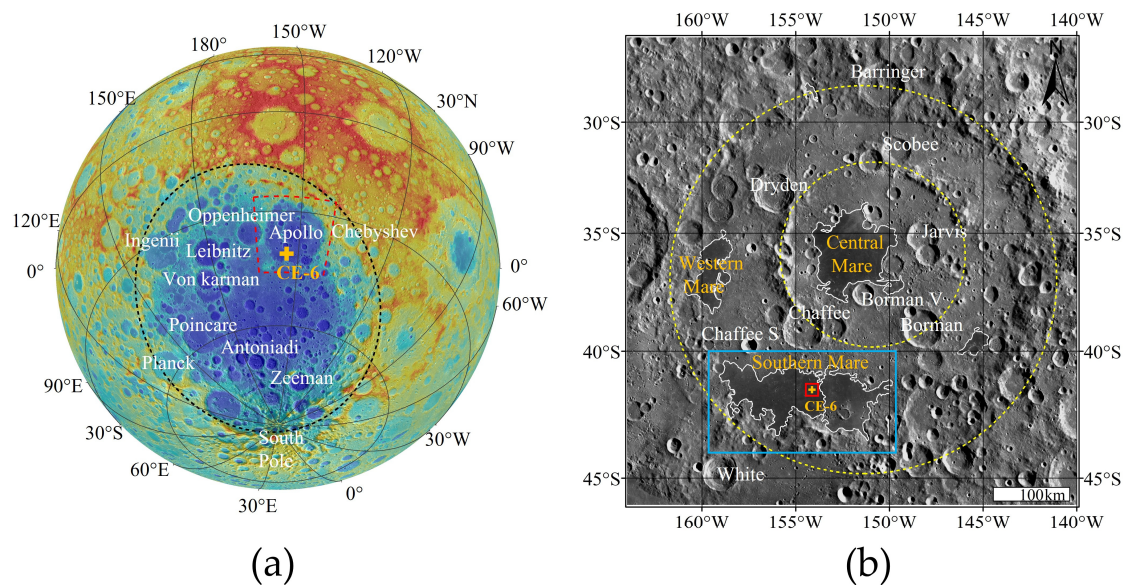


Figure 1. The geological context of the Chang'E-6 (CE-6) landing site. (a) The morphologic and topographic features of the South Pole–Aitken (SPA) and Apollo basins. The CE-6 landing site is marked by an orange cross. The base map consists of the Lunar Orbiter Laser Altimeter (LOLA) Digital Elevation Model (DEM) overlaid on the Lunar Reconnaissance Orbiter (LRO) Wide-Angle Camera (WAC) global mosaic. The black dashed line delineates the rim of the SPA basin, while the red fan-shaped frame indicates the extent of the Apollo basin, which is further detailed in panel (b). (b) An LROC WAC image mosaic of the Apollo basin. The mare boundary is delineated by white lines. The yellow dashed circle outlines the rim and ring of the Apollo basin.

These large impacts directly led to the formation of the basin and exposed deep-seated materials, while volcanic activities provided insights into the compositional and thermal evolution of the lunar interior. The major impact and volcanism events that occurred at the CE-6 landing site are recorded in the stratigraphy of the local area. Determining the thickness of the mare basalt beneath the CE-6 landing site can help us explore the source regions and eruption styles of volcanism on the lunar farside, further contributing to our understanding of the thermal conditions of the lunar mantle and its lateral heterogeneity [8,9]. Lunar regolith, a layer of fragmented and unconsolidated rock materials on the lunar surface, consists of various types of debris resulting from volcanic and impact activities [10–12]. The CE-6 mission collected lunar drilling samples from a depth of approximately 1 m and conducted in situ exploration using the LPR to investigate the regolith structure in this area. Therefore, the regolith thickness of the CE-6 landing site is significant for analyzing lunar samples and interpreting the LPR data.

From the high-resolution images taken by the Lunar Reconnaissance Orbiter Camera (LROC), Narrow Angle Camera (NAC) and Landing Camera onboard the CE-6 spacecraft, it has been noted that small craters of various sizes and shapes are very common in the vicinity of the CE-6 landing site. These small craters provide a natural window for probing the subsurface structure beneath the CE-6 landing site. Small craters have been widely used to estimate the thickness of regolith, ejecta and mare lava flows [13–20]. For example, Yue et al. (2019) estimated regolith thickness in the CE-5 landing area using crater morphology method [13]. Chen et al. (2018) estimated the thickness and volume of late-stage basalt in Mare Imbrium using the crater excavation technique [20]. Fu et al. (2020) employed small craters on the floor of the Von Karman crater to investigate the stratigraphy of the Chang'E-4 (CE-4) landing site [16].

