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Schedule Constraints for Terraforming Exoplanets

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The thought experiment that places life on a newly formed rocky planet and asks whether its transformation to habitability could proceed more quickly than Earth's must evaluate the processes that govern terrestrial development, be they stellar, orbital, geological, or biological. Aspirationally, humans thrive on a geologically-active planet with a temperate climate and low atmospheric pCO_2, but planets persisting in host-star habitable zones first need a CO_2 warming blanket that protects from extreme radiation of young suns. The desired operating point occurs eons later, midway into the stellar lifespan, yet prior to the radioisotope decay that stalls tectonic cycles. Planetary transformation, including thermally-regulated CO_2 drawdown and atmospheric oxygenation, must match this schedule.

Focusing on the Archaean Era, cyanobacteria and their microbial cohorts work to oxidize a ferruginous ocean. Precipitated iron oxides contribute to Banded Iron Formations (BIFs), whose layers record the cyclic evolution of ecosystems corresponding to orbitally-forced excursions in seasonality and outgassing. Dense BIF sediments subduct into the mantle generating magma plumes that source a more felsic crust, a process requiring hundreds of Myr to complete. Simulations demonstrate that crustal growth controls the timing of the Great Oxidation Event (GOE), indicating therefore that adaptive ecosystem engines stir deep biogeochemical cycles to pace major planetary transitions. Living systems need sufficient time to transform their host planet (Fig. 1).

Extending this analysis to other main-sequence stars finds that F-type stars require planets with more rapid geological processes than earth, but this leads to undersized planets that struggle with atmospheric retention in the glare of bluer stars. Conversely, large rocky water worlds orbiting K-type stars would drawdown atmospheric CO_2 so slowly that advanced life's arrival would meet inactive geology. Earthlike exoplanets orbiting within the photosynthetic habitable zone of G-type stars are best candidates for hosting advanced life (Fig. 2). Future terraforming designs must consider these constraints.

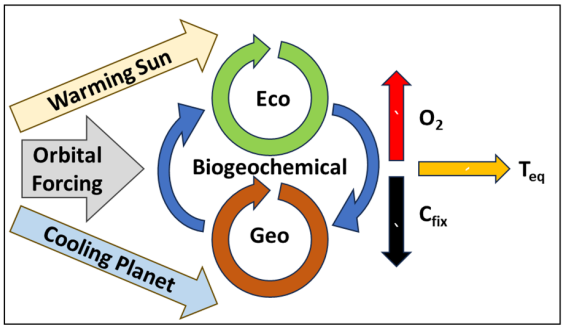

Figure 1. Orbitally-forced ecosystem engines pace planetary transitions.

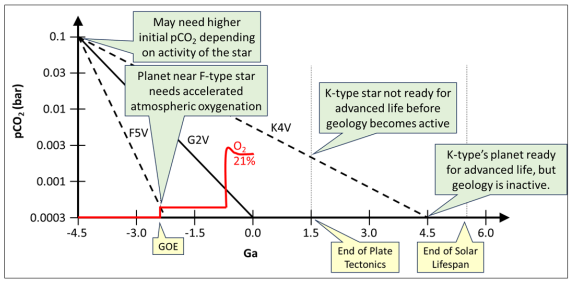

Figure 2. CO_2 drawdown on F5V, G2V (sun), and K4V main-sequence stars corresponding to lifespans of 5, 10, and 20 Gyr, respectively.