ANALYSIS OF LUNAR SEISMIC AND TEMPERATURE PROFILES BY THERMODYNAMIC MODELING. E. V. Kronrod, O. L. Kuskov and V. A. Kronrod (Vernadsky Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences, Moscow, Russia, Kosygin st.19, kendr_ka@bk.ru).

Introduction: Until recently most of published seismic models of the Moon were represented as a vertical profiles divided into several zones with medium value of P- and S- velocities [1,2]. In the recent work [3] the distribution of seismic velocities is more complicated that gives new opportunities for lunar thermal state and chemical composition researching. The main problem of this work is estimating of seismic models confidence and determination of lunar models constraints by using the methods of physic-chemical modeling.

Computer simulation and results

The approach consists of the seismic velocities calculation from temperature distribution and geochemical data (direct modeling) and retrieving the chemical composition and temperature from the geophysical constraints including the seismic data, the moments of inertia and mass of the Moon (inverse modeling) [4-8]. The direct and inverse problems are solved by the minimization of the Gibbs free energy incorporating equations of state of minerals, phase transformations, anharmonicity (thermal expansion and compressibility), and attenuation effects (anelasticity of mantle material at high temperatures), which should be considered due to nonlinear variations in thermodynamic and seismic properties with increasing of temperature and pressure [4,6]. There is rich variety of bulk composition models proposed for the Moon: from models enriched in Ca and A1 to Earth-like compositions in which Ca and AI content is lower [6].

Different petrological models of the Moon were considered. Three basic petrological models [6]: olivinic pyroxenite (Ol-Px), pyrolite, Ca, Al-fertile composition (olivine-clinopyroxene-garnet – Ol-Cpx-Gar).

Calculation models: Khan model [5] (the values of concentrations were taken from the histogram), constant-depth composition that satisfies geophysical constraints and Mis – composition, that optimally satisfies geochemical and geophysical constraints [7].

I. Analysis of temperature profiles calculated from seismic models and composition

Calculated from inverse modeling of seismic velocities [3] temperature profiles contain negative trend. Negative trend of temperature profiles calculated for constant composition disagrees with physical constraints. Also calculated from P- and S-velocities temperature profiles have essential distinctions. Hence it appears that in model [3] P- and S-velocities are discordant.

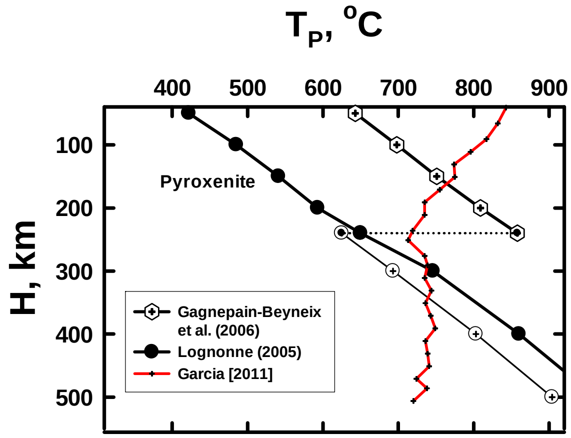

Fig.1 Temperatures calculated from seismic data

II. Analysis of seismic profiles calculated from temperature and composition

To estimate seismic profile accuracy we have calculated computational thermodynamic seismic profile. Using input data of chemical composition solving the direct problem of thermodynamic modeling seismic velocities can be calculated. It is necessary to estimate optimal temperature profile for calculating thermodynamic profile.

Constraints on the temperature profile. We determine the probable temperature profile T_{pm} from several criterions: solution of the full inverse problem [9], determined from seismic velocities inversion temperature profile [6], temperature melting of the upper zone of the core [10], absence of melting geological material on the depth upper 1000 km, positive or zero vertical density gradient. Determined temperature should be close to the one-dimensional thermal conduction model. Further constraints of the lunar mantle temperature profile will be considered in details.