Using multiple remote sensing datasets, we identified small craters of different sizes and shapes in the adjacent region of the CE-6 landing site. We applied the crater morphology method and crater excavation technique to estimate the thicknesses of regolith and basalt, and then constructed a stratigraphic profile at the CE-6 landing site. Based on this analysis, we gained insights into the geological evolution of this region. This study provides valuable information on the geological context and subsurface structure of the CE-6 landing area.

2. Data and Methods

2.1. Data

Lunar Reconnaissance Orbiter (LRO) Wide-Angle Camera (WAC, 100 m/pixel) and Lunar Orbiter Laser Altimeter (LOLA, 100 m/pixel) Digital Elevation Model (DEM) data were used to analyze the geological background of the SPA and Apollo basins [21,22]. High-resolution imagery allows for more precise measurements of crater diameters, with the LRO Narrow-Angle Camera (NAC, up to 0.5 m/pixel) currently providing the highest-resolution lunar orbital images available [21]. Seven selected NAC images, covering the CE-6 landing site and sharing similar incidence angles (35°–75°), were used to visually identify the morphologies of concentric craters (<150 m). The NAC Experiment Data Record (EDR) products were downloaded from the Planetary Data System (PDS) website and preprocessed using the Integrated System for Imagers and Spectrometers (ISIS 7.2.0) software.

Kaguya Terrain Camera (TC) Ortho Map products (10 m/pixel) were used to identify fresh craters with varying excavation depths around the CE-6 landing site [23]. The Multiband Imager (MI, 20 m/pixel), another scientific instrument onboard Kaguya, was used to investigate the TiO₂ and plagioclase content of these fresh craters. Plagioclase abundance was derived from the global mineral abundance map (60 m/pixel) produced by Lemelin et al. (2016), which was based on data from the Kaguya MI spectrometer [24]. TiO₂ abundance was calculated using the method proposed by Otake et al. (2012) [25]:

$$\theta_{Ti} = \arctan \left\{ \frac{\frac{R_{415}}{R_{750}} - 0.208}{R_{750} + 0.108} \right\} \quad (1)$$

$$TiO_2(wt.%) = \arctan \left\{ \frac{\frac{R_{415}}{R_{750}} - 0.208}{R_{750} + 0.108} \right\} \quad (2)$$

where the R_{415} and R_{750} represent reflectance at 415 and 750 nm, respectively.

In the present study, the CraterTools toolkit extension in ArcMap 10.8 was used to measure the diameter of the identified craters [26]. Three points were manually selected on the crater rim to delineate a best-fit circle for measuring the diameter, with the center of the circle representing the crater's center coordinate.

2.2. Methods

2.2.1. Crater Morphology Method

On the surface of the Moon, the fragmental lunar regolith layer lies over more cohesive bedrock. Laboratory experiments by Quaide and Oberbeck (1968) demonstrated that meteorite impacts at the regolith–bedrock interface can form four types of craters with different morphologies: bowl-shaped, flat-bottomed, central mound, and concentric [27]. These crater morphologies provide a method to estimate regolith thickness. However, recent studies have shown that flat-bottomed and central mound craters can also form due to low-velocity clustered impacts [28]. The laboratory studies of Schultz and Gault (1985) further support this finding [29]. To eliminate potential errors caused by such craters, this study selected only concentric craters (<150 m) for estimating regolith thickness. These craters are the best candidates for determining regolith thickness in the range of 1–10 m,

which is the typical thickness of lunar regolith. According to the method proposed by Quaide and Oberbeck (1968), the regolith thickness can be estimated as follows [27]:

$$t = \frac{1}{2} \left(k - \frac{D_F}{D_A} \right) D_A \tan \alpha \quad (3)$$

where t is the regolith thickness, D_F is the inner ring diameter of the concentric craters, D_A is the outer rim-to-rim diameter of the concentric craters, k is a constant (0.86), and α is the angle of repose of the material (31°). Therefore, the regolith thickness can be calculated by measuring both D_F and D_A .

2.2.2. Crater Excavation Technique

When a meteorite impacts the lunar surface, it excavates subsurface materials, exposing them on the crater floor and dispersing them around the crater as ejecta. Small impacts excavate only surface materials, while large impacts can reach deeper strata and excavate deep-seated materials. The larger the impact, the deeper materials it excavates and the more stratigraphic layers it penetrates. Melosh (1989) proposed an equation describing the relationship between the diameter and maximum excavation depth for simple craters [30]:

$$H_{exc} = 0.1 \times D_t \quad (4)$$

$$D_t = 0.84 \times D \quad (5)$$

where H_{exc} is the maximum excavation depth, D_t is the transient crater diameter, and D is the rim-to-rim diameter. This equation allows for a straightforward estimation of maximum excavation depth based on crater diameter. The lower and upper bounds of basalt thickness are constrained by the excavation depths of the smallest crater that penetrates the basalt layer and the largest crater that does not.

