The Co-Evolution Of The Nitrogen, Carbon And Oxygen Cycles

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Geochemical evidence suggests that the deep ocean remained anoxic for several hundred million years after the establishment of oxygenic photosynthesis. I will examine the possibility that this extraordinary delay was caused by a geochemical "bottleneck" imposed by feedbacks between carbon burial, net oxygen evolution, and the evolution of the nitrogen cycle in the early Proterozoic oceans. Whereas under anoxic conditions oceanic ammonium would have been relatively stable, as oxygen concentrations rose, nitrification and subsequent denitrification would have rapidly removed fixed inorganic nitrogen from the oceans. Denitrification restricted the further rise of free oxygen by depriving oxygenic photoautotrophs of an essential nutrient. Model simulations, initiated under anaerobic conditions with no free oxygen in the atmosphere or ocean, are characterized by an initially reduced deep ocean with abundant ammonium, followed by a low-nitrogen phase where neither form of fixed nitrogen is stable, and a fully oxidized phase with abundant nitrate. The model indicates that, in the process of oxidizing the early Proterozoic ocean, Earth had to go through an extended nitrogen-limited phase during which time carbon burial and net oxygen evolution of the atmosphere was severely attenuated. These factors continue to play out in the modern oceans, where the metabolic processes responsible for redox coupling between C, N, and O have remained virtually unchanged for the past 2.5 billion years, but yet are catabolically inefficient. The inefficiencies, which reflect negative biochemical feedbacks, impose strong constraints on the upper bound of oxygen in Earth's atmosphere.