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Carbonate uranium isotopes record global expansion of marine anoxia during the Toarcian Oceanic Anoxic Event

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The Mesozoic Era hosted several oceanic anoxic events that may serve as pseudo-analogues to understand, and even predict, ocean deoxygenation triggered by current and future climate change. Among them, the Toarcian Oceanic Anoxic Event (T-OAE; ~183 million years ago) was a globally significant carbon-cycle perturbation linked to massive volcanic CO_2 release, marine faunal extinction, a crisis in carbonate production related to ocean acidification, elevated seawater temperatures, and widespread deposition of organic-rich sediments. Despite its recognition as a potential pseudo-analog for future ocean deoxygenation, current knowledge on the severity of global ocean anoxia is limited largely to studies of the trace element and isotopic composition of black shales, which are strongly affected by local processes. In this contribution, we examined the record of the T-OAE from open marine platform limestones of the southeastern Tethys Ocean through the study of carbonate-based uranium isotopes ($\delta^{238}U$), a proxy for global seawater redox conditions. Our results show a significant negative $\delta^{238}U$ excursion (~0.4‰) recorded just prior to the onset of the negative carbon isotope excursion that characterizes the T-OAE, followed by a long-lived recovery of $\delta^{238}U$ values, confirming the global expansion of marine anoxia during the event. Interestingly, this is a similar trend to that observed during Cretaceous OAE 2 and other anoxic events in Earth history, where the $\delta^{238}U$ excursion precedes the carbon excursion, suggesting a redox driver of carbon isotope change. Using a Bayesian inverse isotopic mass balance model, we estimate that the expansion of anoxic waters covered ~6-8% of the global seafloor during the peak of the T-OAE, representing 28-38 times the extent of anoxic conditions in the modern ocean. These data, combined with $\delta^{238}U$-based estimates of seafloor anoxic area for other CO_2-driven Phanerozoic OAEs, suggest a common response of ocean anoxia to carbon release, thus improving prediction of future anthropogenically induced ocean deoxygenation. When compared with estimates of seafloor anoxic area for other CO_2-driven anoxic events, the T-OAE represents the second largest anoxic event of at least the last 300 million years, surpassed only by the Permo-Triassic event, which is also related to the largest extinction event in Earth history.