Goldschmidt 2025 Abstract
https://doi.org/10.7185/gold2025.32390

Atmospheric chemical compositions of Earth-like planets with a global carbon cycle and implication for habitability

YOSHIAKI ENDO[1], YASUTO WATANABE[2] AND KAZUMI OZAKI[1]

[1]Institute of Science Tokyo
[2]The University of Tokyo

Atmospheric compositions of lifeless Earth-like planets are affected by various processes such as volcanic gas emissions, atmospheric chemistry, and the carbonate-silicate geochemical cycle. One of the most dynamic features of the atmosphere of lifeless Earth-like planets is the accumulation of CO produced by CO_2 photolysis in the atmosphere (Kasting et al., 1983). This "CO runaway" atmosphere may be crucial in planetary habitability because it promotes organic synthesis in the atmosphere. The conditions for CO runaway atmospheres are influenced by atmospheric $p\mathrm{CO_2}$, volcanic outgassing fluxes, profiles of air temperatures, and host star spectral types (Watanabe and Ozaki, 2024). However, atmospheric $p\mathrm{CO_2}$ and surface temperature on Earth-like planets would, in reality, be regulated by the carbonate-silicate geochemical cycle. To estimate the atmospheric compositions of various lifeless Earth-like planets, this should be accounted for consistently while considering the stellar irradiance that the planet receives, volcanic outgassing flux from the interior of a planet, and weathering of continental and oceanic crusts.

In this study, we employed a one-dimensional photochemical model (*Atmos*; Arney et al., 2016) coupled with a global carbon cycle model (Krissansen-Totton et al., 2018), zero-dimensional energy balance climate model, and a thermodynamic model of volcanic gas compositions (Wogan and Catling, 2020) to investigate the atmospheric compositions of lifeless Earth-like planets under different orbital distances and central stars. Our results show that atmospheric $p\mathrm{CO}$ increases as a planet is located farther from the central star owing to the high atmospheric $p\mathrm{CO_2}$ and a suppressed water vapor photolysis, while it decreases when the temperature of the central star increases. We further show that the production rate of formaldehyde, whose availability may be important for prebiotic synthesis (Cleaves, 2008), would increase as the temperature of the central star increases, while it tends to be high when planets are located near the central star. These results would indicate that the availability of molecules essential for prebiotic synthesis on Earth-like exoplanets would depend on the location of a planet and types of a central star. These results would extend our understanding of the habitability of a planet and conditions required for the origin of life.