Rapid microbial-methane deglaciation of the Marinoan Snowball Earth

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The Marinoan glaciation of the Cryogenian Period (635 Ma) was the last of the global ice ages (Snowball Earth) reaching low latitudes, and the end of it is marked by a global carbonate unit with distinct depositional and geochemical features. The appearance of the cap dolomite ushered in a new climatic era coupled to an explosive expansion of animal life. A number of models, for example, from overturn of an anoxic deep ocean, to massive drawdown of atmospheric CO_2, to release of methane clathrates, and postglacial low-salinity plumeworld have been suggested for the origin of the cap carbonate. However, clues to the deglaciation process and end of the Marinoan Ice age must be sought from the cap dolomite overlying the glacial diamictites.

Here, we report on an integrated suite of petrographic, cathodoluminescence, geochemical (TE, SI, RI, Δ47), microthermometry and gas-inclusion results of the cap dolomite (member 1) of the Doushantuo Formation of China. The cap dolomite of the Doushantuo, signaled the end of the Marinoan glaciation, and it shares many physical features, geochemical signatures and depositional settings with lowermost unit's of other cap carbonates from around the world. The cap dolomite exhibits many common depositional features (e.g., laminations, teepee), and geochemical signatures (rhodocrosite, rambergite) of an anoxic environment. This is further supported by similar negative $\delta^{13}C$ values, and of similar $\delta^{18}O$ and clumped isotope-based water temperatures (32 to 57°C). We provide evidence that the pervasive vein calcite was controlled by methane-based thermochemical sulfate reduction processes. More importantly, we provide the first direct evidence for anaerobic methane and methanogenic Archaea facilitated the formation of the cap dolomicrite. After a small hiatus, high temperatures increasing upsection in the basal dolomicrite speak to the rapid transition from the Marinoan Snowball Earth icehouse to the subsequent super greenhouse world of the earliest Ediacaran.

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