# #176 This rock is

# Banded Iron Formation.

IT IS A FAMOUS KIND OF IRON ORE
FROM THE UPPER PENINSULA OF MICHIGAN.
YOU HAVE PROBABLY BEEN IN AN OFFICE BUILDING OR SHOPPING MALL HELD UP BY THE IRON THAT WAS MELTED OUT OF THIS FORMATION.

BANDED IRON IS FAMOUS FOR ANOTHER REASON:
IT TELLS US WHEN OXYGEN BECAME A SIGNIFICANT GAS IN THE EARTH'S ATMOSPHERE.

**Q1:** What percentage of our atmosphere today is composed of oxygen?

**HINT:** Take all the water vapor out of a cubic meter of air anywhere on earth. What's left is mostly nitrogen ($N_2$) gas and oxygen ($O_2$) gas. About 78% is nitrogen.

## Banded Iron began as rusty mud in an ancient ocean about two billion years ago!

**Q2:** What geologic era did I form in?

**HINT:** Look for 2,000,000,000 years on the Geologic Time Scale

## Scientists disagree about my origin...

| Some scientists think I formed when two water masses mixed together in the ancient ocean. |
|---|

**Q3:** How can two water masses exist together in the same ocean?

**HINT:** Think of adding heavy, dense ice water to a glass of less dense warm water.

| Other scientists think I formed during periodic blooms of iron-oxidizing bacteria. |
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**Q4:** How can bacteria make rusty, iron-rich mud?

**HINT:** Think of rusting old ships at the bottom of the ocean.

# ANSWER SHEET
# #176

## MYSTERY SAMPLE:

— A piece of Banded Iron Formation from the Upper Peninsula of Michigan

## OBJECTIVES:

— To introduce Banded Iron Formation and the iron mining industry in Michigan

— To study very old rocks and continents from the Proterozoic Geologic Era, two billion years ago

— To introduce the concept of photosynthesis, microorganisms containing chloroplasts that can produce organic matter from carbon dioxide, water, and sunlight; and, give off oxygen as a waste product.

— To present two models (nonbiological and biological) explaining the origin of Banded Iron Formation

— To introduce the nonbiological model in which iron turns into rusty particles of iron oxide without the influence of microorganisms; the iron is supplied by the interaction of hot sea water with magma erupting onto the ancient sea floor. Oxygen is dissolved in the sea water from an atmosphere rich in oxygen produced by terrestrial (on the land, rather than in the ocean) photosynthetic organisms.

— To introduce the biological model in which iron from ocean water is turned into rusty sheaths of iron oxide around the cells of iron-oxidizing bacteria. The bacteria utilize oxygen produced by photosynthetic microorganisms that live in the ocean. Terrestrial photosynthesis is limited, so there is little or no oxygen in the atmosphere. The iron comes from weathering of rocks on the land surface, and magma erupting onto the sea floor. The iron-coated cells die and tons collect on the ocean floor.

## ANSWERS:

Q1: — About 21% of the modern atmosphere is composed of oxygen ($O_2$) molecules

Q2: — Banded Iron Formation was deposited during the Early Proterozoic Era of the Precambrian Eon of Geologic Time

Q3: — Large water masses with different densities are found in ocean basins. The denser masses will tend to sink and the less dense to float. Water masses mix when an upper heavy mass slides below a lighter water mass or conversely, when a light mass wants to pop up thru a heavy one. It was this latter process that some scientists believe led to the formation of the Banded Iron Formation. When the two water masses mixed, the iron formed rusty particles in the water and tons sank to the bottom making a thick layer of finely banded iron-rich mud.

Q4: — Oxygen was toxic to most ocean-dwelling microorganisms, so they evolved strategies to detoxify the oxygen by combining it with iron from the water to form protective sheaths around their cells. The iron oxide rusty particles accumulate into mud on the ocean floor, or a coating on sunken ships.

## TEACHING TECHNIQUES FOR THE "STAFF MEETING":

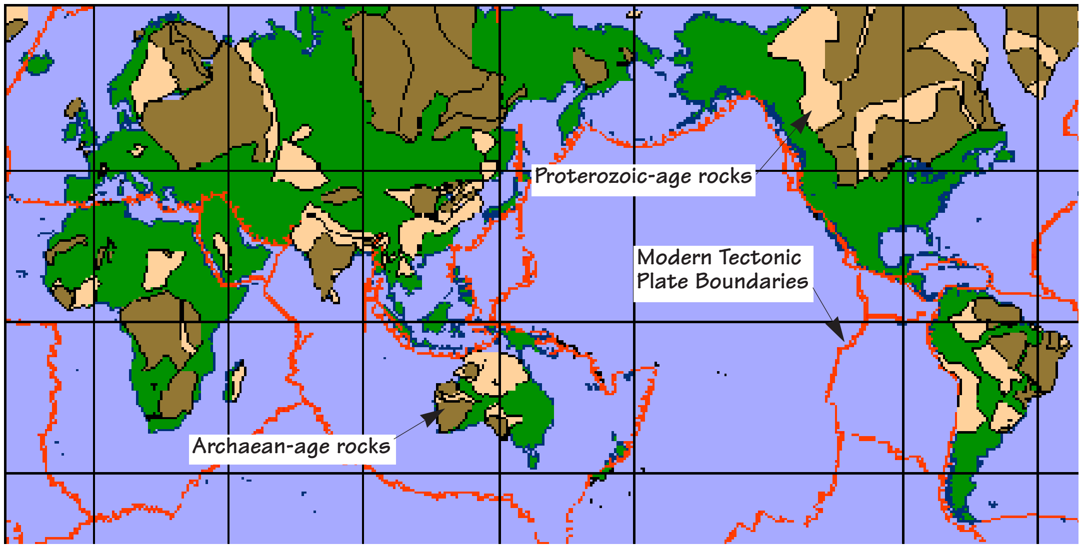
Hold up the sample of Banded Iron Formation and note that two billion tons of this iron ore have been mined from the Lake Superior Region of the United States!

