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The importance of the Earth's biosphere in stabilizing the large fraction of continental coverage and the wet mantle of present day Earth

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Abstract

Recent studies have suggested that bioactivity may have caused a change in the redox-state of the mantle and provided a path for the formation of continents. We here present an evolution model of Earth that assumes that bioactivity increases the continental weathering rate and that relates the sedimentation rate to the growth of continents and to the hydration of the mantle using elements of plate tectonics and mantle convection. We show that even a late origin of photosynthetic life (2.0 – 2.5 Ga) could have stabilized the large continental surface area of Earth and its wet mantle we observe at present.

1. Introduction

Did the origin and global evolution of life on Earth contribute to its interior evolution? By harvesting solar energy and converting it to chemical energy, photosynthetic life plays an important role in the energy budget of Earth [4], leading to alterations of chemical reservoirs [1,3]. Since the surface is recycled into its interior at subduction zones, a direct connection to the Earth’s interior is given [5,7], and it has been speculated [6] that the formation of continents may be a consequence of the evolution of the biosphere. Subducted sediments, in particular if they have been formed by biological weathering processes, have the potential to impact processes in subduction zones. A steady state model [2] suggests that the Earth without its biosphere would evolve to a steady state with a smaller continent coverage and a dryer mantle than is observed today. However, the actual growth of continental crust and the evolution of the mantle water concentration strongly depend on both the thermal evolution of the planet and on the onset time of photosynthetic life.

2. Model

We present a model including (i) parameterized thermal evolution of Earth with a mantle viscosity depending on temperature and the concentration of water, (ii) continental growth and destruction, and (iii) mantle water regassing and outgassing. The biosphere enters our model through an enhanced production rate of sediments which eventually are subducted. These sediments are assumed to (i) carry water to depth bound in stable mineral phases and (ii) have the potential to suppress shallow dewatering of the underlying sediments and crust due to their low permeability. We run a Monte Carlo simulation for various initial conditions (initial mantle water concentration and mantle temperature) and onset times of photosynthetic life (2.0 – 2.5 Ga). We treat all those parameter combinations as success which result in the fraction of continental crust coverage observed for present day Earth (40 ± 1 %) and simulate the evolution of an abiotic Earth using the same set of parameters but a reduced rate of continental weathering and erosion.

3. Results

Fig. (1) and Fig. (2) show a superposition of several continental crust growth curves and mantle water concentration evolution curves with various initial conditions of the Earth (blue) and its abiotic analogue (red). The onset times of photosynthetic life (biotic cases) are between 2.0 and 2.5 Ga (green area).

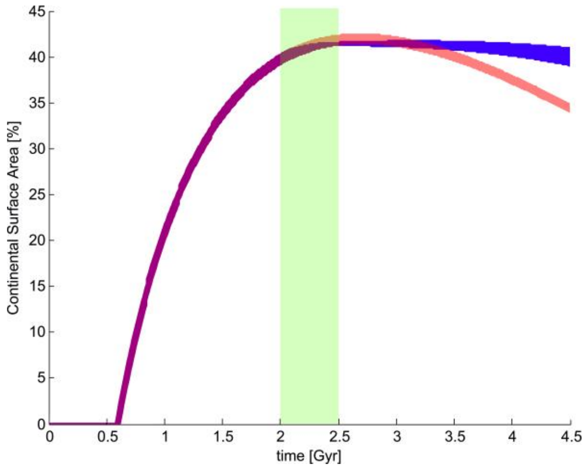

Figure 1: Continental crust growth of the Earth (blue) and its abiotic analogue (red). The onset times of photosynthetic life are in the green area.

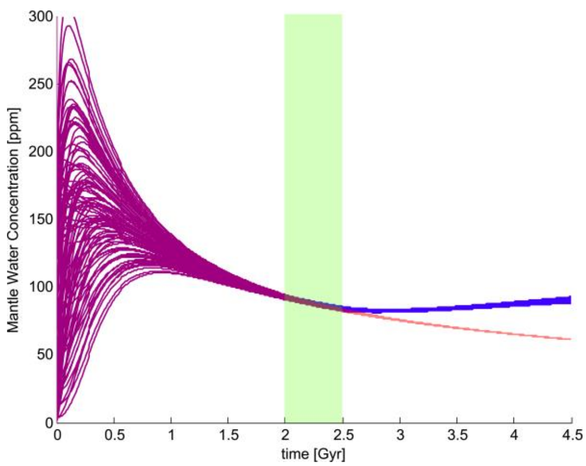

Figure 2: Mantle water concentration evolution of the Earth (blue) and its abiotic analogue (red). The onset times of photosynthetic life are in the green area.

4. Summary and Conclusions

Our results suggest that even a late origin of photosynthetic life (2.0 – 2.5 Ga) could have stabilized the large continental surface area of Earth and its wet mantle, leading to the relatively low mantle viscosity we observe at present. Without photosynthetic life on our planet, the Earth would be geodynamical less active due to a dryer mantle, and would have a smaller fraction of continental coverage than observed at present day Earth.

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