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 an 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 H$_2$-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.

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