Note also that this rock is TWO BILLION YEARS OLD. Ask your group what Geologic Era that represents. With the Geologic Time Scale in the notebook, your group can determine that Banded Iron dates from the Early Proterozoic part of the Precambrian Eon of Geologic Time. This period of Earth's history began 2.5 billion years ago and ended 544 million years ago. It is divided, rather arbitrarily, into the Early, or Paleoproterozoic (2.5 to 1.6 billion years ago), Middle, or Mesoproterozoic (1.6 billion to 900 million years ago) and Late, or Neoproterozoic (900 to 544 million years ago). Near the beginning of the Proterozoic, stable continents first appeared and began to accrete, a long process taking about a billion years.

Using a globe of the Earth, and Figure 1, make the point that very old iron-rich rocks are found in the cores of several continents: North America (Lake Superior Region, Canada, and Greenland); Australia (particularly western); Africa (southern); ; and, South America (Brazil and Venezuela). Two billion years ago these continents were smaller than they are today. Over time new continental material was added as islands and other continents collided with the old, hard central rocks. These early continents were apparently located in tropical areas of the Earth. Fossils associated with the Banded Iron Formation tell scientists that the iron-rich muds were formed in a warm climate. Exactly how the muds formed is still a real scientific mystery!

Figure 1

Map showing Proterozoic Rocks (light gray); Archaean Rocks (medium gray); Modern Continents (dark gray); and, Modern plate boundaries by Paul Stoddard -- http://jove.geol.niu.edu/faculty/stoddard/keels.html




Researchers agree that a very large source of oxygen was required to form the massive amounts of iron ore found today in these Early Proterozoic rocks. It is believed that approximately 3.5 billion years ago little plant-like organisms evolved chloroplasts and began to use the sun's energy to make oxygen by photosynthesis. Many of these oxygen-producing organisms lived in ocean basins. One abundant and widespread organism called, cyanobacteria (see Figure 2) covered the floor of warm, shallow oceans with a finely layered mat of microscopic sticky fibers; busily producing oxygen during the day and trapping muddy sediment at night. Eventually, after nearly two billion years the cyanobacteria produced enough oxygen to change the chemistry of the Earth's early oceans and create the world's richest iron deposits.

There are two major ideas or models to explain the formation of Banded Iron. The non-biological model: One group of scientists believe the iron beds formed as two water masses mixed in the ancient ocean. These researchers have analyzed very rare elements occurring with the Banded Iron Formation and were intrigued to learn that the iron may have come from magma erupting over the ocean floor. They think that sea water, heated by the magma could have dissolved the iron and carried it upward in a large mass of warm water. Near the ocean surface, the warm iron-rich ocean water mixed with cooler water that contained oxygen. Iron easily combines with oxygen--the result is rust--and rust, it was that accumulated on the ancient ocean floor. Tons of it--in fine, laminated layers.

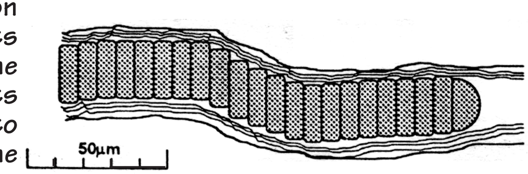



Figure 2. Cyanobacteria, the photosynthetic organism that produced vast quantities of oxygen in the early Earth's oceans.

The biological model: Another group of scientists have found microfossils in the Banded Iron Formation that are strikingly like the iron-rich sheaths produced by modern iron-oxidizing bacteria. Oxygen was toxic to the ancient ocean-dwelling bacteria, and these researchers suspect that the bacteria evolved strategies to detoxify the oxygen by combining it with iron from the water to form protective sheaths around their cells. The sheaths were shed off to keep the organism from being trapped inside the rusty shell. During periodic blooms of these bacteria, tons of these sheaths made the rusty mud layers.

It would be interesting for your group to imagine what the ancient ocean environment was like; how oxygen might accumulate in the early atmosphere from microorganisms (where did they live, and how many were there?); and, where does magma erupt onto today's ocean floor (Hint: Think of black smokers!).

## References

About cyanobacteria and the early production of oxygen
http://www.ucmp.berkeley.edu/bacteria/cyanointro.html

About early bacteria (mostly cyano)
http://www.ucmp.berkeley.edu/bacteria/bacteriafr.html

About the Archaean 3.8 to 2.5 billion years ago
http://www.ucmp.berkeley.edu/precambrian/archaean.html

About the global position of ancient continental plates
http://www.scotese.com

About the Proterozoic
http://www.ucmp.berkeley.edu/precambrian/proterostrat.html

Richard Fortey, 1998. Life: A Natural History of the First Four Billion Years of Life on Earth. Paperback: ISBN 037570261X,

Holland, H.D. 1994. Early Proterozoic atmospheric change. In: Bengtson, S. (ed.) Early Life on Earth. Columbia University Press, New York, p. 237-244.