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The end of the Marinoan Glaciation: an enigma shrouded in Ice, Methane and Carbon dioxide

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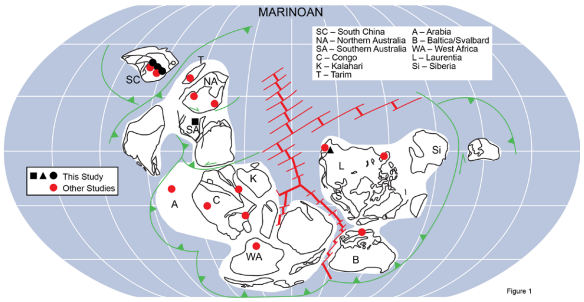

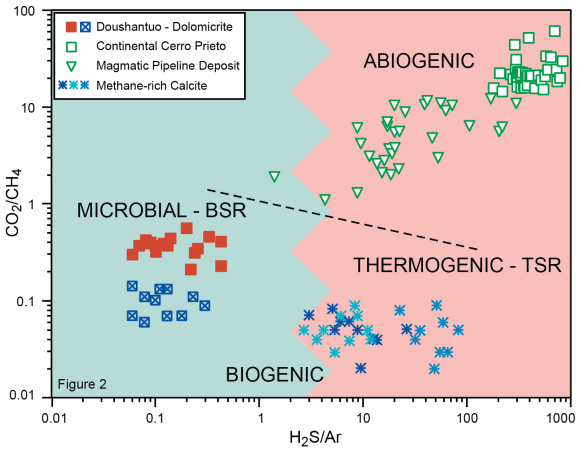

The end of the Marinoan Glaciation, signalling the transition from an icehouse to a greenhouse, is still the subject of much speculation among scientists. We are using a multitude of proxies from a number of archives from the cap carbonate marking this geologic event. The cap carbonate was collected from outcrops in China (Doushantuo), Australia (Nuccaleena) and the United States of America (Noonday) and consists of micrite, dolomicrite, dolosparite and sparite cement material (Figure 1). Its history and that of the Earth was teased from the rocks using the following proxies: trace elements (Mn, Sr, Ce*), stable isotopes ($d^{13}C$, $d^{18}O$), radiogenic isotopes ($^{87}Sr/^{86}Sr$), ultra-microanalytical gas analysis linked to petrography, cathode luminescence and microthermometry.

Deposition of the cap carbonate was a synchronous event marking the end of the Marinoan Glaciation mainly consisting of microbial dolomicrite/lime mudstone injected with several generations of calcite cement (Zhou et al., 2019). The origin of the dolomite is supported by their CO_2/CH_4 and H_2S/Ar ratios that plot in the 'Microbial-Bacterial Sulphate Reducing' regime (Figure 2; Stolper et al., 2014). The microbial dolomite formed under alternating anoxic and oxic seawater/freshwater mixtures driven by a highly methane-enriched environment and the presence of hydrogen sulfide gas (atmosphere). Subsequently, the microbial dolomite environment transitioned into a setting dominated by carbon dioxide and minor amounts of free oxygen gas in a generally dysoxic setting. Eventually, the 'upper' microbial dolomite formed under a nitrogen-oxygen atmosphere in generally oxic water conditions (Blamey et al., 2016). The cement filling the veins and fractures of the cap carbonate formed well after deposition and lithification of the microbial dolomite.

Methane emissions from various sources may have been the 'beginning' of the end for the Marinoan Glaciation, but elevated atmospheric carbon dioxide appears to have provided the 'heater' for the end of Ice on Earth.

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