

Science & Literacy Activity

GRADES 9-12

OVERVIEW

This activity, which is aligned to the Common Core State Standards (CCSS) for English Language Arts, introduces students to scientific knowledge and language related to Earth Science. Students will read content-rich texts, visit the David S. and Ruth L. Gottesman Hall of Planet Earth and use what they have learned to complete a CCSS-aligned writing task, creating an illustrated text about how Earth's systems and life on Earth co-evolved to create an oxygen-rich atmosphere.

Materials in this activity include:

- Teacher instructions for:
 - Pre-visit student reading
 - Visit to the Gottesman Hall of Planet Earth and Student Worksheet
 - Post-visit writing task
- Text for student reading: "Footprints of the Air "
- Student Worksheet for the Gottesman Hall of Planet Earth visit
- Student Writing Guidelines
- Teacher rubric for writing assessment

Common Core State Standards:

WHST.9-12.2, WHST.9-12.8, WHST.9-12.9
RST.9-12.1, RST.9-12.2, RST.9-12.7, RST.9-12.10

New York State Science Core Curriculum:

PS 1.2h

Next Generation Science Standards:

PE HS-ESS 2-7
DCI ESS2.E: Biogeology
The many dynamic and delicate feedbacks between the biosphere and other Earth systems cause a continual co-evolution of Earth's surface and the life that exists on it.

SUPPORTS FOR DIVERSE LEARNERS: An Overview

This resource has been designed to engage all learners with the principles of Universal Design for Learning in mind. It represents information in multiple ways and offers multiple ways for your students to engage with content as they read about, discuss, view, and write about scientific concepts. Different parts of the experience (e.g. reading texts, or locating information in the hall may challenge individual students. However, the arc of learning is designed to offer varied opportunities to learn. We suggest that all learners experience each activity, even if challenging. We have provided ways to adapt each step of the activities for students with different skill-levels. If any students have an Individualized Education Program (IEP), consult it for additional accommodations or modifications.

1. BEFORE YOUR VISIT

This part of the activity engages students in reading a non-fiction text about investigating Earth's early atmosphere to learn how it changed over time. The reading will prepare students for their visit by introducing them to the topic and framing their investigation.

Student Reading

Have students read "Footprints of the Air." Have them write notes in the large right-hand margin. For example, they could underline key passages, paraphrase important information, or write down questions that they have.

Ask:

- The reading states that the scientists are "poring over their favorite Earth history book." What are they hoping to learn from the "book," and how are they "reading" it?
(Answer: The "book" is a rock outcrop called the Huronian Supergroup. It formed about 2.2.-2.5 billion years ago [BYA], around the same time when oxygen began to accumulate in the atmosphere. The scientists are hoping that "reading" it will help them attach firm dates to the rise of oxygen in Earth's early atmosphere. The rocks are in sequence, like the pages of a book, and can be read from the bottom layer upward to learn how Earth's atmosphere underwent a transition from containing no free oxygen to containing some free oxygen.)
- What created the "footprints" that the scientists are investigating and how did they find them?
(Answer: The "footprints" are traces of sulfur left behind by active volcanoes. They are able to find these by grinding up rocks from the Huronian Supergroup and other deposits around the world.)

- What information are they able to get from the “footprints”? Does this help them find the answer they were looking for?

(Answer: In old rocks, before the buildup of atmospheric oxygen, the ratio of sulfur-33 to sulfur-32 varies; in young rocks it is constant and in the same ratio as today. The “footprints” helped them attach firm dates to the rise of oxygen in Earth’s early atmosphere: free oxygen began to accumulate in the atmosphere about 2.45 BYA and was well established by 2.1 BYA.)

SUPPORTS FOR DIVERSE LEARNERS: Student Reading

- “Chunking” the reading can help keep them from becoming overwhelmed by the length of the text. Present them with only a few sentences or a single paragraph to read and discuss before moving on to the next “chunk.”
- Provide “wait-time” for students after you ask a question. This will allow time for students to search for textual evidence or to more clearly formulate their thinking before they speak.

2. DURING YOUR VISIT

This part of the activity engages students in exploring the Gottesman Hall of Planet Earth.

Museum Visit & Student Worksheet

Let students know that they will be using worksheets to gather information about how Earth’s systems and life on Earth co-evolved to create an oxygen-rich atmosphere. Explain to students that they will be focusing on three sections of the hall to gather this information: (1) “How has the Earth Evolved?”, (2) “Why is the Earth Habitable?”, and (3) “How do Scientists Read the Rocks?”. You may want to provide students with a copy of the map from the Educator’s Guide to help them find these areas more easily. To allow for easier data collection, you may want to break students into groups and have them start their exploration at different sections. Tell students that back in the classroom, they will refer to these notes when completing the writing assignment.

If students are able to take pictures of specimens in the hall, encourage them to do so. They can use the images to illustrate their writing assignment. If taking pictures is not possible, students can access digital images of the specimens on the Museum’s website: amnh.org/rose/hope

SUPPORTS FOR DIVERSE LEARNERS: Museum Visit

- Review the Student Worksheet with students, clarifying what information they should collect during the visit.
- Have students explore the hall in pairs, with each student completing their own Student Worksheet.
- Encourage student pairs to ask you or their peers for help locating sources of information. Tell students they may not share answers with other pairs, but they may point each other to places in the hall where answers may be found.

3. BACK IN THE CLASSROOM

This part of the activity engages students in an informational writing task that draws on the pre-visit reading and on observations made at the Museum.

