A cold and alkaline Hadean ocean caused by impact ejecta weathering

*門屋 辰太郎[1]、David Catling[1]
*Shintaro Kadoya[1], David C Catling[1]

1. ワシントン大学
1. University of Washington

Life probably arose in the Hadean (either on land or in the sea) and then would have spread through the early ocean. Hence, determining constraints on the early marine environment is essential for understanding conditions for the spread of early life, in addition to the history of the Earth itself. In this study, we modelled the evolution of the surface environment of the Earth, including the surface temperature, pCO_2, and oceanic pH.

As revealed by previous works (e.g., Krissansen-Totton et al., 2018, PNAS), Earth's long-term surface environment is controlled by the carbonate-silicate geochemical cycle. This negative feedback has moderated the surface temperature, resulting in the continuous existence of surface liquid water, even when the solar luminosity was smaller in the past than today. To compensate for the faint Sun, the feedback sets a high pCO_2 in the past, which would result in a more acidic ocean. The same mechanism can be applied for modelling the Hadean eon. However, we have to add another factor: impact ejecta weathering. As indicated by impact craters on the Moon, the Earth would also undergo intense meteorite impacts during the Hadean. Since the impact ejecta are easily weathered, they provided an additional sink of CO_2. Hence, previous works (e.g., Sleep & Zahnle et al., 2001, JGR) suggested that the surface temperature and pCO_2 would actually be low, i.e., a cold Hadean Earth –an idea that has been controversial.

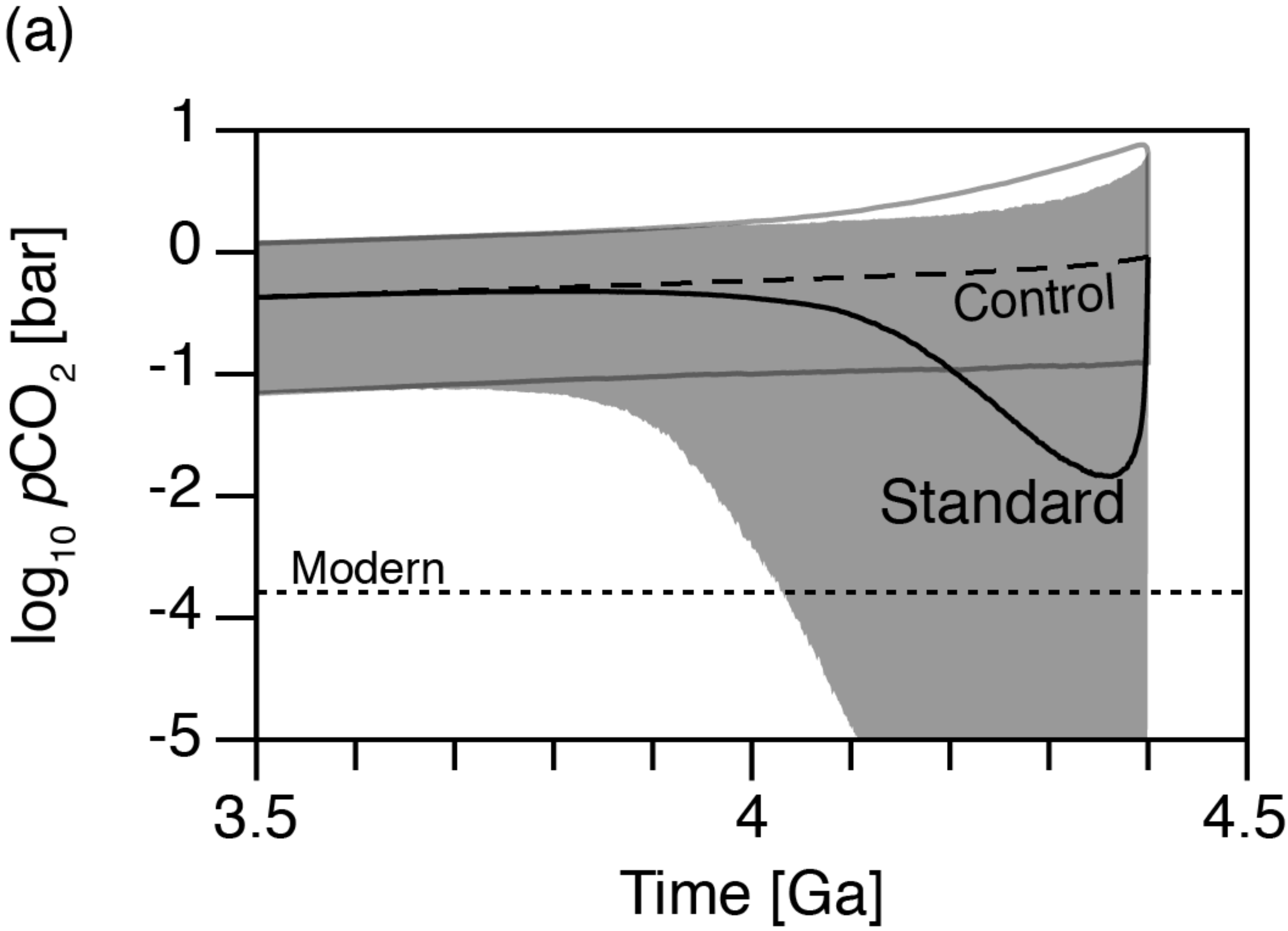
In this study, we calculated the evolution of the surface environment by varying parameters in a geologic carbon cycle model within their ranges of uncertainty. Since the ejecta weathering is a source of carbonate alkalinity (i.e., a sink of CO_2), the pCO_2 and surface temperature of cases with ejecta weathering (hereafter, standard cases) are lower than those of cases without ejecta weathering (hereafter, control cases), as shown in Figure 1a and 1b. The surface temperatures of some standard cases are even lower than 273.15 K (Figure 1a). The coldness does not always mean that the Earth was in a snowball state during the early Hadean; instead, it just indicates a high likelihood of a cold climate. The low pCO_2 of standard cases also results in high ocean pH (Figure 1c). In addition, because the high pH results in a high precipitation rate of carbonate, the carbonate alkalinity of standard cases tends to be lower than that of control cases.

