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The lunar heat flow and the bulk composition

V. A. Kronrod, O. L. Kuskov and T.M. Kronrod
Vernadsky Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences, Moscow, Russia,
va kronrod@mail.ru

1. Introduction

The internal structure of the Moon strongly depends on its composition and thermal regime. However, geochemical surveys of returned lunar samples do not give direct information about the composition and physical properties of the mantle. Seismic models and surface heat-flow measurements provide only indirect information about the composition and temperature of the Moon. Heat flow measurements provide the most direct method of estimating the bulk abundance of refractory elements such as U and Th.

In situ heat flow measurements were carried out during the Apollo 15 and 17 missions. The heat flow values derived from these two measurement sites were 21 mW/m^2 and 14 mW/m^2 respectively [1]. Reanalysis of Apollo heat-flow data concluded that these heat-flow estimates had been too high by a factor of two to four. In the present work, we suggest a new model of distributions of radiogenic heat sources and Al_2O_3 in the Moon and of surface heat-flow.

2. Computer simulation and result

The problem of heat-flow estimation is divided into two stages.

1. At the first stage, the mass, moment-of-inertia factor, seismic velocities and the hypothesis of magma ocean are used to model the internal structure of the Moon. The chemical composition of the lower (undifferentiated) mantle, which is not affected by melting, is assumed to be similar to the average composition of the overlying lunar shells and to reflect the bulk composition of the silicate portion of the Moon. The phase composition and the physical parameters of the mantle are calculated using the method of the Gibbs free energy minimization and the equations of state for the mantle material in the system CaO-FeO-MgO-Al_2O_3-SiO_2 [2]. A Monte-Carlo inversion procedure has been used to estimate the distributions of the density, composition and velocities in the mantle and Fe-FeS core radii [2, 3]. There were found possible values of temperature and major oxide concentrations in the mantle. The minimal temperature of the upper mantle at depth 150 km (500^{o}C) has been found from numerical experiments, the maximal temperature in lower mantle at the depth of 1000 km was set at 1300^{o}C. Probable temperature profile in the mantle is determined, Fig. 1.

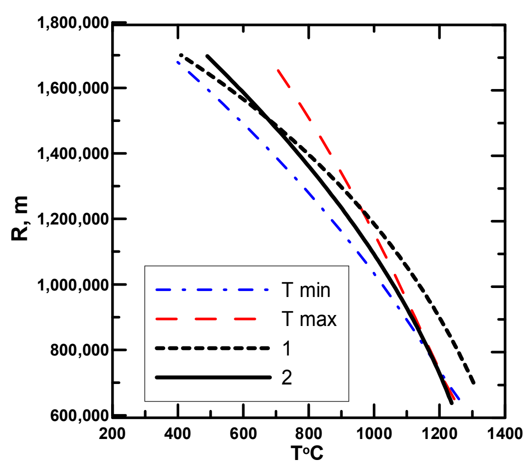

Figure 1: Temperature distributions in the mantle. T_{min} , T_{max} – the minimal and maximal temperature in our models. 1 – [2], 2 - Probable temperature profile.

We also have determined bulk concentration FeO=11-12wt.% and the relationship of the concentration Al_2O_3 (wt. %) as function of the T_{mean}, were T_{mean} – the mean volume temperature in the mantle, ^{o}C [4]:

$$Al_2O_3 = -5.7 + 0.0113 T_{mean} \quad (1)$$

2. Temperature profile has been adjusted to a thermophysical model of conductive transfer. It is assumed that the nonstationarity effects are small compared to other uncertainties of the model. Therefore, following [5], we adopt a 1-D stationary

model of heat conduction. The mantle flow and radiogenic heat sources are estimated from temperature profile of the mantle.

We propose that the thermophysical model of the Moon consists of crust, two-layered mantle and core. Following parameters of model were considered: crust depth was taken in the interval of 40-50 km км, upper-middle mantle boundary - 500-1000 km., radius of the core - 350 km. The heat sources in the upper and lower mantle and surface heat flow q have been determined, Fig .2.

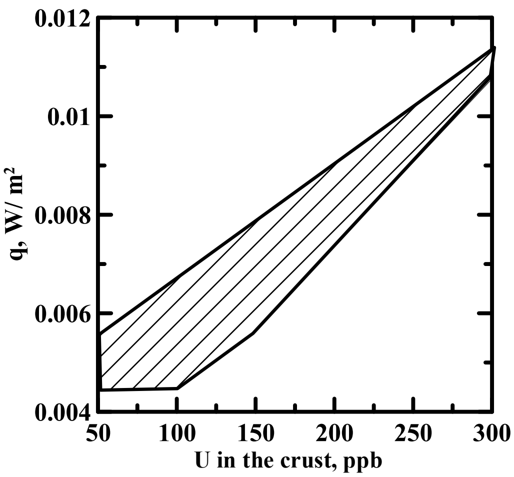

Figure 2: The lunar surface heat flow q

Assuming model of magma ocean, a crust containing an average of 28 wt% Al_2O_3, Th/U=3.8, K/U=2000, we were estimated the variation in Al_2O_3, U in the lunar mantle as a function of the average Th concentration in the crust, assuming that the Moon has a chondritic Al/Th ratio [6], Fig.3.

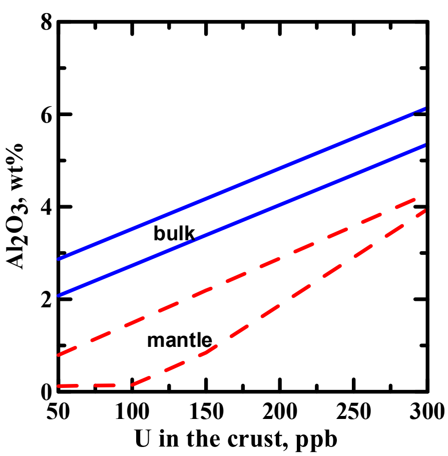

Figure 3: The lunar concentration Al_2O_3.

We have assessed Al_2O_3= 4±0.5 wt. % from (1) and probable concentration in the crust Th=300-400 ppb [7]. The discrepancy ($\delta F=F_{SN}-F_S$) between the stationary (F_S) and nonstationarity (F_{NS}) models (F=bulk Al_2O_3, bulk U) have been estimated:

$$\delta F \approx -(0.15 - 0.3)F \qquad (2)$$

The major results of our investigations are following: The surface heat flow $q \approx$ 4.5-7.0 mW/m^2, bulk concentration U ≈ 8-15 ppb, bulk concentration Al_2O_3 ≈ 4wt.%. The Moon's bulk composition is probably far less exotic than generally assumed.

Acknowledgements

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