3. Results

3.1. Estimation of Regolith Thickness

We used the crater morphology method to estimate the regolith thickness within a $15 \text{ km} \times 15 \text{ km}$ study area centered on the CE-6 landing site (Figure 2). A total of 53 concentric craters were identified in this region (Table S1), which were distributed evenly. The shadows cast by the crater walls in the northwest direction fall onto the crater floors, while the inner rings remain unobscured due to their higher elevations (Figure 3). The identified concentric craters exhibit a variety of morphologies. Figure 3a shows a typical concentric crater with a well-defined and intact inner ring. Additionally, some concentric craters exhibit irregular or partially eroded inner rings (Figure 3b,c). Figure 3d displays a concentric crater with two distinct inner rings. Given that this is the largest identified concentric crater in the study area, it is reasonable to speculate that the formation of multiple inner rings may result from penetration through multiple layers with varying material strengths.

The diameters of the outer (D_A) and inner (D_F) rings of these craters (Table S1) were measured following the approach reported by Bart (2014) [31]. It is recommended that the optimal location for measuring D_F is where the normal crater wall begins to be disturbed. Among the 53 concentric craters, the largest has a diameter of 140.9 m, while the smallest has a diameter of 12.2 m. Based on measured D_A and D_F , the regolith thickness can be calculated using Equation (3). The obtained results indicate that the regolith thickness across the study area ranges from 1.1 to 7.0 m (Table S1), with an average thickness of 3.5 m and a median thickness of 3.3 m. Figure 4 presents a histogram of the estimated regolith thicknesses. Notably, 46 concentric craters exhibit a regolith thickness of 1–5 m, while only 7 concentric craters exhibit a thickness greater than 5 m (Figure 4).

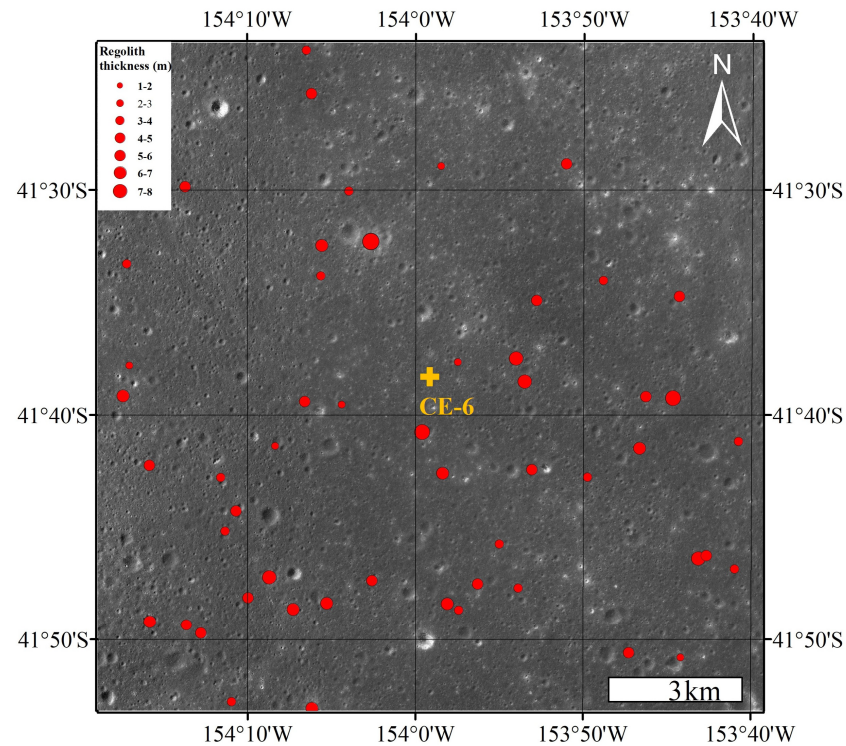


Figure 2. The distribution of concentric craters in a 15 km $\times$ 15 km study area. The boundary of the area in this figure is also marked by a red box in Figure 1. The orange cross marks the location of the CE-6 landing site, while the red dots mark the locations of the concentric craters. The base map consists of the LRO Narrow-Angle Camera (NAC) images. The NAC image IDs are M166854798LE, M166854798RE, M1250563929LE, M1250563929RE, M1400946505LE, M1400946505RE, and M1429099389LE.

