

¹MULTI-FACTOR ANALYSIS FOR SELECTING LUNAR EXPLORATION SOFT LANDING AREA AND THE BEST CRUISE ROUTE

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ABSTRACT:

Selecting the right soft landing area and planning a reasonable cruise route are the basic tasks of lunar exploration. In this paper, the Von Karman crater in the Antarctic Aitken basin on the back of the moon is used as the study area, and multi-factor analysis is used to evaluate the landing area and cruise route of lunar exploration. The evaluation system mainly includes the factors such as the density of craters, the impact area of craters, the formation of the whole area and the formation of some areas, such as the vertical structure, rock properties and the content of (FeO + TiO₂), which can reflect the significance of scientific exploration factor. And the evaluation of scientific exploration is carried out on the basis of safety and feasibility. On the basis of multi-factor superposition analysis, three landing zones A, B and C are selected, and the appropriate cruising route is analyzed through scientific research factors. This study provides a scientific basis for the lunar probe landing and cruise route planning, and it provides technical support for the subsequent lunar exploration.

1. INTRODUCTION

On December 15, 2013, the CE-3 successfully landed in the Sinus Iridum on the front of the moon has made China the third country in the world to achieve a soft landing on the moon (Li, 2017). Soft landing detection is a kind of in situ detection method, which can get finer and deeper detection results than satellite-borne remote sensing (Li, 2017) and (Hang, 2006). The main terrain on the moon's surface is the lunar mare, lunar land and craters (Luo, 2006), in which the lunar mare topography is mostly distributed on the front of the moon. From the perspective of lunar landing safety, the lunar front with flat topography and easy communication is preferred, but from the point of scientific research, the lunar back with a rich topography is a more suitable choice. Although many surround detectors have been used for remote sensing of the back of the Moon, no astronaut or detector has been detected in this area nearly (Wu, 2017), and people few known about its terrain, topography, mineral composition, etc. For example, the Apollo region in the South Pole-Aitken is a representative area for studying the volcanic activity on the back of the moon (Xiao, 2016). In the area of Compton-Belkovich on the back of the moon, high-silicon products of burst volcanism have also been detected (Wilson, 2015) and (Jolliff, 2011), making the back of the moon an ideal area for lunar exploration and becoming a popular landing spot for the "CE-4" exploration satellite to probe the moon.

Because the lunar rotation is only 1.58 degrees. So the Lunar South Pole's light will form close to the polar day or

permanently illuminated, and the temperature will few difference between day and night in this area (Wu, 2017) and (Li, 2015). The area not only has a large number of plains but also has a higher content of ferrous oxide (FeO) and titanium dioxide (TiO₂). With the oldest moon rock, it is also of great importance to the study of the formation of the lunar geology (Li, 2017) and (Yu, 2012).

At present, Suweyong, Apollo, Luna and CE-3 have achieved many lunar landing surveys. Lunokod 1 landed in the northwestern part of the Mare Imbrium, traveling at a distance of 9.93 kilometers. The absolute elevation of the surveyed area was less than 50 meters. The slope of the surveyed path was less than 10°. The survey was conducted for more than 500 sites. During the entire lunar exploration, the detection of the moon's soft landing, and the assessment of the exploration area and exploration path are important steps. At present, the research methods of the lunar exploration landing area are diversified. For example, Xu et al. used the surface roughness and the projection area ratio to calculate the flatness of the terrain (Xu, 2012). Meng et al. Based on the microwave radiation in Antarctica Counting data The bright temperature map of the microwave radiation in Antarctica (37 GHz) was used for sounding analysis. Jia et al. analyzed the composition and structure of lunar rock minerals by studying the visible-near-infrared spectral characteristics of the lunar surface material to help (Meng, 2010) the lunar The selection of the exploration area (Jiao, 2012). Zhang et al. detected the formation and evolution of the early moon by analyzing the morphology and structural features of the SPA basin, the composition and distribution of materials, and the formation

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mechanism(Zhang,2011).

