

A first glimpse beneath the ice: molecular fossils of a Snowball Earth ecosystem

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The rise of green algae as an efficient food-source may have played an important role in the emergence of the first animals. However, it is uncertain whether chlorophytes radiated in the Cryogenian Period or later in the Ediacaran, closer to the emergence of large metazoans. To date, there is virtually no empirical evidence of Cryogenian life from either of the Snowball Earth events, whether in oceans beneath the ice or freshwater sources above the ice.

We present biomarkers from the Marinoan glacial period. A 1700-m-thick sedimentary succession records cycles of massive diamictite and intercalated shales, representing the waxing and waning of an ice-grounding line. These sediments appear to preserve a nearly complete history of the glaciation in the epeiric sea of Australia's Centralian Superbasin. Basal sediments represent ice-free waters with approaching glaciers, followed by a long deep-freeze with increasingly hypersaline, stratified waters beneath ice.

The biomarkers are distinct from any pre-Cryogenian assemblage and record a gradual increase in thermal maturity downcore, supporting a syngenetic origin and negating detrital provenance. The oxic layer of stratified waters beneath the ice harboured a nearly exclusively bacterial community as well as Protosterol biota organisms, representing extinct stem-group

eukaryotes and/or protosterol-producing bacteria. Traces of the steroid cholestane may stem from faint activity of rhodophyte algae, but aquatic fungi and myxobacteria might also be the source. Other eukaryotic steroids are absent throughout. Upsection, sub-ice waters became oxic and returned to normal marine salinity, supporting the growth of benthic microbial mats. These mats exclusively harboured bacteria and Protosterol biota but excluded crown-group eukaryotes. Thus, the entire planktonic and benthic assemblage, from open water to ice-covered, is characterized by a near-absence of modern eukaryotes and no detectable green algae.

At a broader temporal perspective, a new timeline for the rise of algae emerges. In Australia, the Cryogenian saw a return to largely bacterial primary production, while green algae became dominant only in the early Ediacaran between >635 Ma and ~620 Ma. This timeline brings strong algal activity closer to the emergence of large animals, encouraging a search for links between the evolution of Metazoa and efficient food sources.