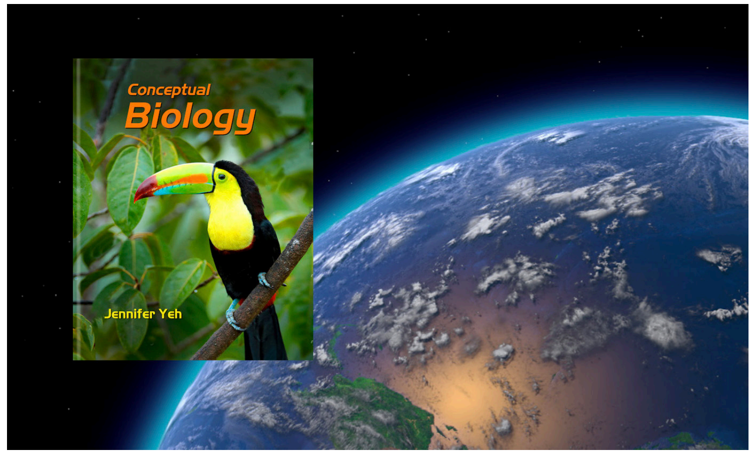
Chapter 5

DNA and Genes

Living Earth



5.7 The Great Oxygenation Event

The Story of Banded Iron Formations

After a tree is cut down, its stump reveals a series of tree rings that grew in response to seasonal changes over the tree's life. Simply count the number of rings and you have a good estimate of how many years the tree was alive. Beside the tree's age, the rings also reveal information about the past climate. Times of high moisture result in lots of growth so the rings will be rings farther apart. Times of drought result in rings close together.

In a similar manner, Earth's rocks reveal much about our planet's history. A good example of rocks that provide key information about Earth's history are the **Banded Iron Formations** (Figure A). While a cut tree can provide information about the recent past, Banded Iron Formations provide information about the deep, deep past. How far into the past? Answer: From the formation of our planet 4.5 billion years ago to about half a billion years ago.

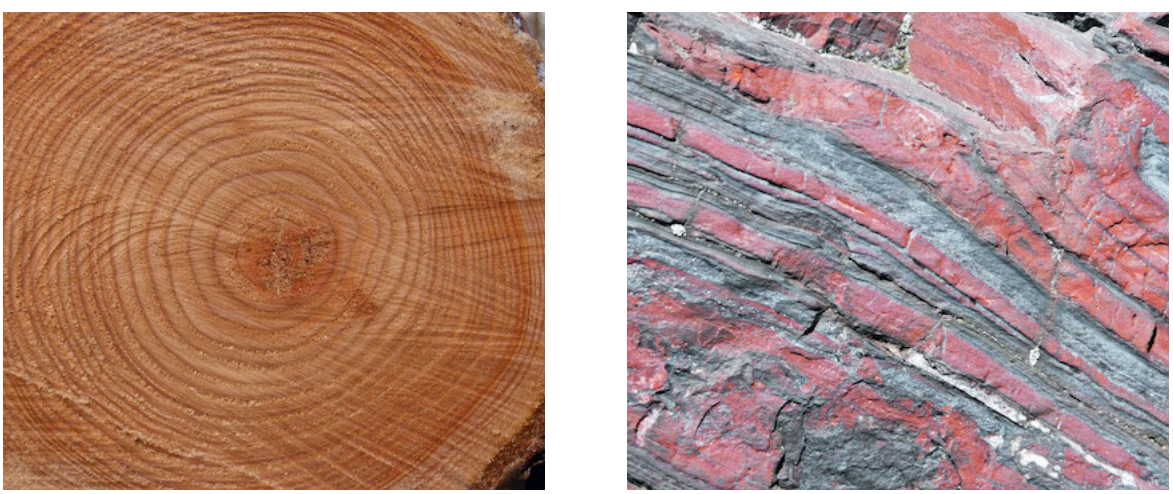


FIGURE A
Like tree rings (left), Banded Iron Formations (right) provide important clues about the past.

Banded Iron Formations were created within bodies of waters that had great changes in their oxygen, O_2, content. It started when iron was pumped into anoxic water, which is water lacking oxygen. Sources of iron include underwater volcanoes, hydrothermal vents, or runoff from land. As oxygen was introduced, it quickly reacted with this iron to form iron oxide, which is a form of rust. This iron oxide has poor solubility and so it would have come out of solution (precipitate) and sink to the bottom (Figure B).

