
AUSTRALIAN EARTH SCIENCE EDUCATION
Evidence for the Development of Photosynthetic Life
Resourced by
EARTH SCIENCE WESTERN AUSTRALIA
GOLD INDUSTRY GROUP
ausearthed.com.au

Cover Slide

What is photosynthesis?

- A light-harvesting pigment absorbs light and converts light energy into chemical energy
- Converts inorganic carbon (CO_2) into biological molecules

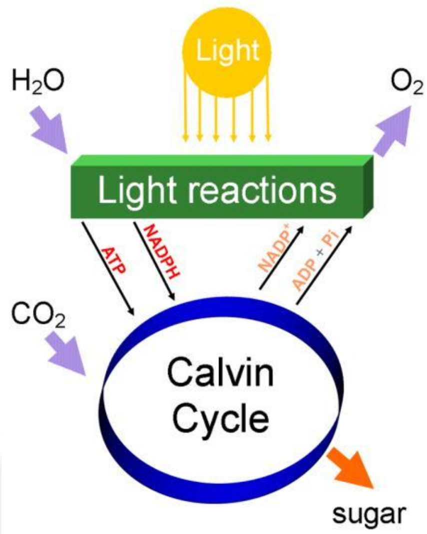
ausearthed.com.au

Light energy removes an electron from the pigment. The electron is picked up by other molecules, but must be replaced.

Photosynthesis also moves inorganic carbon (usually from carbon dioxide) into the biosphere.

Oxygenic photosynthesis

- Oxygenic photosynthesis uses water as an electron donor and produces oxygen as a waste product



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

Oxygenic photosynthesis uses energy from light to remove an electron from a light-harvesting pigment. The electron powers the light reactions and must be replaced. A water molecule is split to replace the electron and oxygen is produced as a byproduct. Cyanobacteria are the only bacteria that use this process.

Cyanobacteria and oxygenic photosynthesis

- Oxygenic photosynthesis in cyanobacteria
- Uses a more complex molecular pathway
- Arose approximately 2.35 Ga (billion years ago)

Cyanobacteria (Dr J Reischig, Creative Commons)

ausearthed.com.au

Oxygenic photosynthesis only arose once – in the cyanobacteria.

Both photosystems are combined and the process is more efficient than anoxygenic photosynthesis.

The oldest cyanobacteria fossils are at 1.9 Ga. However, genetic evidence places the evolution of oxygenic photosynthesis at 2.35 Ga and this is generally consistent with geological evidence of oxygen after 2.4 Ga. Some scientists suggest that oxygenic photosynthesis may be 3.2 Ga old based on evidence of ‘whiffs of oxygen’ preserved in the geological record. The figure of 2.35 Ga is widely accepted, because it correlates with the Great Oxidation Event.

Anoxygenic photosynthesis

- The first forms of photosynthesis
- Simpler molecular pathways than oxygenic photosynthesis
- Anoxygenic photosynthesis may use
  - Hydrogen sulfide
  - Sulfur
  - Hydrogen
  - Ferrous iron
  - Nitrite

Sulfur bacteria live in extreme modern environments such as Morning Glory Pool at Yellowstone National Park (daveynin 2010, Creative Commons)

ausearthed.com.au

Anoxygenic photosynthesis is the most ancient type of photosynthesis. It is still used by a diverse range of Bacteria and Archaea living in lakes, hot springs and soil. None of the electron donors produce oxygen as a byproduct.

Microbes using anoxygenic photosynthesis use one of two different molecular pathways – photosystem I or photosystem II.

Ferrous iron (Fe^{2+}) is the most efficient of these systems and probably dominated in the early Archaean. Oxidation of ferrous iron causes precipitation of ferric iron (Fe^{3+}) compounds. This type of photosynthesis is observed in some deep lakes. It is called photoferrotrophy.

Camacho A, Walter XA, Picazo A, Zopfi J (2017). Photoferrotrophy: remains of an ancient photosynthesis in modern environments. *Frontiers in Microbiology* **8**: 323. doi: 10.3389/fmicb.2017.00323 (Open Access)

Canfield DE, Rosing MT, Bjerrum C (2006). Early anaerobic metabolisms. *Philosophical Transactions of the Royal Society B* **361**: 1819-1836. doi: 10.1098/rstb.2006.1906 (Open Access)

Evidence for photosynthesis: Stromatolites

- Stromatolites are formed by microbial mats that trap sediment and deposit carbonates

Stromatolite in Shark Bay, WA. Oxygen bubbles are visible on the upper surface due to photosynthesis by cyanobacteria.

ausearthed.com.au

Although known from fossils for many years, modern stromatolites were first described in 1954. They are sedimentary structures formed when bacteria trap sediment AND deposit carbonate.

