Primitive microbial ecosystem and the faint young Sun paradox

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Climate of the Earth in the Archean is thought to have been warm or even much warmer than it is today, although the Sun was much (about 20%) dimmer. This "faint young Sun paradox" is solved if the level of carbon dioxide (CO_2) in the atmosphere was much higher in the Archean. It is however revealed that pCO_2 in the late Archean was not as high as the levels predicted from the climate models. It is therefore considered that concentration of methane (CH_4) in the atmosphere should have been higher, which compensated for the deficit of greenhouse effect of CO_2. However, because CH_4 is photochemically unstable, it is uncertain that such a high level of CH_4 could have been maintained in the Archean atmosphere.

Primary productivity in the Archean ocean is important to estimate CH_4 flux to the atmosphere, because CH_4 was produced from activity of methanogen. Primitive photosynthetic bacteria, which did not produce oxygen, were probably primary producers in the Archean oceans. They probably used H_2 and Fe^{2+} as a electron donor for photosynthesis. We therefore try to estimate CH_4 flux and concentration in the atmosphere with a coupled model of primitive microbial ecosystem, photochemical reactions, biogeochemical cycle, and climate.

We found that, the CH_4 flux to the atmosphere is too low to form warm climate when only one photosynthesizer (H_2-based or Fe-based anoxygenic photoautotroph) is considered in the ecosystem, but the CH_4 flux becomes enough to create warm climate when hybrid ecosystem of H2-based and Fe-based anoxygenic photoautotrophs is considered. This is because of a nonlinear amplification of methane cycle due to nonlinear increases of CH_4 and H_2 concentrations in the atmosphere against increase of CH_4 flux.

We conclude that diversity of primitive anoxygenic photoautotrophs was important for stabilization of warm climate in the Archean. It also implies that microbial activity and CH_4 are important to understand environment of young Earth-like habitable planets in the exoplanetary systems.

Keywords: Archean, faint young Sun paradox, methane

