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The evolution of oxygenesis in the Archaean

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The evolutionary history of oxygenesis is controversial. For most of the Archaean the sedimentary record shows that liquid water was present, implying a strong greenhouse effect. There may be two stable states in which the biosphere flourishes. If the atmosphere is anoxic, CH_4 and CO_2, plus water vapour feedback, can support liquid oceans. However, in oxygen-rich air, only trace CH_4 can exist and warmth depends on CO_2. The transition from anoxic to oxic states is likely to lead to glaciation, with productive photosynthetic oxygenesis destroying CH_4 and drawing down CO_2.

C and S isotopic evidence from the $\sim$2.7 Ga Belingwe belt, Zimbabwe, together with other evidence, imply that the reef-building autotrophs were aerobic oxygenic photosynthesisers (cyanobacteria) using Form I Rubisco. Anaerobic methanogens (Rubisco III) were also present, in muds. Similar results come from $>$2.83 Ga stromatolites from Steep Rock (Canada), Mushandike, (Zimbabwe), as well as published work on Pongola (S.Africa). There is also evidence for 2.9 Ga glaciation. This suggests Rubisco I organisms first appeared $>$2.83 Ga ago, and were abundant at 2.7-2.65 Ga ago. Prior to this, the absence of carbonate reefs may mean atmospheric CO_2 was too high to permit precipitation except in special local environments (e.g. hydrothermal systems).

The atmospheric CO_2:O_2 ratio, and hence greenhouse warming, is linked to Rubisco I's specificity for CO_2 over O_2 and compensation limits. If CO_2 is too low, autotrophy fails; if O_2 is too high, respiration dominates. Rubisco compensation constraints may explain the paradox that, despite the supposed evolution of oxygenesis as early as 2.9 Ga ago, the Δ^{33}S record is chaotic, in a system that may have oscillated between anoxic and oxic states. Only when very high CO_2 levels built up during the 2.3 Ga snowball-Earth event may it have been possible for the atmosphere to move permanently to a warm O_2-rich system, limited by compensation barriers and Rubisco I specificity.