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The analysis of seismic profiles of the Moon 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,
va kronrod@mail.ru

1. Introduction

Until recently most of published seismic models of the Moon were represented as a vertical profile 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 possibilities 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 methods of physic-chemical modeling.

2. Computer simulation and result

The approach consists of calculating the seismic velocities from temperature distribution and geochemical data (forward modeling) and retrieving the chemical composition and temperature from the geophysical constraints including the seismic data, the moment of inertia and mass of the Moon (inverse modeling) [4-7]. The forward 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 taken into account due to nonlinear variations in thermodynamic and seismic properties with rising temperature and pressure [4,6,7]. 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.
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].

Three basic petrological models of the Moon: olivinic pyroxenite (Ol-Px), pyrolite, Ca, Al-fertile composition (olivine-clinopyroxene-garnet – Ol-Cpx-Gar) [6] and calculation models Khan et al. model [5] (the values of concentrations were taken from the histogram) were considered.

2.1 The analysis of temperature profiles calculated from seismic data and composition.

We found that a negative trend (Fig.1) of temperature profiles calculated from inverse modeling for constant composition disagrees with physical constraints. Also calculated from P- and S-velocities temperature profiles have essential distinctions (Fig. 2). Hence it appears that in model [3] P- and S-velocities are discordant.

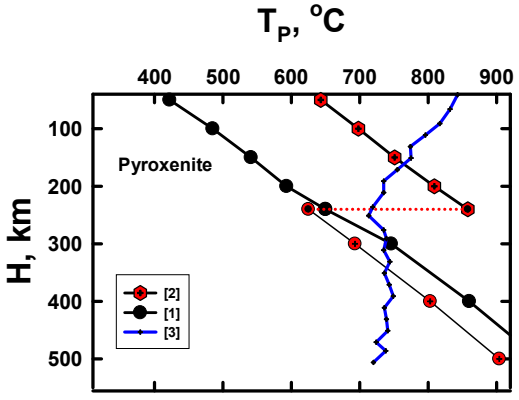

Figure 1: Calculated temperature distributions for pyroxenite (Ol-Px) composition for different seismic models.

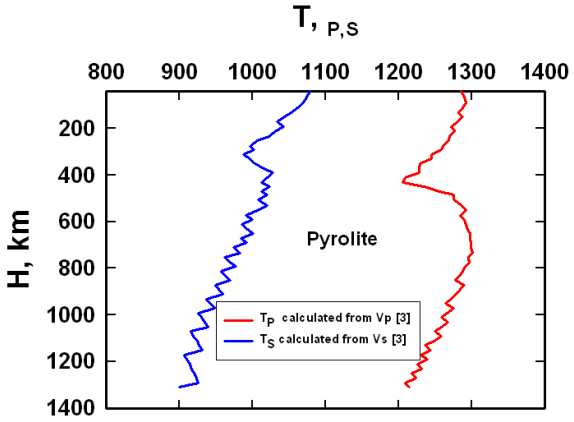

Figure 2: Calculated temperature distributions for pyrolith composition for model [3]

2.2 The analysis of seismic profiles calculated from temperature and composition

We have calculated probable temperature profile for lunar mantle on basis of numerical experiment:

$$T^oC=448+1.05H-0.0003H^2 \quad (1),$$

H – depth in kilometers.

Using input data of chemical composition and method of forward modeling, on the base of (1) seismic velocities can be calculated.

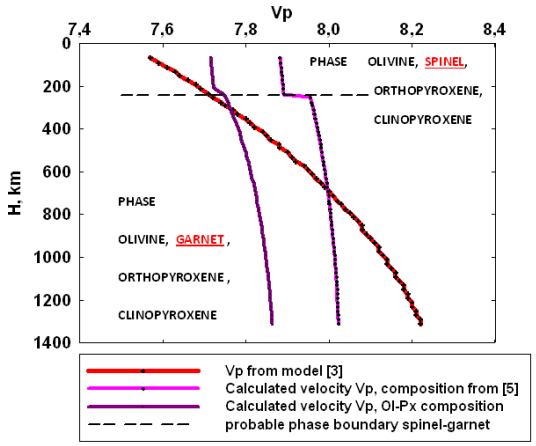

Figure 3: Comparison of seismic velocities calculated from forward modeling and Vp [3]

Thus we have estimated probable distribution of seismic velocities for the whole range of chemical composition. Veloicity gradient for model [3] varies greatly from calculated models (Fig. 3). Due to our analysis there are no constant composition models with similar velocities.

2.3 Summary and Conclusions

Following conclusions from our investigation of model Garsia et al. [3] can be done:

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

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