Goldschmidt 2021 Abstract
https://doi.org/10.7185/gold2021.4926

Conditions required for oceanic anoxia/euxinia revisited

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Earth's modern ocean is well-oxygenated, making the ocean interior habitable for the complex eukaryotic life. However, there are growing concerns about the expansion of oxygen-poor environments caused by human activities that have promoted global warming and have accelerated the global phosphorus cycle. The magnitude, patterns, and consequences of ocean deoxygenation have significant ramifications for both the distribution and abundance of animal populations and feedbacks to climate. Recent advances in numerical modellings reveal the spatial and temporal scales of ocean deoxygenation and its uncertainty on millennial timescales. However, given the long residence time of phosphorus in the ocean (~15-20 kyr), the ocean deoxygenation could last for longer time scales. Understanding the mechanistic link between global phosphorus cycle and ocean deoxygenation on timescales exceeding 10 kyr would also help shed light on the questions regarding the causal mechanisms for large-scale ocean anoxia occurred in the geological past.

Here we employ an Earth system model of intermediate complexity with the goal of assessing the major uncertainties in global phosphorus cycle, with special attention to the anthropogenic P loading, anoxia-induced phosphorus recycling from marine sediments in coastal regions, and the impact of phosphorus cycling on climate. Our stochastic approach provides an integrated, quantitative, and statistically informative picture of future ocean deoxygenation and highlights the remaining uncertainties. In particular, our results support the previous arguments that the enhanced phosphorus input to the ocean is a critical factor responsible for large-scale oceanic anoxia and that the development of anoxia in coastal regions would have a potential to dramatically change the phosphorus cycling in the global ocean.