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Widespread euxinia in the aftermath of the Lomagundi event: insights from a modeling study of ocean biogeochemical dynamics

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The emergence of strongly sulphidic oceanic waters (euxinia) during the Proterozoic may have affected biological turnover, extinction, and evolution, not only because of its toxicity to eukaryotes but also because of its fundamental role on bioessential trace metal availability. From this point of view, the evidence for euxinic environments in the Lomagundi-Jatuli event (LJE) aftermath ($\sim$2.08$-$2.05 billion years ago) in Gabon and Karelia are notable because their low $\delta^{98/95}$Mo values (less than 0.95‰ and 0.85‰ respectively) imply widespread euxinia at that time. The Francevillian Group in Gabon represents the oxic-anoxic/euxinic transitional sequence, implying a fluctuation in the atmospheric redox condition from oxic to relatively reducing, possibly due to the oxidation of substantial amount of organic matter deposited during the LJE. The large positive anomaly of sulphur isotopes and a substantial contraction of marine sulphate reservoir size through the latter part of the LJE also imply a fall in surface oxidation state. Variations of the oxygenation state of the Earth's surface would have caused substantial changes in oceanic chemical composition and, in turn, would surely have impacted the biosphere. However, the nature and dynamics of oceanic biogeochemical cycles for this interval are poorly understood.

To unravel cause and effect of the variations of oceanic redox state in the Paleoproteorozoic, we improved the CANOPS model (a 1-D advection-diffusion-reaction marine biogeochemical cycle model), in which coupled C-N-O-P-S marine biogeochemical cycles and a series of redox reactions were adequately taken into account. Through systematic sensitivity experiments we show that a substantial drop in atmospheric oxygen level could cause a widespread euxinia for millions of years, which provides a theoretical explanation consistent with the geological records, such as large positive anomaly of δ^{34}S, low $\delta^{98/95}$Mo, and a decrease in SO_4 concentration, in the aftermath of the LJE. A mass balance calculation of Mo also demonstrates that the period is marked by an expansion of euxinia to ca. 9$-$40% of the whole seafloor. Under such conditions Mo levels would decrease to as low as ca. 2.0$-$6.5 nM where nitrogen fixation by Fe-Mo nitrogenase is very sensitive to Mo concentration. We propose that a pervasive euxinia was established in the wake of the LJE as a direct consequence of a substantial drop in atmospheric oxygen level and that such waxing and waning of the atmospheric oxygenation state in the Paleoproterozoic could have caused biological upheavals through dynamic oceanic euxinia, followed by long-term stability of anoxic/non-sulphidic conditions during the mid-Proterozoic.