Water, the Geomagnetic Field and Plate Tectonics: The Loop of Life

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The long-term preservation of water on Earth, which was essential for the development of complex and intelligent life, has resulted from the coupled interaction of water, the geomagnetic field and plate tectonics. Since this topic deals with the geophysical conditions underlying Earth as a habitable planet, it should be of broad interest to the readership of EOS and beyond. To my knowledge, this topic has not been addressed previously in EOS; it was incorporated in an invited presentation to the General Assembly of IAGA in 2005.

Water is lost from Earth by photo-dissociation within the stratosphere, followed by escape of hydrogen to outer space. The loss rate is limited by the ‘cold trap’ at the top of the troposphere, and (due to the adiabatic lapse rate) is dependent on the thickness of the troposphere, which is limited by UV heating of ozone within the stratosphere. This heating is relatively weak and occurs at high altitude, giving a relatively thick troposphere and an effective cold trap for water. A stronger source of heating is available: ionized particles carried by the solar wind. However, virtually all of these particles are prevented from reaching the atmosphere by the geomagnetic field. If the field were significantly weaker, energetic ions would reach and heat the atmosphere, lower the height of the tropopause, thereby allowing a much greater flux of water from the troposphere to the stratosphere and a much greater loss of water from the planet.

The geomagnetic field results from dynamo action of fluid motions within Earth’s liquid outer core. These motions stir the liquid outer core vigorously, maintaining it in a state very close to adiabatic. The outer core is a good conductor of heat, and a significant amount of heat is conducted down the adiabatic thermal gradient and transferred to the mantle. This heat loss is the ‘cost of doing business’ for the geodynamo; if the rate of core heat loss falls below this amount, the dynamo very likely would cease to operate. The dynamo requires the mantle to convey a large heat flux to the planetary surface, and plate tectonics is the only mode of planetary heat transport capable of providing a sustained large flux.

Liquid water is essential for plate tectonics. Hydrated minerals make the oceanic lithosphere more ductile, permitting plates to bend rather than break at subduction zones, and subducting hydrated minerals provide the water necessary to lubricate the slip zone between the subducting and non-subducting plates, preventing plate lock-up.

To summarize, preservation of water requires a strong magnetic field, the only viable mechanism for producing such a field is dynamo action in the liquid outer core, maintenance of dynamo action requires a large heat flux from the planet, plate tectonics is the only mode of planetary heat transport capable of the large fluxes needed, while plate tectonics requires the presence of liquid water. These dependencies form ‘the loop of life’, which sustains life on Earth.