INTERNAL STRUCTURE OF THE MOON INFERRED FROM APOLLO SEISMIC DATA, SELENODETIC GRAIL AND LLR DATA AND THERMODYNAMIC CONSTRAINTS

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In the recent paper (1) lunar interior models by complementing Apollo seismic travel time data with selenodetic data which have recently been improved by GRAIL and LLR. Important information on the thickness of the crust, LVZ, core structure and seismic velocities was obtained. But this problem statement retains lunar mantle composition to be uncertain. In (2,3) mantle composition can be simulated based on thermodynamic approach and petrological evidence from seismic data, MOI and mass. The goal of this paper is to investigate lunar internal structure models which are consistent with the seismic and the selenodetic (GRAIL and LLR) data and thermodynamic constraints.

We apply spherically symmetric viscoelastic hydrostatic model of the Moon (1). The Moon consists of nine layers: megaregolith, crust, four-layers mantle, low viscosity zone (LVZ), liquid outer core and fluid inner core. In each zone physical properties are assumed to be constant. We employed same data as (1): four selenodetically observed data of mean radius, mass, MOI, and tidal Love number *k2* (4). Seismic travel time data was selected by (5).

Geochemical models of bulk Al and Fe composition: Currently there are two main groups of geochemical models of the Moon (6): 1. Moon's composition with Al content similar to models with Earth's Al_2O_3 content; 2. The Moon is enriched in Al against Earth. We consider models with Earth's Al_2O_3 content. Analysis of majority of current Moon's composition models (6) revealed that for group 1 Al_2O_3 = 4,05 ± 0,36 wt.% and Fe_2O_3 = 12,25 ±1,33 wt.%. Division mantle into 4 layers was performed according to (7) model. Concentrations of main oxides were equal in first 3 upper mantle layers (Mantle 1-3 in Fig.1) and we applied the model of magma ocean to calculate oxide concentrations in fourth lower mantle layer (Mantle 4 in Fig.1) (which implies that concentrations of main oxides in the lower mantle is equal to average concentrations in upper mantle and crust and equal to bulk concentrations). The models of the magma ocean in such a formulation were considered in our previous work (3). Temperature in the lunar mantle is defined by equation from (8).

Thermodynamic approach: The general our methodology is to combine the geophysical and geochemical constraints and thermodynamic approach, and to develop, on this joint basis, the self-consistent models of the Moon. The crustal composition of Taylor (1982) are taken as representative of the crust material. Thermodynamic modeling of phase relations and physical properties in the multicomponent mineral system CFMAS was used to develop a method for solving the inverse problem [3].

Inversion: A Bayesian inversion approach is an effective method to solve for a nonlinear problem such as planetary internal structure modeling, e.g., [7], [9]. The solutions of the parameters and their uncertainties are obtained from the posterior distribution which is sampled by the MCMC algorithm. In the present model bulk Al content and bulk Fe content are included into likelihood function (LHF).

Results: The main results are shown in Fig.1. Probable concentration of Al_2O_3 is 2,7-2,9 wt.% in the upper mantle and 4,1-4,3 wt.% in the lower mantle. Bulk Fe_2O_3 is within 11,5-12,5 wt.%. Seismic P-wave velocity (~7,92 km/s) in the lower mantle is close to lower bound of velocity range from (7). From these results it can be concluded that the models of the Moon with Earth's bulk Al content is in a good agreement with geophysical data.

References: [1] Matsumoto et al. (2015),GRL, 42, i18, 7351–7358; [2] Khan et al.(2007), Geophys. J.,168, 243–258; [3] Kronrod, Kuskov (2011) Izvestiya. Phys. Solid Earth (Rus), 47, 711-730; [4] Williams J. G. et al. (2014) *JGR, 119*, 1546- 1578; [5] Lognonne P. et al. (2003) *EPSL, 211*, 27-44; [6] Kuskov O.L.et al. (2014) *PEPI*, 236, 84-95; [7] Gagnepain-Beyneix et al. (2006) PEPI,159,140–166; *[8] E. V. Kronod et al.* (2013), Solar System Study: 4M-S3 IKI RAN,94-104.