However, there is no fixed method for the selection of the current landing detection routes. And most of the considerations are relatively single, lacking a complete evaluation system of lunar landing route selection. Therefore, in this paper, the Von Karman craters in the South Pole-Aitken basin on the back of the moon are taken as the research area, and the combination of multiple factor probing analysis is used to analyze the lunar probe's best landing area and the safe landing area Best exploration route. This paper presents for the first time a multi-factor analysis technique that provides a scientific basis for the lunar probe landing and cruise route planning and provides scientific technical support for subsequent lunar exploration.

2. OVERVIEW

The study area is the Von Karman craters located in the South Pole-Aitken (SPA) basin on the back of the moon, with a range of 171 °E-177 °W and 41 °S-49 °S . The SPA basin, the largest

and oldest impingement basin in the solar system, has rocks of primordial crust and is also the basin most likely to excavated mantle material with a diameter of 2000-2600 km. The basin has a complex topography with numerous large impact topographies. And it contains higher iron (Fe) and titanium (Ti) and other chemical elements^[1, 8, 14], with high scientific research value. Von Karman Crater, located in the middle of the Aitken Basin, is a typical landform type in the SPA basin. It has high FeO and TiO₂ contents and lower elevations relative to other parts of the basin . The crater has a diameter of about 186 kilometers and a center coordinate of (44.8 ° S, 175.9 ° E), as shown in Figure 1.

Source data from NASA's(National Aeronautics and Space Administration) original image data on the lunar surface and DEM (Digital Elevation Model) data acquired by LOLA on a lunar orbiter laser altimeter (as shown in Figure 2). The image data,used in this experiment,is based on the original image cropping and stitching generated.