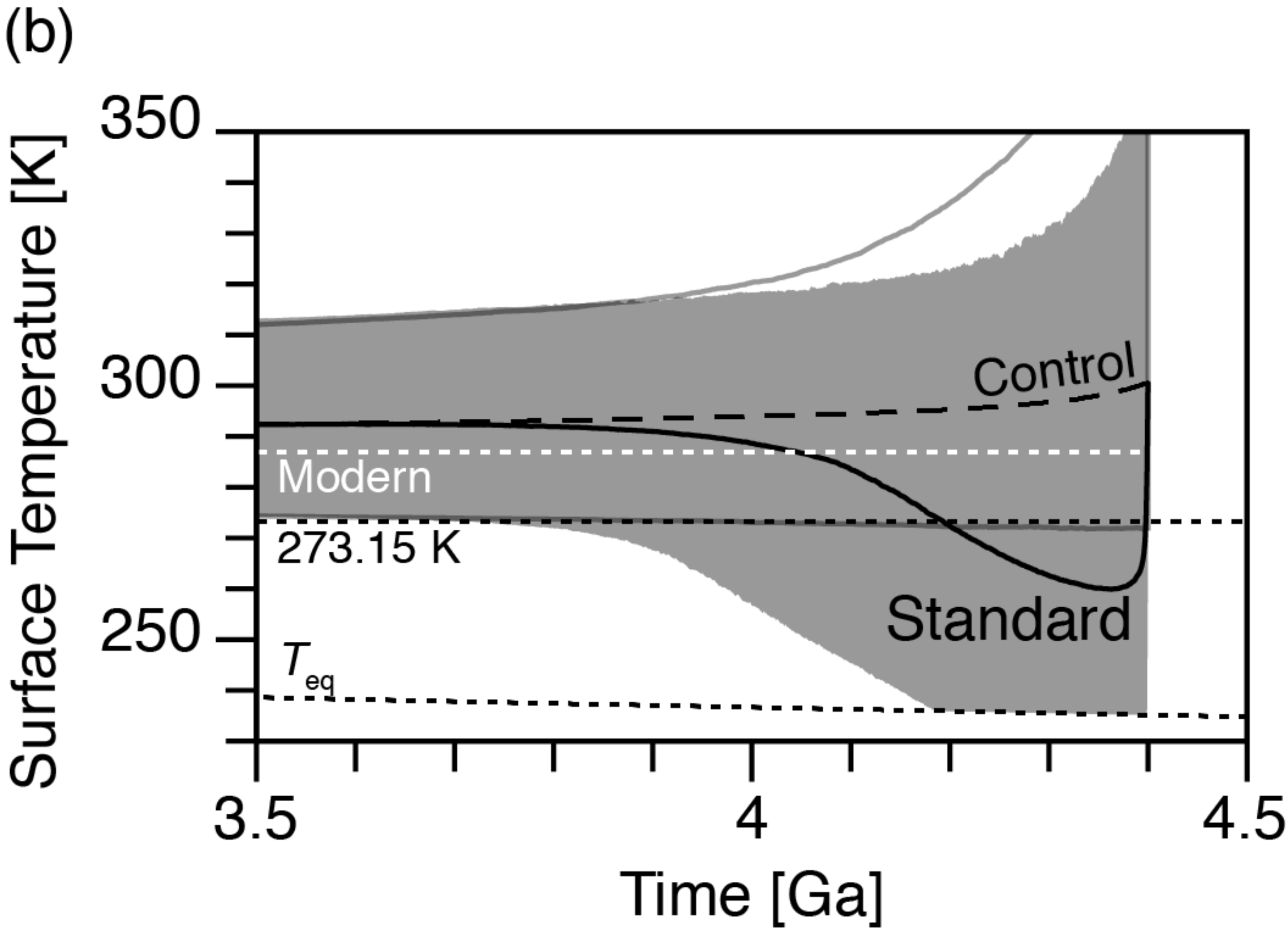
For the standard case, such a relatively cold surface and alkaline ocean are confined to the early Hadean, in which the impact flux (i.e., ejecta production rate) is high. However, the impact craters on the Moon also indicate the possibility of an enhanced impact flux around 4 Ga (i.e., the late heavy bombardment; LHB). The estimated impact flux for the LHB is also high enough to result in a cold surface and alkaline ocean. Hence, we should consider the possibility that life existed in a cold and alkaline early ocean.
Fig. 1. Results with control (without ejecta weathering) and standard cases (with ejecta weathering) for the geologic carbon cycle model for (a) atmospheric partial pressure of CO_2, pCO_2, (b) global mean surface temperature, and (c) ocean pH.

©2019. Japan Geoscience Union. All Right Reserved.

キーワード：冥王代、気候進化、炭素循環
Keywords: Hadean, Climate evolution, Carbonate-silicate geochemical cycle

©2019. Japan Geoscience Union. All Right Reserved.





©2019. Japan Geoscience Union. All Right Reserved.

©2019. Japan Geoscience Union. All Right Reserved.