PALAEOCLIMATE

Snowball climate conundrum

Evidence for a Neoproterozoic Snowball Earth in the sedimentary record has been controversial. A weathered horizon preserved in sedimentary rocks from Svalbard may provide a rare signature of prolonged global glaciation.

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In the ancient past our planet may have frozen globally, from pole to pole, to form a Snowball Earth. One of the most enduring sources of disagreement in the debate of the Snowball Earth hypothesis is the seemingly contradictory evidence from some climate models, which predict a completely frozen planet in the Neoproterozoic, compared with the geological record, which preserves evidence for the advance and retreat of ice sheets, indicative of a dynamic water cycle. Writing in *Nature Geoscience*, Benn and colleagues⁴ argue that a long period of cold hyper-aridity identified from a weathered horizon preceded a short period of pulsed, dynamic deglaciation as the Earth’s icy shroud was lifted. Only the brief latter stage is commonly preserved in sedimentary rocks.

Geochronological constraints on the timing of Neoproterozoic glaciations indicate that two globally synchronous ice ages occurred, an older one between 717 and 660 million years ago, and a younger one that terminated 635 million years ago¹. However, sedimentary deposits that bear evidence of glacial activity demonstrate that the ice ages were characterized by repeated advances and retreats of ice caps and glaciers. This indicates that the water cycle remained active throughout the ‘snowball’ glaciations, rather than effectively shutting down for long periods of time, as favoured by proponents of the hard snowball model⁴⁻⁵.

To investigate how these apparently disparate viewpoints might be reconciled, Benn and colleagues⁴ analyse sedimentary rocks in northeastern Svalbard, known as the Wilsonbreen Formation. These sedimentary rocks were originally deposited in a broad, long-lived basin situated in tropical latitudes at a time coincident with the younger of the Neoproterozoic glaciations and its aftermath. The team identify a weathered zone at the base of the Wilsonbreen Formation that consists of broken fragments of preglacial carbonate rocks, dense networks of fractures attributed to frost-shattering, and pebbles with facetted faces fashioned by ancient winds (Fig. 1).

Taken together, these features indicate that the weathered horizon experienced a period of exposure to the atmosphere during glaciation. The observation of exposure is consistent with a drop in sea level of several hundred metres caused by the locking up of ocean water in terrestrial ice sheets as the glacial phase intensified. The authors therefore suggest that this weathered zone at the base of the Wilsonbreen Formation provides a direct record of global glaciation, the existence of which is consistent with the Snowball Earth hypothesis.

Benn et al. also measure the oxygen and sulphur isotopic signatures of the Wilsonbreen Formation rocks to infer atmospheric CO₂ concentrations during the Neoproterozoic. They detect a covariation of δ¹⁸O values with δ³⁴S throughout the limestone rocks in the formation, which suggests high atmospheric concentrations of CO₂ during a relatively short period of deposition, perhaps just 100,000 years. Three cycles of glacial advance and retreat are recorded in the Wilsonbreen stratigraphy during this time. The authors argue that this short period of fluctuating climate must have been preceded by a cold phase of much longer duration to allow atmospheric concentrations of CO₂ to build up from values compatible with the onset of low-latitude glaciation⁶. This long, cold period could represent a true snowball phase. Simulations with a numerical climate model show that tropical ice sheets would indeed advance and retreat in response to orbital forcing at the atmospheric CO₂ concentrations that prevailed during deposition of the Wilsonbreen Formation.

The sedimentary record from Svalbard thus indicates that whereas the long period of cold hyper-aridity left only the small trace of a weathering horizon in the geological record, the ensuing dynamic deglaciation resulted in a rich variety of depositional products driven by orbital forcing. Hence, although most of geological time passed when the Earth was a snowball, almost all of the preserved sedimentary record accumulated during the relatively short period of time when the Earth was already deglaciating. If correct, these findings reconcile the collision between sedimentological observations and some climate model predictions. They also reveal the range of conditions on the Neoproterozoic Earth at which a climate transition could take place from a fully glaciated planet⁷⁻⁸ to non-glacial via a glacial–interglacial phase of orbitally driven fluctuations. This would amount to a striking confirmation from geological evidence of radiative energy balance models.

Benn et al.¹ identify a weathered basal zone in the Wilsonbreen Formation in Svalbard that provides a direct record of a fully glaciated Snowball Earth phase. We do not know, at this point, whether the frost-
shattered and wind-eroded features of the stones and pebbles of this layer are typical of the continental surfaces underlying other glacial successions from the Neoproterozoic. Analogous features are, for instance, found in the Neoproterozoic rocks of the Stuart Shelf, South Australia. Clearly, there is now an added incentive to investigate, where possible, the basal surfaces of other Neoproterozoic glacial successions worldwide.

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References

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