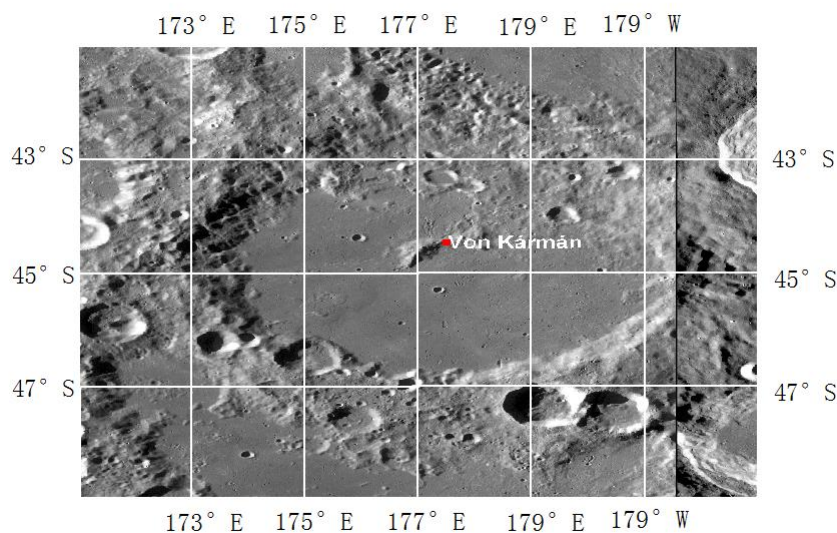


Figure1. The remote sensing image of Von Karman crater

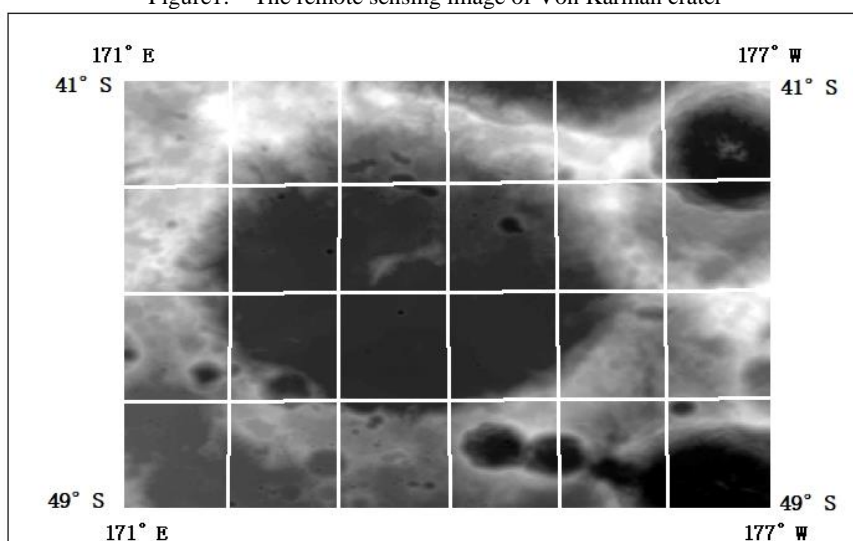


Figure2. Von Karman crater' DEM

3. MULTIFACTORIAL ASSESSMENT ANALYSIS

The choice of a reasonable lunar landing area and a cruise route requires comprehensive consideration of various factors. Under the premise of the safety of the soft landing, it is also necessary to design the area and routes from the scientific research level as much as possible. The evaluation of this paper is divided into two parts: selecting a safe area and evaluating the best cruising route. Among them, the evaluation factors of the safety zone are as follows: the density of the impact crater, the affected area of the impact crater, the formation of the whole area and the formation of some areas. In this paper, the terrain undulation of the research area is judged according to the slope of the terrain. The smaller the slope, the more gentle the terrain. The cruise route selection has the following factors: the vertical structure of the area, the properties of the rock and the elemental content factors. The complete assessment process is shown in Figure 3.

In the process of selecting a safe area, we first need to observe the trend of the terrain and the ups and downs from the perspective of the whole. Then, based on the slope grade map of Von Karman region, we classify the slope into: $<2^\circ$, $<4^\circ$, $<6^\circ$ and $>6^\circ$ four grades of soft landing selection area; and then we perform buffer analysis and distance analysis on impact crater data; Finally, a suitable safe landing area is obtained by a comprehensive analysis of the results of each factor stack analysis.

In view of scientific research, firstly, we need to designate three landing points A, B and C in the selected safety zone and plan

the cruising route for it. Then, based on each cruising route, we make a profile analysis to analyze the elevation change of the route size, geological rock properties and the content of metal elements. Finally, the paper gets the best cruise route by performing a comprehensive analysis.

3.1 Select the Soft Landing Area

3.1.1 the 3D of Terrain Von Karman Region : Von Carmen impact crater elevation of more than 7000 meters, with rich terrain. To assess the safe area of lunar exploration, it is first necessary to observe the formation of the study area from a holistic perspective by fitting the three-dimensional model of the area. The digital elevation model is the basis of the subsequent DEM analysis. It can also assist us to grasp the fluctuation in the Von Carmen impact craters more clearly. The fitting result is shown in Figure.4.

It is clear from Figure 3 that the Von Karman Crater at the bottom is relatively flat and low-lying and has a large basin plain, making it a good landing alternative. There is a clear central peak at the bottom of the impact crater. The central peak is generated by rebound and uplift when the impact occurs. Generally, the central peak has the composition of the next moon shell, which has a great significance for geological research. Therefore, in this paper, the follow-up analysis will be carried out mainly on the basin plain at the bottom of Von Carmen.

