Geophysical Research Abstracts
Vol. 18, EGU2016-18377, 2016
EGU General Assembly 2016

Plate tectonics, habitability and life

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The role of plate tectonics in defining habitability of terrestrial planets is being increasingly discussed (e.g., Elkins-Tanton, 2015). Plate tectonics is a significantly evolved concept with a large variety of aspects. In the present context, cycling of material between near surface and mantle reservoirs is most important. But increased heat transport through mixing of cold lithosphere with the deep interior and formation of continental crust may also matter. An alternative mechanism of material cycling between these reservoirs is hot-spot volcanism combined with crust delamination. Hot-spot volcanism will transport volatiles to the atmosphere while delamination will mix crust, possibly altered by sedimentation and chemical reactions, with the mantle. The mechanism works as long as the stagnant lithosphere plate has not grown thicker than the crust and as long as volcanic material is added onto the crust. Thermal evolution studies suggest that the mechanism could work for the first 1-2 Ga of planetary evolution. The efficiency of the mechanism is limited by the ratio of extrusive to intrusive volcanism, which is thought to be less than 0.25. Plate tectonics would certainly have an advantage by working even for more evolved planets.

A simple, most-used concept of habitability requires the thermodynamic stability of liquid water on the surface of a planet. Cycling of CO_2between the atmosphere, oceans and interior through subduction and surface volcanism is an important element of the carbonate-silicate cycle, a thermostat feedback cycle that will keep the atmosphere from entering into a runaway greenhouse. Calculations for a model Earth lacking plate tectonics but degassing CO_2, N, and H_2O to form a surface ocean and a secondary atmosphere (Tosi et al, 2016) suggest that liquid water can be maintained on the surface for 4.5Ga. The model planet would then qualify as habitable. It is conceivable that the CO_2 buffering capability of its ocean together with silicate weathering of possible land surfaces and a biosphere could set up a CO_2 sink that would further stabilize the temperature. As long as the planet keeps degassing CO_2 at a sufficient rate, CO_2 recycling through the mantle may not be required. However, this would require a sufficiently oxidized planet early on. If not sufficiently oxidized during accretion and core formation, oxidization of the planet would require cycling of matter between surface and interior reservoirs. Oxidization of an initially reduced Earth interior with the help of plate tectonics has been cited as a possible mechanism to allow the building up of oxygen in the terrestrial atmosphere around 2.3Ga b.p. (e.g., Catling and Claire, 2005), a pre-requisite for more evolved eukaryotic life. The oxidization would diminish a sink in the oxygen budget of the atmosphere by lowering the rate of outgassing of chemically reducing gases from the interior. Clearly, plate tectonics is a mechanism more potent of keeping a planet habitable and allow evolution of the biosphere than alternative concepts such as crust delamination.

Catling, DC, Claire DW (2005), EPSL, 237, 1-20

Elkins-Tanton, L (2015) AGU Fall Meeting Abstract

Tosi, N et al. (2016) EGU Abstract