Analysis of Topography and Composition of the Von Kármán Impact Crater

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Abstract. The Von Kármán impact crater in the Chang’E-4 landing area is located in the Northwestern South Pole-Aitken (SPA) basin on the back of the Moon, and the analysis of its topography and compositional characteristics is essential for the landing of the probe and the exploration of the lunar surface, which plays a fundamental role in obtaining information on the geomorphology and geology of the lunar surface. In this paper, the topography of the Von Kármán impact crater is analyzed based on DEM, slope and terrain roughness, then the compositional characteristics of the Von Kármán impact crater are analyzed according to TiO$_2$ and FeO content through combining LRO LOLA data and Clementine UV-VIS data. This study is a basis for revealing the surface characteristics and structure of the Moon.

1. Introduction

The Moon is the Earth’s natural satellite, the study of the Moon is an indispensable step for space exploration, China successfully launched the Chang’E-4 lunar exploration satellite on May 21, 2018 at the Xichang Satellite Launch Center, and on January 3, 2019, it landed at the Von Kármán impact crater in the South Pole-Aitken (SPA) basin on the back of the Moon, achieving the first soft landing of a human probe on the back of the moon[1]. Most of the 126 lunar missions carried out worldwide since 1958 have been remote sensing of the back of the moon[2]; and the Von Kármán impact crater has never been detected in place[2]. Therefore, the Chang’E-4 lunar exploration mission is an important supplement to the history of human lunar exploration, and it is also an important monument in the process of human understanding of the moon.

One of the scientific goals of the Chang’E-4 lunar exploration mission is to observe and study the topography of the inspection area on the back of the moon. The size of the slope is directly related to the complexity of the terrain and also hides the evolutionary history of the moon[3]; the terrain roughness can reflect well the changes in the undulation and erosion of the surface, as well as partially reflect the magnitude of tectonic movements, which is very helpful in determining the relative geological age of geological units[4]. One of the key issues of lunar science research is the deep lunar crust and
mantle material composition and structure[5], so the analysis of TiO₂ and FeO content can reveal the lunar crust and mantle composition, and provide important reference material for the evolutionary history of the lunar surface[6].

Based on this, this paper uses LRO satellite LOLA data, Clementine UV-VIS data, and combined with Digital Terrain Analysis (DTA) to analyze the terrain and composition characteristics of the Von Kármán impact crater in the Chang’E-4 landing area, which is helpful for the probe landing and lunar surface exploration, and provides theoretical support for the realization of the scientific goal of Chang’E-4.

2. Materials and Methods

2.1. Study area
The SPA is located on the back of the Moon (Figure 1), and its precise position is 40°S to 60°S. The center of the basin is located at (50°S, 180°E), with a diameter of about 2480km and a depth of 12.8km, it is currently the largest crater in the solar system known. The SPA stretches from a short distance above the southern pole of the moon and passes over the Aiken Crater near the middle of the back. It was first observed by Apollo 8 in 1968.

The Von Kármán impact crater is located in the middle of the SPA (Figure 2). The research scope selected the Von Kármán impact crater and its surrounding areas, specifically 40°S~50°S, 170°E~180°E. After billions of years of baptism, the center of the Von Kármán crater formed a relatively flat plain, with a small central peak in the middle of the crater, and a relatively flat terrain in the south. The north of the Von Kármán crater is the Leibnitz crater, the northeast is the Finsen crater, and the southeast is the Alder crater.

2.2. Methods
DTA refers to the digital information processing technology for terrain attribute calculation and feature extraction on the digital elevation model. Firstly, the existing LOLA and Clementine data were converted to GCS_Moon_2000 datum (ellipsoid: Moon_2000_IAU_IAG) and latitude and longitude coordinate system, and then use ARCGIS software to extract terrain features from the DEM data. Figure 3 is the DEM map of the Von Kármán impact crater, and the subsequent slope and terrain roughness maps are made on this basis; Figure 4 is the DEM three-dimensional display map, which can help us analyze the DEM map more intuitively.
The slope is the angle between the tangent plane over a point and the horizontal ground, which indicates the degree of slope of the surface at that point and reflects the degree of undulation of the terrain surface. The slope is extracted by selecting the Spatial Analyst tool in ArcToolbox, performing the slope analysis in the surface analysis, setting the relevant parameters, and the results are shown in Figure 5.