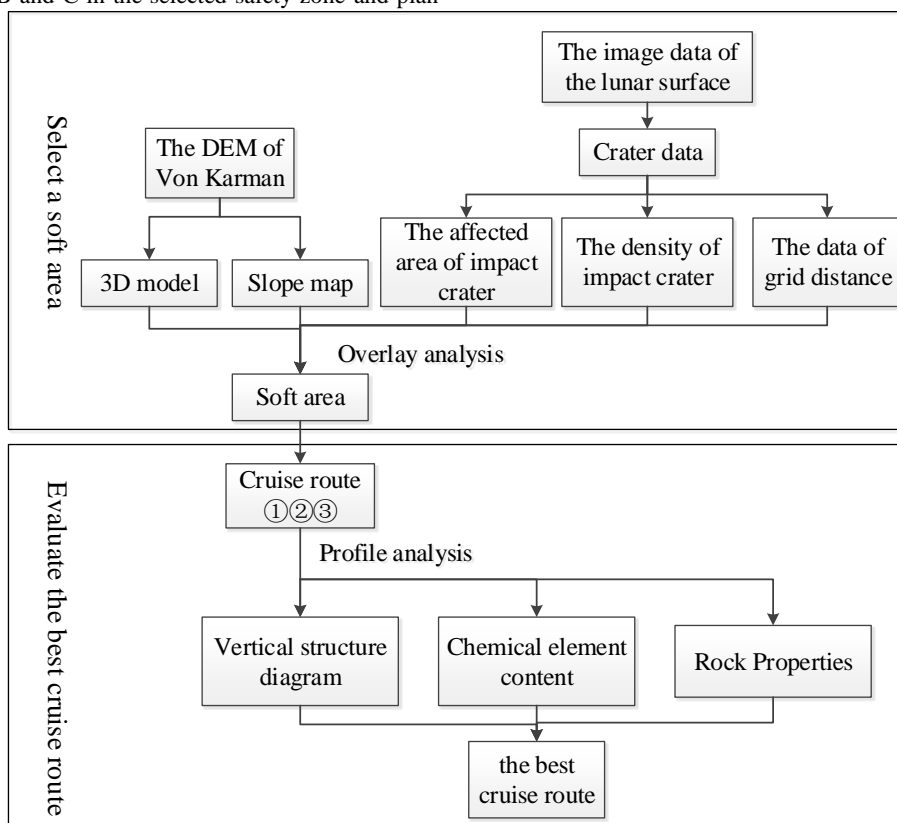


Figure3. Flow chart of the assessment of the moon

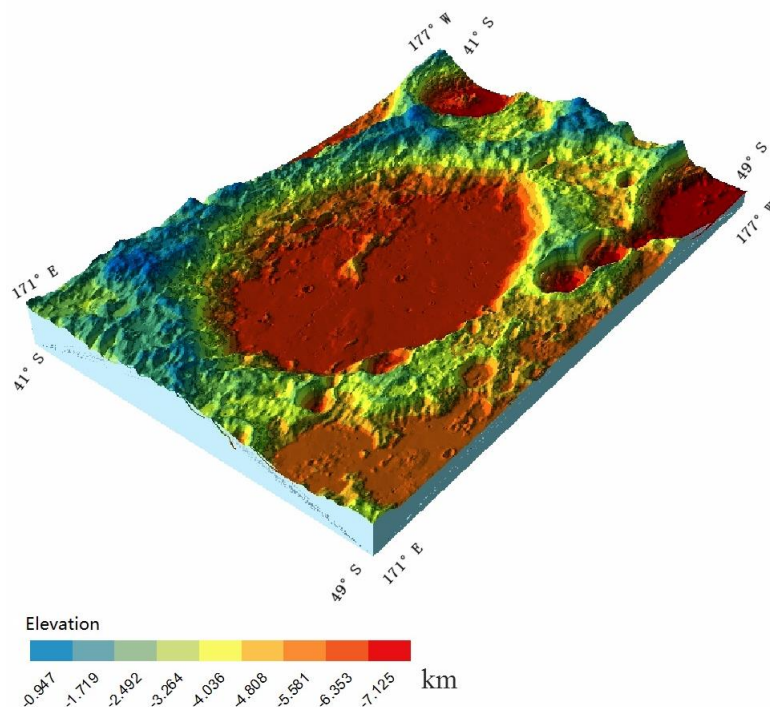


Figure4. Von Karman's three-dimensional elevation model

3.1.2 Slope Analysis: In the cruising area of the landing vehicle, if the terrain slope is too large, the cruising vehicle will be difficult to navigate. Therefore, it is necessary to select a smaller slope area. During the tour of lunar surface by the former Lunokhod 1 patrol, the slope of the patrol path is generally less than 10° ^[14]. In order to improve the safety factor of the lunar rover, the slope classification is as follows

