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Fires and the rise and regulation of atmospheric oxygen

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When did oxygen first approach 21% of the atmosphere, and what regulates it there? These are enduring puzzles in Earth system science, and fire science provides a key part of the answers.

The results of ignition experiments with natural fuels indicate that to start a fire requires at least 17% oxygen in the atmosphere. Thus, the appearance of charcoal in the fossil record around 420 million years ago in the Silurian Period indicates atmospheric oxygen was >17% then. Here we hypothesise that the first non-vascular plants, which began colonising the land surface around 50 million years beforehand (in the Ordovician Period), caused a rise in atmospheric oxygen concentration to a level >17% sufficient to support fires. We base this on weathering experiments with an analogue for the first non-vascular plants, and modelling with the COPSE model of the coupled phosphorus, carbon and oxygen biogeochemical cycles. The experiments reveal that a non-vascular plant (the moss *Physcomitrella patens*) hugely amplifies phosphorus weathering by a factor of up to 60. The modelling shows that early plant colonisation could hence have increased phosphorus supply to the ocean, fuelling photosynthetic production and organic carbon burial, which is the long-term source of oxygen to the atmosphere. Atmospheric oxygen is predicted to have risen through the late Ordovician and into the Silurian.

Since 370 million years ago, the nearly continuous record of charcoal indicates that oxygen has remained above 17% of the atmosphere. At the same time, the continued persistence of forests means fires have never been so frequent as to prevent trees from regenerating, setting a contested upper limit on oxygen of around 30%. The restriction of oxygen variation within a factor of two suggests remarkable regulation, because the whole oxygen reservoir has been replaced over 100 times in this interval. Fires are a prime candidate for forming part of the regulating mechanism, and giving it a ‘set point’, as they show a strongly non-linear sensitivity to oxygen variations around the present concentration. Fires in turn suppress vegetation and phosphorus weathering and transfer phosphorus to the ocean. Both processes reduce the long-term oxygen source from organic carbon burial, producing negative feedback. Here we explore their relative importance using the COPSE model, and revise our predictions of atmospheric oxygen variation over Phanerozoic time.