Berner Lecture: Exploring Earth's redox landscape

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Robert Berner was a pioneer in the study of early diagenesis in marine sediments. These seminal early contributions led to fundamental new insight into controls on sedimentary pyrite formation, highlighting the interplay between C, S and Fe systematics. Building upon this, and in collaboration with colleagues, Berner was responsible for developing the first robust indicators of water column redox conditions, which, in one form or another, have been at the forefront of paleo-redox research for around 35 years.

Over the last decade or so, paleo-redox indicators based on Fe-S-C systematics have been refined further, and in combination with enhanced understanding of trace metal cycling and biomarker signatures, we are now able to provide much more detailed information on the precise redox state of the paleo-water column in both space and time. Indeed, it is no longer sufficient to simply refer to an ancient water column as being either oxic or anoxic. Biogeochemical feedbacks that control nutrient availability (which ultimately links to atmospheric oxygenation, climate, and biological evolution and extinction), vary hugely dependent on the precise redox state of the water column. Thus it is essential to identify whether the water column was fully oxic or whether there was a degree of oxygen depletion. Similarly, the prevailing paradigm of the past, whereby anoxic water column conditions were often assumed to be euxinic (sulphidic), no longer stands. Our refined paleo-redox indicators have increasingly highlighted the prevalence of a second anoxic state, termed ferruginous, where reduced iron (rather than sulphide) was present in the water column.

Differences in nutrient cycling and bioavailability under ferruginous and euxinic conditions cannot be understated. Euxinia tends to promote recycling of phosphorus to the water column, whereas trace metal micronutrients may be fixed in the sediment. The exact opposite may occur under ferruginous conditions, whereby phosphorus may be fixed in the sediment in association with Fe minerals, but trace metals are much less efficiently removed. Here, I will highlight some recent advances in reconstructions of paleo-redox conditions across various time intervals, with a focus on the role of nutrients in driving, maintaining and limiting variability in water column redox.