The Rise of Oxygen in the Earth's Atmosphere

This article is provided courtesy of the American Museum of Natural History.

On a chilly October afternoon, Grant Young and Jay Kaufman stand along a busy roadside in northern Ontario, poring over their favorite Earth-history book. Young, a professor of geology at the University of Western Ontario, and Kaufman, a geoscientist from the University of Maryland, are among the leading scientists trying to attach firm dates to the rise of oxygen in Earth's early atmosphere — an event that, when it occurred more than 2 billion years ago, dramatically altered the planet's development.


The Huronian Supergroup © AMNH

The book they are reading is an ancient geological masterpiece: the Huronian Supergroup, a massive formation of rock laid down gradually between about 2.5 billion and 2.2 billion years ago, precisely the period when oxygen began to accumulate in the atmosphere. The Huronian Supergroup is 10 or 11 kilometers (six or seven miles) thick and extends well below ground. From atop a nearby outcrop, a viewer can survey the landscape for miles around. At the moment, however, Kaufman and Young are at road level, examining a segment of the outcrop that was exposed back when the highway was built. Individual layers of ancient sediment form horizontal stripes on the rock. From a few steps back, the rock wall looks like a cross-section of a giant, stone encyclopedia.

"When we look at a sequence of rocks, it's like the pages of a book," Young says. "The page at the bottom is the oldest and the page at the top is the youngest. We read history by starting at the bottom layer and working our way up. The Huronian Supergroup is particularly exciting and interesting because, by chance, these rocks were laid down at a period when the atmosphere underwent a transition from containing no free oxygen to containing at least some free oxygen."

It may seem at first like an odd strategy: studying rocks in order to understand the atmosphere. It's one thing to examine fossils, the solid remains of ancient, solid creatures. But what can rocks reveal about something as formless as air, much less air that existed billions of years ago? How does one study the ancient atmosphere when no samples of it are left to collect?

Fortunately, the geological record contains a history of more than just rock. The atmosphere, then as now, constantly interacts with Earth's crust. As exposed rock weathers, its composition is altered by compounds in the air. This alteration is apparent even billions of years later and reveals important details about the atmosphere at the time. By studying a shoeprint in the mud, a police detective can determine not only the kind of shoe that made it, but also critical details about its wearer: size, weight, gender, even age, and whether or not he or she walked with a limp. The ancient atmosphere left an equally telling signature in the rock record. By flipping backward through pages of rock, a geologist can begin to form a picture of that atmosphere and how it changed through time.


Jay Kaufman, of the University of Marylan, looking at Huronian stratigraphy © AMNH

"I've often wished that I had a time machine to go back and collect a sample of ancient atmosphere or an ancient bit of seawater," says Kaufman. "But we can't. All we can do is collect rocks that were formed under those waters and under that atmosphere."

Oxygen is a highly reactive element; it readily combines with other elements to form new compounds. As these compounds form, they become part of the geological record, leaving behind a trail of molecular "crumbs" that point to oxygen's whereabouts through history. One clue to the nature of the ancient atmosphere comes from rock formation known as "redbeds," the oldest of which date back about 2.2 billion years. Redbeds are sediments that were deposited on floodplains by water exposed to the atmosphere. They contain a mineral called hematite, a compound of iron and what must have been atmospheric oxygen. After 2.2 billion years ago, redbeds become increasingly common in the geological record.

"It's a very simple kind of test," says Young, who has studied redbeds extensively over the course of his career. "But it does give us at least a first-order idea as to whether there was free oxygen and whether there wasn't."

In recent years Kaufman's colleague James Farquhar, a geochemist at the University of Maryland, devised an even more precise method of dating the rise of oxygen. He collected rocks from the Huronian Supergroup and other deposits around the world, ground them to powder in the laboratory, and studied them for traces, not of oxygen, but of an entirely different element: sulfur. Sulfur compounds are emitted in vast quantities by volcanoes, which were especially active during Earth's youth. Like other airborne compounds, they undergo reactions in the atmosphere and eventually end up deposited in the geological record.

As it happens, there are four different kinds, or isotopes, of sulfur. By far the most common — about 95 percent of all atmospheric sulfur — is sulfur-32, or sulfur with an atomic weight of 32. The other isotopes are sulfur-34 (4.2 percent), sulfur-33 (0.75 percent), and sulfur-36 (0.02 percent). The relative proportion of these four isotopes has tended to remain steady over time. But Farquhar and his colleagues found that in rocks older than about 2.4 billion years, the proportion of sulfur-33 varied widely, whereas rocks younger than about 2.1 billion years showed no significant variation. What accounted for the variation, and for the change?

