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Planetary Interior Evolution and Life

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The habitability of planets has received increasing interest in recent years, in particular in view of the increasing number of detected extrasolar planets. Planetary habitability (for life as we know it) is usually thought to require water on (or near) the surface, a magnetic field to protect life against radiation, and transport mechanisms for nutrients. A chemoautotrophic biosphere would also require volcanic activity and the associated large thermal gradients. Volcanic activity is usually thought to have been instrumental for the formation of (initially chemoautotrophic) life on Earth. A magnetic field also serves to protect an existing atmosphere against erosion by the solar wind and thus helps to stabilize the presence of water and habitability. Magnetic fields are generated in the cores of the terrestrial planets and thus habitability is linked to the evolution of the interior through magnetic field generation and volcanic activity. Moreover, the interior is a potential source and sink for water and may interact with the surface and atmosphere reservoirs through volcanic activity and recycling. The most efficient known mechanism for recycling is plate tectonics. Plate tectonics is known to operate, at present, only on the Earth, although Mars may have had a phase of plate tectonics as may have Venus. Plate tectonics also supports the generation of magnetic fields by effectively cooling the deep interior. (In addition, plate tectonics rejuvenates nutrients on the surface and generates granitic cratons.) On the Earth, surface water is stabilized by complex interactions between the atmosphere, the biosphere, the oceans, the crust, and the deep interior in the carbon-silicate cycle. As plate tectonics is widely believed to require water in the mantle to operate, it can be argued that plate tectonics is another element linking the biosphere to the evolution of the planet's interior. Single-plate tectonics associated with stagnant lid convection would also allow for transfer water from the interior through volcanism but a simple recycling mechanism is lacking for this tectonic style. Stagnant lid convection will evolve to thicken the lid and increasingly frustrate volcanic activity and degassing, though. The question of whether or not extrasolar earthlike planets more massive than the Earth are likely to have plate tectonics or rather single-plate tectonics is hotly debated. We would argue that the large interior pressure and its effect on the rheology of the mantle of these planets may frustrate plate tectonics and magnetic field generation altogether. We would even argue that surface volcanic activity may become increasingly difficult with increasing mass of a rocky planet. On Earth, mantle melt is buoyant at depths smaller than 200 – 300km. At larger than this critical depth, the melt will be negatively buoyant because of its greater compressibility in comparison with that of solid rock. The critical depth below which melt ceases to be buoyant will decrease with increasing mass of the planet and may become shallower than the depth to the base of the stagnant lid of mantle convection on massive terrestrial extrasolar planets. We find the ratio between the stagnant lid thickness and the critical depth to increase approximately linearly with the radius of the planet. The great diversity of extrasolar planets may suggest a diversity of life forms and associated habitability parameters, however, and extrapolations from the Earth may be overly naive.The habitability of planets has received increasing interest in recent years, in particular in view of the increasing number of detected extrasolar planets. Planetary habitability (for life as we know it) is usually thought to require water on (or near) the surface, a magnetic field to protect life against radiation, and transport mechanisms for nutrients. A chemoautotrophic biosphere would also require volcanic activity and the associated large thermal gradients. Volcanic activity is usually thought to have been instrumental for the formation of (initially chemoautotrophic) life on Earth. A magnetic field is argued to serve to protect an existing atmosphere against erosion by the solar wind and thus to help stabilize the presence of water and habitability. Magnetic fields are generated in the cores of the terrestrial planets and thus habitability is linked to the evolution of the interior through magnetic field generation and volcanic activity. Moreover, the interior is a potential source and sink for water and may interact with the surface and atmosphere reservoirs through volcanic activity and recycling. The most efficient known mechanism for recycling is plate tectonics. Plate tectonics is known to operate, at present, only on the Earth, although Mars may have had a phase of plate tectonics as may have Venus. Plate tectonics also supports the generation of magnetic fields by effectively cooling the deep interior. (In addition, plate tectonics rejuvenates nutrients on the surface and generates granitic cratons.) On the Earth, surface water is stabilized by complex interactions between the atmosphere, the biosphere, the oceans, the crust, and the deep interior in the carbon-silicate cycle. As plate tectonics is widely believed to require water in the mantle to operate, it can be argued that plate tectonics is another element linking the biosphere to the evolution of

the planet's interior. Single-plate tectonics associated with stagnant lid convection would allow for transfer water from the interior through volcanism but a simple recycling mechanism is lacking for this tectonic style. Stagnant lid convection will evolve to thicken the lid and increasingly frustrate volcanic activity and degassing, though. The question of whether or not extrasolar earthlike planets more massive than the Earth are likely to have plate tectonics or rather single-plate tectonics is hotly debated. We would argue that the large interior pressure and its effect on the rheology of the mantle of these planets may frustrate plate tectonics and magnetic field generation altogether. We would even argue that surface volcanic activity may become increasingly difficult with increasing mass of a rocky planet. On Earth, mantle melt is buoyant at depths smaller than 200 – 300km. At larger than this critical depth, the melt will be negatively buoyant because of its greater compressibility in comparison with that of solid rock. The critical depth below which melt ceases to be buoyant will decrease with increasing mass of the planet and may become shallower than the depth to the base of the stagnant lid of mantle convection on massive terrestrial extrasolar planets. However, the lid thickness should also decrease with increasing planetary mass because of the planet's greater heat content. Our calculations suggest the ratio between the two very little with planetary mass therefore allowing for volcanic activity mostly independent of the mass of the exoplanet. The great diversity of extrasolar planets may suggest a diversity of life forms and associated habitability parameters, however, and extrapolations from the Earth may be overly naive.