Climatic consequences of methane boosting by photoferrotrophs in the Archean atmosphere

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Photosynthesis powers the biosphere, and the evolution of different forms of photosynthetic life would have profoundly altered the activity of biosphere and reshaped the composition of Earth's atmosphere and climate. Here, we use a novel global redox balance model to explore the biogeochemical and climatological effects of different forms of primitive photosynthesis, and find that a hybrid ecosystem incorporating a mixed assemblage of H_2-using and Fe^{2+}-using anoxygenic photoautotrophs (photoferrotrophs) would have played a crucial role in regulating Earth's early climate before the evolution of oxygenic photosynthesis. In particular, we find a strong nonlinear amplification of the biospheric CH_4 cycle upon the inclusion of photoferrotrophs, whereby increased biogenic CH_4 fluxes to the atmosphere lead to increased deposition of photochemically produced H_2 and CO to the oceans, promoting further biogenic CH_4 production. Exploration of a more parameterized version of our model via a Monte Carlo approach reveals that the marine iron cycle should fundamentally control on the activity level of the primitive photosynthetic biosphere, atmospheric chemistry, and surface temperatures. Our results thus suggest that the stability of Earth's early climate was governed by a novel and poorly explored set of regulatory feedbacks among H-C-Fe cycles in the anoxic biosphere, with important ramifications for the sustained habitability of Earth-like planets with reducing atmospheres.