Seismic tomography of the Moon

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During the U.S. Apollo project from late 1960s to early 1970s, six seismometers were installed on the near-side lunar surface to record moonquakes. Four seismometers had been operational from 1969 to 1977, which recorded about 12,000 moonquakes (Nakamura et al., 1982). One-dimensional (1-D) seismic velocity structure of the lunar interior was estimated by using the P and S wave arrival time data from the moonquakes (e.g., Nakamura, 1983; Goins et al., 1981; Lognonne et al., 2003). However, three-dimensional (3-D) velocity structure of the Moon has not been determined yet.

In this study, we have attempted to apply the seismic tomography method of Zhao (2001, 2004) to the arrival time data from the moonquakes recorded during the Apollo project to estimate the 3-D P wave velocity structure of the lunar interior. We used the data from 8 artificial impacts, 19 meteorite impacts, 8 shallow moonquakes, and 57 deep moonquakes. Most of the deep moonquakes occurred at depths of 800-1000 km, which enabled us to determine the deep lunar structure (note that the radius of the Moon is 1738 km). 3-D grid nodes were set up in the lunar crust and mantle down to 1000 km depth under the near side of the Moon. The grid spacing is 10 degrees (about 303 km) in the horizontal direction and 20-100 km in the depth direction. Velocity perturbations at the grid nodes are taken as unknown parameters. The velocity perturbation at any point in the model is calculated by linearly interpolating the velocity perturbations at the 8 nodes surrounding that point.

Our results show that significant lateral heterogeneities exist in the lunar interior. In particular, low-velocity anomalies exist in the depth range of 100-400 km, which may suggest the existence of asthenosphere in the Moon. Since there is no plate tectonics in the Moon, these lateral heterogeneities may be produced at the early stage of the Moon formation and evolution, and they are preserved till today. There seems some correlation between the distribution of the deep moonquakes and lateral velocity variations in the lower lunar mantle, suggesting that the occurrence of the moonquakes may be affected by the lunar structural heterogeneity in addition to the tidal forces caused by the Earth and the Sun. Our results are still preliminary. Further efforts are needed on the observational aspects to obtain sufficient lunar seismological data, which is possible only after installing more seismometers on the lunar surface.

Zhao, D. (2001) Seismic structure and origin of hotspots and mantle plumes. Earth Planet. Sci. Lett. 192, 251-265.

Zhao, D. (2004) Global tomographic images of mantle plumes and subducting slabs: insight into deep Earth dynamics. Phys. Earth Planet. Inter. 146, 3-34.