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Carbonate-Associated Phosphorus Reveals a Large and Persistent Phosphorus Reservoir During the Marinoan Glaciation

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The Marinoan glaciation is considered a hard Snowball Earth event in which continents and oceans were completely covered by ice. How eukaryotes survived under such extreme conditions is a key question in the history of life evolution. The most conservative view holds that eukaryotes barely survived through meltwater and nutrients in cryoconite holes. Evidence also suggests the existence of locally active ecosystems such as the Songluo biota during the Snowball Earth glaciation. A more radical perspective proposes that primary productivity persisted widely during the Marinoan glaciation and maintained a substantial dissolved organic carbon (DOC) reservoir in seawater.

Phosphorus and other key nutrients are core factors affecting productivity. Whether seawater contained sufficient phosphorus is also a critical prerequisite for the organic carbon reservoir hypothesis during the glaciation. Although reliable carriers of seawater phosphorus records are lacking in glacial diamictites, we discovered carbonate strata deposited during the Marinoan glaciation in multiple sections in South China. We constrained seawater phosphorus concentrations through carbonate-associated phosphorus (CAP).

CAP exhibits relatively uniform compositions of 0.3–0.6 mmol/mol across multiple shallows to deep water sections, representing relatively high values in geological history. Due to extremely low organic carbon content in the samples, the decomposition and release of organic phosphorus during diagenesis is insufficient to affect the CAP signal. The data indicate a large and relatively uniform phosphorus reservoir during the Marinoan glaciation.

Unlike the extreme phosphorus depletion in surface seawater of the modern ocean, this uniform phosphorus reservoir suggests that widely distributed primary productivity did not exist during the Marinoan glaciation. However, CAP differences of ~0.1 mmol/mol between sections indicate possible productivity hotspots, causing some heterogeneity in seawater phosphorus concentrations.

The large and relatively uniform phosphorus reservoir during the Marinoan glaciation supports the possibility of biological flourishing in certain warm environments. It may have produced a substantial DOC reservoir during the glaciation, which could have regulated atmospheric carbon dioxide concentrations and climate change through variations in seawater redox conditions.