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Evaluation of the maximum detection depth of the Kaguya Lunar Radar Sounder

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Introduction: Recent studies based on the subsurface radar sounding of the Moon by Kaguya Lunar Radar Sounder (LRS) have prominently shown that the radar sounder is a powerful tool for geological investigations of the planets and satellites [cf. Ono et al., 2009; 2010]. On the other hand, we have also recognized several limitations in the actual radar sounder observations. Based on Kaguya/LRS data, it was reported that there were found inhomogeneity of the subsurface reflectors in the Oceanus Procellarum [Oshigami et al., 2009]. As for the inhomogeneity, it was also pointed out that the abundance of the ilmenite such as FeO and TiO_2 affects the detectability of the subsurface echoes [Pommerol et al., 2010]. The result suggests that rich ilmenite in the lunar surface material could cause the radio wave attenuation and degrade the detectability of the subsurface echoes and maximum detection depth of the radar sounder. In the present study, we performed estimation of the subsurface echo powers based on the reflection coefficient at the buried regolith layers and attenuation rate in the basalt lava flow layers. Then we also estimate the maximum detection depth of Kaguya/LRS.

Estimation of Subsurface Echo Power: We made the following assumptions: (i) The subsurface reflectors detected by LRS are buried regolith layers. Their thickness is several meters, which is much less than LRS range resolution (75 m in vacuum). Their permittivity is ˜4. (ii) The layers between the subsurface reflectors are basalt lava flow layers. Their thickness is several hundred meters, which can be determined by LRS. Their permittivity is ˜6.25. The mass density is ˜3 g/cm^3. (iii) The abundances of FeO and TiO_2 of the subsurface basalt layers are almost similar with those on the lunar surface, which can be derived from Clementine UV-Visible image data [Lucey et al., 2000]. Based on the assumptions, we can calculate the reflectance at the buried regolith layers, and attenuation per meter in the basalt lava flow layers. Due to the interference between radio wave reflected at the upper and lower boundaries of the buried regolith layer, the total reflectance at the buried regolith layer depends on the thickness of the buried regolith layer. It also depends on the permittivity gap between basalt layers above and below the buried regolith layer. The loss tangent map was derived from the FeO and TiO_2 map. The loss tangent in the nearside maria was estimated to be ˜0.016, which is much more than that assumed in the prelaunch estimations [Ono et al., 2000; 2008]. Based on the calculated reflectance and attenuation rate, and noise level of Kaguya/LRS, which is 50 dB less than the nadir surface echo level, the maximum detection depth of Kaguya/LRS, Dmax, can be estimated. Dmax in the nearside maria is estimated at ˜1 km if assuming permittivity of ˜6.25.

Discussion: In the prelaunch studies, maximum detection depth of the Kaguya/LRS was estimated to be 5 km because loss tangent of 0.006 was assumed in them. That was, however, too small in the nearside maria. It was reported that Apollo Lunar Sounder Experiment (ALSE) detected the subsurface reflectors at depths of 1 km and 2 km in Mare Serenitatis [Peeples et al., 1978]. Because the transmitting power and dynamic range of ALSE are almost the same with those of Kaguya/LRS, the maximum detection depth of ALSE should be about 1 km. Therefore, it is quite unnatural that ALSE detected reflectors at a depth of 2 km. It was found in the present study that the subsurfcae echo power depends on the thickness of the buried regolith layers and permittivity gap among the basalt lava flow layers. The results will enable us to discuss the regolith accumulation rate, deference of lava flow compositions, and the evolution of the volcanic activity in the lunar maria in future works.

Keywords: Kaguya (SELENE), Lunar Radar Sounder (LRS), Subsurface radar sounding, Buried regolith layers, Basalt lava flow layers, Ilmenite abundance