# SHALLOW SUBSURFACE STRUCTURE OF THE MOON AT CHINA'S CHANG'E-4 LANDING SITE OBSERVED BY THE LUNAR PENETRATING RADAR.

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**Chang'E-4 Lunar Farside Landing Mission:** As the largest, deepest and oldest well-preserved impact structure on the Moon, the South Pole-Aitken (SPA) basin plays a critical role in understanding the interior and evolution of the Moon. Therefore, a landing or sample-return mission to the SPA is regarded as one of the highest priorities in lunar exploration [1, 2]. On 3 January, 2019, China's Chang'E-4 (CE-4) spacecraft (including a lander and a rover) successfully landed in the northwest of the SPA, becoming the first soft landing mission on the Moon's farside [3, 4]. Till now, the Yutu-2 rover has conducted in situ observations for 13 lunar months with a surface traverse of ~357.6 m. Observations from the Panoramic Camera (PCAM), Lunar Penetrating Radar (LPR), and Visible–Near Infrared Spectrometer (VNIS) can provide important information about surface geology, physical and chemical properties of the regolith, and subsurface structure at the landing site, which is critical to understanding the formation and evolution of the SPA basin [2].

**Geological Context of the Landing Region:** The CE-4 landing site (45.456°S, 177.588°E) is on the eastern floor of the Von Kármán crater (~186.3 km in diameter; Fig. 1), which is located in the northwest of the SPA. Von Kármán crater was formed ~3.97 Gyr and its floor was later flooded by Imbrian age mare basalts, with an Absolute Model Age of 3.6 Ga [5]. The floor of the Von Kármán crater is relatively flat, with a slope generally less than 5° [3]. Judging from the optical and multispectral images, the northeastern portion of the crater floor is covered by non-maria materials that appear bright, which are mostly distal ejecta from Finsen, Kármán L, and other large craters surrounding Von Kármán. From Kaguya Multiband Imager (MI) data, the FeO and $TiO_2$ abundances are estimated to be 12.9 and 1.2 wt.% at the landing site [5].

From optical images obtained by the Landing Camera, the CE-4 landing site is surrounded by three degraded impact craters with diameters of ~29, 21, and 23 m. The surface lacks meter-scale rocks, which is totally different from the Chang'E-3 (CE-3) landing region. During the first eight months, the Yutu-2 rover travelled for ~240 m (Fig. 2). High-resolution topography data shows that variation in surface elevation is ~2.2 m.

**Shallow Subsurface Structure from LPR Observations:** CE-4 LPR system parameters and working status are the same as those of CE-3 LPR. Here we present the high frequency (500 MHz) LPR observation results during the first eight lunar months.

*LPR data processing*. In total, 6800 tracks of raw data were obtained by the high frequency LPR. The raw data were processed using the standard GPR data processing procedures, as in Fa et al. [6]. The processed LPR image (Fig. 3) is displayed in B-scan format, where the horizontal and vertical axes represent lateral distance and time delay (left). To convert time delay to real depth, real part of the relative permittivity is chosen as 3.0 based on surface FeO and $TiO_2$ abundances [6].

*Penetration depth.* From Fig. 3, time delay of the deepest detectable radar echo is ~500 ns, which is ~3 times larger than that at the CE-3 landing site. This implies that subsurface materials at the CE-4 landing site are more transparent to radar waves, i.e., dielectric loss of the materials is much lower. Several possible reasons for such a large penetration depth might be low ilmenite abundance, low dielectric loss distal ejecta from highlands, and few subsurface rocks.

*Subsurface structure*. A strong reflector is obvious at a time delay of ~150–170 ns (depth: ~12–14 m). The region from the surface to this reflector is homogeneous and the radar echo strength is relatively low. This region contains many random irregular layers with lateral continuity of several meters, and tens of hyperbolic curves, which are most probably caused by buried rocks. We interpreted this region as distal ejecta from large craters (e.g., Finsen and Von Kármán L) surrounding the Von Kármán crater.

Below this region, to a time delay of ~450 ns (a depth of ~40 m), is a heterogeneous region containing bright reflectors alternating with more uniform dark intervals. These strong reflectors have a thickness of several meters and extends for tens of meters laterally. These strong reflectors could be irregular interface geometry or discontinuities of dielectric permittivity, or densely distributed rocks [6]. The uniform intervals could be fine-grained paleoregolith.

A weak reflector can be identified at a time delay of ~500 ns (~42 m), and this reflector extends more than ~180 m laterally. Radar echoes below this reflector are weak and become noisy, which are beyond the

LPR detection ability. An independent analysis of dark-haloed craters shows that depth of buried mare basalt is ~40 m [3], which might correspond to this reflector.

**Summary and Future Work:** According to the high frequency LPR observations and other remote sensing data, the evolution order over the CE-4 landing region might be reconstructed. After the formation of the Von Kármán crater ~3.97 Ga, its floor was flooded by mare basalts of Imbrian age. Impact cratering then modified surface basalts, producing chaotic ejecta containing large rocks. During the time intervals between different impacting events, fine-grained surface regolith was produced because of micrometeoroids bombardments, and was later buried by crater ejecta of other impacting events, and thus became paleoregolith. The surface was then buried by distal ejecta possibly from the relatively young large craters like Finsen and Alder, with an ejecta thickness of 10–12 m. All these indicates a complex geological history over the CE-4 landing site and the modification process after the formation of the SPA basin.

