Internal structure of the Moon: Thermodynamics vs seismology

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Based on a self-consistent thermodynamic-geophysical approach, we convert the recent seismic models of the lunar mantle to the temperature-depth profiles using Gibbs free energy minimization in the Na_2O-TiO_2-CaO-FeO-MgO-Al_2O_3-SiO_2 system [1]. The results lend support to the chemically stratified lunar mantle with a change in composition from predominantly pyroxenite upper mantle depleted in Ca and Al (~2% CaO and Al_2O_3) to predominantly fertile lower mantle enriched in Ca and Al (4-6% CaO and Al_2O_3). Such a zoned structure places significant constraints on any theory of lunar origin. Seismically derived temperatures allow us to constrain thermal structure of the lunar mantle and estimate the upper mantle heat flow (3.8-4.7 mW m^{-2}), which is not consistent with that found from the Apollo heat flow and thorium abundance measurements. Lower mantle temperatures are well below the probable solidus condition and can be evaluated at the level of 1420-1550ºC at the core-mantle boundary without requiring a melt layer. We find that regardless of the composition, the positive *S*-wave velocity gradient in the lunar mantle leads to a negative temperature gradient, which has no physical basis [1]. The physical properties of the lunar Fe–S core are modeled with molecular dynamics and the Embedded Atom Model potential; the density of the liquid core may vary from 7.4 (liquid iron) to 6.75 g/cm^3 (Fe-10 at.% S) [2].

Support: Prog. No 9,28 RAS, RFBR grant No 15-05-01161.

[1] Kuskov, O.L. *et al*. (2015) *Solar System Research* **49**, 75.
[2] Belashchenko, D.K., Kuskov, O.L. (2015) *Doklady Earth Sci.* **460**, 37.