Infiltration of Fe-S Melt into Ilmenite: Implications for the Lunar Low-Velocity Zone

*高木 彪[1]、芳野 極[1]
*Hyu Takaki[1], Takashi Yoshino[1]

1. 岡山大学惑星物質研究所
1. Institute for Planetary Materials, Okayama University

Seismic observations have shown the presence of a low-velocity zone (LVZ) at the base of the lunar mantle above the core–mantle boundary (CMB), where wave velocities decrease from ~8.5 to ~7.5 km/s in V_P and from ~4.5 to ~3.2 km/s in V_S (Weder et al., 2011). This zone has commonly been interpreted as an ilmenite-rich partially molten layer formed after a mantle overturn event, during which dense ilmenite-bearing cumulates sank and accumulated near the CMB (Zhao et al., 2019). However, the estimated CMB temperature of ~1400 °C (Khan et al., 2006) raises questions about whether extensive partial melting of ilmenite-rich material is thermodynamically plausible under present lunar CMB conditions.

In this study, we evaluate the possibility that the LVZ is a region where Fe–S melt infiltrates into an ilmenite-rich layer. The lunar outer core is estimated to contain approximately 10–20 at.% sulfur (Antonangeli et al., 2015), implying the presence of Fe–S liquid at the base of the mantle. Because of the density contrast between Fe–S melt and surrounding mantle materials, simple porous percolation is unlikely to sustain melt transport over ~150 km, corresponding to the inferred thickness of the LVZ. Therefore, an additional mechanism is required to enhance Fe–S melt infiltration. Morphological instability (Mullins-Sekerka instability), which amplifies small perturbations on a phase boundary through diffusion-controlled processes, may facilitate localized, deeper infiltration beyond what is expected from simple porous flow (Otsuka and Karato, 2012).

To evaluate this hypothesis, we conducted high-pressure infiltration experiments between sintered ilmenite aggregates or single-crystal ilmenite and $Fe_{60}S_{40}$ melt at 4.5 GPa and 1400 °C. The results show that Fe–S melt readily infiltrates sintered ilmenite aggregates along grain boundaries. In natural single-crystal ilmenite, melt infiltration exhibits deep finger-like structures resembling textures attributed to morphological instability. These observations indicate that Fe–S melt can effectively infiltrate ilmenite-rich layers under lunar CMB conditions.

The presence of Fe–S melt within an ilmenite-rich layer may significantly reduce seismic velocities and could account for the observed decreases in both V_P and V_S without requiring ilmenite or silicate partial melting. Our results suggest that Fe–S melt infiltration into an ilmenite layer is a plausible mechanism for generating the seismic low-velocity structure at the base of the lunar mantle.

キーワード：月コア–マントル境界、低速度層、Fe–Sメルトの浸透、イルメナイト、高圧実験
Keywords: lunar core–mantle boundary, low-velocity zone, Fe–S melt infiltration, ilmenite, high-pressure experiment

