

Vertical distribution of KREEP explored by lunar seismic tomography

Tomoko Arai[1]; Dapeng Zhao[2]

[1] Univ. of Tokyo; [2] RCPEV, Graduate School of Sci., Tohoku Univ.

The local enrichment of heat-producing elements, such as Th, in the Procellarum KREEP Terrane (PKT) of the lunar nearside is considered to be linked with a magma ocean residue, and to be causes of the extensive and long-lived magmatism. Understanding vertical and lateral distributions of the KREEP materials within the PKT is important to properly estimate the bulk-Moon abundance of heat-producing elements, which provides critical constraints on the origin and the thermal evolution of the Moon. The lateral distribution has been surveyed by remote sensing, but the vertical distribution has been unclear. In this study, the lunar internal structure inside and outside the PKT is explored by seismic tomography.

We determined the 3-D seismic velocity structure of the lunar interior down to 1000 km depth, by applying seismic tomography to the moonquake arrival-time data recorded by the Apollo seismic network operated during 1969 to 1977. Deep moonquakes are observed to occur repeatedly at some fixed nests in a depth range of 750-1400 km [1]. Six layers of grid mesh are set up at depths of 20, 150, 300, 500, 700 and 900 km. The grid spacing is 10 degrees in the horizontal direction (about 303 km at the lunar equator), which is comparable to that in the global tomography of the Earth. The lunar 1-D seismic velocity model [1] is taken as the starting model of the 3-D tomographic inversion, because the hypocenter parameters of all the deep moonquakes used here are determined with the model [1]. Although the Apollo seismic network consists of only four stations, the seismic waves from the deep moonquakes can sample a large fraction of depth range in the lunar interior even with a local seismic array. The analytical method is presented in Zhao et al. (2008) [2].

The tomographic results show significant structural heterogeneities both laterally and vertically. In the western area of the central nearside, the low-velocity (low-V) anomalies of S-wave tomography prevail in the shallow mantle down to 200-300 km depth, and the high-velocity (high-V) zones are located in the middle to lower mantle (400-600 km depth). In contrast, the high-V zones are present in the upper mantle, and the low-V anomalies occur in the middle to lower mantle, in the eastern area. Note that some of the low-V zones in the shallow mantle of the western area extend continuously down to the middle to lower mantle under the eastern area. Patches of the low-V zones are also visible in the lower mantle (500-900 km depth) beneath both the western and eastern areas.

Because no plate tectonics occurs in the Moon, the observed lateral and vertical seismic-wave variations likely represent structural and compositional variations generated during a magma ocean crystallization and subsequent magmatism. The distribution of the low-V materials in the shallow mantle of the western area is consistent with the surface distribution of the high-Th region (PKT), while the surface areas corresponding to the high-V zones are either anorthositic highland or basaltic mare. Thus, the low-V or high-V zones are probably attributed to different abundances of heat-producing elements. The distribution of low-V zones likely represents the distribution of KREEP materials in the lunar interior. The upside-down distribution of the low-V and high-V zones inside and outside the PKT suggests a mantle overturn due to density instability. The low-V patchy zones in the deep mantle (500-1000 km depth) inside and outside of the PKT imply that the overturned KREEP materials provided a heat source for the partial melting associated with mare basalt volcanism. The thickness of the low-V zone indicates that the KREEP layer (about 300 km) is much thicker than the current estimate (50-60 km). The 3-D tomography reveals that the depth of the magma ocean is at least as deep as 1000 km.

References:

[1] Nakamura Y. (1983) JGR 88, 677-686.

[2] Zhao D. et al. (2008) Chinese Science Bulletin 53, 3897-3907.