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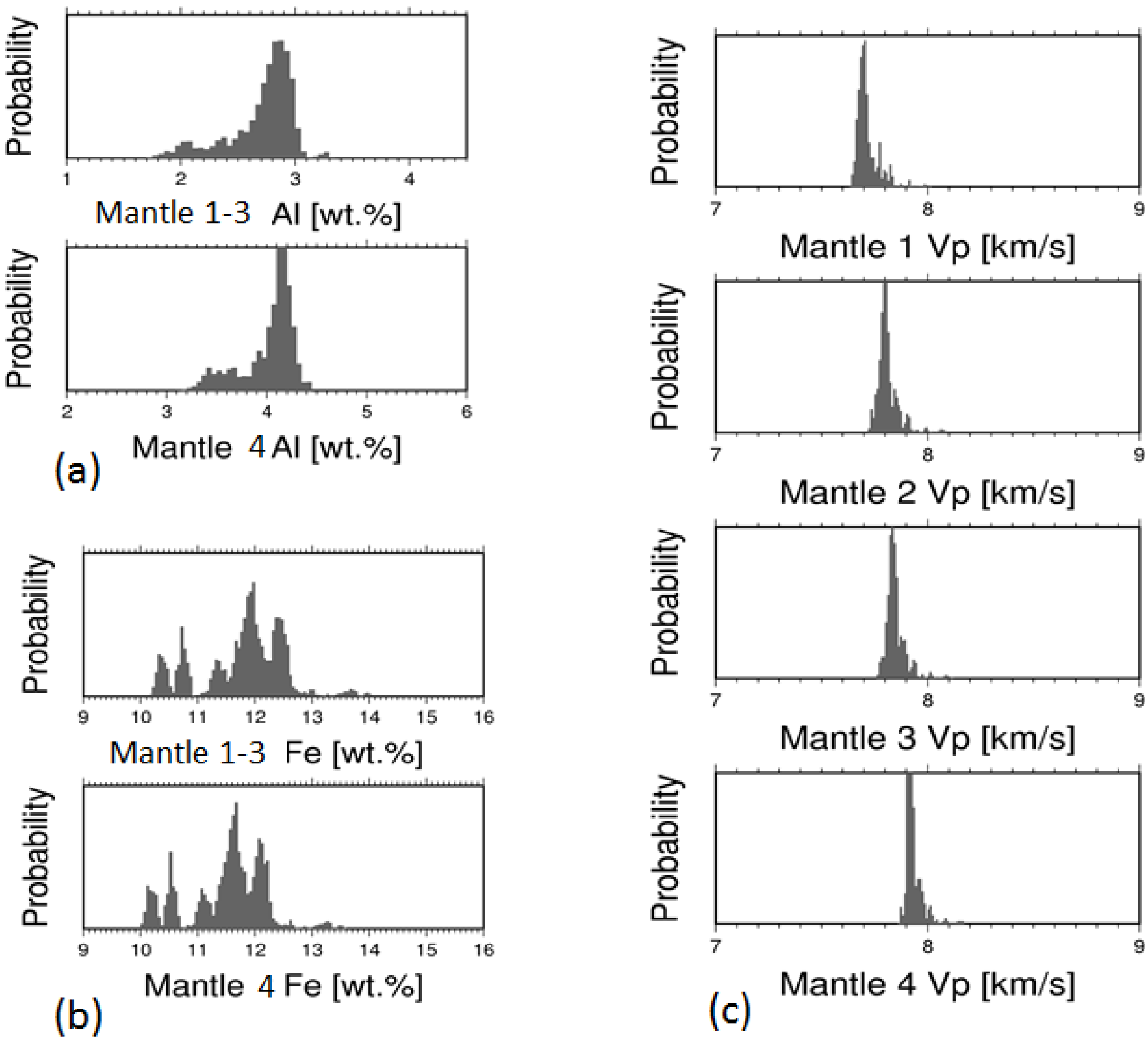

Fig. 1 Posterior probability density functions: Al (a) and Fe (b) concentrations and P-wave seismic velocities distribution in layers 1-4 of the lunar mantle.