When uranium isotopes tell decoupled ocean anoxia tales

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A rapidly growing number of studies utilise measurements of uranium isotopes ($\delta^{238}U$) in carbonates to make inferences of the changing extent of ocean anoxia. This is usually predicated on the assumption that the uranium cycle is close to steady state, in which case a simple istotopic mass balance links greater extent of seafloor anoxia to more negative $\delta^{238}U$, because the strongly positively fractionating anoxic uranium sink is increased relative to other sinks.

However, the residence time of uranium in the ocean today (~475 kyr) is much longer than the timescale of changes in ocean anoxia, which can be governed by changes in the limiting nutrient phosphorus, with a ~40 kyr residence time. Transient changes in ocean anoxia can therefore be decoupled from changes in $\delta^{238}U$.

To illustrate this we use a simple model of the coupled global C, P, U cycles subjected to perturbations representing carbon injection by large igneous provinces (LIPs) of order ~10^{18} molC. Three different $\delta^{238}U$ response regimes emerge:

For smaller C injections, causing a few % ocean anoxia, minimum $\delta^{238}U$ occurs long (>100 kyr) after peak anoxia, which is declining. Minimum $\delta^{238}U$ instead faithfully reflects a (lagged) minimum in the U reservoir size.

For larger C injections, causing 10s of % ocean anoxia, minimum $\delta^{238}U$ can correspond to the maximum extent of anoxia, but it transiently reaches values well below the limit of ~ -0.9‰ for steady state global anoxia, because the anoxic U sink transiently exceeds the river U input.

For the largest C injections that do cause global anoxia, minimum $\delta^{238}U$ ~ -1.6‰ can occur before the maximum extent of anoxia, producing an interval where $\delta^{238}U$ is increasing to plateau ~ -0.9‰ whilst anoxia is still increasing.

Hence whilst there is some overall negative correlation between ocean anoxia and $\delta^{238}U$ there is no simple transient relationship between them. Intervals of positive correlation can occur, with $\delta^{238}U$ declining as anoxia is declining for small perturbations, or $\delta^{238}U$ increasing as anoxia is still increasing under large perturbations. There is a a consistent relationship between declining ocean U content and declining $\delta^{238}U$, which could be tested in empirical data, but the larger the perturbation the less faithfully the recovery of $\delta^{238}U$ tracks the recovering ocean U content.