Rapid oxygenation of Earth's atmosphere at ~2330 MA

GENMING LUO[12], SHUHEI ONO[1], NICOLAS J. BEUKES[3], DAVID T. WANG[1], SHUCHENG XIE[2] AND ROGER E. SUMMONS[1]

[1]Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, 77 Massachusetts Avenue E25-608, Cambridge, MA 02139, USA;

[2]State Key Laboratory of Biogeology and Environmental Geology, China University of Geosciences, Wuhan 430074, People's Republic of China;

[3]Paleoproterozoic Mineralization Research Group, Department of Geology, University of Johannesburg, P.O. Box 524, Auckland Park 2006, South Africa

Multiple lines of evidence suggest that the Earth's early atmosphere >2.45 billion years ago (Ga) was anoxic. The irreversible oxygenation, generally denoted as the great oxidation event (GOE), was a pivotal point in Earth's history and paved the way for the emergence and diversification of eukaryotes.

The sedimentary rock record of multiple sulfur isotopes is one of the most important proxies with which to explore the oxygenation of the atmosphere. Although the mechanisms for the mass independent fractionation of sulfur isotopes (S-MIF) are still under investigation, it is thought to arise from photochemical processes involving atmospheric SO_2. The production and preservation of S-MIF signals are only possible under an atmosphere with pO_2 less than 10^{-5} times the present atmospheric level (PAL). Previous measurements of S-MIF in pyrite and sulfate minerals roughly constrained the anoxic-to-oxic transition to between 2.5 and 2.3 billion years ago. Details of the process and its duration, however, have been poorly constrained. Here, through analyses of multiple sulfur isotope ratios in diagenetic pyrite grains from three drill cores through a continous sedimentary package from the Upper Rooihoogte to the lower Timeball Hill formations, South Africa, we show that the oxygenation occurred at ~ 2330 Ma as indicated by the disappearance of S-MIF signals. The transition occurred rapidly, probably in 5 million years or less, and was likely followed by intensive oxidative pyrite weathering and an increase of seawater sulfate levels recorded in highly ^{34}S-depleted pyrite grains.

The rapidity of the oxygenation suggests that the Earth's surface redox systems were delicately-balanced and is consistent with an origination of oxygenic photosynthesis well before 2.3 Ga. Our results further suggest that this oxygenation postdated the initial Paleoproterozoic glaciation.