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Protracted global anoxia across the Frasnian-Famennian biotic crisis

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The drivers of the Frasnian-Famennian boundary biotic crisis (also known as the Kellwasser events), one of the "Big Five" Phanerozoic mass extinctions, remain unclear, with no broad consensus on whether anoxia, cooling, or sea-level change played the dominant role. This uncertainty hampers our ability to identify the ultimate triggers of the event—such as volcanism, land plant evolution, astronomical cycles, or paleogeographic configurations—leading to competing and sometimes contradictory hypotheses. Here, we present a carbonate uranium isotope ($\delta^{238}U_{carb}$) record of the Lower and Upper Kellwasser (LKW and UKW) from two classical sections in the Rhenish Massif, Germany, as a proxy for global seawater redox conditions. A progressive negative $\delta^{238}U_{carb}$ excursion (~0.4‰) is recorded coincident with the onset of the LKW, reaching a nadir (~0.8‰) between the events, and followed by a recovery of $\delta^{238}U$ values which terminates after the end of the UKW. Contrary to previous results, our study suggests widespread anoxia prevailed in the oceans for approximately 500 kyr. Using a dynamic mass balance model of the marine uranium cycle, we estimate that anoxia may have covered up to ~18% of the global seafloor or more than ~half of the later Devonian shelf areas. With anoxia spreading over a significant portion of the Late Devonian shelves with a large potential for nutrient recycling when covered by anoxic waters, paleogeographic configuration appears to have been a key factor escalating the Frasnian-Famennian boundary biotic crisis.