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Ediacaran-Cambrian biogeochemical cycling during the Neoproterozoic Oxygenation Event: The 'free lunch' model for the Shuram anomaly

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A diverse range of geochemical proxies, including Fe speciation, Mo and U isotopes and redox-sensitive trace metals, inform us that the sea floor became extensively oxygenated during the Ediacaran-Cambrian transition interval. However, C-S isotope systematics, rare earth element anomalies and Fe speciation data tell us also that this transition witnessed marked fluctuations in both redox conditions and oxidant fluxes. Negative carbon isotope excursions accompany the 'Neoproterozoic Oxygenation Event' but are hard to understand in terms of conventional carbon isotope mass balance. The largest of these, the Shuram anomaly, can be interpreted to relate to the oxidation of huge amounts of old organic carbon prior to the evolutionary radiation of bilaterian animals. However, it is unclear how Earth's oxygen budget could have sustained such additional oxidant demand without 'running out' of atmospheric oxygen or seawater sulphate. To illustrate this dilemma, several proposed mechanisms to generate the Shuram anomaly explain DOC remineralisation, but in so doing generate an oxidant imbalance that would ultimately prove self-limiting. Seen in this light, the spectacular radiation of multicellular aerobes during the Ediacaran-Cambrian transition would seem to require the equivalent of a free (oxygen) lunch, provided by extrinsic (tectonic) rather than intrinsic (biological) changes. Although many authors have rejected a primary interpretation for the Shuram anomaly on this basis, huge amounts of C-13-depleted carbonate deposited over millions of years presents the same mass balance problem whether the carbonate is primary or not. One possible way out of this conundrum considers the effects of high nutrient and weathering fluxes into a predominantly anoxic ocean. This would generate euxinic (sulphidic) conditions at highly productive, eutrophic margins, such as can be found across South China where sharp redox layering constrains the distribution of early animal-based ecosystems (Miaohe biota). In mass balance terms, a 'Shuram' anomaly can only occur when surplus oxidant overwhelms the amount of oxygen released by organic burial, thus overprinting the effect of organic carbon burial on the carbon isotope mass balance. Surplus oxidant refers to any net oxygen released following organic carbon or pyrite burial that is not consumed by the terrestrial oxygen sink, which is mostly related to oxidative weathering. Assuming present-day weathering fluxes and high erosion rates, enough surplus oxidant can be generated from bacterial sulphate reduction linked to organic carbon remineralisation and pyrite burial to sustain negative excursions at steady state. The interplay between C and S biogeochemical cycles is extremely complex across the Ediacaran-Cambrian transition, making it all the more important that early animal radiations are considered within their immediate environmental surroundings as well as wider Earth system changes.