Atmospheric CO_2 levels during the Paleoproterozoic Makganyene glaciation

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The Paleoproterozoic Makganyene Glaciation is a particularly enigmatic geologic event in that ice covered the oceans even at the low latitude (Snowball Earth) [1]. This event might have drastically curtailed biological productivity but melting of the oceanic ice presumably induced a cyanobacterial bloom, leading to an acceleration of global oxygenation [2]. It has been predicted that this event occurred as a result of the drawdown of greenhouse gases in the atmosphere [3-4]. However, even the atmospheric CO_2 level at that time is still under debate. Here, we constrained the CO_2 concentration in seawater based on the fluid inclusions in subseafloor hydrothermal quartz deposits from the 2.2 Ga Ongeluk volcanics, South Africa, in which the ancient water and carbon dioxide are preserved. The quantitative analysis of the concentration and stable carbon isotopes of CO_2 in the fluid inclusions revealed that CO_2 in the seawater was limited to less than 5.5 mmol/kg. Because the Ongeluk seawater was locally open to the atmosphere, atmospheric CO_2 level was also estimated to be lower than 21 times the present atmospheric level (PAL) assuming equilibrium between the Ongeluk seawater and atmosphere. This CO_2 level was insufficient to compensate the faint young sun and keep the ocean temperature above freezing point by itself. Our results demonstrate that the deficient atmospheric CO_2 level was a significant contributing factor to the 2.2 Ga global glaciation.

[1] Kirschvink (1992) *The Proterozoic Biosphere: A Multidisciplinary Study*, 51–52. [2] Kirschvink *et al*. (2000) *Proc. Natl. Acad. Sci. USA* **97**, 1400–1405. [3] Kopp *et al*. (2005) *Proc. Natl. Acad. Sci. USA* **102**, 11131–11136. [4] Condie *et al*. (2009) *Earth Planet. Sci. Lett*. **282**, 294–298.