The answer, Farquhar and Kaufman believe, was oxygen. Early in the planet's history, before enough free oxygen had accumulated to form a protective layer of ozone (O3), Earth's atmosphere was scorched by intense ultraviolet radiation from the Sun. The UV radiation may have reacted with the atmosphere to produce some compounds with a high sulfur-33 to sulfur-32 ratio and other compounds with a low sulfur-33 to sulfur-32 ratio. Later, with the rise of oxygen and the formation of an ozone layer which blocked incoming UV radiation, that photochemical reaction stopped, and the ratio of sulfur-33 to sulfur-32 ceased to vary. Amazingly, these signatures of sulfur isotopes are recorded in the rocks. In old rocks, before the buildup of atmospheric oxygen, the ratio of sulfur-33 to sulfur-32 in rocks is variable; in young rocks it is constant and in the same ratio as today.

Farquhar's technique, though indirect, is remarkably exact: he has determined that free oxygen began to accumulate in the atmosphere about 2.45 billion years ago and was well established by 2.1 billion years ago. He also has been able, for the first time, to provide a rough measure of how much oxygen there was compared to today. “The sulfur research probably provides the strongest evidence for the buildup of oxygen in the atmosphere,” Farquhar says. “The change from a large signature to a much smaller signature is a result of a large change in atmospheric oxygen content, from levels 100,000 times less than present to levels within about 100 times less than the present level.”

“The most exciting thing to me about this research is that it quantifies amounts of oxygen in the atmosphere,” Kaufman adds. “Before, we just had this qualitative sense of, well, it was low here, it must have risen here. But the signatures that we're seeing allow us to actually get at numbers — to get at the timing of this rise, so it's not just a fairytale. We can actually write some sentences on the pages of the book of atmospheric oxygen.”

Name: _______________________________________ Date: _________________________

1. Why is the Huronian Supergroup rock formation particularly interesting to scientists?

A because it looks like a cross-section of a giant, stone encyclopedia
B because it formed during the period when oxygen began to accumulate in the atmosphere
C because it contains unusually large amounts of oxygen and sulfur
D because it dramatically altered the planet's development when it first formed

2. In this article the author explains what scientists are trying to find out. What are the scientists in the article trying to find out?

A how the proportions of different sulfur isotopes change in the geologic record
B how the ozone layer formed and the effects of its formation
C when oxygen increased in Earth's early atmosphere
D when sulfur first appeared in Earth's early atmosphere

3. Read these sentences from the article.

"I've often wished that I had a time machine to go back and collect a sample of ancient atmosphere or an ancient bit of seawater," says [Jay] Kaufman. "But we can't. All we can do is collect rocks that were formed under those waters and under that atmosphere."

Which conclusion does this statement support?

A Scientists are skeptical about their ability to determine when oxygen levels in the Earth's early atmosphere rose.
B Scientists are unable to study what the Earth was like millions of years ago because they do not have the materials needed to do so.
C Scientists study the atmosphere in order to learn what the Earth's seawater was like millions of years ago.
D Scientists study rock formations in order to learn what Earth's atmosphere was like millions of years ago.

4. Read these sentences from the article.

"Individual layers of ancient sediment form horizontal stripes on the rock. From a few steps back, the rock wall looks like a cross-section of a giant, stone encyclopedia."

Why might the author have included this description of the rock wall?

A to explain why the author quotes scientists in the article
B to show why the author presents information about different compounds in the article
C to demonstrate why the author explains two different methods used to date the rise of oxygen in the atmosphere
D to clarify why the author compares studying a rock formation to studying a book

5. What is the main idea of this article?

A Scientists learn about sulfur by studying ancient rocks.
B Scientists learn about redbeds by studying the history of Earth's atmosphere.
C Scientists learn about the history of oxygen in Earth's atmosphere by studying rocks.
D Scientists learn about the history of sulfur in Earth's atmosphere by studying oxygen.

6. The author asks these questions in the article.

"But what can rocks reveal about something as formless as air, much less air that existed billions of years ago? How does one study the ancient atmosphere when no samples of it are left to collect?"

Why might the author ask these questions? Consider both the questions themselves and their context in the article.

A to get the reader thinking about something that will be explained later in the text
B to force the reader to come up with ways to study the ancient atmosphere without collecting samples
C to invite the reader to learn more about the questions scientists ask themselves
D to suggest to the reader that it's impossible to learn about the ancient atmosphere using today's rocks

7. Look at the underlined word in this sentence from the article.

"As exposed rock weathers, its composition is altered by compounds in the air."

Which of the following words could replace "its" without changing the meaning of the sentence?

A the rock's
B the weather's
C the Earth's
D the compounds'

8. In order to determine when oxygen levels increased in the Earth's atmosphere, which element did James Farquhar and his team search for in rocks?

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9. Jay Kaufman said that while scientists cannot collect and study samples of the ancient atmosphere, they can "collect rocks that were formed… under that atmosphere." Why are scientists able to learn about the ancient atmosphere by studying the rocks that came into contact with the ancient atmosphere?

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10. Explain what scientists might be able to learn about the seawater that existed millions of years ago by studying rocks that came into contact with seawater at that time in the past. Use evidence from the text to support your inference.

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