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Thermal state and uranium content in the lunar mantle

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1. Introduction

Recent study of the Moon's gravitational field has been performed and the Love numbers have been estimated with high accuracy (the Chang'E and GRAIL missions). Obtained values can be achieved in case of the presence of the partial melting of the near-core zone. In the recent papers [7,2] the analysis of seismic waves reflected from the core has been used. The results suggest the presence of a solid inner and fluid outer core, overlain by a partially molten boundary layer [7], which gives the constraints on the temperature at the core-mantle boundary (the temperature should be close to the solidus temperature). According to [6], the solidus temperature of the probable lunar mantle rocks with the pressure of 4 GPa is about 1600^{O}C. The goal of this work is to estimate the temperature distribution, uranium content in the lunar mantle and surface heat flow for the model of the Moon with a partial melting in the lower-most mantle.

2. Computer simulation

Following [3], we apply one-dimensional stationary thermal conductivity model. We suppose that non-stationary effects are insignificant or at least are equal to other assumptions of the model. The Moon consists of the crust, the upper mantle with source intensity Q_{upper} and the lower boundary at the depth interval (H_{upper}) of 500-1000 км and the lower mantle with source intensity Q_{lower} and the depth from the upper mantle to the core with fixed radius R_{core} =350 km. We apply the model of the lunar magma ocean. Obtained by thermodynamic methods temperature of the lunar mantle at the depth of 1000 km is 1200-1350^{o}C [5]. The presence of the partially molten boundary layer [7] imposes constraints on the temperature. The temperature at a depth of 1250 km should be higher (about 1600^{o}C) than a value in the most models.

Following restrictions on the model have been accepted in this study:

1. Temperature at the crust-mantle boundary (from inversion of seismic velocities to temperature): $T_{cr\text{-}mantle}$ =350 – 550 ^{o}C [5]

2. Temperature gradient in the upper mantle (from seismic data inversion [5]): dT/dH ≈1.17 K/km

3. Temperature at the depth of 1250 km (from melting condition): $T_{1250} \approx 1600$ ^{o}C.

4. The composition of the lower (undifferentiated) mantle should be identical with the composition of overlying layers (the model of a lunar magma ocean) [4].

It is impossible to determine the derivative of temperature in the lower mantle because of the large errors in seismic velocities. Therefore, the coupling procedure of mantle temperatures (T_{seimic}), determined by inversion of seismic data and temperatures (T_{cond}), calculated with a one-dimensional heat equation is applied.

3. Results

Due to the uncertainty in estimation of the uranium content in the crust (U_{crust}) by different authors, it is regarded as a parameter. In the range of U_{crust} = 80–240 ppb, the temperature distribution (Fig. 1), the temperature gradient (Fig. 2), the uranium content in the upper (U_{upper}) and lower (U_{lower}) mantle, and also heat flow from the Moon's surface (J_{Moon}) were calculated. The magma ocean depth is 750 km (a sharp seismic velocity increase in seismic models [1]), the crust density ρ=2550 kg/m^{3}, probable temperature of the crust-mantle boundary $T_{cr\text{-}mantle}$=350^{o}C. There exists a solution that is in agreement with the seismic data and the statement of the thermophysical problem under a limited range of the required parameters. The results obtained show a weak dependence of U_{bulk} and J_{Moon} on the thickness of the Moon's upper mantle and the temperature at the crust-mantle boundary (*T*cr-mantle).

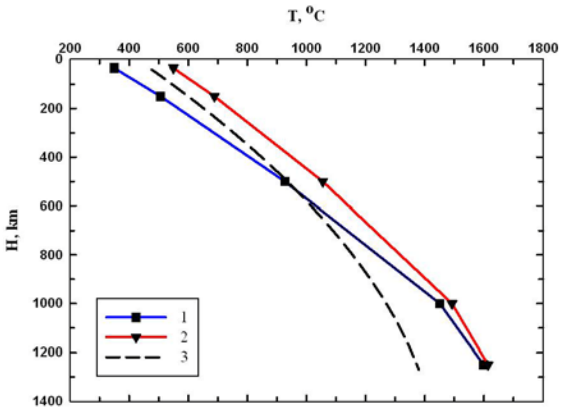

Figure 1: The temperature in the lunar mantle. 1 – typical profile for the temperature $T_{cr\text{-}mantle}$= 350°C; 2 – typical profile for $T_{cr\text{-}mantle}$= 550°C; the depth of boundary crust-mantle $H_{crust\text{-}mantle}$=750 km, crust density ρ=2580 kg/m^3, the depth of the crust H_{cr}=34 km; 3 – typical profile for the model without melt [3].

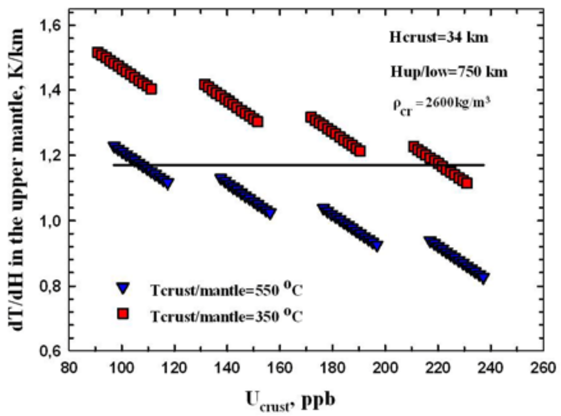

Figure 2: Temperature gradient in the upper mantle; red squares - $T_{cr\text{-}mantle}$= 350°C, blue triangles - $T_{cr\text{-}mantle}$= 550°C; Solid line – the gradient dT/dH = 1.17 K/km.

Bulk uranium concentrations in the silicate Moon have been estimated at the level of 15-19 ppb. Calculated values of surface heat flow (6-8 mW/m^2) are two or three times less than Apollo-15 and -17 estimations. Temperature profiles with $T_{cr\text{-}mantle}$=550°C are less probable because of too high temperatures in the upper mantle. For the model with the $T_{cr\text{-}mantle}$=350°C, the resulting uranium bulk concentration is about 19 ppb. Numerical experiments show that the restrictions of the seismic velocities [1] allow us to obtain the temperature required to melt the mantle at a depth of 1250 km.

Acknowledgements

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