Terrain roughness is the ratio of the surface area of the surface to the projected area on the horizontal plane, which is the reciprocal of the cosine of the slope. Terrain roughness describes the macro-topography of the region. The larger the feature value, the more complex the terrain. The formula used in this paper to calculate terrain roughness is as follows

$$R = \frac{1}{\cos(slope \times \pi/180)}$$  

where \(R\) represents terrain roughness and slope is regional slope, the result is Figure 6.

The algorithm for mapping Fe element minerals is based on the reflectance ratio of the near-infrared (NIR) and visible light (VIS) bands based on Clementine data, and compare this with the reflectance of the visible light (VIS) band to obtain the distribution map of FeO content on the moon surface. Titanium is also calculated using Clementine's UV/VIS band ratio and the reflectance of VIS visible light band. Lucey et al. [7] proposed the formula for calculating TiO2 and FeO as follows

$$\text{wt.}\%\text{TiO}_2 = 3.078 \arctan\left(\frac{R_{415}/R_{750}-0.42}{R_{750}}\right)^{5.979}$$  

$$\text{wt.}\%\text{FeO} = -17.427 \arctan\left(\frac{R_{950}/R_{750}-1.19}{R_{750}-0.08}\right)-7.565$$  

where TiO2% and FeO% are their content percentages, respectively, \(R_{415}\), \(R_{750}\) and \(R_{950}\) are the reflectances of UV/VIS camera 415, 750 and 950nm respectively. The results are shown in Figures 7 and 8.

3. Result and Discussion
As shown in Figures 3 and 4, there are small impact craters around the Von Kármán impact crater, and there is another impact crater edge in the south of the impact crater. The topography of the northeastern
part of the V on Kármán impact crater is more complicated, and the southeastern edge is most well preserved. There are some miniature impact structures inside the impact crater, as well as a central peak, about 45km long and 13km wide. The elevation of the V on Kármán impact crater is significantly lower than that of the surrounding area. It has a higher elevation in the west of its interior, the lowest elevation in the south, and little topography.

It can be seen from Figure 5 that the slope of the V on Kármán impact crater varies from 0° to 56.22°, according to the natural break classification method, the internal slope of the impact crater is concentrated at 0°-3.75°, and the crater wall slope value is 10°-45°, the areas with larger slopes are distributed around the impact crater and near the central peak, and there are some areas around the impact crater that have larger slopes and are ring-shaped, indicating that there are small and medium-sized impact craters around the V on Kármán impact crater. The DEM map of the V on Kármán impact crater is consistent with the three-dimensional display of the impact crater.

Figure 5Slope of the V on Kármán impact crater    Figure 6Terrain roughness of the V on Kármán impact crater

Figure 7TiO₂ content inversion             Figure 8 FeO content inversion
Figure 6 shows that the terrain roughness of the Von Kármán impact crater ranges from 1 to 1.80. On the whole, the larger terrain roughness is distributed on the edge of the impact crater and the edge of the small impact crater around the impact crater. Through the natural break classification method, it is concluded that the internal roughness of the Von Kármán impact crater is relatively low, concentrated in 1-1.03, and the micro impact structure near the central peak and within the impact crater has a relatively large roughness.

The TiO₂ and FeO content maps obtained from the inversion of Clementine data show that the interior of the Von Kármán impact crater is poor in TiO₂ (about 1.3-2.8 wt%) and rich in FeO (about 11-18 wt%), with local TiO₂ reaching 3 wt% and FeO reaching 20 wt%, and it is inferred that the main rock type in the impact crater is low-ti basalt. The TiO₂ in the northern part of the crater bottom is obviously high, while the higher content of FeO exists in the southern part of the crater bottom, and this inconsistency of TiO₂ and FeO content indicates the complexity of magmatic activities in this area.

4. Conclusion
The Chang'E-4 lunar exploration mission is the first soft landing and in-position detection on the back of the moon in human history. The research on the landing area will be of epoch-making significance in the field of lunar science. Based on the DEM data obtained by LOLA and Clementine spectral data, this paper combined DTA technology to analyze the slope and terrain roughness characteristics of the Von Kármán crater and its surrounding area, and maps the TiO₂ and FeO content of the Von Kármán impact crater. The conclusions of the analysis are as follows: On the whole, except for a central peak in the middle and upper part of the Von Kármán impact crater, the rest area is relatively gentle. The internal slope of the impact crater is concentrated at 0°-3.75°, and the larger slope is concentrated on the pit wall. And near the central peak, the internal roughness of the impact crater is low, so it can meet the landing requirements of the Chang'E-4 lander. The inside of the impact crater is poor in TiO₂ (about 1.3-2.8 wt%) and rich in FeO (about 11-18 wt%), so it can be considered that the main rock type is low-ti basalt.

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