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Feedback-Controlled Carbon Cycle Dynamics During OAE2

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Stabilizing feedbacks within the Earth system must regulate atmospheric CO_2 over geological timescales to prevent runaway warming following massive carbon release. However, our recent modelling work [1] suggests that strong interacting feedbacks among carbon, oxygen, and nutrient cycles between the water column and sediments can generate inherent system instability, including transient overcooling and positive carbon isotope excursions. Here, we apply this framework to Oceanic Anoxic Event 2 (OAE2; ~93 Ma), one of the most enigmatic Mesozoic perturbations of the global carbon cycle. OAE2 is commonly linked to CO_2 release from large igneous province (LIP) volcanism, triggering rapid warming, widespread marine anoxia, and major shifts in nutrient cycling. Proxy records show a broad positive $\delta^{13}C$ excursion (2–5‰) and extensive black shale deposition, but strong spatial variability and a poorly constrained event duration (~500–900 kyr). Elevated sedimentary C/P ratios suggest enhanced phosphorus (P) regeneration, highlighting its role as a key feedback in both the onset and termination of OAE2.

We present transient experiments using the 'cGENIE' Earth system model forced by carbon emission rates constrained by different LIP scenarios. The model reproduces key features of the OAE2 $\delta^{13}C$ record, including the Plenus Cold Event, which emerges from a temporary reduction in net carbon input and enhanced organic carbon burial. This leads to partial reoxygenation, suppressed P recycling, and cooling consistent with proxy-based pCO_2 minima. Modeled spatial heterogeneity in surface and deep-water $\delta^{13}C$ matches the wide range of observed excursion magnitudes, highlighting the role of regional productivity and redox conditions in shaping the recorded signal and governing carbon cycle recovery.

[1] Hülse and Ridgwell (2025), Science 389 10.1126/science.adh7730