Geochemical stratigraphy in the Sturtian Port Askaig Formation – testing palaeoenvironmental implications for the Snowball Earth Hypothesis

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Snowball Earth (Hoffman et al. 1998) refers to a deep-frozen Earth, initiated by low pCO_2 and characterized by high albedo. Late Neoproterozoic major glaciations with ice sheets extending to sea level near the equator have been evidenced by analysis of sedimentary successions characterized by numerous diamictite beds and associated cryogenic phenomena on most continents. The original Snowball Earth Hypothesis predicted a multimillion years hiatus when the Earth's anoxic and ferruginous oceans were completely frozen over and the hydrological cycle was shut down. Although compelling, the hypothesis is still debated, particularly for the long Sturtian episode (716-660 Ma).

The Port Askaig Formation (PAF) is a ~ 1,100 m thick, well exposed Sturtian deposit which crops out over ~700 km in NW Ireland, the Hebrides and mainland Scotland and consists of 48 diamictite beds interlayered with non-glacial rocks (Spencer 1971, Ali et al 2018). As part of research by a diverse multinational team led by A.M. Spencer the geochemical study presented here will constitute one chapter of a Memoir planned to be published by the Geological Society of London.

A geochemical log based on 300 stratigraphically positioned samples from Scotland and Ireland, covering the entire sequence of the PAF, was used to analyze the character and stratigraphic pattern of the PAF sediments, with these palaeoenvironmental and provenance interpretations:

At a level of ~ 15% of the stratigraphic thickness of the PAF there is an abrupt break in the element composition of the diamictites. New components, precipitated iron and manganese and granitic detritus are added, and limestone supply is suddenly cut-off. The mix of compatible to incompatible elements also changes here. A Snowball Earth deep-freeze hiatus just below this level would allow processes on tectonic time scales to explain these changes in sediment supply.

Studies of chemical weathering using quantitative indices show a glacial clay composition in the lower diamictite beds, above which there is a sudden shift to a well-weathered shale just below the stratigraphic break. A fast return to an un-weathered state is then followed by a gradual move towards shale at the top of the PAF.

The palaeoenvironmental mechanisms controlling the PAF sediments have generated the same stratigraphic geochemical pattern over a lateral distance of more than 250 km, including the replacement of carbonates by siliciclastic detritus and the occurrence of precipitated iron beds. This negates localized causes for the stratigraphic break in sediment supply.

Five cyclic changes following a saw-tooth pattern are seen in elements associated with glacial silt in the diamictite beds, possibly indicating a variation between glacial and glacifluvial processes. Together with the interlayered non-glacial sand- and siltstone beds in the PAF and observations of periglacial sandstone wedges and frost-shattered stones, they point to an active hydrological cycle.

In summary, findings from this geochemical study of the sediment stratigraphy of the PAF can both support the multi-million years hiatus of the Cryogenian Snowball Earth Hypothesis, but also disprove the shut-down of an active hydrological cycle then.

References

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