Early Earth's Atmospheric Evolution

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Atmospheric composition in the Hadean is barely constrained. Zircon data indicate continents, oceans, and maybe life. In models, mean Hadean-Archean climates are not hot because even without land, weathering of seafloor and impact ejecta moderates CO_2 levels and temperature [1, 2].

Rocks indicate oceans, an atmosphere, and land by 3.8 Ga [3], and then, in the Paleoarchean, widespread signs of life. A faint Sun, biospheric gas exchange, and effects of anoxia all bear consideration. Glacial rocks (3.5, 2.9, and 2.7 Ga) suggest global mean temperatures below ~20°C, which can be supported by a CO_2-rich atmosphere (or CO_2-rich with biogenic CH_4). High Archean pCO_2 does not conflict with paleosol inferences with a range 0.02-0.75 bar [4]. Inferred pN_2 <0.5 bar at 2.7 Ga [5] causes a few °C loss of warming, but plausible CO_2 and CH_4 levels can compensate.

A geologic N cycle in an anoxic world may cause low pN_2. Today, oxidative weathering of organics releases nitrate and nitrate denitrification to N_2 is almost half the long-term N_2 flux; the other half is outgassing [6, p.204]. Archean oxidative weathering was absent, so pN_2 was plausibly lower and would have risen at the Great Oxidation Event (GOE) [5].

What of Archean CH_4 levels? Mass-independently fractionated S isotopes require >20 ppmv [7]. But evidence of H escape to space (light ocean D/H [8] and Xe isotopes that lighten in time [9]), require $2H_2+CH_4$ levels >10^3 ppmv.

Finally, global redox is key to the GOE, which requires oxidation of the surface environment by reductant removal. H escape to space driven by CH_4-enriched Archean air is by far the biggest net oxidation effect over time [10], so its effect of diminishing the pre-GOE O_2 sinks cannot be ignored.

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