- { slope > 6° danger area
- { slope < 6° soft area

The area of $<6^\circ$ is further divided into three different safety levels of $4^\circ < \text{slope} < 6^\circ$, $2^\circ < \text{slope} < 4^\circ$ and $\text{slope} < 2^\circ$. When the slope is smaller, the safety level is higher. The paper first

performs slope analysis based on DEM. And then it divides the slope according to the above. The result of division is shown in Fig.5. The area of von Karman craters with slope less than 2° is the largest, accounting for 48.5% of the whole area. The slope in the edge area is larger and the area of the area with lower gradient is smaller, which is not conducive to the exploration of landing vehicles. In contrast, the bottom of the impact crater except for the center of the central peak area is mostly less than 2° , less undulating terrain, and the larger area, meeting our practical application requirements.

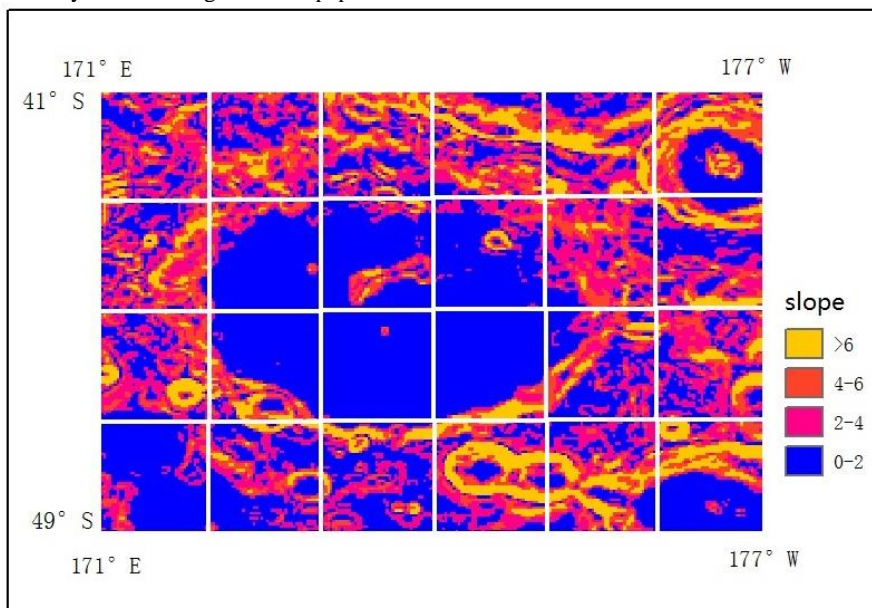


Figure 5. Slope grade map of Von Karman area

3.1.3 the Impact Crater Affected Area: As can be seen from Figure 1, there are still many craters in the Von Carmen, of

which large craters are mainly concentrated in the southwestern region. And the bottom of the pit mainly clumps into small craters. If the impact crater is too large, it will lead to the normal operation of the landing vehicle rollover situation occurs. It is necessary to remove the part of the area. In this paper, vector data of craters are extracted from the bottom of the basin plain and buffer analysis is done. Referring to the landing area of "CE-3", the buffer zone is analyzed by using the buffer radius of 50 meters (as the range of allowable landing error)(Qiao,2016) and (Yang,2014) and (Yang,2014) , and the impact area of the impact pit is shown in figure.6.

With reference to the "CE-3" and other overseas experiences of soft landing, the location of the soft landing needs to be as close to the small craters as possible away from the large craters. In order to meet this demand, the density of craters is firstly calculated. And the study area is divided into 24 areas by 2°

difference between latitude and difference. As shown in Figure 6, the numbers are from left to right and from top to bottom respectively area 1-24, the statistical results shown in Table 1.

As can be concluded from table 1, there are fewer craters in the northern part of the bottom of the pit. In contrast, there are a large number of craters in regions 16 and 17 in the southern part, and most of them are small craters. So the landing area should be chosen as far as possible in the 16/17 area.

Then the paper performs distance analysis on the buffer data to get a grid distance map centered on each buffer, which will be divided 0-1 km into the most appropriate landing area, followed by the security level followed by 1-5, 5-10, 10-30, > 30 km decreasing, the results shown in Figure 7. The safe landing areas are concentrated at the bottom of Von Karman crater, specifically in areas 8-11 and 14-17, and the closer the location to the small impact, the higher the safety factor.