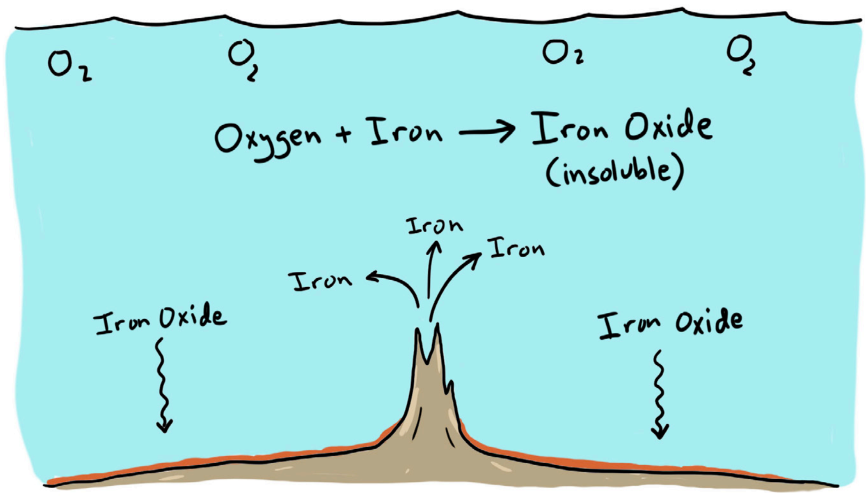


FIGURE B

Iron introduced to a body of water will react with any available oxygen to form insoluble iron oxide, which sinks to the floor.

Changes in the amount of oxygen resulted in differing amounts of iron oxide produced. Over many years, this resulted in stratified bands of iron oxide collecting on the floor of the body of water. Like all sediments, these bands became compacted into a hard material that geologists identify as a Banded Iron Formation, or BIF. Plate tectonics have since moved Banded Iron Formations to areas where we can easily study them.

While tree rings can tell us about recent weather patterns, Banded Iron Formations can tell us about the history of oxygen, O_2, on our planet. For insight into this history, it's important to recognize that oxygen, O_2, is a very reactive molecule. For large amounts of oxygen to accumulate, there must be a continual source of it. By analogy, consider a bubble machine creating bubbles at a birthday party. Bubbles easily pop. You'll only get lots of bubbles so long as the bubble machine keeps generating them. Likewise, oxygen molecules quickly react. To have lots of oxygen molecules, they need to be generated perpetually.

The first BIFs did not start forming until about 3.8 billion years ago. This represents the date at which oxygen first started to accumulate on this planet, likely after the evolution of oxygen producing photosynthetic cyanobacteria. But because of its great reactivity, oxygen can also be quite toxic. Those early photosynthetic bacteria would have been poisoning themselves with the oxygen they were producing. Any iron in the water, however, would quickly react with and remove the poisonous oxygen. Thus the cyanobacteria became highly dependent upon this iron.

This was apparently a cycle that lasted for millions of years. The cyanobacteria produced lots of oxygen that was removed by the iron. Periodically, however, the iron was depleted resulting in a build-up of the toxic oxygen, which would kill the cyanobacteria. Ocean currents and upwellings would then bring a fresh supply of iron, which would allow the cyanobacteria to prosper once again. From these cycles bands of iron oxide accumulated on the ocean floor (Figure C). The resulting Banded Iron Formations are the physical record of these happenings.

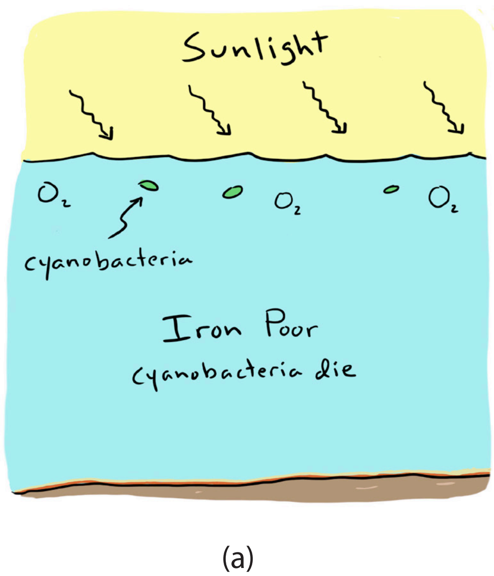


FIGURE C

(a) Early cyanobacteria within iron-poor waters would die from the toxicity of the oxygen they produced. (b) Within an iron-rich environment, the cyanobacteria could thrive as the oxygen would be removed by the iron.

