Subsurface Structure Analysis of Chang'E-3 Landing Site. Jialong Lai，Yi Xu，Xiaoping Zhang and Zesheng Tang， Lunar and Planetary Science Laboratory, Macau University of Science and Technology, Macau (jiallai2014@gmail.com).

Introduction: The surface of the Moon is covered by the lunar regolith, which records vital clues about history of surface processes and contains potential resources for future lunar exploration, and the structure of the lunar mare subsurface and its thickness as a function of time are important in setting constraints on the petrogenesis of lunar mare basalts and understanding the formation and thermal history of the Moon [1,2]. Early work focused on estimating the thickness of mare regolith and shallow subsurface basalt layer filled in the mare basins with approaches such as direct detection, crater morphometry, crater penetration, and stratigraphy [3]. Recently, Chang'e-3 Lunar Penetrating Radar (LPR) equipped on Yutu rover performed in situ measurement for unraveling the structure of lunar regolith and mare subsurface of the high titanium region located in the northern part of Mare Imbrium .

The Chang'E-3 Lunar Penetrating Radar Experiment: On December 14, 2013, China's Chang'E-3 (CE-3) spacecraft successfully landed in the northern Mare Imbrium at 44.1213 °N, 19.5115 °W. Figure 1 was taken by the descent camera of Chang'E-3 when the lander was lowered to around 150 meter height. The black line shows the motion path of Yutu rover. The landing site is within an Eratosthenian-aged geologic unit, consisting of high titanium mare basalts. The north of the landing site, about 10 kilometer, is the boundary with an older low titanium mare basalt [5]. These geologic units indicate that Mare Imbrium underwent prolonged magmatic activity and thus its subsurface stratigraphic structure might be very complicated.

CE-3 LPR is an ultra wide band impulse ground penetrating radar (GPR) operating at two channels - center frequencies of 60 MHz and 500 MHz [6]. The bandwidths of the two channels are 40 MHz and 450 MHz, respectively, corresponding to a range resolution of 3.75 m and 0.3 m in vacuum. Here, we report the results of both channels. The raw data were processed with repetitive observation removal, horizontal band removal, band-pass filtering and gain control method [7].

Lunar Regolith Layer Revealed by LPR: Figure 2 shows the processed 500 MHz radar data image from G to M. The most important observations about the data are that the lunar regolith at 500 MHz is dominated by discrete scatterers indicating numberous stones, and that the thickness of the regolith may be defined where these scatterers die out denoted by the black line between region III and region IV in Figure 2.

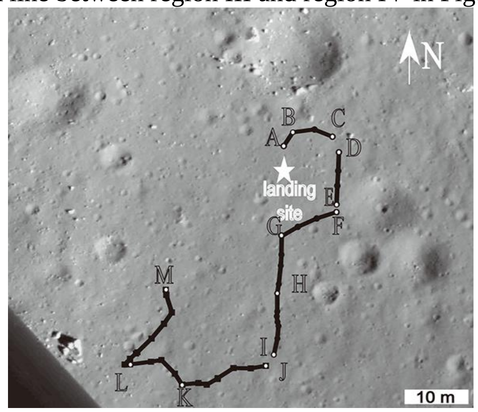

Figure 1. An image from CE-3 landing camera showing the route of the Yutu rover, the star is the CE-3 landing site, and A, … L, M are surface navigation points.

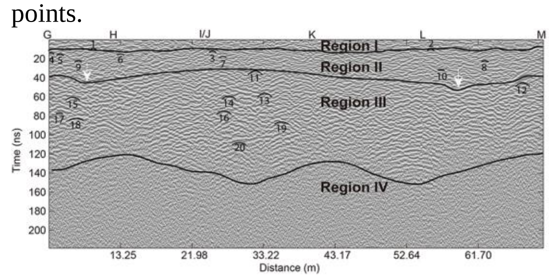

Figure 2. LPR image of channel 2.

Since there are many hyperbolae in the radar image, hyperbolae fitting method is employed to inverse the real part of dielectric constant of lunar regolith. 20 hyperbolae at different depths are selected from the radar image as shown in Figure 2. Figure 3 shows the relationship between the two-way travel time of radar signal at hyperbola position and derived stacking dielectric constant. The stacking ε increases with the depth. Based on the calculation, the average stacking dielectric constants and uncertaintie of the top layer, the second and third layer in Figure 2 are 2.47 ± 0.09, 3.40 ± 0.15 and 6.16 ± 0.21, respectively. The thickness of each layer are 0.95 ± 0.02 m, 2.3 ± 0.07 m, 2.79 ± 0.10 m, respectively.

The rover motion path is near (~40 m away) the impact crater [8, 9]. Thus, we infer that the second layer is the ejecta blanket of the crater, the thickness of which is consistent with predications of related models. In addition, we observe two parabolas around ~40 ns marked by white arrows in Figure 2. These parabolas might be small impact craters and exposed on the lunar surface in the past. Hence, we speculate that the two hyperbolaes indicate the position of the second interface shown in Figrue 2. The upper layer can be interpreted as the weathered layer of ejecta blanket.

