Interactions of atmosphere and marine biosphere after the emergence of oxygenic photosynthesis in the early Earth

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Activity of oxygenic photosynthesis impacted the atmospheric composition in the early Earth, as evident from the Great Oxidation Event (GOE), the first major rise of the atmospheric oxygen level (~2.4–2.2 Ga). The marine biosphere before the emergence of oxygenic photosynthesis in the early Earth would have been dominated by anaerobic photoautotrophs and chemoautotrophs, who can utilize reduced chemical components in anoxic ocean as electron donors (e.g. H_2, CO, Fe(II), etc.) (e.g. Kharecha et al., 2005; Ozaki et al., 2018). The emergence of oxygenic photosynthesis would have affected the chemical condition of the ocean-atmosphere system and primitive marine biosphere by oxidizing such reduced chemical components in the ocean-atmosphere system. Thus, the behavior of the atmospheric photochemical reactions and marine biogeochemical cycles with marine biosphere in the early Earth after the emergence of oxygenic photosynthesis is crucial for understanding the co-evolution of atmospheric composition, climate, and biosphere.

Here we employed a novel coupled model of atmosphere photochemistry and marine biogeochemical cycles with the marine microbial ecosystem to demonstrate the chemical evolutions of ocean, atmosphere, and marine microbial ecosystem before the GOE. We found that the primary productivity of anaerobic marine microbial ecosystem diminishes when the primary productivity of oxygenic photosynthesis becomes so large that the supply rate of oxygen from the ocean exceeds that of methane, which leads to the decrease in the atmospheric methane level and the supply rate of electron donors to the ocean (H_2 and CO). This novel feedback is explained by the supply of OH-radicals from the biogenic oxygen, which becomes the primary sink of biogenic methane and electron donors (H_2 and CO). The surface cooling due to weakening of atmospheric methane cycle may have facilitated the supply of nutrients from the continent by increasing the atmospheric CO_2 level and the contribution of continental weathering relative to seafloor weathering (Watanabe and Tajika, 2021), enhancing the variability of the primary productivity of oxygenic photosynthesis. These results enlighten the intimate links between the atmospheric oxygenation, climate cooling, and transformations in the Earth-like marine biosphere. The behaviors of the coupled system may represent a fundamental aspect during the oxygenation of the planetary surface with the existence of marine biosphere, which would contribute to interpreting the sign of life on life-bearing Earth-like planets for the future direct-imaging missions.

Keywords: Atmospheric Photochemistry, Early Earth

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