Eventually, the cyanobacteria evolved ways to detoxify the oxygen they produced. This was a key moment in the history life on Earth. No longer so dependent upon the iron, this allowed the cyanobacteria to proliferate. As a result, the oxygen levels in the water increased dramatically. Any iron that was introduced to the water would immediately react to form iron oxide and sink to the ocean floor. There would still be iron oxide in the sediments. But the degree of banding would be greatly decreased.

Thus, the disappearance of Banded Iron Formations about 2 billion years ago suggests that this was a time of great oxygenation, sometimes referred to as the **Great Oxygenation Event**. An oxygen build-up in the water would also mean that oxygen would start diffusing into the atmosphere, which would have been mostly empty of oxygen since the formation of the planet (Figure D). So how

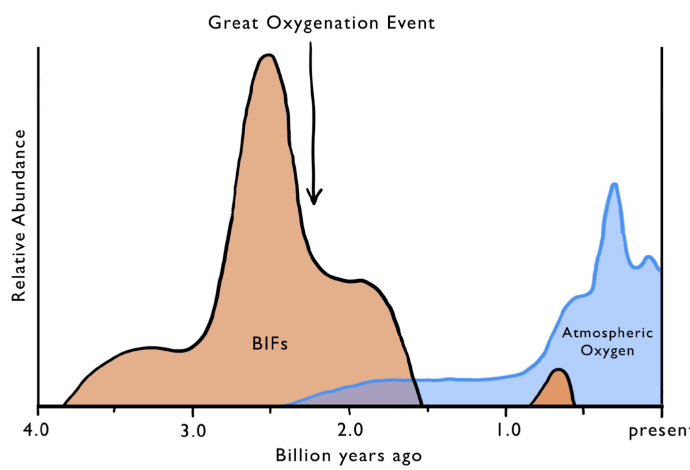


FIGURE D

The brown graph shows the relative abundance of Banded Iron Formations (BIFs) dating back to about 4 billion years ago. The Great Oxygenation Event likely began when the formation of BIFs started to decline rapidly. In blue are the relative amounts of oxygen found in the atmosphere.

do we know that Earth's atmosphere started to contain oxygen about 2 billion years ago? We find a key source of evidence in the Banded Iron Formations.

As oxygen moved into the atmosphere it would then start to react with minerals on land. This tells us that atmospheric oxygen levels were still relatively low for many years, on the order of 5%, compared to today's 21%. Only after all the minerals in the oceans, lakes, and land were fully oxidized would oxygen levels start to rise above the 5% mark. This, in turn, set the stage for the further evolution of oxygen-requiring multicellular living organisms.

Extensive Banded Iron Formations have not been formed since the Great Oxygenation Event. But there is an intriguing exception ranging from about 800 to 600 million years ago. During this time there was a small resurgence of BIFs. This raises the question: With oxygen freely available in the atmosphere how could these have formed? One theory is that the polar ice caps grew closer to the equator resulting in what could be called a snowball Earth. The snow would reflect the sunlight thus helping to maintain that cold period for millions of years. Ice over most of the oceans would prevent an exchange of gases with the atmosphere as well as block sunlight from the water bound cyanobacteria. This would favor anoxic waters, which is a condition needed for Banded Iron Formations. Most interesting, the BIFs of this period stopped forming just before the Cambrian explosion. Thus it's possible that the snowball Earth provided the conditions needed to allow for the evolution of more complex living organisms.

Of course, there is still much to learn about our deep past. The tantalizing clues, however, lie right beneath our feet in the rocks of this living Earth.

READING CHECK

According to our current understanding, what evolutionary event triggered the Great Oxygenation?

CHECK YOUR ANSWER

The Great Oxygenation Event may have been triggered after photosynthetic cyanobacteria developed the means of detoxifying the oxygen, O_2, they produced. This made them less dependent upon available iron and allowed for a population explosion that significantly increased the amount of oxygen on this planet.

To learn more, read the first page of the original article by biogeologist Preston Cloud on the role of BIFs in the evolution of Earth's primitive atmosphere:

https://science.sciencemag.org/content/160/3829/729