ON THE EFFECT OF THE Mg/Si RATIO ON THE MANTLE DYNAMICS OF THE MASSIVE ROCKY PLANETS. IMPLICATIONS FOR THE HABITABILITY AND SUPERHABITABILITY OF HZ-SUPER-EARTHS.

Péter Futó [1]

1. University of Debrecen, Department of Mineralogy and Geology, Debrecen, Egyetem tér 1. H-4032, Hungary (dvision@citromail.hu)

Introduction

Rocky planets, possibly habitable-zone (HZ) super-Earths, may have highly favorable conditions for a complex biosphere making the planet more hospitable for life than Earth. These are the so-called superhabitable worlds [1]. The one of the plausible conditions for superhabitability (SH) is likely to be the relatively long-time plate tectonics, which depends on the physical requirements of mantle convection. The strong effect of adiabatic compression on the mantle convection due to the high viscosity contrast may result in stagnant or sluggish lid regime in more massive terrestrial planets than Earth [2].The low efficiency of convective heat transport in the mantle can hinder the cooling of the core and thus the maintenance of the magnetic field. It is known that the planetary composition may significantly affect the mantle dynamics. The observed stellar abundances of the key rock-forming elements, the low C/O (<0.8) and the Mg/Si ratios (mainly 1<Mg/Si<2) in photospheres of planet host stars indicates that the Earth-like magnesium silicate composition may be relatively common for terrestrial planets in the Milky Way Galaxy [3, 4].

Surface conditions, thermal evolution and planetary habitability of rocky planets are strongly depend on their tectonic regime [5]. Accordingly, long-time active tectonics has been assumed to be crucial to long-term habitability, mostly for SH. Therefore, this study is being based on the importance of the active-lid tectonic regime and the mineralogical composition of mantles of super-Earths. I focus on that silicate mineralogy and a favorable range of Mg/Si ratio.

Modeling the effect of Mg/Si ratio on the mantle convection in rocky planet interiors: I investigated the conditions of mantle convection by making simple magnesium silicate mantle models for rocky super-Earths (Ses) with masses ranging from 1-5 $M_\oplus$. Scaling laws of $R_p = M^{267}$, $d = M^{0.29}$ have been applied for total radius and mantle thickness.

The Rayleigh number Ra is defined by $\rho_0 g\ \alpha\ \Delta T\ D^3/\ \eta_0\ \kappa$. Rayleigh number parameters for the mantle are ρ_0 = 3416 kg m^{-3}, g = 9.81-20.8 ms^{-2}, the coefficient of thermal expansion $\alpha = 4 \times 10^{-5}\ K^{-1}$, the temperature contrast is being calculated in all model $\Delta T = (T_b - T_s)$, mantle thickness D = 2900 - ~ 4600 km, η_0 = is the viscosity on the bottom boundary of the model layer ($T=T_b$) and the average thermal diffusivity $\kappa = 10^{-7}\ m^2/s$. Pressure-dependence of ✔ has been taken into accounted based on the study of Tachinami et al. 2014 [6] while as opposed to it κ is constant for simplicity.The viscosity predictions for the mantle-models can be expressed in terms of the Arrhenius law and the viscosity contrast (r) across the mantle has been pescribed by $r = \eta(T_s)/\ \eta(T_b)$.The activation energy E_a=30 kJ/mol^{-1} and the activation volume V=10^{-6}. The effects of the adiabatic compression is considered and it has been computed by utilizing model parameters of this study and considering the methods and results of previous studies.

(Mg, Fe)SiO_3 bridgmanite and ferro-periclase (Fp) [(Mg, Fe) O] are known as major mineral constituent in Earth's lower mantle. Fp is in rock-salt (B1) phase (Fp is in B2 phase only at core mantle boundary (CMB) pressure of ~ 5$M_\oplus$) and its molar ratio increases with increasing Mg/Si ratio related to the perovskite (pv) and post-perovskite phase (ppv) bridgmanite, respectively. The mantle volume fraction (MVF) of $MgSiO_3$ pv and ppv + B1 (+B2) Fp layer increases with increasing planet mass.

The increased amount of Fp may have a considerable impact on mantle dynamics by decreasing the lower mantle viscosity [7]. The pressure-induced high-to-low-spin transition of iron may have a large effect on the viscosity of Fp [8]. Computing the effects of varying molar Mg and Si ratios, Fp has been characterized by a composition of $Mg_{(1-x)}Fe_xO$ with iron concentrations (x) of 0.2.