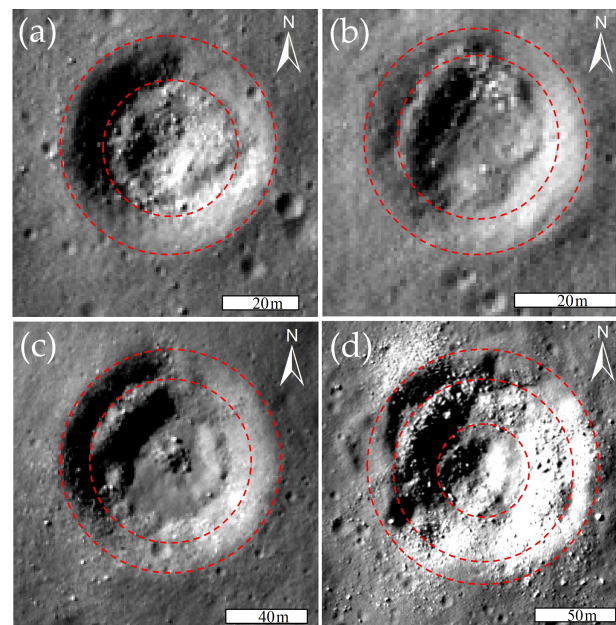


Figure 3. Concentric craters with different morphologies. The red dashed lines delineate the outer and inner rings. (a) A typical concentric crater. (b) A concentric crater with an irregular inner ring. (c) A concentric crater with a partially eroded inner ring. (d) A concentric crater with two inner rings.

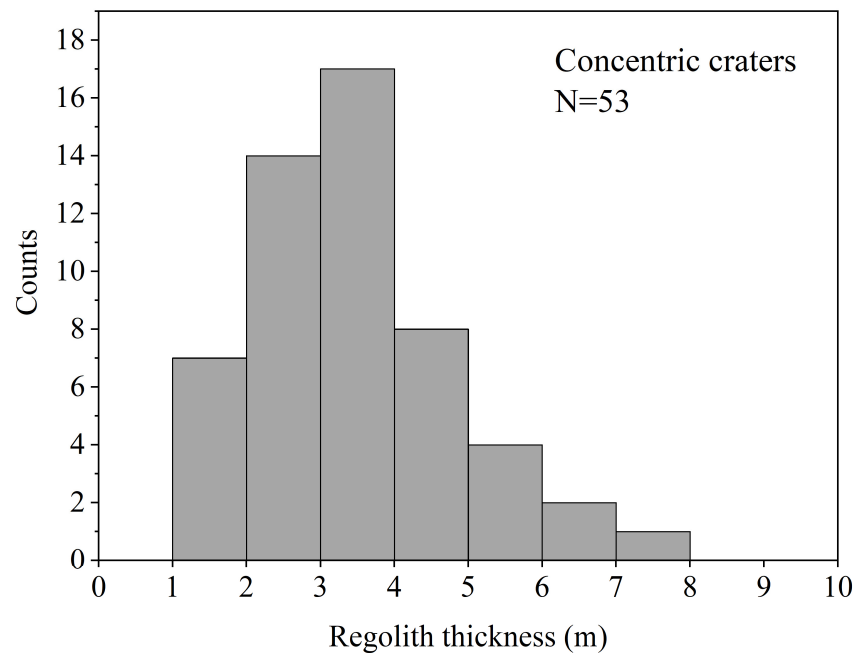


Figure 4. A histogram of lunar regolith thickness in the study area. The horizontal axis is the regolith thickness, while the vertical axis is the number of concentric craters corresponding to that thickness.

3.2. Estimation of Mare Lava Thickness

The mare basalt beneath the CE-6 landing site consists of two sublayers, with a younger high-Ti basalt layer overlaying an older low-Ti basalt layer [2,7]. We used the crater excavation technique to estimate the thickness of both basalt layers. Kaguya MI TiO₂ and plagioclase abundance data were used to analyze regional composition variations and assess whether different craters have penetrated through the top layer and excavated the underlying materials. To achieve a more accurate estimation of basalt thickness, it is crucial to select as many suitable craters as possible within the mare unit. Considering that exotic ejecta and space weathering may affect the spectral characteristics of craters, we focused on fresh craters exhibiting the following features: (1) high albedo, (2) high optical maturity, (3) surrounded by ejecta, and (4) sharp crater rims.