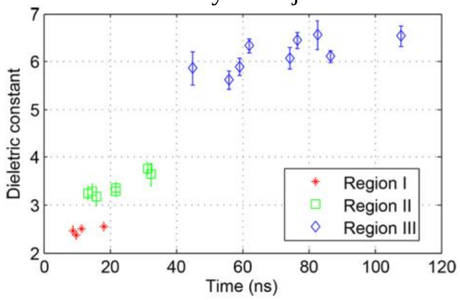

Figure 3. Travel time v.s. stacking dielectric constant.

Mare Subsurface Layers Revealed by LPR: Figure 4 shows the LPR image at 60 MHz from Point G to L along the Yutu survey line. From Figure 4, five layers can be recognized, named as a, b, c, d, e, respectively. As the landing site is within an Eratosthenian-aged geologic unit, a is considered as Eratosthenian basalt. Figure 4 reveals that the basalts at the landing site extend to 26.8-32.9 ±1.5 m with the relative dielectric constant 6.5 [10], which is well consistent with previous estimations of Scaber et al. (30-35 m [11]), Hiesinger et al. (32-50 m, +11/-5 m [12]) and Chen et al. (15.65-43.72 m [13]).

No strong echo is observed between the two interfaces at depth ~30 m and ~40 m which may indicate the region b is an relatively uniform layer, hence, it is interpreted as the paleo-regolith formed layer. Its thichness is between 5.2 to 8.6 m with an uncertainty ± 3 m.

The layer c interpreted to be another basalt layer has a thickness ranging from ~40 to ~72 m. As b is the weathering layer of c, so the thickness of this layer is 40 ±4.7 m

Two clear reflectors can be observed at~194.6 and ~ 339.6 m, respectively. The location of these two reflectors is similar to previous measurements of KAGUYA Lunar Radar Sounder (LRS), the shallower interface at 247 ± 127 m and the deeper interface at 488 ±210 m [14] around 10 km north away from CE-3 landing site, and related work of Xiao et al. [8] and Fang et al. [15]. These two layers are interpreted to be Mare Imbrium period basalts and their thickness are 122.5 and 145.0 m, respectively. Multiple horizontal lines appear at the depth of ~200 m, which may indicate several small volcanic eruptions.

Conclusions: According to the LPR data, the near surface structure at the CE-3 landing site are very complex, and can be constructed as (from top to bottom): weathered layer (~0.95 m), ejecta blanket layer (~2.3 m), rock and regolith mix layer (~2.79 m), Eratosthenian period basalt layer a (~29.9 m) , paleoregolith layer b (~6.9 m), basalt layer c (~40 m), Mare Imbrium period layer d (~122.5 m) and e (~145.0 m). These results may provide valuable information for understanding the evolution of the lunar regolith and the mare thermal history.

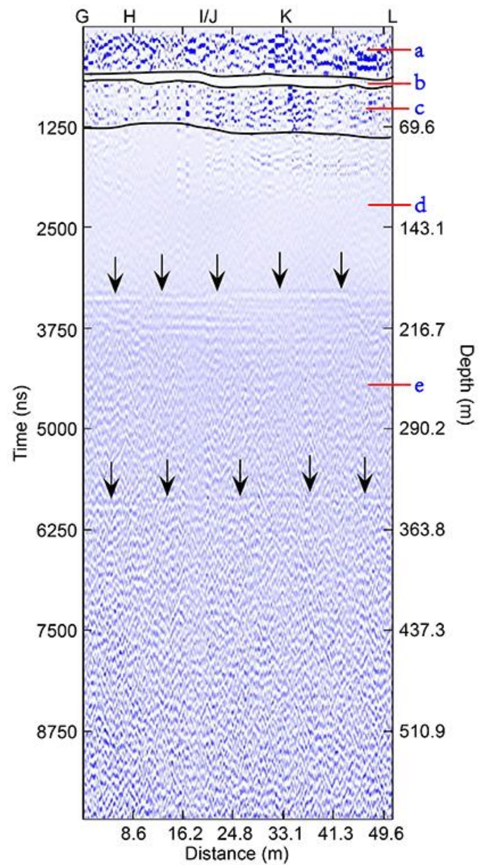

Figure 4. LPR image of channel 1. The depth is calculated with dielectric constants 6.5.

Acknowledgements: CE-3 data were provided by the Lunar and Deep Space Exploration Department, National Astronomical Observatories, Chinese Acadmy of Sciences (NAOC). Supported by the Key Research Program of the Chinese Academy of Sciences (grant KGZD-EW-603), the Science and Technology Development Fund of Macau under grant No.048/2012/A2, 039/2013/A2, 091/2013/A3 and 020/2014/A1.

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