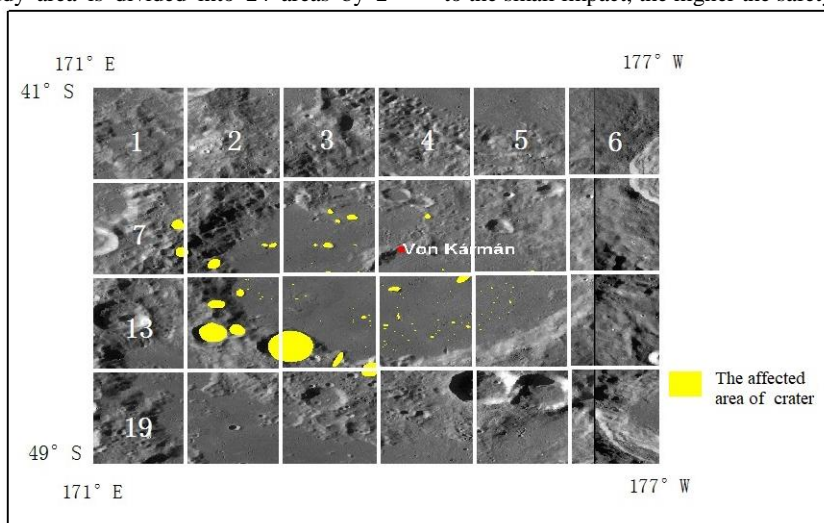


Figure6. Coverage of the crater

Grid number	The number of crater	Grid number	The number of crater
1—6	0	14	13
7	2	15	25
8	4	16	59
9	12	17	36
10	4	18—20	0
11	8	21	1
12—13	0	22—24	0

Table 1. Data statistics for percussion pits in each area

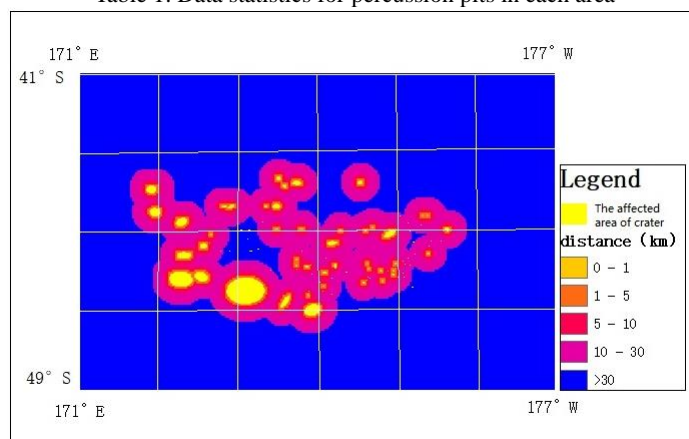


Figure 7. Raster distance map based on crater

3.1.4 Multi-factor Analysis: After the analysis of a single factor, based on a variety of factors, we selected the areas with relatively flat topography, gentle slope, large craters and away from large craters. Then, the data of the safety level of the soft landing area is obtained through the grid overlaying (the buffer area of the impact crater needs to be removed in the safe area) and divided into four categories. The larger the value is, the higher the security level is. The result is shown in figure. 8. It can be observed from Fig.7 that the safety factor of landing is lower in the edge area. Most of the areas with higher safety level are located in the basin plain of Von Carmen craters, and mostly concentrated in the 16th and 17th areas.

3.2 Best Cruise Route Analysis

In the safe area resulting from the above analysis, landing sites A, B, C are assumed and their cruise routes are planned separately. Then, by analyzing the regional profile of each cruising route, the vertical structure of craters, chemical elements and rock properties between different cruise routes are analyzed and compared to fit the optimal cruising route. The assumed landing point and the pending cruise route are shown in Figure 9.

