EPSC Abstracts
Vol. 6, EPSC-DPS2011-175, 2011
EPSC-DPS Joint Meeting 2011


# Geochemical and geophysical constraints for thermal state of the Moon

E. V. Kronrod, O. L. Kuskov and **V.A. Kronrod**
Vernadsky Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences, Moscow, Russia,
kendr_ka@bk.ru

In this work we found the probable temperature distribution and its influence on the internal structure of the Moon. The problem of thermal state of the Moon was provisionally divided into two parts:

1. The probable temperature distributions in the mantle were found from seismic and geochemical data for various geochemical models of the Moon.

2. Using these data and mass and moment of inertia of the Moon as well as seismic velocities we determine temperature distributions and major oxide concentrations in the lunar mantle.

We consider these tasks more carefully:

**1.** The temperature field of the Moon was defined by a new method of inversion of seismic information into temperature distribution using P- and S-velocity information. In order to scrutinize thoroughly the likely effects of seismic and compositional models on the temperature distribution in the lunar mantle, we use the method described in detail in our previous publications [2,5]. Briefly, this is a thermodynamically self-consistent approach in which the isotropic seismic velocities are converted to temperature profiles and vice versa, based on a method of minimization of the total Gibbs free energy in conjunction with a Mie-Grüneisen equation of state[6].

Converted temperature profile allows detect the preference of upper and lower mantle composition and estimate the degree of uncertainty of lunar composition. Three basic petrological models of the Moon were considered: olivine pyroxenite (Ol-Px) [3], pyrolite [8], and Ca, Al-enriched composition (olivine-clinopyroxene-garnet – Ol-Cpx-Gar) [3].

As a result of moon's thermal field computational modeling, geophysical and geochemical constraints on composition and temperature distribution in up and low mantle of the Moon were determined. Following conclusions were done:

1. Chemical composition is the most important parameter in conversion of seismic velocities into temperature effects. Calculated temperature for pyrolite composition in the upper mantle doesn't satisfy seismic constraints. Pyroxenite composition (~2 wt% CaO and $Al_2O_3$) [fig.1] do satisfy seismic constraints in the upper mantle. Lower mantle composition can be presented by either the pyrolite or olivine-clinopyroxene-garnet assemblages.

2. Temperature distribution in the depth range 50-1000 km can be described by approximate equation (1) [5].

$$T(^oC) = 351 + 1718[1 - exp(-0.00082 \cdot H)] \quad (1)$$

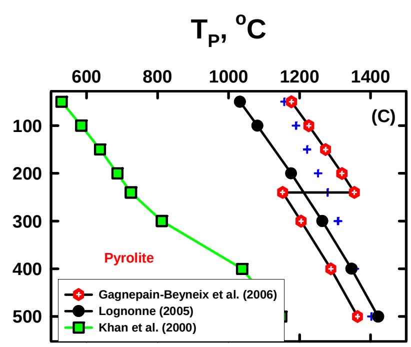


Figure 1: Temperature distribution in the upper mantle of the Moon, derived from recent seismic data [1,7] and geochemical constraints for pyroxenite composition.

**2.** On the basis of gravity (mass, moment of inertia) and seismic data (P- and S-velocities) and using Monte-Carlo method all the lunar thermal state constraint set is analyzed. Consequently qualitative dependences between bulk composition, core size and lunar mantle temperature distribution were gained. Problem statement is described in [4]. Calculations of the phase composition and physical properties of the mantle were done using Gibbs free energy minimization technique and equation of state of minerals in the system CaO-FeO-MgO-$Al_2O_3$-

$SiO_2$ [6]. Input data are: mass, radius, moment of inertia of the Moon and seismic velocities in the mantle. According to seismic data we propose that the model of the Moon consists of crust, three-layered mantle and Fe-10%S core. The core sizes were determined from calculations. Following parameters of a model were considered: crust depth was taken in the interval of 40-55 km, upper-middle mantle boundary - 250-300 km, middle-lower mantle boundary - 625-750 km. Mantle-core boundary defines from calculations. Minimal temperature of the upper mantle at depth 150 km (500 $^oC$) was defined from numerical experiment. Maximal temperature in the lower mantle at the depth of 1000 km is 1400$^oC$ (that is 150 $^oC$ less than the solidus temperature). Estimations for different temperature profiles were done. The temperature for the upper mantle is set as 500-750 $^oC$, for the middle mantle – 750-1200 $^oC$, for the lower mantle – 950-1400 $^oC$. As gradients of temperature in initial profiles were different, a comparison of the results was done for an average temperature of the mantle:

$$T_{mean} =( T_{up}V_{up}+ T_{mid}V_{mid} +T_{low}V_{low})/( V_{up}+ V_{mid} +V_{low}) \quad (2)$$

Indexes up, mid, low correspond to upper, middle and lower mantle, V – volume of corresponding mantle zone.

The results of modeling $Al_2O_3$ in lower mantle are presented in fig.2

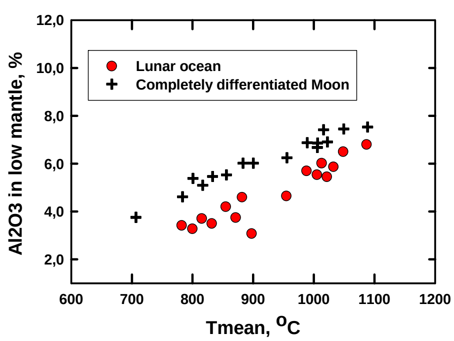


Figure 2: Concentration of $Al_2O_3$ as functions of $T_{mean}$. Crust - upper mantle bound is 40 km, upper-middle mantle -250 km, middle-lower mantle bound is 625 km.

The following conclusions for part 2 can be done:

1. Temperature distributions in the lunar mantle essentially influence on bulk composition of silicate Moon, especially on the concentration of $Al_2O_3$.
2. The lunar mantle is stratified by the chemical composition.
3. The silicate part of the Moon is essentially enriched in FeO (10.5-13 wt. %) and depleted in MgO (28.5-32.5 mas.%) in comparison with the earth's mantle. MG# lies in the range of 0.82-0.84.

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