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A strategy of detection of the lunar core using a single seismic station

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Abstract

Seismic observation is a primal way to investigate the interiors of the earth and planets, as well as the moon. However, deployment of seismic stations requires an enormous fund, and it is generally not easy to make a seismic station network on the moon and planets. Here we propose a strategy to detect the lunar core with a single station by making use of scattering property of lunar seismic waveforms and long period waveforms.

1. Introduction

To clarify the interior of the moon is necessary for understanding the present thermal structure, history of the lunar dynamo and the origin and evolution of the moon [1]. The moon is the best object to verify the giant impact hypothesis [2] which is considered to be occurred in the last stage of building of the earth. The size of the core is key information on the formation of the earth-moon system [3]. Recently seismic trials to detect the lunar core using the Apollo's seismic data have been attempted and one of them reported a 330 km core [4]. However, due to the limitation of the Apollo seismic data, the reliability of the phase identifications is still controversial, and we still do not have a consensus about the core size. A new seismic experiment to obtain more suitable data for detecting the core must be expected. SELENE-2 is the next lunar exploration project of Japan in which we plan to install a broadband seismometer with sensitivity of about 10 times larger than that of the Apollo seismic sensor. It is, however, a single seismic station, which is usually considered as a significant limitation of seismic observation. Thus we need a good device to overcome the single station issue and we propose it in this article.

2. Use of Seismic Coda

The strong scattering waves (codas) observed in Apollo's seismic records are a striking feature of moonquake waveforms [5]. They have two effects on seismological analyses of seismic waveforms. One is on identification of deep moonquake nests. The scattering is so strong that waveforms of P-waves and S-waves generated by a moonquake are completely different from those by another event if the two events belong to different nests. Thus the strong scattering feature can be used to identify moonquake nests with the aid of the Apollo's seismic records if we install a seismometer at the same place of one of the Apollo's landing sites. The other is a negative effect of strong scattering codas to hide later phases reflected and converted at a structural interface which have much information on the depth of the interface. This is a primary reason that makes analyses of the internal structure of the moon difficult. The scattering codas are thought to be generated in the surface regolith/mega-regolith and fracture zones produced by meteorite impacts since the fractures producing codas cannot be preserved in a deep interior because of compaction and annealing. Using the standard seismic structure model of Nakamura (1983) [6], we found a characteristic frequency of 0.12 Hz (i.e. a period of about 8 sec) of the surface very low velocity layer with a thickness of about 1 km. Hence waveform components longer than the period can be expected to suffer less scattering. They have also a merit to be able to propagate over a long distance because of less damping.

3. Core Detection

From the above discussion, we propose a strategy to identify the core of the moon using a single seismic station with a sensor that covers a frequency range of 0.02 to 50 Hz. For the core identification, we must determine a moonquake location, detect core phases and read polarities and arrival times of them.

Applying a band pass filter with the same response of the Apollo's LP peaked mode to broadband data and calculating cross-correlations with the Apollo's LP records, we can identify deep moonquakes. The state (solid or fluid) of the core is determined by the existence of SJS (S-waves traveling throughout the core and mantle) (Figure 1). The polarity of ScS (S-waves reflected at the core-mantle interface) may also help the determination. The core size is determined by the relative arrival times of ScS to direct S. Amplitudes and frequency responses of ScS and SJS are not so different each other and difficulty of detection is on the same degree (Figure 1). Our calculations show that long period waveforms of the core phases can be expected to be observed without suffering codas. If observation period is about two months, we can expect an occurrence of a deep moonquake with a moment magnitude of about 2.3 and an amplitude of long period (> 10 sec) waveforms of an order of 3×10^{-11} m/s. This indicates that one-year observation of seismic sensor with a sensitivity 10 times higher than the Apollo LP seismic sensor leads us to a reasonable determination of core reflection waves which provides us with new information on the size and state of the lunar core.

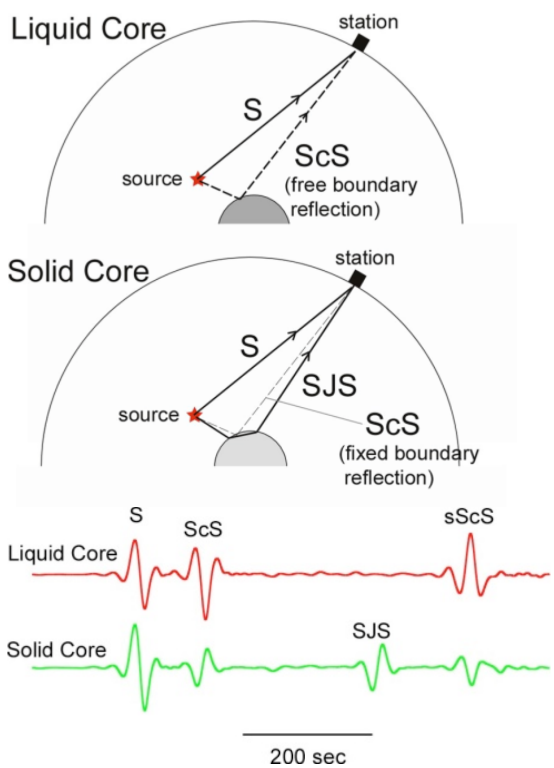

Figure 1: Core phases and their ray paths for a liquid core model and solid core model (top), and theoretical long period waveforms for the two models (bottom). For the solid core, the polarity of ScS is reverse and SJS can be observed. The core radius of 300 km and an epicentral distance of 60° are assumed.

4. Summary and Conclusions

The scattering codas are usually considered as an undesirable characteristic in the lunar ground motions. With a single station located at one of the Apollo landing sites, they can be used as a device to identify moonquakes. Long period waveforms of so identified events can be used to determine the core size and state. Reflection phases in the long period waveforms (> 10 sec) are clearly observable if a seismic sensor has effective sensitivity with 10 times higher than that of the Apollo LP sensors.

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