A total of 108 fresh craters were identified within the high-Ti basalt unit and categorized into three types (Figure 5) (Table S2). Type I craters exhibit extremely lower TiO₂ abundance and higher plagioclase abundance in their crater floors and ejecta compared to the surrounding basalt (Figure 6a–c). The compositions of Type I craters resemble the plagioclase-dominated kipukas within this region (Figure 6j–l). Therefore, Type I craters likely penetrated both mare basalt layers and excavated the underlying highland materials, potentially related to the impact breccias or melts of the Apollo basin. Type II craters exhibit lower TiO₂ abundance and similar plagioclase abundance compared to the surrounding basalt (Figure 6d–f). Due to the significant difference in TiO₂ content between the two basalt layers, they likely penetrated the high-Ti basalt layer and excavated low-Ti basalt materials. Type III craters show no significant TiO₂ or plagioclase abundance differences from the surrounding basalt (Figure 6g–i), indicating that they likely did not penetrate the upper high-Ti basalt. The numbers of identified Type I, II, and III craters are 10, 18, and 80, respectively (Figure 7). Their diameter ranges are approximately 900–2300 m, 300–800 m, and 50–300 m.

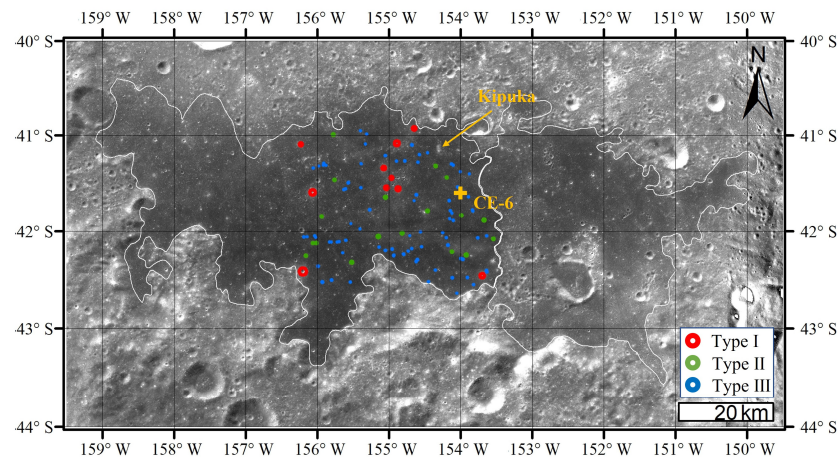


Figure 5. The distribution and locations of the three types of craters within the high-Ti mare basalt region. The boundary of the area in this figure is also marked by a blue box in Figure 1. The red, green, and blue circles represent Type I, Type II, and Type III craters, respectively. The orange cross marks the CE-6 landing site, while the orange arrow points to a kipuka. The white solid line delineates the mare boundary. The base map consists of Kaguya TC images.

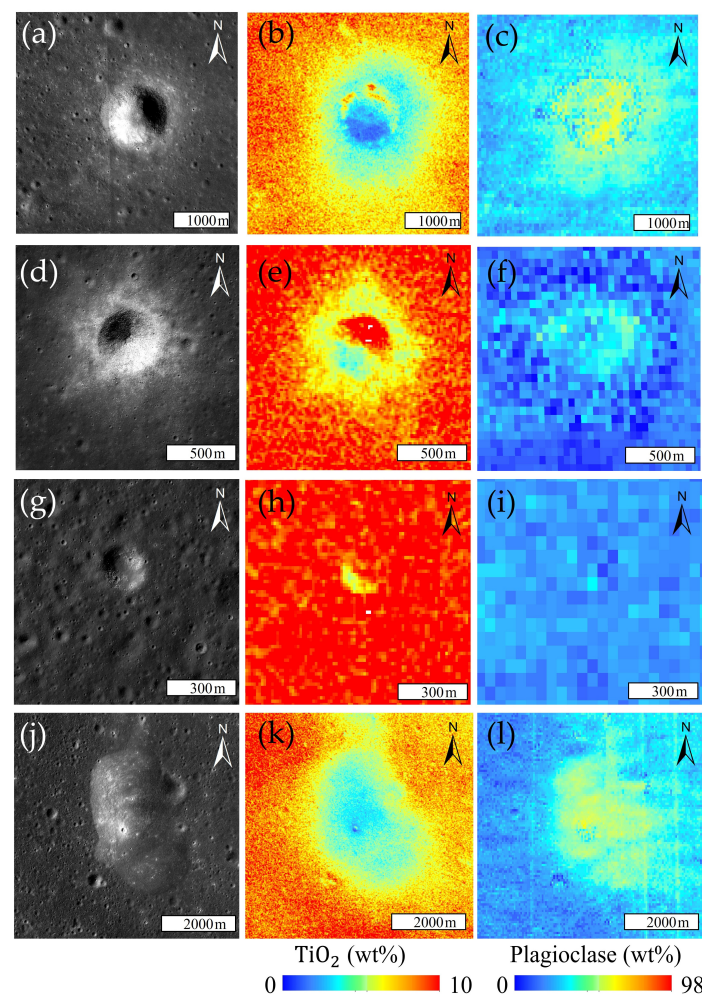


Figure 6. The three types of typical craters and a kipuka located within the study area. (a–c) Type I. (d–f) Type II. (g–i) Type III. (j–l) Kipuka. The base maps for the first, second, and third columns are LRO NAC images, Kaguya MI TiO₂ abundance images, and Kaguya MI plagioclase abundance images, respectively.

