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Nitrogen and sulfur isotope evidence for enhanced marine anoxia during the Capitanian mass extinction

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Marine anoxia has long been considered a major cause of the Capitanian mass extinction, but its spatiotemporal evolution in different environments remains unclear. Here we conduct detailed geochemical analyses of both bulk nitrogen and pyrite sulfur isotopes from Middle Permian strata at different water depths across the shelf-basin transect of the lower Yangtze region, South China. Our results show a three-stage variation of N-S isotopes: (1) the Roadian stage is characterized by relatively high and stable $\delta^{15}N_{bulk}$ values (average +10.4‰) but very low $\delta^{34}S_{pyrite}$ values (average -32.7‰); (2) the early Wordian-Capitanian stage is marked by gradually decreasing $\delta^{15}N_{bulk}$ values (average +6.8‰) but significant spatial differences in $\delta^{34}S_{pyrite}$ values (high in deep water [-25.5‰] but low in shallow water [-38.6‰]); and (3) the middle-late Capitanian stage is featured by relatively low $\delta^{15}N_{bulk}$ values (average 4.3‰) and still-maintained spatial differences in $\delta^{34}S_{pyrite}$ values (high in deep water [-28.6‰] but low in shallow water [-36.7‰]). The gradually decreasing $\delta^{15}N_{bulk}$ values in all study sections, coupled with increasing $\delta^{34}S_{pyrite}$ values only in deep water, could suggest enhanced anoxic-euxinic conditions. This further confirms our previous hypothesis that intensified euxinia caused by the expanded OMZ during the Capitanian, as supported by integrated Fe speciation and redox-sensitive trace element data. Notably, the consistent decrease in $\delta^{15}N_{bulk}$ could indicate enhanced stratification and a raised chemocline, which may further intensify the bacterial sulfate reduction and restrict the replenishment of sulfate, causing the spatiotemporal fluctuation of $\delta^{34}S_{pyrite}$. Combining our previous results on basinal restriction, we reconstructed the spatiotemporal evolution of marine anoxic-euxinic conditions throughout the Middle Permian. Through a comparison of available global data, we suggest that widespread anoxia-euxinia was prevalent during the Capitanian and could have triggered the Capitanian biotic crisis.