Evolution of a Habitable Planet

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Earth has remained habitable, and inhabited, over most of its 4.5-Gyr history despite an appreciable (30%) increase in solar luminosity over time and despite catastrophic events such as asteroid impacts and "Snowball Earth" episodes that have threatened biological survival on a global scale. Life has survived partly because of the resilience of the biota and partly because of feedback mechanisms that help to stabilize Earth's global climate. In particular, buildup of volcanic CO_2 during times when the climate is cold provides a strong negative feedback that helps keep Earth within the temperature regime favorable to life. During the first half of Earth's history, when atmospheric O_2 concentrations were low, CH_4 was probably an important greenhouse gas as well. The Paleoproterozoic glaciations at ~2.4 Ga were likely triggered by the rise of O_2 and a corresponding decrease in atmospheric CH_4 concentrations. A possible mid-Archean glaciation at ~2.9 Ga may have been caused by the formation of hydrocarbon smog. Both glaciations correspond with anomalies in the sulfur MIF (mass-independent fractionation) record, which has proven to be a wonderful source of information about the nature of the early atmosphere.

The same processes that help stabilize Earth's climate should operate on other Earth-like planets, if they exist; thus, it is plausible that life could exist elsewhere. This hypothesis is now on the verge of being tested. NASA's twin *Terrestrial Planet Finder (TPF)* missions, which could be launched as early as 2015-2020, will look for Earth-like planets around nearby stars and, if they are found, provide spectroscopic information on their atmospheres. Between them, these missions should be able to look for absorption bands of O_2, H_2O, CO_2, and O_3. Both O_2 and O_3 are considered to be good indicators of life for planets orbiting within the liquid water habitable zone of their parent star. NASA should be encouraged to give these missions high priority, so that we can answer these fundamental questions about the distribution of life in the universe.