Effect of Hydrocarbon Haze on Climate Stability under Mildly Oxidized Late-Archean Environment

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The atmospheric oxygen level (pO_2) is suggested to have been lower than 10^{-5} PAL (present atmospheric level) based on an existence of mass-independent isotope fluctuation of sulfur in the Archean (e.g. Pavlov and Kasting, 2002). During the Late Archean (3.0-2.5 Ga), temporal increases of pO_2 are suggested from concentrations of redox sensitive trace elements (e.g. Anbar et al., 2007), which might have been associated with the onset of oxygenic photosynthesis in the ocean. On the other hand, there is a record of co-variation of carbon and sulfur isotopes, which might have reflected a transient formation of hydrocarbon haze, meaning a transient appearance of very reducing atmosphere in the Late Archean (Zerkle et al., 2012; Izon et al., 2017). These records suggest that the atmospheric composition in the Late Archean could have significantly varied. Previously, how the rise of oxygen in the atmosphere affects the global carbon cycle has been discussed in various context and in different ages. However, how the formation of haze has affected global carbon cycle in the Late Archean has not been investigated considering the atmospheric and marine microbial reactions. Here we used a coupled model of atmospheric photochemimstry-marine microbial ecosystem-global carbon cycle, in which the photochemical model "Atmos" (Arney et al., 2016) is included, to investigate how the production of the hydrocarbon haze affected the global carbon cycle and climate stability under mildly oxygenized condition in the Late Archean ($f(O_2)$ ~10^{-6} PAL) and under completely anoxic condition in the Middle Archean ($f(O_2) < 10^{-10}$ PAL). In both cases, hydrocarbon haze is formed in the atmosphere when CH_4/CO_2 is more than around 0.2, consistent with Arney et al. (2016). We found that, the formation of hydrocarbon haze works as a CO_2 consumption pathway in the atmosphere under completely anoxic condition, because the formation/removal rates of hydrocarbon haze increase according to the decreasing pCO_2. This means that, hazy climate state is unstable under anoxic condition. In the mildly oxidized world, on the other hand, the formation/removal rates of hydrocarbon haze were not affected significantly by the change in pCO_2, so that the hazy condition becomes stable by the silicate weathering negative feedback. This result suggests that there is a negative feedback mechanism concerning the formation rate of hydrocarbon haze under mildly oxidized atmosphere, through changes in the UV flux in the atmosphere and atmospheric redox condition. Our result is consistent with the geological records that suggests the transient formation of hydrocarbon haze in the Late Archean.

Keywords: Archean, Early Earth, Carbon Cycle