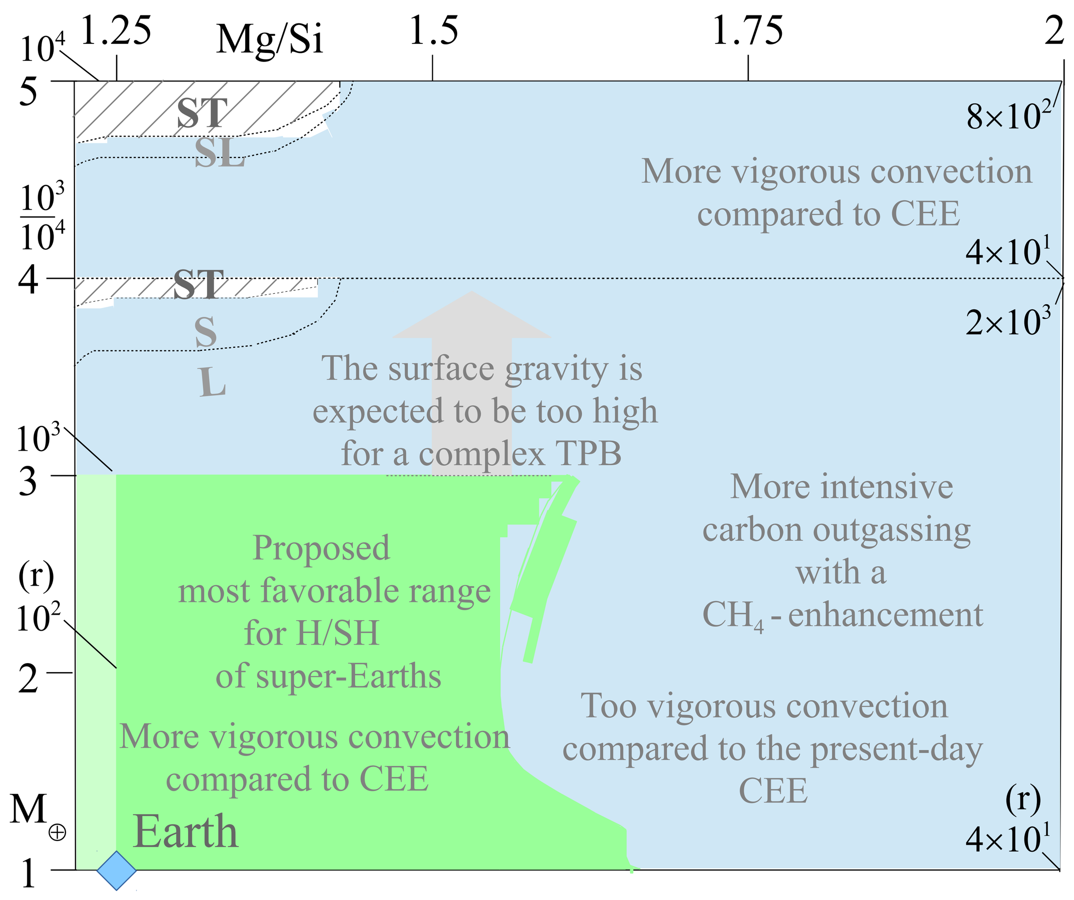

Fig 1. ST-L and SL-L denote the stagnant- and sluggish lid modes of convection. TPB: terrestrial-type photosynthetic biosphere. CEE: The level of present-day convection efficiency in Earth's mantle, which is based on the calculated Ra and convective velocities.

A favorable mantle compositional range for H- and SH-super-Earths: In the range of Mg/Si ratio >1.25, a decrease may occur in r compared to that of an Earth-analog mantle composition by up to a factor of ~1-3 due to the reduced viscosity of ppv with an enhanced Fp ratio. A ~10^2 viscosity reduction occurs by the B1-B2 phase transition in MgO (at 0.5 Tpa) [9], which can enhance the theoretical maximum mass limit of mantle convection. I find that planets with higher Mg/Si ratios relative to Earth, may have a limited growth in mass, within which the mantle convection may be more efficient compared to planets with lower bulk Mg/Si ratios (Fig.1). It can have a small favorable effect on H and SH of SEs, moreover, as planet mass increases in this range MVF of lower mantle viscosity region also grow. In terms of this model, those rocky planets can provide most favorable conditions for H and SH, which have a mineral compositions in the range of 1.25-2 Mg/Si ratios, total masses between 1 and ~3 $M_\oplus$ and CMFs ~ 0.25-0.4.

Summary: A determined range of elevated Mg/Si ratio can helps to form the neccessary conditions for being a super-Earth is habitable or „superhabitable”.

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