OPTIMAL CORE SIZES FOR EARTH-LIKE HABITABILITY.

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Introduction: It is proposed that the molten core plays an extraordinally important role in Earth's habitability by generating the magnetic field, which protects the complex lifeforms from the harmful solar UV radiation.

It is believed that the absence of dynamo-generated magnetic field on Venus is due to the lack of plate tectonics (PT) [1]. For massive rocky planets, an entirely core-cooling driven dynamo can operates in planets more massive than 3 ($M_\oplus$) but only if they have PT [2]. However, these massive rocky planets have a relatively weak dynamo, depending on the mass and the surface temperature. Planets larger than 2-2.5 $M_\oplus$ do not develop solid inner cores. In the mass range between 2-3 $M_\oplus$ rocky planets will not be able to maintain long-lived dynamo, it can only operate within several billion years. 1-2 $M_\oplus$ rocky planets with PT can sustain a dynamo by core cooling before inner core formation to several gigayears yielding a sharp increase in the strength of the planet's magnetic field.

I found that rocky planets need to have more requirements to able to host complex life as expected. An Earth-like habitable world, being a cored rocky planet, is necessary to have a favorable mantle structure and mineral composition. The formation of a favorable mantle structure is likely depends on more factors, thus on relative size of the core, the core radius fraction (CRF).

The outermost zone of the core and the D" region, which is an important thermo-chemical boundary layer in the mantle, play a critical role in the Earth's evolution [3]. The source of the large mantle plumes has been assumed to be in the D"region due to the developed thermal instabilities [4]. Accordinghly, it has been assumed that an optimally developed D"region in the rocky planetary interior may have a favorable impact on the geological conditions and the criteria of plate tectonics, which support the development of a complex biosphere with high biodiversity.

Medium- and small -sized metallic cores have been calculated for rocky planets with masses between 0.9-3 $M_\oplus$ focusing on those geological and mineralogical conditions, which can be optimally favorable to the formation of an Earth-like character. This study is based partially on the importance of being a determining role of deep mantle D" region in efficient mantle dynamics.

Model: The model planets has been calculated to having mantles with Earth-like composition and metallic cores composed entirely of Fe. They have no significant water and iron content in the mantle. The mineral compositions of the mantle are being modeled taking into account the relevant thermodynamic parameters of the olivine with its high-pressure polymorphs: wadsleyite (wdl) plus ringwoodite (rwd) in the upper mantle; $MgSiO_3$ pv (perovskite) + Mw magnesiowustite) and ppv (post-perovskite)+Mw in the lower mantle. For simplicity, the metallic cores modeled by hcp – phase of Fe in all planet model.

The utilized zero-pressure densities of hcp - Fe[1] , MgO[2] , ppv[3] , pv[4], wdl/rwd[5] and olivine[6] are 8.255[1] [5], 3.67727[2] (calculated for MgO by the data of Strachan et al. 1999) [6], 4.27[3] [7] , 4.152[4] [8] , 3.644[5] [8] , and 3.347[6] [8] g cm^3. Vinet EOS [9, 10] has been used for computing the material properties in the upper mantle and in the pv belt in the lower mantle. Murnaghan equation of state [11] is being applied to calculate the pressure/density relation in the ppv belt.

In the core-mantle boundary (CMB) region of the Earth's lower mantle, the $MgSiO_3$ pv $\rightarrow$ ppv phase transformation at ~ 2700 km depth matches the location of D" seismic discontinuity.

As planet mass increases, the VF (volume fraction) of lower viscosity region of the mantle is also grow. While VF of the D" region decreases with decreasing planet mass.

Optimal sizes of planetary cores for Earth-like habitability: For small-Earth-sized planets, considering that driving forces of PT are weaker than on Earth, tectonic plates may became stronger in a shorter period of time for the case of more rapid cooling a smaller sized core due to that the mantle also cool faster. Otherwise, a relatively slight decrease in core size reduces to a greater extent the optimal strength of magnetic field compared to super-Earths. A significant decrease in core size results in the increase of mantle thickness with elevated viscosity contrast (r), which can cause convective shutdown, leading to the stagnant-lid style of convection (mostly for Mg/Si ratios < 1-1.2). The hot mantle being isolated may prevent the effective core cooling and the operation of dynamo process, yielding a much weaker magnetic field around the planet.

It is proposed that, the iron-cored HZ-super-Earths with masses ranging from ~ 1-3 $M_\oplus$ may be able to host complex life if they have favorable bulk silicate planet (BSP) composition and an optimal size of their cores. It has also been suggested that rocky planets with Earth-like bulk silicate composition and Earth-like CMF (0.3259) may harbor terrestrial-type complex biosphere above a limited planet mass, which is calculated to be ~ 0.915 $M_\oplus$ (Fig.1) under conditions yielding from this model. For an Earth-like habitability, rocky planets slightly less than Earth are necessary to have a medium-sized core, which is similar in mass fraction to that of Earth. Considering the geophysical, geological and compositional conditions, the small Earth-sized rocky planets with Earth-like CMF and masses ranging from 0.95 - 1 $M_\oplus$ (Fig.2), while the low-mass rocky super-Earths with masses ranging from 1 – 2 $M_\oplus$ can be the most favorable planets for harboring complex photosynthetic biosphere with high biodiversity.

