Limited primary production in the early Archean oceans and its biogeochemical consequenses

*Kazumi Ozaki[1]

1. Toho University

The activity level of the biosphere is a critical factor controlling the chemical composition of the atmosphere. The modern Earth's biosphere is powered by the oxygenic photosynthesis, which utilizes ubiquitous water as their electron donor, with the result that Earth's surface environment is extremely well oxygenated. Before the advent of the oxygenic photosynthesis, in contrast, primary production would have been limited by the geophysical input rate of critical electron donors (e.g., H_2 and Fe^{2+}) from the Earth's interior to the exogenic system. Here, we revisit previous modelling of the global biogeochemical cycles of H, C, and Fe in order to more precisely reconstruct global net primary production (NPP) during an interval of early Archean time before the advent of oxygenic photosynthesis. The biogeochemical model includes a series of metabolic reactions in the primitive anoxic biosphere (e.g., anoxygenic photosynthesis, methanogens, and fermenters) and takes redox (H) balance in the ocean-atmosphere system into account. I explore the effect of a variety of combination of key parameters (e.g., atmospheric CO_2 levels, geophysical input flux of Fe^{2+}, and volcanic outgassing flux of H_2) with a stochastic approach in order to search the possible solutions which allow for creating a warm climate state (>288 K) during the Archean. The results suggest that NPP by anaerobic metabolisms has been a few percent of the modern value. The H-based producers, photoferrotrophs, and CO-consuming acetogens contribute ~80%, ~18%, and ~2% of total NPP, respectively. The estimated extremely low NPP implies the geological fluxes of H_2 and Fe^{2+} as a limiting factor for biological productivity. The results also show that the atmospheric CO_2 levels are needed to be >~70 PAL (present atmospheric level) for maintaining warm climate state and that atmospheric CH_4 levels would have been >100 ppm despite the limited activity of the biosphere.

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