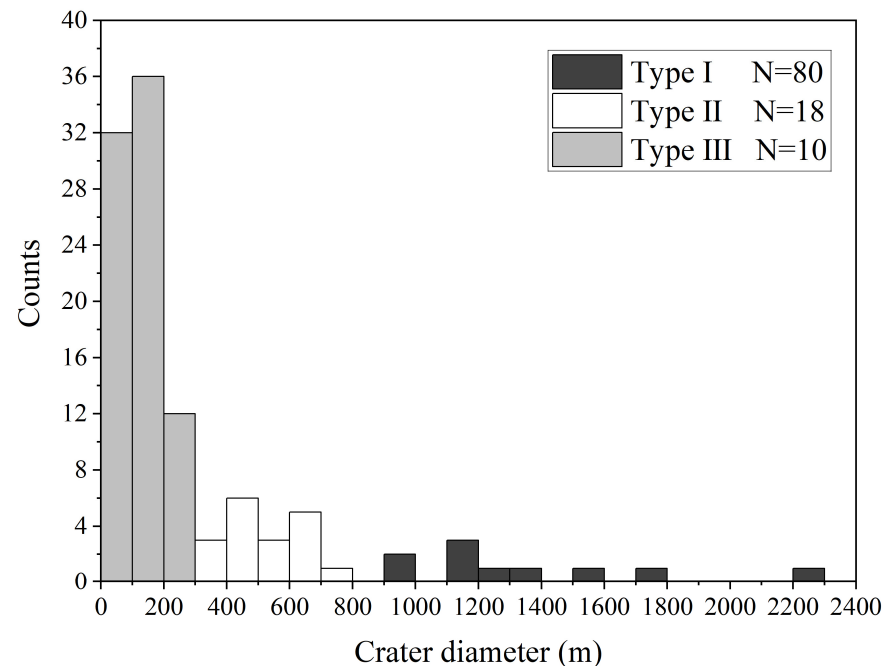


Figure 7. A histogram of the diameters for the three types of craters identified within the study area. The black, white, and gray bars represent Type I, Type II, and Type III craters, respectively. The horizontal axis is the crater diameter, while the vertical axis is the number of craters corresponding to that diameter.

The depths of the interfaces between different stratigraphic layers were constrained by the smallest crater that penetrated the interface and the largest crater that did not. According to Equations (4) and (5), the total thickness of both basalt layers was estimated to be between 64 and 82 m, based on the smallest Type I crater (971 m) and the largest Type II crater (759 m). Similarly, the thickness of the upper high-Ti basalt layer was estimated to be between 22 and 30 m, constrained by the smallest Type II crater (355 m) and the largest Type III crater (265 m).

4. Discussion

4.1. Geological Implications of Lunar Regolith

Lunar regolith is primarily formed from local bedrocks via continuous bombardment, meaning that regolith samples can reflect the composition of the underlying bedrock [32]. Impacts mechanically pulverize the bedrock and pre-existing regolith into fine particles, while molten glass re-cements the rock fragments. The interplay of these two processes controls the formation and evolution of lunar regolith. Under the gardening effect of impacts, the regolith is thoroughly mixed and stirred through vertical overturning and lateral ejecting. For the CE-6 landing site, the regolith is mainly composed of local materials derived from the impact-modified young mare basalts, mixed with some exotic ejecta from younger craters of the Eratosthenian and Copernican periods, particularly Chaffee S and White craters [33,34] (Figure 1b). The collected CE-6 regolith samples may contain valuable information about the local lithology, mare volcanism, impact history, and regional geological evolution. A future laboratory analysis of the CE-6 samples can provide ground truth for remote sensing detection of the lunar farside.

Thickness is a key parameter for lunar regolith, as it can reflect the relative geologic age and space weathering processes of the lunar surface [35,36]. However, regolith thickness is not uniform and can vary significantly, even over short distances within the same geological unit [37]. Our results indicate that the average regolith thickness at the CE-6 landing site is 3.5 m, with a median of 3.3 m. This is not only closely aligned with the ~3 m thickness for mare regions reported by Oberbeck and Quaide (1968), but it also falls within the 2–4 m

range estimated for mare areas by Bart et al. (2011) [27,38]. Orgel et al. (2024) estimated the regolith thickness at three regions of interest (ROIs) within the Apollo basin using the crater morphology method [39]. ROI 3, which is located in the same mare unit as the CE-6 landing site, has an average thickness of 4.6 m. This value falls within the estimated range of our results (1.1 to 7.0 m) but is slightly larger than the average value (3.5 m). This discrepancy is possibly due to the differences in the extent and location of study areas. Additionally, ROI 3 is closer to the Chaffee S and White craters, so it likely contains more external ejecta from these young craters.

