Geophysical Research Abstracts
Vol. 19, EGU2017-2747, 2017
EGU General Assembly 2017

Earth's magnetic field, preservation of the hydrosphere and planetary habitability (Petrus Peregrinus Medal Lecture)

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The geodynamo appears to have been remarkably continuous since its inception, which probably occurred shortly after the lunar-forming impact. Here, I will discuss the history of the geodynamo in the context of planetary habitability, as well as what might be gleaned from the terrestrial record to understand other solar system bodies and exoplanets. The "habitable zone" is classically defined as that distance from a star where liquid water can exist. However, even given birth of a planet in this zone, there is no assurance that a habitable planet will evolve because an atmosphere and the associated planetary hydrosphere can be stripped from a planet by intense stellar winds streaming from rapidly rotating young stars. Magnetic shielding is a key factor that might determine whether a terrestrial-like planet will retain its water. Salient variables include the time of onset and duration of the dynamo. These variables are in turn related to the efficiency of heat removal from the core, governed by the mantle, and/or exsolution processes that might drive core convection. The magnetic field has competing effects with respect to atmospheric retention (and ultimately water survival). For example, an increased magnetic field provides more pressure to abate the solar wind dynamic pressure and increase the magnetopause radius. However, the larger magnetopause also implies a larger collecting area for solar wind flux during phases of magnetic reconnection. This ordered field provides the magnetic topology for recapturing this mass in the opposite hemisphere such that the net global atmospheric mass loss might not be greatly affected. I will argue that available data support the net protective role of dynamo magnetic fields for atmospheres that are relevant to habitability (i.e. those that envelope a hydrosphere). Paleomagnetism, utilizing the single silicate crystal approach, defines a relatively strong field some 3.45 billion years ago (the Paleoarchean), but with a reduced standoff of the solar wind to 5 Earth radii, implying the potential for some atmospheric loss. Our efforts to test the presence/absence of a terrestrial dynamo and magnetic shielding during Eoarchean to Hadean times based on the study of single zircons provide evidence of the field to ages as old as 4.2 Ga. For intervals >100,000 years long, magnetopause standoff distances may have reached 3 to 4 Earth radii or less. These reduced standoff distances again imply some atmospheric erosion and water loss. Water can be added by a "late veneer", but the strong solar forcing extended into the Paleoarchean. This suggests the presence of an initial water reservoir much greater than that of today to account for Earth's present-day large water inventory. Thus, this terrestrial history suggests that should a very young Earth 2.0 be discovered, considerations for its habitability on billion-year time scales would be not only an operating dynamo, but also the presence of a superocean.