

かぐや衛星観測データに基づいた月上層玄武岩の誘電率と空隙率の推定 Estimation of the permittivity and porosity of the lunar uppermost basalt layer based on the SELENE observation data

石山 謙^{1*}, 熊本 篤志¹, 小野 高幸¹, 山口 靖², 春山 純一³, 大竹 真紀子³, 加藤 雄人¹, 寺田 直樹¹, 押上 祥子⁴

Ken Ishiyama^{1*}, Atsushi Kumamoto¹, Takayuki Ono¹, Yasushi Yamaguchi², Junichi Haruyama³, Makiko Ohtake³, Yuto Katoh¹, Naoki Terada¹, Shoko Oshigami⁴

¹ 東北大学, ² 名古屋大学, ³ 宇宙科学研究所/宇宙航空研究開発機構, ⁴ 国立天文台

¹Tohoku University, ²Nagoya University, ³ISAS/JAXA, ⁴NAOJ

Permittivity is an important parameter for understanding the results obtained from various radar observations. For the investigation of lunar subsurface structures, Lunar Radar Sounder (LRS) onboard the SELENE (KAGUYA) spacecraft emitted the electromagnetic wave (4 - 6 MHz), and measured the delay (dt) between the electromagnetic waves reflected at a lunar surface and at subsurface boundaries [Ono et al., 2009]. In this study, we define an apparent radar depth (D), which is expressed as a function of $D=(c*dt)/2$, where c is the speed of light in vacuum. The apparent radar depth relates to the thickness (T) between the surface and subsurface boundaries, at which the electromagnetic wave is reflected. However, we must note that the apparent radar depth is not equal to its thickness. Because the lunar subsurface layer has a bulk permittivity (E_{bulk}), it varies the velocity (v) of the electromagnetic wave in the subsurface layer. The thickness can thus be given as $T=v*dt/2=(c/(E_{bulk})^{0.5})*dt)/2=D/(E_{bulk})^{0.5}$. In radar observations, the information of the thickness of lunar basalt layer is significant for discussing the lunar volcanic activity [e.g., Hiesinger et al., 2003].

The values of the bulk permittivity (4 - 11), based on Apollo basalt samples, have been used in previous works [e.g., Peeples et al., 1978; Cooper et al., 1994; Oshigami et al., 2009]. We, however, cannot easily use the bulk permittivity. Because Apollo samples were collected on the lunar surface, we suspect whether the bulk permittivities based on Apollo basalt samples reflect the bulk permittivity of the lunar basalt layer. In this study, the bulk permittivity of the lunar uppermost basalt layer is estimated from the rate of D and T. In general, the subsurface bulk permittivity relates to the subsurface porosity [e.g., Shkuratov and Bondarenko, 2001]. The information of the porosity is important for discussing lunar geological conditions, so that the porosity is also estimated by using an empirical relationship between the bulk permittivity and porosity [Shkuratov and Bondarenko, 2001; Huang and Wicczorek, 2012].

We have used data sets obtained from three instruments onboard SELENE: LRS, Multiband Imager (MI), and Terrain Camera (TC). We first focused on the ejecta composition (FeO and TiO₂) around two types of impact craters (the haloed crater and non-haloed crater) due to the estimation of T. The non-haloed crater has the same ejecta composition with the surface composition of uppermost subsurface layer, while the haloed crater has the different ejecta composition from the surface composition of uppermost basalt layer. The haloed craters would be formed when meteorites excavate a lower basalt layer with the different composition from the uppermost basalt, which is lied on the lower basalt layer. The haloed crater and non-haloed crater are identified on the basis of FeO and/or TiO₂ maps created from the MI data. We would therefore constrain T from the depths of haloed crater and non-haloed crater (d_h and d_{non}) measured from the TC data: $d_{non} < T < d_h$. We note that the distance between haloed crater and non-haloed crater should be as short as possible. The true lunar subsurface boundary is probably oblique, so that the oblique subsurface boundary produces a bad limitation of T. In this study, the distance is limited within 6 km. D is also determined within 6 km from these craters by using the LRS data.

As the results, the bulk permittivity was estimated to be 2.3 - 4.2 in Unit 85 of Mare Humorum and 1.8 - 13.1 in Unit S13 of Mare Serenitatis. In particular, the bulk permittivity of Unit 85 of Mare Humorum was limited within a low bulk permittivity. This low bulk permittivity is indicative of a porous basalt layer with a porosity of 36 - 58%. This estimated porosity would be explained mainly by two different sources: intrinsic voids (vesicles and micro cracks) and impact-induced cracks (micro and macro cracks).