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Estimation of the permittivity of the lunar basalt layer based on the Kaguya observation data

ISHIYAMA, Ken[1*], KUMAMOTO, Atsushi[1], ONO, Takayuki[1], YAMAGUCHI, Yasushi[2], HARUYAMA, Junichi[3], OHTAKE, Makiko[3], KATOH, Yuto[1], TERADA, Naoki[1], OSHIGAMI, Shoko[2]

[1]Tohoku University, [2]Nagoya University, [3]JAXA/ISAS

Lunar Radar Sounder (LRS) onboard the SELENE [Ono et al., 2009] discovered subsurface layers in lunar maria. The depth, T, of the subsurface reflector is a few hundred meters, and is given by $T=(c/E_r^{0.5})t/2$, where c is the speed of the light in the vacuum, E_r is the permittivity of basalt, and t is delay time of the subsurface echo from the surface echo. The permittivity of Apollo basalt samples returned from the lunar surface was in a permittivity range from 4 to 11 [e.g., Carrier et al., 1991]. These values are useful for the rough estimation of the thickness of the basalt layer. However, in order to obtain accurate thickness of the lava flow layers, we need to know the reliable permittivity of the lunar basalt layers. Using the LRS data applied Synthetic Aperture Radar (SAR) processing [Kobayashi et al., 2011], Terrain Camera (TC) data [Haruyama et al., 2008], and Multiband Imager (MI) data [Ohtake et al., 2008], we estimate the permittivity in each lunar lava flow units: Unit 85 of Mare Humorum [Hackwill et al., 2006], Unit Unit Sy1 of Mare Smythii [Hiesinger et al., 2010], and S13 of Mare Serenitatis [Hiesinger et al., 2000]. The permittivity E_r is calculated as $E_r=(ct/(2T))^2$ [Ono and Oya, 2000].

In order to determine T, we focus on the ejecta composition (TiO_2 and FeO). When the meteorite digs up different subsurface layers from the lunar surface layer, the formed ejecta composition would differ from that of lunar surface layer if subsurface layers have the different composition. Firstly, we compare the composition of the ejecta with that of the lunar surface by MI data and distinguish the haleod crater, around which ejecta composition is different from that of the lunar surface layer, from the non-haloed crater, around which ejecta composition is the same with that of the lunar surface layer. Secondly, using TC data, we investigate the depth of these craters, and determine the boundary-depth range around these craters by a pair of the haloed and non-haloed craters. For assumption of the heterogeneity of subsurface structure, the non-haloed crater must be close to the haloed crater. The distance between these craters is limited within 6 km, and the deepest non-haloed crater is selected. Thirdly, in order to determine ct/2, we use the LRS data applied SAR processing. The synthetic aperture is 5 km, and the spatial resolution is 600 m on the lunar surface in the along-track direction [Kobayashi et al., 2011]. We use the LRS data within 2.5 km from the center of these craters. If the ejecta contains the much more highland material, we assume that the deepest subsurface echo shows the boundary between highland and mare, and calculate the permittivity by depth of the deepest subsurface echo. On the other hand, if the ejecta does not contain the mush more highland material, we assume that the shallowest subsurface shows the boundary between the lunar lava flow units, and calculate the permittivity by the depth of the shallowest subsurface echo. The exsitence of the highland material in the ejecta is decided by the abundance of TiO_2 and FeO.

As the results, the ejecta composition in Unit 85 and Sy1 indicates the rough intermediate composition.The derived relative permittivity ranges of Unit 85, Sy1, and S13 are 3.3-6.0, 3.0-5.7, and 1.7-5.8, respectively.The estimated bulk density ranges in Unit 85, Sy1, and S13 are 1.8-2.7 g/cm^3, 1.7-2.6 g/cm^3, and 0.8-2.7 g/cm^3, respectively. The average density for Apollo basalt particle is $>$3.32 g/cm^3 [Carrier et al., 1991]. Thus, even the derived maximum bulk density is lower evidently than that of the lunar basalt. It is considered that the bulk density of the lunar lava flow layers can decrease by several reasons: composition, vesicles, cracks, tubes, and the existence of the paleoregolith layer. If the low permittivity results only from the porosity in the rock, the derived porosity is about 18-20% in each unit.