**Acknowledgments:** This work was supported by the National Natural Science Foundation of China (No. 41941002).

**References:** [1] Jolliff B. L. et al. (2017) *LPSC XLVIII,* Abstract #1300. [2] Jia Y. et al. (2018) *PSS, 162,* 207–215. [3] Guo D. et al. (2019) *LPSC, L,* Abstract #1844. [4] Li C. et al. (2019) *Nature,* 569, 378–382. [5] Huang J. et al. (2019) *JGR-Planets, 123*, 1684–1700. [6] Fa W. et al. (2015) *GRL, 42*, 10,179–10,187.

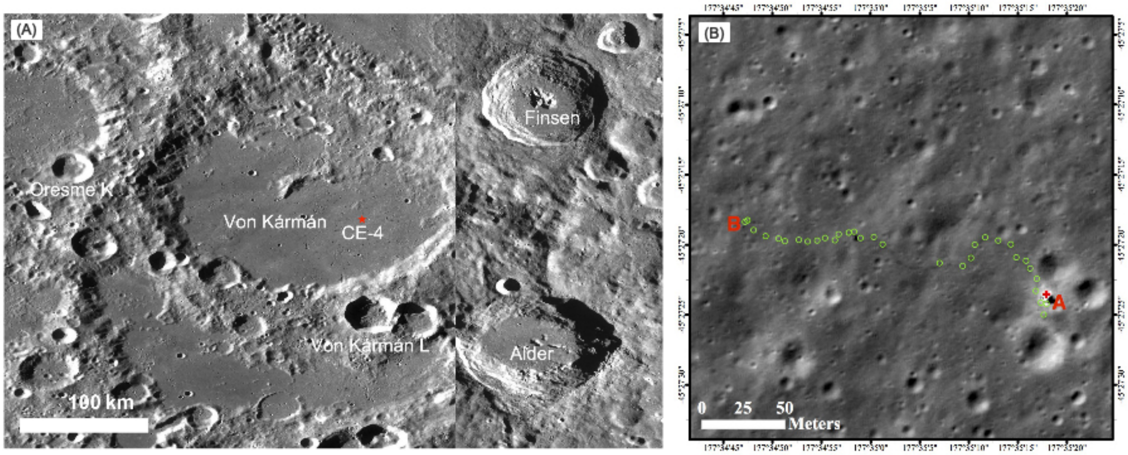

**Figure 1**. (a) LROC Wide Angle Camera (WAC) mosaic for the Von Kármán crater. (b) A LROC Narrow Angle Camera (NAC) image showing the surface traverse of the Yutu-2 rover during the first eight months. The red star and cross show the CE-4 landing site.

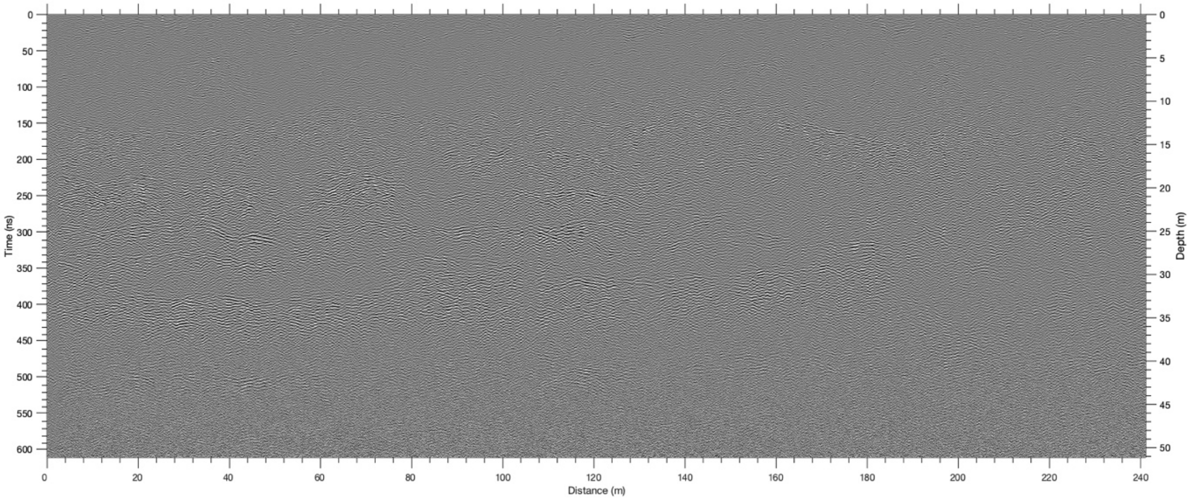

**Figure 2**. Processed high-frequency LPR image from Point A (left) to B (right) along the Yutu-2 survey line. White tone represents strong echoes and gray denotes weak echoes.