Behaviors of carbon cycle system and inevitability of the hot climate in the Archean Earth

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Although the luminosity of the Sun in the Archean (from 4.0 Ga to 2.5 Ga) was dimmer than that of today, geological records of $d^{30}Si$ and $d^{18}O$ from marine cherts suggests that the terrestrial surface environment may have been warm or even hot (328-358 K). Recently, along with these geological records, thermostability of reconstructed ancestral enzymes of cyanobacteria, which reflects the temperature of marine photic zone, also supports the hot surface environment.

To achieve such hot environment under the dimmer Sun, greenhouse effect of carbon dioxide and methane is considered to be necessary. Previous study using a coupled model of atmospheric photochemistry and ocean microbial ecosystem showed that the warm climate can be achieved by non-linearly amplified flux of methane to the atmosphere from the marine ecosystem only when H_2-using photosynthetic bacteria and Fe-using photosynthetic bacteria coexisted in the Archean marine ecosystem. This means that the photochemical processes and the marine microbial processes would have been important in realizing the hot environment under low pO_2 condition in the Archean. However, few studies investigated how these processes affected the global carbon cycle in the Archean.

Here we developed a coupled atmosphere photochemistry-marine microbial ecosystem-global carbon cycle model and assessed how the hot climate suggested from the geologic records can be achieved in the Archean. We found that, there are high pCO_2 (hot climate) stable solutions and low pCO_2 (warm climate) unstable solutions against the range of CO_2 degassing rate similar to that of today. In the low pCO_2 solutions (<~100 PAL), CO_2 is removed from the atmosphere-ocean system as the haze particle, hence such a condition is unstable in the Archean carbon cycle system. This finding strongly supports the results of the hot terrestrial environment in the Archean as suggested from many previous studies. The hot climate may be an inevitable result in the Archean carbon cycle system.

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