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Constraints on Toarcian seawater redox conditions from combined U-Mo isotopes in black shales

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Variations in seawater chemistry through time, particularly in its redox state, provide critical insights into Earth system evolution, with Oceanic Anoxic Events (OAEs) representing episodes of widespread marine oxygen depletion. Isotopic signatures of redox-sensitive elements preserved in sedimentary archives, such as Mo and U, provide powerful constraints on past ocean oxygenation. However, variations in Mo and U isotope compositions can reflect both variations in the global expansion of seafloor anoxia and local changes in depositional (e.g., redox) conditions. In sedimentary archives, which were deposited under anoxic conditions, Mo and U isotopes fractionate in opposite directions (Mo towards light and U towards heavier isotopes), whereas a global expansion of seafloor anoxia is expected to drive both Mo and U towards lighter values. This behavior makes combined U-Mo isotope analyses a robust tool for separating local from global redox shifts. The Toarcian-OAE (T-OAE; ~182.9 Ma) represents an interval of Early Jurassic marine deoxygenation and environmental disturbance, as recorded in numerous sedimentary archives around the globe. However, it is still uncertain whether this reflects a global expansion of seafloor anoxia or local changes in depositional conditions.

In this study, we present combined U-Mo isotope records from black shales deposited during and after the T-OAE at three sites of the European Epicontinental Sea (Southwest-German Basin: Metzingen, Dotternhausen, and North-German Basin: Schandelah). During the T-OAE, the sections show light Mo and U isotope compositions, with δ^{98}Mo values as low as 0.61 to 0.73 ‰ and δ^{238}U values of -0.21 to -0.13 ‰. Both isotope systems shift towards heavier compositions above the event, reaching δ^{98}Mo values of 1.66 to 2.39 ‰ and δ^{238}U values of 0.12 to 0.24 ‰. This coupled response from Mo and U isotopes is consistent with a global expansion of seafloor anoxia. Local redox- and salinity-proxies (Fe/Al, Sr/Ba, B/Ga, TS/TOC) show no systematic changes across the T-OAE interval and beyond, suggesting stable local depositional conditions. The combined U-Mo isotope shifts are therefore unlikely to reflect local environmental variability, but rather appear to reflect an expansion of seafloor anoxia during the T-OAE, affecting the oceanic Mo-U isotopic mass balance at global scales