Insights into short-term changes in local and global seawater redox conditions during Cretaceous OAE 2

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The mid Cretaceous was a time of extreme greenhouse conditions. Related to this were a series of major black shale deposition events associated with global perturbations of the carbon cycle (ocean anoxic events; OAEs). These units potentially document periods of rapid climate change where the redox state of the Cretaceous ocean repeatedly fluctuated between oxic, anoxic and euxinic depositional conditions, linked to orbital-driven natural processes. Understanding these short-term cycles is essential for improving our knowledge of how future rapid climate warming may affect ocean chemistry.

Global seawater $\delta^{98/95}$Mo is reflected in euxinic environments, and differs accordingly to the extent of oxic and anoxic sinks [1]. To recognise short-term changes and relationships in the local, regional, and global redox state of seawater, high-resolution (millennial – centennial) Fe, S and redox sensitive trace elements (Mo, V, U, Cr) were paired with Mo isotopes ($\delta^{98/95}$Mo). The study site was a low latitude Palaeo-North Altantic shelf region, deposited ~ 94 Ma ago.

In terms of local conditions, iron-sulphur systematics and biomarker evidence point to a predominantly sulphidic water column with short, periodic intervals of ferruginous conditions. Severe trace element depletion is mainly connected to sulphidic intervals, whereas ferruginous intervals show elemental recovery via continental input. A steady Mo isotopic composition is identified during local euxinia, indicating a reduction of the oceanic oxic sinks during OAE 2. During ferruginous conditions $\delta^{98/95}$Mo is affected by regional Mo uptake mechanisms. Conspicuous is an ~10-15 ky decrease in $\delta^{98/95}$Mo during euxinic deposition, coinciding with the peak of the positive carbon isotope excursion. This could be indicative of a massive increase in the spatial extent of ocean anoxia/euxinia in the Cretaceous oceans.

[1] Anbar & Rouxel (2007) *Annu. Rev. Earth Planet. Sci.* **304**, 87-90.

Clouds and the Faint Young Sun Paradox

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We investigate the role which clouds could play in resolving the Faint Young Sun Paradox (FYSP). Lower solar luminosity in the past means that less energy was absorbed on Earth (a forcing of -50Wm^{-2} during the late Archean), but geological evidence points to the Earth having been at least as warm as it is today, with only very occasional glaciations. We perform radiative calculations on a single global mean atmospheric column. We select a nominal set of three layered, randomly overlapping clouds, which are both consistent with observed cloud climatologies and reproduced the observed global mean energy budget of Earth. By varying the fraction, thickness, height and particle size of these clouds we conduct a wide exploration of how changed clouds could affect climate, thus constraining how clouds could contribute to resolving the FYSP. Low clouds reflect sunlight but have little greenhouse effect. Removing them entirely gives a forcing of $+25\text{Wm}^{-2}$ whilst more modest reduction in their efficacy gives a forcing of +10 to $+15\text{Wm}^{-2}$. For high clouds, the greenhouse effect dominates. It is possible to generate $+50\text{Wm}^{-2}$ forcing from enhancing these, but this requires making them 3.5 times thicker and 14K colder than the standard high cloud in our nominal set and expanding their coverage to 100% of the sky. Such changes are not credible. More plausible changes would generate no more than $+15\text{Wm}^{-2}$ forcing. Thus neither fewer low clouds nor more high clouds an provide enough forcing to resolve the FYSP. Decreased surface albedo can contribute no more than $+5\text{Wm}^{-2}$ forcing. Some models which have been applied to the FYSP do not include clouds at all. These overestimate the forcing due to increased CO_2 by 20 to 25% when pCO_2 is 0.01 to 0.1 bar [1, 2].

[1] Goldblatt and Zahnle, *Clim. Past*, **7**, 203-220, 2001, doi:10.5194/cp-7-203-2011. [2] Goldblatt and Zahnle, *Nature*, in press, 2011, doi:10.1038/nature09961.