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Sound velocity and density of iron-titanium-rich melt support an overturned melt layer in the deep lunar interior

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Fe-Ti-rich cumulates, formed as the last dregs of the crystallizing lunar magma ocean, are thought to drive a large-scale overturn of the lunar mantle. Such a process could introduce Fe-Ti-rich bodies into the deep lunar interior, where they may become part of the source for Fe-Ti-enriched Apollo basalts and ultramafic glasses [1]. Analysis of lunar seismic and laser ranging data has implied that some of the overturned Fe-Ti-rich bodies may have reached the lunar core-mantle boundary and become a partially molten layer [2-3] due to their enrichment in heat-producing elements (e.g., KREEP). However, whether such a molten layer could be stable during the post magma-ocean lunar history and explain lunar seismic observations are still debated. Here we report the first ultrasonic velocity measurements on an Fe-Ti-rich lunar melt of Apollo 14 black glass composition up to 4.3 GPa and 2010 K, corresponding to the conditions of the lowermost mantle of the Moon. Our velocity data, combined with room-pressure density calculated from the partial molar volumes of oxides [4], tightly constrain the equation of state (EOS) for lunar Fe-Ti-rich melt. The modeled density and velocity profiles of Fe-Ti-rich melt-bearing lunar mantle using our EOS and velocity results are compared with various lunar seismic models [5], which suggests that at least 20% of Fe-Ti-rich melts, formed from melting of the overturned Fe-Ti-rich cumulates, are trapped atop the lunar core-mantle boundary (~1200-1350 km) until the present day, strongly influencing the thermochemical evolution of the lunar interior. In addition, our results indicate that Fe-Ti-rich lunar melts are able to rise from their source regions (~250-500 km) estimated by multiple-saturation experiments [6] to form the Fe-Ti-enriched basalts and glasses collected by the Apollo missions on lunar surface, which is contrary to previous studies [7-8] on the buoyancy of Fe-Ti-rich melts.

References

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