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Linkage of the late Cambrian microbe-metazoan transition (MMT) to shallow-marine oxygenation during the SPICE event

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Microbe-metazoan transitions (MMTs), representing a switch from microbe-mediated to metazoan-mediated carbonate production, have been linked to major changes in Earth-surface conditions. The 'late Cambrian MMT' (*nomen novum*), during which microbial reefs were replaced by maceriate and lithistid sponge reefs, coincided with a sharp rise in atmospheric O_2 levels attributed to the Steptoean Positive Carbon Isotope Excursion (SPICE) at ~497-494 Ma. However, relationships between atmospheric oxygenation, marine redox conditions, and the MMT have not been thoroughly investigated to date. Here, we conducted paired analyses of carbonate carbon isotopes ($\delta^{13}C_{carb}$), sulfur isotopes of carbonate-associated sulfate ($\delta^{34}S_{CAS}$) and pyrite ($\delta^{34}S_{Py}$), pyrite morphologies, and fossil assemblages of two upper Cambrian shallow-marine sections on the North China Platform (Tangwangzhai and Huangyangshan). The sulfur isotopic composition of framboidal pyrite ($\delta^{34}S_{FrPy}$) was calculated from that of total pyrite ($\delta^{34}S_{TPy}$) assuming a varied fractionation with euhedral pyrite based on pyrite morphological analyses. Modelling of S-isotope fractionations ($\delta^{34}S_{CAS-FrPy}$) indicates that contemporaneous seawater had low sulfate concentrations (i.e., $[SO2- 4]_{sw}$ ~4-6 mM) with locally high spatial heterogeneity during the Rising SPICE (early to middle Paibian), which were the product of massive burial of pyrite (together with organic matter) as a consequence of extensive oceanic anoxia. Immediately following the SPICE, a reduced pyrite burial rate and an increased flux of terrestrially sourced, ^{34}S-depleted sulfate to shallow-marine environments resulted in lower $\delta^{34}S_{CAS}$ values. At that time, $[SO2- 4]_{sw}$ rose to a maximum of ~9-16 mM and became more uniform during the Post-SPICE (middle to late Jiangshanian), suggesting a more oxidized condition of seawater and the atmosphere. Rising O_2 levels in both the atmosphere and marine environments triggered the late Cambrian MMT and set the stage for the subsequent Great Ordovician Biodiversity Event.