CO-rich atmospheres on terrestrial planets: the role of deep carbon cycling

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Atmospheric compositions of terrestrial planets control their climates and the possibility of abiotic formation of biologically relevant species that may give rise to the emergence of life. Though the terrestrial planets in our Solar System today possess CO_2 as the major form of carbon in the atmosphere, CO-rich atmospheres have been theoretically predicted for planets orbiting M-type stars and for those receiving only low stellar irradiation, the latter of which include early Mars. In these environments, CO produced by photodissociation of CO_2 piles up because of lower H_2O photodissociation rates which lead to slower CO oxidation by OH than that on Earth. Meanwhile, it has also been suggested from the record of sulfur isotope anomaly that Earth also had a CO-rich atmosphere in the Archean era, which may imply unknown mechanisms of CO accumulation. Because such reducing atmospheres are more suitable to form organic compounds relevant to life via atmospheric chemistry, elucidating mechanisms to form CO-rich atmospheres are important.

Here we propose new mechanisms to form a CO-rich atmosphere by considering the role of deep carbon cycling, namely, CO_2 drawdown via carbonate precipitation and CO degassing from the reducing mantle. We constructed a model for deep carbon cycle combined with atmospheric photochemistry and climate modeling to simulate the evolution of CO and CO_2 contents in the atmosphere from the time of magma ocean solidification and formation of oceans. We found that rapid CO_2 drawdown from the initially-dense atmosphere leaves CO and naturally leads to the formation of a CO-rich atmosphere. When the CO partial pressure is a few bars (depends on the initial condition), the CO-rich atmosphere could remain over ~1 billion years. The long lifetime is caused by the self-stabilizing effect –CO reduces water vapor mixing ratio in the atmosphere and, consequently, CO oxidation rate by photochemically-produced OH. Moreover, the lifetime of CO becomes longer if the mantle is reducing to directly release CO via volcanism.

In this presentation, we further discuss the implications for evolution of Earth and other terrestrial worlds and for observations of extrasolar systems.

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