Geophysical Research Abstracts
Vol. 20, EGU2018-4435, 2018
EGU General Assembly 2018

Towards a mechanistic understanding of marine anoxia development during the end-Permian mass extinction

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It is generally accepted that wide stretches of the world's oceans turned anoxic during the Permian–Triassic transition. Although it is often invoked that these anoxic regions experienced an extreme redox state signified by free hydrogen sulfide in the water column (euxinia), recent studies employing iron speciation suggest that some regions were anoxic and non-sulfidic (ferruginous). Furthermore, the mechanism that drove large parts of the ocean to an anoxic state is poorly understood. Temperature-driven de-oxygenation, global-scale reduced ocean circulation and increased respiratory oxygen demand, are considered to be the most prominent candidates. Here, we investigate the distribution of the bio-essential nutrient: phosphorus, over a depth transect on the northern Pangaean margin (Festningen and Deltadalen, Spitsbergen) with a novel sequential P extraction scheme, targeting individual P containing sediment phases, such as; apatite and iron-oxide bound P. In addition, the redox state of the depositional setting is reconstructed with proxies that are sensitive to a range of redox conditions, including; iron speciation, trace element and sulfur isotope analysis. The latter is of importance as burial of phosphorus is highly dependent on local redox conditions, where euxinic basins experience intense recycling of P but ferruginous conditions might scavenge P through sorption on iron-oxide particles. The combined redox proxy records indicate diachronous development of anoxia, where the proximal shelf environment (Deltadalen) turns euxinic before the main extinction pulse. By contrast, the distal (Festningen) response is delayed and ferruginous conditions signified the initial stage of anoxia development before euxinic conditions developed in the Early Triassic. In conjunction, the proximal record is marked by decreased P contents up-section (as diagenetic apatite), tracking the development of euxinia and hence increased recycling of P. By contrast, the sedimentary P content of the distal site is comparatively low but drastically increases during the initial phase of ferruginous anoxia. These observations suggest that redox-controlled P remobilization on the shelf might have been a prominent mechanism that initiated more widespread development of anoxia concomitant with the maximum extinction pulse.