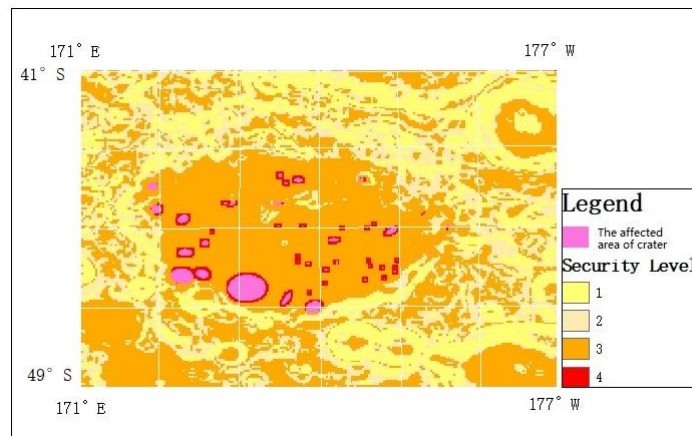


Figure8. Security analysis results

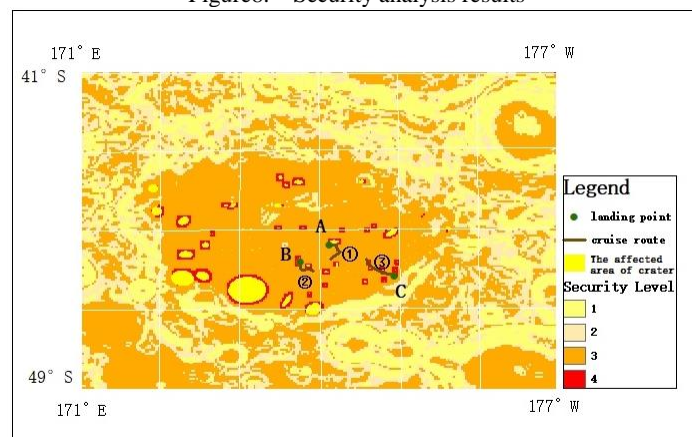


Figure9. Landing and cruise road map

3.2.1 Vertical Structure: Based on the elevation data of the study area, the profile analysis is performed to obtain the vertical structure of the area where the cruise route passes through ① ② ③. As can be seen from Figure 10, the maximum elevation difference between landing A and landing B is 45m, and the maximum elevation difference of landing area C is 70m. Obviously, the cruising route ③ area by elevation difference is higher than the other two routes. Cruise routes ① and ② are more conducive to the safety of landing vehicles. However, comparing the elevation profiles of cruise routes ① and ②, the elevation of the cruising route ① that passes through slowly is more conducive to the inspection of the landing vehicle.

3.2.2 Chemical Element Content: Similarly, based on the chemical element content data (Borst,2012) (Figure 11),The chemical content of each cruise route changes chart was obtained. We can see from Figure 11, Von Carmen has a higher chemical content than the rest of the South Pole-Aitken Basin. In Von Carmen's interior, the basin plain is significantly taller than the marginal area, especially at the bottom southwest. As can be seen from Figure 12, the cruise route planned for landing point B has the highest elemental content of 20.5. And the elemental contents of the other two routes are almost the same with the highest values around 15. Obviously, cruise route ② is more in line with the conditions.