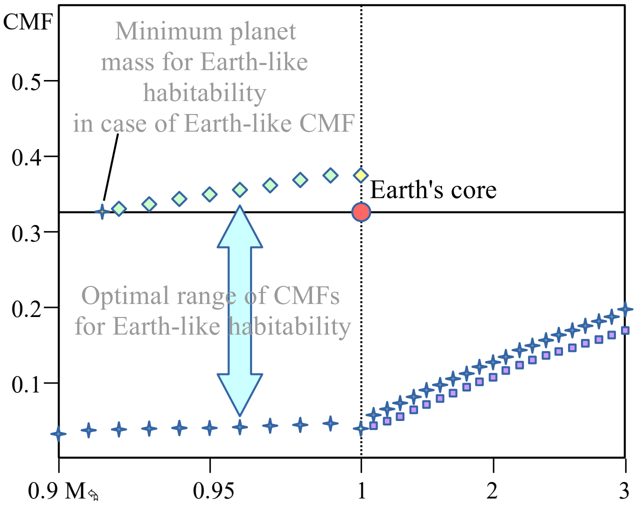

Figure 1. The minimum (denoted by blue stars) and maximum limits (indicated by green squares) of core sizes has been shown for rocky planets with masses ranging from 0.9-1 $M_\oplus$. The minimum CMFs for super-Earths (1 – 3 $M_\oplus$) are also being denoted by blue stars, while magenta squares indicate the smallest core mass fractions for efficient mantle dynamics in case of a magnesium-rich mantle (Mg/Si = 2). The maximum (0.3739 - yellow square) and minimum (0.039 - yellow star) CMFs of an optimal geodynamics for Earth have also been calculated for comparison.

Conclusion: In terms of this model, those small-earth-sized rocky planets may have Earth-like character, which have a CRF smaller than the depth of pv-ppv phase transition. It is suggested that optimal CMFs for Earth-like habitability can not be much smaller than an Earth-like value owing to the higher viscosity contrast between the uppermost mantle layer and deep mantle.

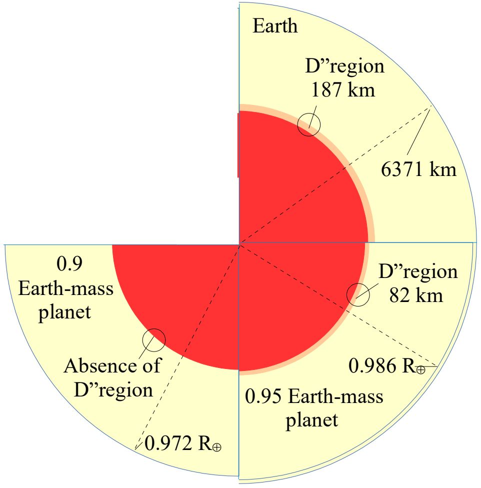

Figure 2. The interior structures of a 0.9, a 0.95 Earth-mass planet and the Earth. All planets have an Earth-like CMF. The 0.95 Earth-mass planet may have even favorable conditions to host a terrestrial-type complex biosphere.

The low efficiency of convection cooling of the mantle can hinder the cooling of the core and to develop dynamo generation of planetary magnetic fields. The variations of mineralogical composition my significantly affect the mantle dynamics, the conditions of PT. Consequently, the planetary mineralogy plays a key role in the efficiency of magnetic dynamo processes. Moreover, the mantle mineralogy has a major impact on the optimal core size for the Earth-like habitability.

References: [1] Nimmo F. (2002): *Geology,* 30, 987-990. [2] Gaidos F. et al (2010): *The Astrophysical Journal,* 718, 596-609. [3] Young C. J., Lay T. (1987): *Annual Review of Earth and Planetary Sciences,* 15, 25-46. [4] Lay T. (2005): *Plates, plumes and paradigms: GSA Special Paper 388,* 193-205. [5] Wu S. Q. et al. (2011): *Physical Review B,* 83, 184102. [6] Strachan A. et al. (1999): *Physical Review B.,* 60, 15084. [7] Tsuchiya T. et al. (2004): *Earth and Planetary Science Letters,* 224, 241 – 248. [8] Stixrude, L., Lithgow-Bertelloni C. (2005): *Geophysical Journal International,* 162, 610-632. [9] Vinet P. et al. (1987): *Journal of Geophysical Research,* 92, 9319. [10] Vinet P.et al. (1989): *J.Phys.-Cond.- Matter,* 1, 1941 [11] Murnaghan F.D. (1944): *Proceedings of the National Academy of Science,* 30, 244-247.