Scattering properties near Apollo 12 landing site inferred from numerical simulation of seismic wave propagation

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Abstract

As demonstrated on the Earth, seismological investigation is a well-established way to constrain the planetary interior, and it has been applied to extraterrestrial bodies, such as the Moon [1] and Mars [2]. Basically, the uncertainty of an inner structure model highly depend on how precisely seismic phases can be read. However, in the case of the Moon, the scattering coda in the data is so intense that it is difficult to determine the phase arrivals, resulting in a large uncertainty in the resulting structure model.

This intense scattering is considered to be caused by the subsurface fractured layers called regolith or megaregolith and local topographies. The previous studies mainly investigated the scattering properties of regolith and megaregolith (e.g. quality factor Q, thickness of the layer) by analyzing the Apollo seismic data (e.g. [3][4][5][6]). Yet, there are several different models, and the lunar scattering property is still under discussion [7]. As for the scattering effect by the lunar topography, few studies looked into this although its influence on scattering-coda development has been discussed [5].

This study conducted numerical simulations of seismic wave propagation in order to constrain the scattering properties around the Apollo 12 and 14 landing sites. Because we introduced both scattering media and topographical models (surface and Moho), the output waveforms include both scattering effects. As reference seismic events, the Apollo artificial impacts were selected because their origin times, impact locations and impact parameters are well-constrained (e.g. [8][9]). The velocity structure consists of 4 layers (scattering layer 1, scattering layer 2, crust, mantle) whose parameters were referred from VPREMOON [10]. In the top 2 layers, 2 different random media based on the results by Blanchette-Guertin et al. [5] and Onodera et al. [11] were inserted. As for the source condition, we assumed isotropic radiation of P-wave as an analogue of an impact [12] and Kupper wavelet as source time function with excitation time of 0.65 s. In the simulations, we performed parameter studies on V_p/V_s ratio and thickness for the top 2 scattering layers. By comparing each simulated wave with the Apollo data in terms of rise time and seismic energy, we evaluated what kind of model is preferable to explain the data.

As a result, one of the coda envelopes for the Apollo S-IVB impact events was well reproduced from the simulations, leading to the constraint on the scattering properties of Mare Cognitum region. Our results indicate that the scattering layer in this region can be modeled with 2 different scattering layers. The first 7.5 km layer consists of 200 m scale heterogeneity with 28% velocity fluctuation while the second layer exists up to 10 km depth including 600 m scale scatterers with 14% fluctuation. As for velocity structure, we obtained the smaller V_p/V_s ratio (1.2-1.4) compared to the previous studies (> 1.7 [13]). Since the P and S-wave velocity ratio becomes smaller as the sample gets drier, our results are consistent with our understandings that the Moon has much drier environment than the Earth.

References

[1]Latham et al. (1970), *Science*, 167, 3918, 455-457.
[2]Lognonné et al. (2020), *Nature Geoscience* (in press).
[3]Cooper et al. (1974), *Rev. Geophys. Space Phys.*, 12, 3.
[4]Dainty et al. (1974), *Earth, Moon, Planets*, 9, 11-29.
[5]Blanchette-Guertin et al. (2012), *JGR Planets*, 117, E06003.
[6]Gillet et al. (2017), *Phys. Earth Planet. Inter.*, 262, 28-40.
[7]Jaumann et al. (2012), *Planet. Space Sci.*, 74, 15-41.
[8]Toksoz et al. (1974), *Rev. Geophys. Space Phys.*, 12, 4, 539-567.
[9]Wagner et al (2017), *Icarus*, 283, 92-103.
[10]Garcia et al. (2011), *Phys. Earth Planet. Inter.*, 188, 96-113.
[11]Onodera et al. (2020), *LPSC 51*th, #1277.
[12]Blanchette-Guertin et al. (2015), *JGR Planets*, 120, E004654.
[13]Nakamura et al. (1982), *LPSC 13*th, part 1, 87, A117-A123.

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