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Constraints on planetary habitability from interior modelling

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Abstract

The most interesting planetary bodies outside the Solar System regarding the search for life are potentially rocky extrasolar planets. Some of them may feature surface conditions that allow for liquid water, which is the elementary prerequisite for life as we know it. The amount of greenhouse gases, like e.g. carbon dioxide (CO_2), plays an important role for the determination of the surface temperature, hence the habitability of an extrasolar planet. The amount of greenhouse gases is strongly influenced by their outgassing from the interior.

In this study, we investigate under which conditions the planetary interior structure and dynamics allow for the build-up of planetary atmospheres which may lead to habitable surface conditions.

1. Model

We investigate the evolution of a secondary atmosphere for Earth-sized planets with different interior structures (i.e. iron-silicate mixing ratios) by applying a two-dimensional model of interior dynamics for an extended Boussinesq fluid [1], which allows for the calculation of the production of partial melt [2]. From this, we estimate the amount of CO_2 outgassing for Earth-sized planets with different core and mantle radii after adapting the total CO_2 outgassing in 4.5 Gyr for a Venus reference simulation to the present-day atmosphere of Venus. We furthermore investigate the possible influence of plate tectonics on outgassing and the likelihood of plate tectonics depending on the interior structure of the planet.

1.1 Parameters

We vary the ratio of core radius to planet radius (RR from here on) between 0.25 and 0.9. The initial upper mantle temperature is varied between 2000 K and 2400 K. We assume a wet olivine rheology but use an increased reference viscosity of 10^{22} Pas for numerical reasons. For our plate tectonics models, we employ a pseudo-plastic yielding and apply a surface yield stress of 50 MPa with different friction coefficients.

2. Outgassing

We find that the size of the iron core has a large impact on the production of partial melt, hence on the possible outgassing of CO_2, which is due to the pressure-dependence of the melting temperature of silicate rocks: for planets with a large core the planetary mass is larger than for a planet with a small iron core, leading to larger melting temperatures in the upper mantle. Therefore only little mantle depletion and outgassing from the interior can be expected for both initial upper mantle temperatures, see fig. 1.

For the determination of the outer edge of the habitable zone it is typically assumed that enough greenhouse gas CO_2 is available in the atmosphere to lead to liquid water at the surface – independent of the interior of the planet [3]. Our results on the other hand suggest that the outer boundary of the habitable zone may be constrained by the production of partial melt in the interior for planets with a large iron core and a thin silicate mantle.

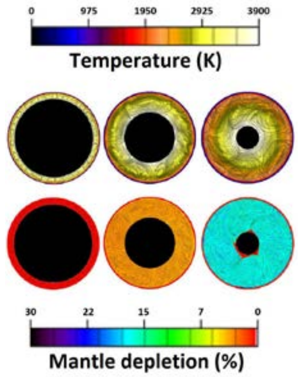

Figure 1: Temperature field and mantle depletion after 4.5Gyr for the Earth-like interior (center) in comparison to a Moon-like (top) and a Mercury-like interior structure (bottom).

2. Plate tectonics

However, if plate tectonics initiates, several tens of bars of CO_2 can be outgassed in a short time also for planets with a large iron core, see fig. 2.

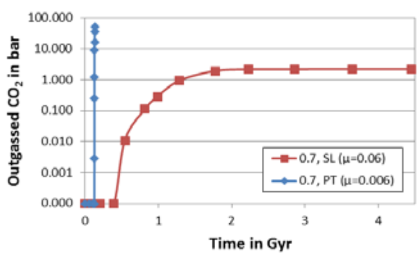

Figure 2: Outgassing for a stagnant lid case (SL) and a plate tectonics case (PT) for a RR of 0.7.

In this case the outer boundary of the habitable zone would not be limited by outgassing as is the case for stagnant-lid planets.

It is, however, questionable if planets with a very thin mantle are able to initiate plate tectonics. Fig. 3 shows the initiation time of plate tectonics depending on RR for the cooler initial upper mantle temperature. The darkest brown color means that no plate tectonics initiated in 4.5 Gyr of thermal evolution. For this set of simulations, plate tectonics is most likely for a RR of 0.7.

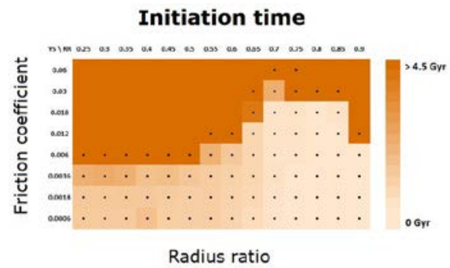

Figure 3: Initiation time of plate tectonics depending on RR and friction coefficient.

3. Conclusions

- We model outgassing via partial melt volumes for Earth-sized planets depending on the interior structure and give possible implications for the outer edge of the HZ.
- Stagnant-lid planets with a thin mantle may not develop a dense-enough secondary atmosphere.
- Initiation of plate tectonics can immediately increase the outgassing of CO_2.
- The likelihood of plate tectonics strongly depends on the interior structure.

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References

[1] Hüttig, C. and Stemmer, K. (2008), PEPI, 171(1-4):137-146.

[2] Plesa, A.-C. and Spohn, T. (2012), Transactions of the HLRS 2011, Springer, 551-565.

[3] Kasting, J., Whitmire, D.P. and Reynolds, R.T. (1993), Icarus, 101:108-128.