Previous studies have attempted to establish an empirical relationship between regolith thickness and surface age [13,17,19,35,38,40]. Fa et al. (2014) estimated the regolith thickness for four geological units in the Sinus Iridum region with ages of 3.39, 3.26, 3.01, and 2.96 Ga, corresponding to median regolith thicknesses of 8.6, 8.5, 8.0, and 7.4 m, respectively [17]. They concluded that older surfaces generally have thicker regolith. Similarly, Yue et al. (2019) compared the regolith thicknesses across five geological units in the CE-5 candidate landing area [13], also supporting that regolith thickness increases with surface age.

However, despite several studies suggesting a positive correlation between regolith thickness and surface age, this relationship remains controversial and should be applied with caution. As mentioned above, regolith thickness depends on many factors, including the nature of target rocks, the size and frequency of projectiles, volcanic activity, and thermal fatigue [10,41–44]. The estimated regolith thickness at the CE-6 landing site is thinner than the 4–7 m reported for the CE-5 landing site [45], even though the surface age of the CE-6 landing site (~3.06 Ga) is older than that of CE-5 (~2.0 Ga) [7,46,47]. Additionally, in situ detections from seismic experiments during the Apollo missions provided varying regolith thicknesses at the six landing sites: 4.4 m (Apollo 11), 3.7 m (Apollo 12), 8.5 m (Apollo 14), 4.4 m (Apollo 15), 12.2 m (Apollo 16), and 4.0 m (Apollo 17) [48,49]. These results do not indicate a clear trend based on surface age. Furthermore, recent research by Atang and Bart (2024) also challenges the correlation between regolith thickness and surface age [50].

4.2. Stratigraphy of CE-6 Landing Site

The stratigraphy at the CE-6 landing site is critical for understanding the geological history and sequence of events in this region, providing essential context for researching the provenance of the samples and interpreting the LPR data. In this section, we integrated our results with those of previous studies to investigate the subsurface stratigraphy and constructed a stratigraphic column for the CE-6 landing site (Figure 8).

The uppermost layer is lunar regolith, with an estimated average thickness of 3.5 m. The primary composition of regolith is likely derived from the local basalt bedrock, and mixed with some exotic ejecta from nearby young craters. Yue et al. (2024) estimated the ejecta thickness at the CE-6 landing site from these young craters, indicating that Copernican ejecta is 21.5 cm (with 16.2 cm from Chaffee S crater), and Eratosthenian ejecta is 57.3 cm (with 49.3 cm from White crater) [33]. These ejecta account for about 20% to 30% of the average regolith thickness.

Beneath the regolith lie two layers of Imbrian-aged mare basalts, with a total thickness of about 64 to 82 m, of which the upper basalt layer accounts for 22 to 30 m. These mare basalts record the volcanic history of the lunar farside. The southern mare was formed by two distinct volcanic eruptions. At 3.35 Ga, low-Ti basalt initially erupted and filled this area, and later, at 3.07 Ga, high-Ti basalt erupted and covered the previous low-Ti basalt [7]. Several wrinkle ridge structures have been observed on the extensive surface of the mare basalt, indicating the presence of a huge volume of dikes in this area.

The next possible layer is composed of ejecta from large impact events during the early Imbrian and Nectarian periods. Some immense impacts, such as those forming the Imbrium (3.85 Ga) and Orientale (3.8 Ga) basins, produced tremendous energy and delivered abundant ejecta to vast areas of the entire lunar surface [51,52]. Additionally,

it was observed that the adjacent Oppenheimer basin (Nectarian period) disrupted the western rim of the Apollo basin (Figure 1), indicating that it formed after the Apollo basin and may contribute ejecta to the CE-6 landing site. However, from the perspective of remote sensing, it is difficult to determine how much ejecta from these large basins has mixed into the local area.

