Pyrite burial, seawater sulfate scarcity, and the end Permian mass extinction

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Extreme dynamics in seawater chemistry are associated with the Permo-Triassic boundary (PTB) and end-Permian biological crisis; the largest mass extinction event of the Phanerozoic Eon. During this critical interval in Earth's history the oceans transitioned from a state of widespread euxinia (anoxic and H_2S-rich) to pervasively ferruginous (anoxic and Fe(II)-rich), implying a general instability in Earth surface redox budgets and a massive perturbation to global biogeochemical cycles. While this dramatic shift in seawater chemistry has been linked to a drawdown of the seawater sulfate reservoir, the precise evolution of seawater sulfate concentrations remains unclear and thus models that aim to mechanistically link ocean anoxia to broad-scale disruptions in the Earth system are poorly constrained. Here we show, using geochemical models tightly tethered to the geologic record and calibrated based on modern marine ecosystems, that the development of ferruginous conditions during the PTB and its aftermath requires seawater sulfate concentrations less than 100 μM—an order of magnitude lower than previous estimates of early Mesozoic seawater sulfate concentrations. While reminiscent of the ferruginous oceans of the Precambrian eons, ferruginous conditions are rare in the Phanerozoic Eon due to generally high sulfate concentrations in seawater. Such low seawater sulfate concentrations imply a reorganization of Earth surface redox budgets at a previously unrecognized scale with major implications for biology and climate.