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Uranium reduction in the photic zone: A modern analogue of $^{238}U/^{235}U$ fractionation in ancient sulphidic oceans

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The redox-sensitive $^{238}U/^{235}U$ isotope proxy ($\delta^{238}U$) serves as a powerful diagnostic tool for reconstructing the redox conditions of the ancient oceans from sedimentary archives, from the initial rise of oxygen that is connected to the evolution and diversification of life, to the subsequent episodic returns to oxygen-deprived oceans as a consequence of extreme global warming. However, comprehensive understanding of the biogeochemical factors which control the U-isotope systematics in modern anoxic environments, with varying levels of oxygen deprivation, is crucial for the reliable deployment of the $\delta^{238}U$ paleo-redox tracer.

Here, we constrain the U-isotope systematics of the water column of Framvaren Fjord, Norway, the most intensely reducing modern marine basin, with H_2S concentrations exceeding 6,000 mmol/L that are 25 times greater than the Black Sea. The extreme deoxygenation of Framvaren Fjord gives rise to a 'redoxcline', separating oxic from anoxic water, being uniquely located high within the photic zone, where it is associated with a layer of intense microbial activity and particle formation. We have investigated, with high depth resolution, the U-isotope systematics of the dissolved and particulate U phases of the water column in parallel. We have quantified the reduction, removal and isotope fractionation of U as it is reduced and removed from the water column, and transported as particulate material into the underlying sediments. This comprehensive dataset provides new understanding of the dynamic behaviour and isotope fractionation of U and its interaction with biology and other trace metals, in this type-location that represents the extreme endmember of ocean de-oxygenation in the ancient sulphidic oceans where euxinia persisted into shallow waters.

This unique setting of Framvaren Fjord, promoting close interaction between microbial reactions, redox transformations, particulate matter and sunlight has not been interrogated previously for the $\delta^{238}U$ tracer. The new U-isotope fractionation behaviour observed in this study reveals U isotopic shifts that are notably larger than observed previously, and has significant implications for reliable application of the $\delta^{238}U$ paleo-redox proxy.