The minimal temperature in the upper mantle. The range of probable temperature variations in the mantle was obtained in the works [6, 8]. We have found the minimal temperature in the upper mantle. The temperature of 500°C at the depth of 150 km satisfies limitations of mass, inertia moment and seismic velocities [2]. For less temperature there is no correct solution.

Gradient dT/dH in the mantle. Absence of density inversion is a natural requirement for the hydrostatic equilibrium satellite. Dimensionless moment of inertia of the Moon is similar with the moment of inertia of homogeneous body. Computational modeling confirms the hypothesis of the density homogeneous mantle. From numerical modeling temperature profile with gradient ***dT/dH =1,05-0,0006*H, (H – km)***, was selected. This profile satisfy zero gradient with acceptable accuracy.

Probable temperature profile. We have found acceptable agreement calculated from absolutely different models - the constant density model and uniformly distributed radiation sources model. The mantle temperature is described by equation:

$T=1.05\ H-0.0003H^2+C$. Constant C evaluates from known temperature in any point in the mantle. Temperature gradient at the depth of 150-1000 km accurate within 1°C, $\delta T_{1000-150}=T_{1000}-T_{150}=600^oC$.

Probable temperature at the depth of 500 and 1000 km. Weber et all [10] gives estimation T=1650° К (1380 C) at the radius R=480км (H=1730-480=1250 km). We have found dT/dH= 0.375-0.45 K/km and the temperature at the depth of 1000 km $T_{1000}=1200\text{-}1250^oC$. It is necessary to set the temperature in some point of the mantle, than calculate constant C. If the minimal temperature is T_{150}=500°C, then the temperature at the depth of 1000 km T_{1000}=1100C. For the temperature T_{1000}= 1200C is needed T_{150}=600C. Probable temperatures T_{150} from different models will be discussed. The temperature T_{150}=570-630C was found from inverse problem with a constraints of moment of inertia, mass and seismic velocities [6, 9]. In the recent paper [9] on the seismic data was obtained $T_{150}=570\pm 100^o\ C$. Summarized these data and constraints $T_{1000}=1200\text{-}1250^oC$ we have initialized $T_{150}=600^oC$. Correlating all of this data gives probable temperature profile of the lunar mantle at the depth less than 1000 km: $T_{pm}{}^oC=449+1,05*H-0,0003H^2$, **H** – depth in kilometers.

We have calculated probable temperature profile for lunar mantle on basis of numerical experiment. Using input data of chemical composition and method of direct modeling, on the base of temperature profile seismic velocities can be calculated. Thus we have estimated probable distribution of seismic velocities for the whole range of chemical composition. Velocity gradient in the article [3] varies greatly from calculated models. Due to our analysis there are no constant composition models with similar velocities.

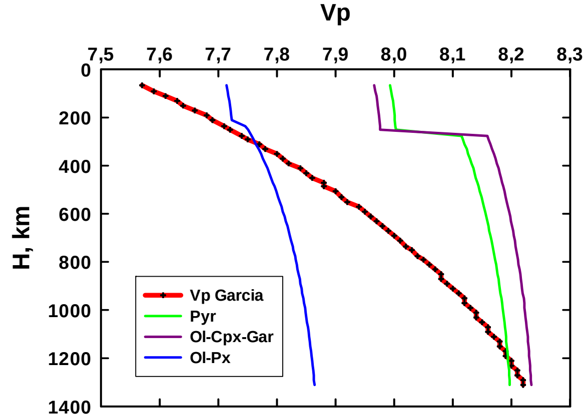

Fig2. Seismic velocities calculated from the direct modeling ($T_{pm}{}^oC=449+1,05*H-0,0003H^2$, H – depth in kilometers)

Following conclusions can be done:

1. Probable temperature profile of the lunar mantle estimated by the following:

$$T_{pm}{}^oC=449+1,05*H-0,0003H^2,\quad H\text{ – km}$$

2. Calculated from seismic velocities [3] and constant composition doesn't satisfy the physical limits.
3. Velocities Vp and Vs in model [3] are not consistent.
4. Seismic velocities gradients for model Garcia et al. [3] can't be calculated for constant composition.

Acknowledgements

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