Stepwise increases in Earth oxygenation are an inherent property of global biogeochemical cycling

LEWIS J. ALCOTT[1]*, BENJAMIN J. W. MILLS[1], SIMON W. POULTON[1]

[1]School of Earth and Environment, University of Leeds, Leeds LS2 9JT, UK (*correspondence: eelja@leeds.ac.uk)

Progressive oxygenation of Earth's atmosphere and oceans was an essential requirement for the emergence and subsequent divergence of complex animal life. It is increasingly apparent that oxygen levels on Earth rose across three major steps (the 'Great Oxidation Event', 'Neoproterozoic Oxygenation Event' and 'Paleozoic Oxygenation Event'), with only moderate variability between these events. Biological or tectonic revolutions have been proposed to explain each of these stepwise increases in oxygen, but the principal driver of each event remains unclear. Here, we employ an Earth system biogeochemical model to show that the oxygenation steps, including possible cyclic ocean oxygenation patterns in the Neoproterozoic Era, are a simple consequence of internal feedbacks within the long term biogeochemical cycles of carbon, oxygen, and the marine limiting nutrient phosphorus. A 'Great Oxidation' of the atmosphere can be driven by the transition from reduced gas regulation to regulation by oxidative weathering of organic carbon. Rapid oxygenation of nearshore shelf environments, and then distal shelf environments occurs through feedbacks between productivity and sedimentary phosphorus recycling, which ultimately leads to resiliant oxygenation of the deep ocean. This sequence of events bears a clear resemblance to the oxygenation history of the Earth as recorded by multiple geochemical redox proxies. Our model suggests that there is no requirement for a specific 'stepwise' external forcing (i.e. the evolution of new modes of life or a major tectonic event) to explain the course of Earth surface oxygenation. We conclude that Earth's major oxygenation events are entirely consistent with gradual oxygenation of the planetary surface following the initial evolution of oxygenic photosynthesis.