Tracking Proterozoic Oxygenation

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Surface oxygen levels in the mid-Proterozoic have been heavily debated over the past few years. Traditionally, mid-Proterozoic atmospheric pO_2 levels have been only broadly constrained to be ~1–40% PAL, and often assumed to be around 10% PAL. We present several geochemical records, and a process-based conceptual framework, that suggest background oxygen levels were below 1% of the present atmospheric level (PAL) during the billon years leading up to the rise of animals. Lower estimates for mid-Proterozoic pO_2 are traditionally derived from measurement of the extent of Fe^{3+} retention in Proterozoic paleosols. However, the only definitive, well-preserved mid-Proterozoic paleosols are actually characterized by iron loss rather than iron retention, relative to the pre-weathering composition of the parent material. In this light, mid-Proterozoic paleosols should be viewed as providing a maximum rather than a minimum constraint on pO_2 of ~1% PAL. Sedimentary Cr isotope records support the rather sparse paleosol record and similarly suggest that there was incomplete iron oxidation in terrestrial environments through most of the mid-Proterozoic. However, the Cr isotope record could be consistent with ephemeral swings to higher pO_2 levels for some intervals in the Proterozoic, which should not be surprising—dramatic swings in surface oxygen levels should be expected at lower background atmospheric oxygen conditions, even with feedbacks stabilizing the Earth system in a low-oxygen state. In addition, a new carbonate REE dataset coupled to a Ce oxidation model provides independent evidence for surface oxygen levels less than 1% PAL as a background mid-Proterozoic state. Evidence for low background oxygen levels through much of the Proterozoic bolsters the case that environmental conditions have been a critical factor in controlling the structure of ecosystems through Earth's history.