Evidence for photosynthesis: Stromatolites

- Stromatolites are formed by microbial mats that trap sediment and deposit carbonates
- Modern mats contain cyanobacteria and 10+ other types of microbe

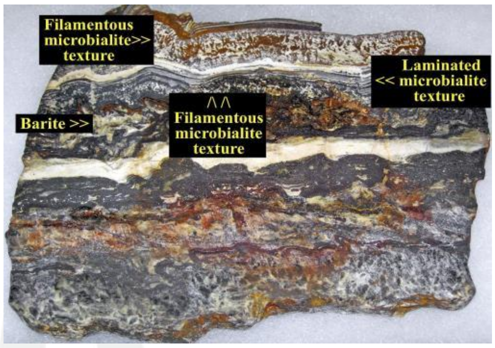
Stromatolite in Shark Bay, WA. Oxygen bubbles are visible on the upper surface due to photosynthesis by cyanobacteria.

ausearthed.com.au

Modern stromatolites occur in hypersaline water (Shark Bay), in the open ocean and in freshwater locations. Mats differ, but all contain cyanobacteria and at least 10 other varieties of microbe. Microbes in the deeper layers are anaerobic. Some can carry out anoxygenic photosynthesis.

Evidence for photosynthesis: Ancient stromatolites

- Very old and often altered



Stromatolite from the 3.48 Ga Dresser Formation of North Pole Dome, Pilbara. This stromatolite formed in a hot spring near a volcanic caldera. (J St John 2019, Creative Commons)

ausearthed.com.au

Stromatolites are the oldest macroscopic fossils and common in Western Australia. The stromatolite in the photo is from the 3.48 Ga Dresser Formation. The textures are characteristic of microbial mats, but it has been affected by a variety of processes including heat and recrystallisation. Thus, microbe fossils cannot be directly examined from early stromatolites.

Evidence for photosynthesis: Ancient stromatolites

- Very old and often altered
- Formed by trapping sediment and secreting carbonates

ausearthed.com.au

Microscopic studies of ancient stromatolites suggests that the microbial mats both trapped sediment and secreted carbonates, just like modern stromatolites.

Evidence for photosynthesis: Ancient stromatolites

- Very old and often altered
- Formed by trapping sediment and secreting carbonates
- Found in shallow waters, suggesting photosynthesis

ausearthed.com.au

The locations in which stromatolites formed were invariably shallow marine environments. These were the first reef-builders. This location suggests that photosynthetic microbes were important in their formation.

Evidence for photosynthesis: Carbon isotopes

- Carbon isotopes rich in carbon-12 indicate biological carbon
- Deposits of organic carbon rose significantly 3.5 Ga, indicating the evolution of photosynthesis

Graphitic BIF from Isua Greenland. Carbon isotopes indicate a biological origin for the carbon. (J St John 2010, Creative Commons)

ausearthed.com.au

The ratio of C12:C13 indicates whether carbon is from an inorganic or organic source. Living things will absorb more C12 (lighter isotope) and thus have a different ratio. The first isotope signatures of life are from 4.1 Ga in the Jack Hills (one sample only) and 3.8 Ga in Isua, Greenland (possibly the result of metamorphic processes). At 3.5 Ga, there was a big increase in organic carbon deposits. This is interpreted as the evolution of photosynthesis and the estimates fit nicely with estimates of carbon fixation due to anoxygenic photosynthesis using iron (photoferrotrophy).

Evidence for photosynthesis: Microbial mat fossils

- Microbial mats fossilised in 3.4 Ga sediments are in shallow water
- Location indicates that photosynthesis was vital to their formation

Cross section of a modern microbial mat. (Alicejmichel 2009, Creative Commons)

ausearthed.com.au

BIF Outcrop (RM Coveney, Jr 2009, Creative Commons 3.0)

Microbial mats did not always form stromatolites. The Buck Reef Chert preserves evidence of a shallow marine microbial mat that extends only within the areas suitable for photosynthesis. This provides indirect evidence for photosynthesis at 3.4 Ga.

Evidence for photosynthesis: BIFs?

- BIFs are very old and have been altered
- Older BIFs are now considered to be produced by chemical processes or anoxygenic photosynthesis
- Cyanobacteria may have contributed to more recent BIFs

ausearthed.com.au

BIF Outcrop (RM Coveney, Jr 2009, Creative Commons 3.0)

The presence of BIFs well before the evolution of cyanobacteria and convincing evidence of other mechanisms means that BIFs are no longer seen as good evidence for photosynthesis. The later, granular BIF deposits may have been formed with input from oxygenic photosynthesis.


AUSTRALIAN
EARTH
SCIENCE
EDUCATION
ausearthed.com.au
Resourced by
GOLD
INDUSTRY
GROUP
EARTH
SCIENCE
WESTERN
AUSTRALIA

Final Slide