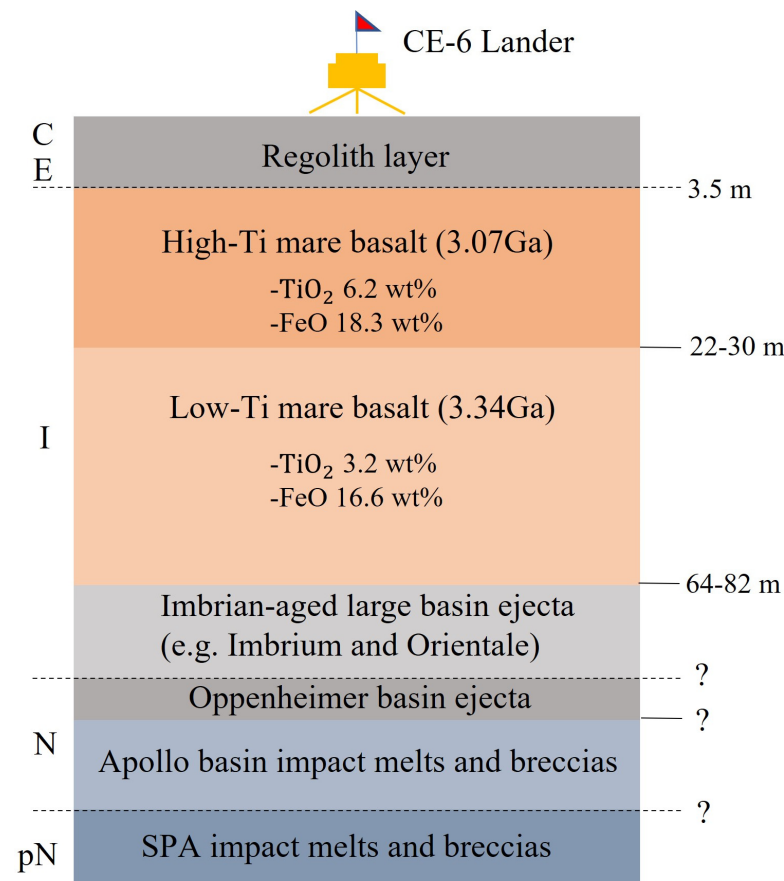


Figure 8. Subsurface stratigraphy at the CE-6 landing site proposed in this study. The depths of the stratigraphic layers are labeled on the right. The letters on the left correspond to lunar geological periods, with pN indicating the Pre-Nectarian, N the Nectarian, I the Imbrian, E the Eratosthenian, and C the Copernican periods. The chemical composition and age of the mare basalts are derived from Qian et al. (2024) [7].

At the base of the stratigraphic column are expected to be impact breccias or melts from the Apollo and the SPA basins. As the largest and oldest (4.2–4.3 Ga) basin on the Moon, the SPA profoundly influenced the morphology, composition, and structure of the lunar farside [53–55]. This catastrophic impact likely removed the upper crust of the Moon and possibly excavated ultramafic mantle materials, generating substantial impact melts on the basin’s floor [56–62]. The Apollo basin (3.9–4.1 Ga), located at the boundary of the SPA transient crater and modification zone, may have further modified the impact melts produced by the SPA and potentially excavated the deeper materials [2,6]. The materials excavated by the SPA may have been locally removed, but some should be residual on the Apollo basin’s ring or wall [63].

The stratigraphy at the CE-6 landing site is proposed based on the results of the present study and the geological history of the local area, providing a detailed understanding of its subsurface composition and structure. The interpretation of LPR data can be used to validate and refine our stratigraphic column. The LPR onboard the CE-6 can determine the thickness of the mare basalt and other underlying layers, which is crucial for assessing the volume of mare deposits and testing the occurrence of possible paleo-deposits [64,65]. In

addition, the internal structure of the regolith layer can be precisely revealed at a meter scale by LPR, which can provide important insights into the formation and evolution of local regolith [66].

5. Conclusions

In this study, we estimated the regolith and basalt thicknesses at the CE-6 landing site using the crater morphology method and crater excavation technique. The regolith thickness at the CE-6 landing site ranges from 1.1 to 7.0 m, with an average of 3.5 m. The total thickness of the two basalt layers is approximately 64 to 82 m, with the upper high-Ti basalt layer accounting for about 22 to 30 m. We discussed the geological implications of lunar regolith, indicating that the regolith at the CE-6 landing site primarily originated from the local basalt and was mixed with some exotic ejecta. Based on our results and the geological history, we proposed a stratigraphy at the CE-6 landing site. Our study provides valuable insights into the interpretation of LPR data and the future laboratory analysis of returned samples.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/rs16213976/s1>, Table S1: Concentric craters identified in the study area; Table S2: Fresh craters with different excavation depths identified in the study area.

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Data Availability Statement: All original LROC data are available at <https://wms.lroc.asu.edu/lroc/search> (accessed on 5 June 2024). All original Kaguya/SELENE data are accessible at <https://darts.isas.jaxa.jp/planet/pdap/selene/> (accessed on 5 June 2024). The Kaguya/SELENE MI mineralogy maps were accessed from <https://astrogeology.usgs.gov/site/annex?target=&system=&p=1&accscope=&searchBar=?> (accessed on 5 June 2024).

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Conflicts of Interest: The authors declare no conflict of interest.

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