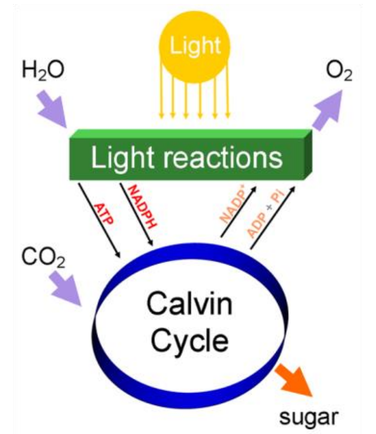
Effect of Cyanobacteria and Oxygen
Teacher Notes

The importance of cyanobacteria and oxygenic photosynthesis

Cyanobacteria were the first organisms to carry out oxygenic photosynthesis. Oxygenic photosynthesis uses light energy to power a series of reactions that use carbon dioxide to make sugar (chemical energy) and release oxygen (O_2) as a waste product.

The reactants in oxygenic photosynthesis (H_2O and CO_2) are readily available in the environment. Cyanobacteria that used this process had a huge advantage over other organisms. Organisms using oxygenic photosynthesis are the basis of Earth's most productive ecosystems. Plants and algae have captured cyanobacteria in chloroplasts, taking advantage of this innovative food production system.



Simplified diagram of oxygenic photosynthesis (D Mayer 2007, Creative Commons)

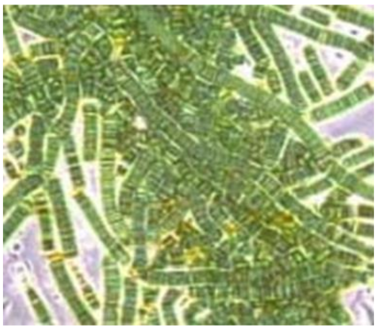
The Great Oxidation Event (GOE)

The evolution of oxygenic photosynthesis led to enormous changes known as the Great Oxidation Event (GOE) which occurred 2.4 – 2.3 Ga ago. All spheres of Earth were changed by oxygen. Scientists investigate the GOE using biological markers preserved in rock and examining minerals formed in the presence of oxygen.

The GOE is the point at which oxygen reached a steady, low level in the atmosphere. Studies of sulfur isotopes suggest that the minimum level of atmospheric oxygen was 0.001% of the current oxygen level. The ozone layer was established and, although oxygen levels have fluctuated, oxygen has been a permanent component of the atmosphere since the GOE.

Changes to the biosphere

Increased primary production
Oxygenic photosynthesis is a very efficient method of obtaining energy from the environment. Ecosystems based on cyanobacteria and oxygenic photosynthesis are at least 10 times more productive than other types of ecosystem. Cyanobacteria were able to live in a wide variety of habitats (ocean, freshwater, soil) and temperatures, further increasing primary production.


Cyanobacteria (NOAA, public domain)

Mass Extinction
Oxygen is deadly to most anaerobic organisms. The oxygen produced by oxygenic photosynthesis is thought to have caused a mass extinction of anaerobic life. The original life on Earth was confined to anaerobic habitats in deep waters and other extreme environments.

Aerobic respiration

Genomic analysis of cyanobacteria lineages suggests that aerobic respiration arose quickly in all lineages (including those that do not photosynthesise) after the evolution of oxygen production. Aerobic respiration releases more chemical energy than anaerobic respiration. There was strong evolutionary pressure to use aerobic respiration after the GOE. Organisms using aerobic respiration are ancestral to all multicellular and complex life.

Changes to the geosphere

The production of oxygen may be responsible for later banded iron formations (BIFs). Although once thought to be entirely due to oxygen production, it is now recognised that BIFs may be created by abiotic processes, anoxygenic photosynthesis and/or oxygenic photosynthesis. The early deposits were not oxygenic in origin.

Oxygenation caused irreversible changes to many sediments and minerals. These included deposits of red beds (iron oxide containing sedimentary rocks) on land and in shallow waters, formation of iron oxide soils and gypsum deposits. Minerals that decompose in the presence of oxygen (pyrite, uranite, siderite) became rare after 2.4 Ga. Fractionation of sulfur isotopes is sensitive to oxygen. Sulfur fractionation places the rise of atmospheric oxygen at 2.35 Ga.

Red beds of Proterozoic age are seen in the lower strata of the Grand Canyon. (J St John 2007, Creative Commons)

Changes to the atmosphere

Oxygenation of the atmosphere led to gradual formation of the ozone layer in the stratosphere. Atmospheric carbon dioxide was decreased as the highly productive cyanobacteria increased the global amount of photosynthesis.

Changes to the hydrosphere

Changes to the hydrosphere mirrored those in the atmosphere (increased oxygen, decreased carbon dioxide). Oxygen production would also have sped up the final depletion of ferrous iron (Fe^{2+}) in the oceans.

Other events influencing the spheres at the time of the GOE

The GOE was not the only major event during the early Proterozoic. A great tectonic transition was occurring. Continent formation had increased and continental crust rose above the oceans at about 2.5 Ga. Volcanoes on land suddenly became dominant and erupted at much higher temperatures, releasing oxidised gases such as sulfur dioxide (SO_2) rather than hydrogen and hydrogen sulfide (H_2S).

The form of tectonics also dramatically shifted at 2.5 Ga. During the Archaean there was a stagnant-lid crust system. Soft crust was overturned and resurfaced. Drifting of weak continents and crustal slabs probably began around 3.9 Ga, but active subduction was not achieved until substantially cooler and stiffer ocean lithosphere formed as Earth cooled. The advent of active subduction changed geochemical cycles and may have been an important factor in cyanobacterial evolution and the GOE.

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