Models of chemical differentiation of the Moon

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On the basis of geophysical constraints (P- and S- wave velocities, moment of inertia and mass of the Moon) and method of mathematical modeling of phase relation and physical properties in the system $CaO-FeO-MgO-Al_2O_3-SiO_2$, we examine the hypothesis of chemical differentiation of the Moon as a result of partial melting of initially homogeneous material (hypothetical magma ocean). We consider models of internal structure of the Moon with five layers including a crust, a three-layer silicate mantle, and a Fe–10 wt.% S-core (ρ=5.7 g cm^{-3}). The general methodology is to combine geophysical and geochemical constraints and thermodynamic approach, and to develop, on this joint basis, the self-consistent model of Moon, accounting for its chemical composition and internal structure. The Al_2O_3 content in the lunar crust (ρ=2.9-3.0 g cm^{-3}) varied between 25 and 30 wt%. The concentrations of major oxides for the entire mantle varied in the ranges $2 \leq CaO$ and $Al_2O_3 \leq 8\%$, $25 \leq MgO \leq 45\%$, $40 \leq SiO_2 \leq 54\%$, $6 \leq FeO \leq 20\%$. The technique of Gibbs free energy minimization was used, and equations of state of minerals and solid solutions were included in the database. The solution of the inverse problem is based on the Monte Carlo method. We determine the ranges of chemical composition, mineralogy, velocities and density in the upper, middle and lower mantle as well as core sizes. The results of our inversion procedure generate velocity and composition distributions in the lunar mantle. The bulk composition of the silicate portion of the Moon (mantle+crust) is estimated (wt. %): $3.<CaO<3.8\%$, $3.7<Al_2O_3<4.7\%$, $11<FeO<12.5\%$, $28<MgO<30\%$, $49<SiO_2<51\%$, MG# ~81. The chemical composition of the Moon bears no genetic relationship to the terrestrial material as well as to any of the known chondrites.

Primordial alkalis in chondrules

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Chondrules are believed to have formed in a high temperature event in the early solar system. High temperature in combination with low fO_2 should lead to rapid loss of Na from the molten chondrules (Yu *et al.*, 2003). Existence of Na-rich chondrules in unequilibrated chondrites can be explained by nebular and/or parent body metasomatism or by the absence of Na loss during melting (Humayun and Clayton, 1995).

We used EMPA to measure sodium in olivine and glass in type I and II chondrules of UOC Semarkona (LL3.0). Goal of our study is to show whether alkalis were present in the liquid during olivine crystallization. Na in olivine was analyzed with a beam current of 300 nA for 600 s on the peak and 2 x 300 s on the background. The detection limit was determined to be ~ 10 µg/g.

Na_2O-concentrations in mesostasis vary in the range of 0-12 wt.%. Na_2O in olivine in chondrules varies in the range of 0-68 µg/g (type I) and 40-110 µg/g (type II).

Our data show that Na was present in chondrules during olivine crystallization. The apparent D_{Na} (ol/mesostasis) is 0.0005 for type I and 0.001 for type II chondrules, respectivly. Calculating the D_{Na} between olivine and bulk gives a D_{Na} of 0.005 for type I and II. Borisov *et al.* (in prep.) give a D_{Na} (ol/melt) of ~ 0.003. This value is in agreement with our data. Absence of loss of alkalis requires either high alkali partial pressures and/or a very rapid heating and cooling of chondrules. Our interpretation of the presence of Na in chondrule olivine explains the absence of K-isotope fractionation in chondrules in the way that evaporation did not take place during chondrule melting.
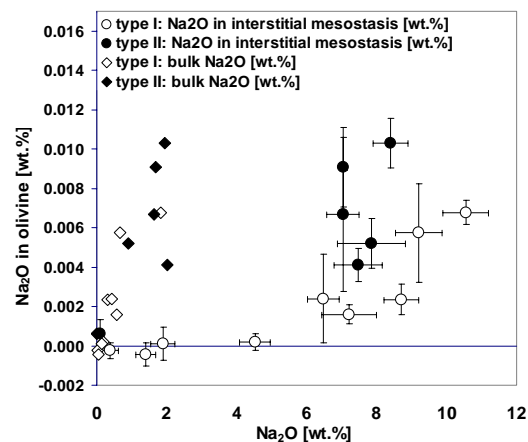
Reference

Yu *et al.* (2003), *Geochim Cosmochim Acta* **67**: 773-786.
Humayun and Clayton (1995), *Geochim Cosmochim Acta* **59**: 2131-2148.