

Bistability of atmospheric oxygen and the Great Oxidation

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Earth history has been characterized by a series of major transitions separated by long periods of relative stability. The largest chemical transition was the 'Great Oxidation', approximately 2.4 billion years ago, when atmospheric oxygen concentrations rose from less than 10^{-5} of the present atmospheric level (PAL) to more than 0.01 PAL, and possibly to more than 0.1 PAL. This transition took place long after oxygenic photosynthesis is thought to have evolved, but the causes of this delay and of the Great Oxidation itself have been unclear. We show that the origin of oxygenic photosynthesis gave rise to two simultaneously stable steady states for atmospheric oxygen. The existence of a low oxygen (less than 10^{-5} PAL) steady state explains how a reducing atmosphere could persist for at least 300 million years after the onset of oxygenic photosynthesis. The Great Oxidation can be understood as a switch to the high-oxygen (more than 5×10^{-3} PAL) steady state. The bistability arises because ultraviolet shielding of the troposphere by ozone becomes effective once oxygen levels exceed 10^{-5} PAL, causing a nonlinear increase in the lifetime of atmospheric oxygen (Goldblatt *et al.* 2006). The long term redox forcing of the surface system was probably a decrease in reductant input due to a progressive oxidation of the crust (Claire *et al.* 2006). Once the system was in a bistable regime, the Great Oxidation could have been triggered by a perturbation to the carbon cycle too small to leave a carbon isotope signal. Our results indicate that the existence of oxygenic photosynthesis is not a sufficient condition for either an oxygen-rich atmosphere or the presence of an ozone layer, which has implications for detecting life on other planets by remote sensing and for the evolution of multicellular life.

References

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A coordinated continental and regional soil geochemical survey of North America

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The U.S. Geological Survey and collaborating partners in Canada and Mexico, have initiated a project that will produce a soil geochemical survey of North America. Pilot phase sampling and analyses have been completed along two continental transects, one of which extends from the west to east coasts of the United States along the 38th parallel. The data for a number of elements in this east-west transect reveal geochemical patterns that correlate with bedrock and glacial deposit composition.

One example of soil-bedrock correlation is elevated Cr concentrations in some California soils, which contain 2000-8000 ppm Cr compared to a median of 27 ppm for all samples across the east-west transect. The origin of this Cr anomaly is revealed by a more detailed regional-scale pilot study north of the San Francisco Bay extending from the Pacific Ocean to the California-Nevada border. This regional study incorporates geochemical data from nearly 2000 soil samples. Cr and Ni in these samples display patterns reflecting the underlying geology.

Elevated concentrations of soil Cr (2000-8000 ppm) and Ni (1000-5000 ppm) overlie serpentinite rocks in the foothills of the Sierra Nevada Mountains and in the Coast Ranges west of the Sacramento Valley. Chromium in these serpentinite-derived soil samples is predominantly in a refractory form, as chromite (FeCr_2O_4). Soils with Tertiary volcanic and granitic parent material located at higher elevation in the Sierra Nevada Mountains, as well as alluvial soil in the eastern Sacramento Valley, have much lower Cr and Ni concentrations relative to serpentinite soil (less than 100 and 50 ppm, respectively). Surprisingly, soil with elevated Cr and Ni content (150-400 ppm and 60-300, respectively) occurs in Sacramento Valley soil west of the Sacramento River. Chromium in this western valley geographic setting is in a less refractory form than that in soil overlying serpentinite, is more easily mobilized from soil into groundwater, and spatially correlates with the elevated groundwater Cr levels.

The geochemical studies at national and regional scales complement each other. The former targets areas of interest and the latter provides more detailed process insights.