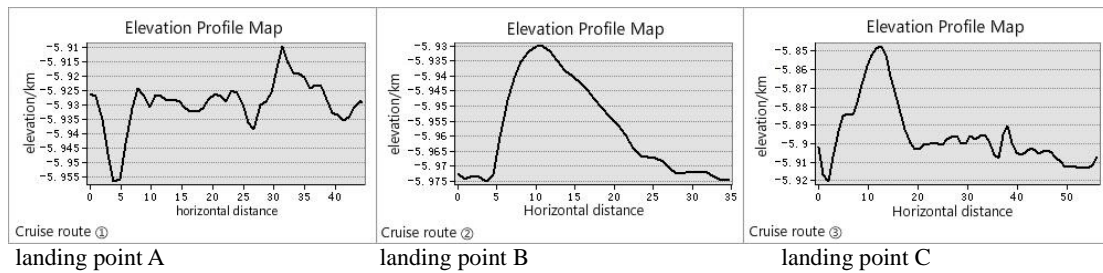


Figure 10. Vertical structure of the cruise route

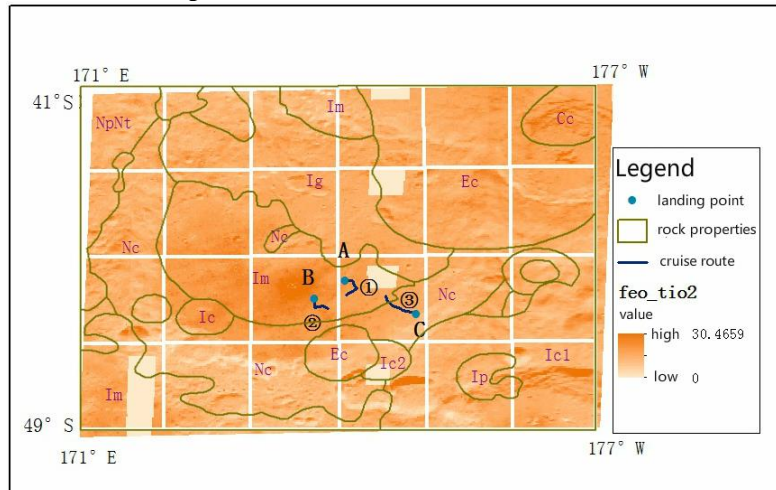


Figure 11. Chemical element content and lithology Von Karman

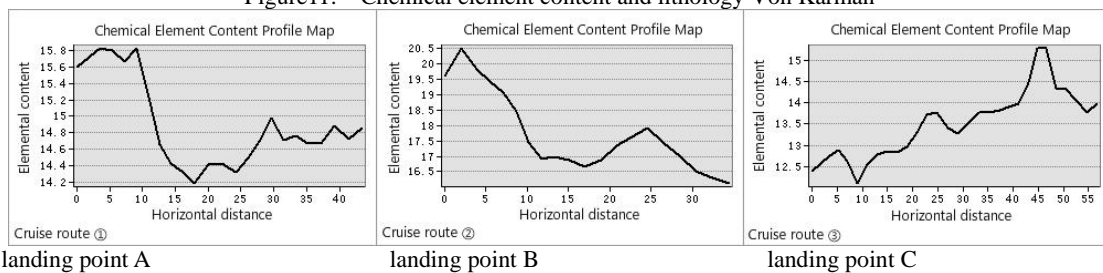


Figure 12. Section of the chemical elements in the area of the cruise route

From the point of the value of scientific research, it is most appropriate to choose a region with a small difference in elevation and a high chemical element content. Although the elevation of cruising route ① is smaller, the elevation difference between cruising route ① and ② is 45m, which is within the range of the current technology. And the chemical element content of cruise route ② is obviously higher than that of route ①. Therefore, cruising route ② is the most qualified route. In addition, it can be seen from Figure 8 that the cruising route ③ passes through two types of rocky areas, which is more conducive to the study of geosciences. From a geological point of view, landing point C where the cruising route ③ best meet the conditions.

4. CONCLUSION

This article describes how to choose the appropriate landing area and the best cruising route. By comprehensively evaluating the safety factors: the overall and local flatness of the terrain, the density of the impact crater and the impact range of the impact crater, the scope of the safe landing is obtained. The study of scientific rationality is mainly based on the selected safe area, with emphasis on factors such as topography, chemical element content and rock properties in the area along the cruising route. The final result shows that route ② is the

best choice from the view of safety and chemical elements. From the view of geology, route ③ is the best under the assumption that the elevation difference of 70m is acceptable choice.

Based on the lunar surface topography and composition data, this study systematically analyzes the possible landing areas and cruising routes of von Karman' craters. It is done through a comprehensive assessment of engineering safety and cruise science. And a number of viable cruise routes and study highlights have been provided. Due to the limited access to data sources, some factors (such as light and soil softness, etc.) are not taken into account. However, after obtaining these data, we can conduct further comprehensive analysis according to the method in this paper.

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