

## A Simple Astrobiological Scenario to go from the Great Oxygenation Event to the Origination of Eukaryotes

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Taken in the context of Earth History, it is now clear that all previously reported Archean biomarkers indicative of oxygenic photosynthesis are most likely in error, a result of contamination during sampling. Reported geochemical whiffs of oxygen from ABDP-9 are also tightly associated with hydrothermal veins of highly crystalline clinocllore, and are thus metasomatic artifacts from hydrothermal vein deposits. Firm evidence for Archean oxygen simply does not exist.

A much simpler scenario will be presented here in which photosystem-II evolves at ~ 3.35 Ga, causing the radiation of the Cyanobacterial clade during the Gowganda glaciation. The resulting drawdown of CO<sub>2</sub>, and destruction of CH<sub>4</sub>, triggered the Makganyene global (snowball) glaciation, freezing the ocean surfaces for ~ 50 to 100 Myr, ending at 2.22 Ga. This is immediately followed by the deposition of the Kalahari Manganese Field, which is the oldest firm geological constraint on copious quantities of free O<sub>2</sub> in Earth's environment. As there must be a time gap between the evolution of Photosystem-II and the origin of oxidative phosphorylation (aerobic respiration), Earth's carbon cycle must have been extremely out of balance. We interpret the Lomagundi/Jatuli Carbon Isotope excursion (about 2.2 to 2.06 Ga) as precisely this imbalance, where the oxygen produced by photosynthesis, and organic matter produced, could not be easily recycled. The fraction of organic carbon buried increased from the long-term average of about 20% up to about ~ 75%, yielding isotopic compositions of carbonate as heavy as +15 per mil. Oxygen in the atmosphere is known to have increased to high levels ? perhaps several bars - resulting in the supergene alteration of the ~ 2.1 Ga iron ores in the Sishen deposit of South Africa during formation of the Hekpoort Paleosol. During this Lomagundi event, the high oxygen levels would be limited by the inability of cyanobacteria to release oxygen against high back pressures, and the remineralization of organic carbon would be accomplished by oxidative weathering of sulfide minerals releasing sulfate, and by the subsequent action of sulfate reducing bacteria to break down the organic carbon.

As the radiation of the Proteobacteria post-dates the radiation of the Cyanobacteria, and the ancestor of the Eukaryotic mitochondria was once a free-living alpha-Proteobacterium, it also follows that the first organelle-bearing eukaryotes must post-date the Makganyene Snowball Earth event. Numerous eukaryotic organelles have ancestry in this bacterial endosymbiont, as do cellular components such as the hydrogenosome in basal Protists.

A puzzling organelle present in both Bacteria and Eukaryotes (including many Protists) is the magnetosome, a membrane-bound, single crystal of biological magnetite (Fe<sub>3</sub>O<sub>4</sub>) or greigite (Fe<sub>3</sub>S<sub>4</sub>). Magnetosome chains orient single cells in the geomagnetic field and allow environmental positioning. Recent work on the genetics of biomineralization in magnetotactic bacteria (MB) has shown that both the greigite and magnetite genetic pathways share a common origin, supporting an earlier suggestion that the biochemistry of magnetotaxis is monophyletic.

Small subunit RNA sequence data from hundreds of extant MB are consistent with the origin of magnetotaxis within the Bacterial domain postdating the separation of stem-group cyanobacteria, but preceding radiation of the Proteobacteria (including the mitochondrial ancestor). We propose that the free-living mitochondrion ancestor was a magnetotactic bacterium. This hypothesis presents attractive implications for adopting cytoskeletal framework throughout the eukaryotic cell, for explaining the presence of magnetosomes throughout the Eukaryotes, and for justifying the demonstrated ability of the bacterial MagA protein to induce magnetite biomineralization in mammalian cells. The radiation of the Eukaryotic Domain of Life would therefore restore balance to the carbon cycle.

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