Ocean oxidation and microbial activity just after the Marinoan Snowball Earth

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The Marinoan Snowball Earth event is one of the most severe environmental changes, and occurred about 650 million years ago in the Cryogenian. It is widely considered that the Earth was completely covered with ice, and that bioactivity significantly collapsed during that event. On the other hand, many fossils including acritarchs, Metazoan eggs and embryos, and algae were found after the Marinoan Snowball Earth event, indicating the bioactivity was completely recovered and organisms quite rapidly evolved in the Ediacaran. However, recovery and extent of bioactivity just after the event is still obscure. Therefore, we tried to estimate the biological activity just after the Snowball Earth event based on geological and geochemical studies of the Cap Carbonate deposited right after the event.

We analyzed aggregate of organic matter, carbonate rocks and pyrites in the Cap Carbonate of the Siduping section, South China. The Cap Carbonate is subdivided into 3 parts: C1, C2 and C3 in an ascending order. The C1 part consists of a stromatactis structure, which forms network structures of many quartz veins, and contains many domains rich in organic materials and pyrite within cavities of the stromatactis structure. The rims of veins comprise quartz, which suggests that carbonate has been silicified and replaced by silica minerals simultaneously or immediately after deposition. Generally speaking, the silicification of carbonate is due to organic acid formed by heterotrophs. Most of the central parts of the veins or cavities of the stromatactis structures contain aggregate of organic matter and pyrite, suggesting active microbial activity within pore water of conduits and among minerals. We call the organic matter as stromatactis organic matter hereafter. The C2 and C3 parts comprise layered dolostone, and the C3 part contains more detrital materials than the C2 part. No stromatactis structure is present in the C2 and Ce parts. We examined the stromatactis organic matter and organic matter within carbonate parts of the carbonate rocks from the C1 to C3 parts in order to estimate the microbial activity in the ocean and sediment.

The isotope ratios of organic carbon within the carbonate parts in the C2 and C3 parts range from -28 to -24‰, corresponding to photosynthesis by cyanobacteria. The carbon isotope ratios of organic matter within the carbonate parts in the C1 part is characterized by a wide range of the values (-34~-22‰), possibly due to mixing between photosynthetic carbon fixation and methane-related processes. In addition, carbon isotope ratios of the stromatactis organic matter are significantly low, ranging from -35 to -30%, possibly due to the methane-related processes. Methanogen and anaerobic methanotrophic Archaea possibly produced the organic matter with the low carbon isotope values. In addition, there are many pyrite grains occur together with the stromatactis organic matter, which also suggests active sulfate reduction together with the anaerobic methanotrophic activity. We try to prove the microbial combination based on sulfur isotopes.

Nitrogen isotope ratios range from -2 to +7‰. The nitrogen isotope values of the stromatactis organic matter in the C1 part ranges from -1 to +1‰, whereas those of carbonate parts abruptly increase from -1~+1‰ in the lower part to +7‰ at the top of the C1 part. The low values around -1 to +1‰ indicate that

nitrogen fixation was dominant after the Snowball Earth event. On the other hand, the high nitrogen isotope values indicate that the nitrification and denitrification restarted at that time possibly because seawater became oxic enough to form nitrate. On the other hand, it is considered that nitrogen fixation by methanogen was also active within the sediment because nitrogen isotope values of organic matter formed in seawater increased to +7‰, but the nitrogen isotope values of the stromatactis organic matter formed within sediment were consistently around 0‰.
Carbon and nitrogen isotope values of the stromatactis organic matter and organic matter in the carbonate parts in the Cap Carbonate suggest that ocean and subseafloor environments shared common biological activity just after the Marinoan Snowball Earth event, and that the ocean was very quickly recovered to oxic and nitrate-rich environment. The rapid recovery probably became a prelude to biological evolution of emergence of the Metazoan.

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