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Double de-oxygenation: Unravelling OAE 2 with U isotopes

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Mesozoic 'Oceanic Anoxic Events' (OAEs) represent some of the most extreme carbon-cycle and climatic perturbations of the Phanerozoic Aeon. These events are typified by the widespread accumulation of organic carbon as marine black shales, which are interpreted to reflect extreme organic-matter production and preservation, associated with water-column oxygen depletion.

We present a new quantitative account of global oceanic redox changes during OAE 2 (Cenomanian–Turonian boundary, ~94 Ma) using a combined geochemical and carbon-cycle modelling approach. We utilize high-resolution U isotope ($\delta^{238}U$) and U/Ca data from carbonate sediments, deposited in the European Shelf Sea, as a proxy for the global extent of seafloor anoxia. These new datasets are then used to test the current leading hypotheses for OAE 2 initiation, and the resulting biogeochemical changes, by constructing a dynamic model of the coupled global carbon (C), phosphorus (P) and uranium (U) cycles. This approach differs from other efforts to model U isotope data in deep time in that it calculates changes to the wider Earth system, including temperature, weathering, nutrient inputs, anoxia and carbon burial, driven by hypothesized perturbations to the carbon cycle over the time period of interest. These changes in turn affect the oceanic U cycle.

These datasets highlight an intra-OAE complexity that has not previously been recognized, with multiple expansions of anoxia. Periods of expanded anoxia are separated by an interval of re-oxygenation associated with the temporary cooling phase known as the 'Plenus Cold Event'. Each anoxic episode was coupled to increases in weathering congruency, as recorded by Li isotopes, empirically supporting a link between increased nutrient supply and expanded oceanic anoxia. The patterns and magnitude of the U isotope and U/Ca records can be reproduced in the C–P–U model through discrete CO_2 perturbations to the ocean–atmosphere system. Feedbacks in the P cycle then help drive rapid re-oxygenation, allowing the carbon cycle to temporarily recover in the early stages of OAE 2.