Writing Task

Distribute the Student Writing Guidelines handout, which includes the following prompt for the writing task:

Based on the reading, your visit to the Gottesman Hall of Planet Earth, and your discussions, write an illustrated essay in which you describe how Earth’s systems and life on Earth co-evolved to create an oxygen-rich atmosphere.

Be sure to include:

- how this evolution can be seen in the Huronian Supergroup
- the role of black smokers, banded iron formations, and stromatolites in the oxygenation of the atmosphere

Support your discussion with evidence from the reading and the information gathered using the Gottesman Hall of Planet Earth worksheet.

Go over the handout with students. Tell them that they will use it while writing, and afterwards, to evaluate and revise their essays.

NOTE: It may be helpful to review the “How do we know about the early atmosphere?” diagram with you students (as a class or in smaller groups during student sharing). This will help ensure that students have an understanding of the relationship between banded iron formations, stromatolites, and the oxygenation of the atmosphere. To access the diagram, go to amnh.org/rose/hope. On the left-side navigation, click on “How has the Earth evolved?” and then “A special planet.”

Before they begin to write, have students use the prompt and guidelines to frame a discussion around the information that they gathered in the Gottesman Hall of Planet Earth, and compare their findings. They can work in pairs, small groups, or as a class. Referring to the writing prompt, have students underline or highlight all relevant passages and information from the reading, and their notes from the hall that can be used in their response to the prompt. Instruct each student to take notes on useful information that their peers gathered as they compare findings. Students should write their essays individually.

NOTE: If students would like to refer to photos of the specimens they examined in the hall, they can search for them on the Museum’s website: amnh.org/rose/hope

SUPPORTS FOR DIVERSE LEARNERS: Writing Task

- Re-read the “Before Your Visit” assignment with students. Ask what they saw in the hall that helps them understand how Earth’s systems and life on Earth co-evolved to create an oxygen-rich atmosphere.
- Allow time for students to read their essay drafts to a peer and receive feedback based on the Student Writing Guidelines.

Student Reading

Footprints of the Air

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 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.

"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.

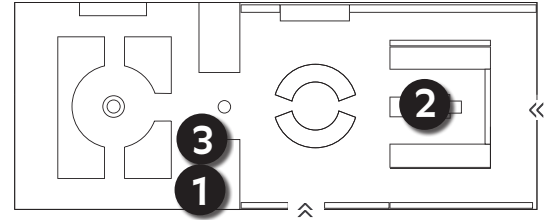
Farquhar's technique, though indirect, is remarkably exact: he has determined that free oxygen began to accumulate in the atmosphere about 2.45 billion years ago and was well established by 2.1 billion years ago. He also has been able, for the first time, to provide a rough measure of how much oxygen 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."

Student Worksheet

Today you will investigate how current conditions on Earth are the result of our physical and its biotic and abiotic systems co-evolving over long stretches of time.

Visit four areas of the Gottesman Hall of Planet Earth to explore the rise of oxygen in Earth's atmosphere.



1 How has the Earth Evolved?

a. Observe specimens #17, #18, and #19, layers of the Huronian Supergroup.

Explain what the color variations and composition of each of these layers tells us about how the atmosphere has changed over time.

- Specimen #17, pyrite-bearing conglomerate:

- Specimen #18, gray-white quartz:

- Specimen #19, red quartzite:

What clues about the conditions on the early Earth are found in rocks like the Huronian Supergroup?

b. Observe specimen #16, the oldest fossil.

What was the Age of Microbes and what was its importance to the evolution of life on Earth?

Describe the specimen and explain how the presence of fossil bacteria supports the idea that the Earth's atmosphere was evolving. How does the presence of these fossil bacteria support the idea that Earth's atmosphere was evolving?

2 Why is the Earth Habitable?

One of the simplest definitions of a life-form is: anything with the capacity to reproduce and regulate itself. Before life began, the complex organic, or hydrocarbon-bearing, molecules that make up RNA and DNA, the building blocks of life, must have formed. No one knows exactly how life formed from these molecules, but many ideas have been put forward.

As you enter this area, go toward the large video screen on the right and explore the "Life at the Hydrothermal Vents" label deck.

Some scientists theorize that life began at deep-sea vents. Find three lines of evidence to support this claim.

Explain how sulfide chimneys can support life without the presence of sunlight.

3 How has the Earth Evolved?

a. Observe specimen #14, stromatolite and the illustrated label deck "How Do We Know About the Earth's Early Atmosphere?"

What are stromatolites?

What was their role in the oxygenation of Earth's early atmosphere?

Why did they flourish when shallow seas became more extensive?

b. Observe specimen #15, banded iron (also see specimen #23 around the corner) and the illustrated label deck "How Do We Know About the Earth's Early Atmosphere?"

Describe the bands and explain how they formed.

When and why did banded iron formations stop forming?

What does the presence of banded iron formations tell us about conditions in the early atmosphere and oceans?

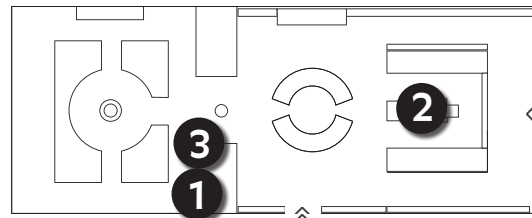
NOTE: Photos of the specimens that you examined in the hall are available at amnh.org/rose/hope.

ANSWER KEY

Student Worksheet

Today you will investigate how current conditions on Earth are the result of our physical and its biotic and abiotic systems co-evolving over long stretches of time.

Visit four areas of the Gottesman Hall of Planet Earth to explore the rise of oxygen in Earth's atmosphere.



1 How has the Earth Evolved?

a. Observe specimens #17, #18, and #19, layers of the Huronian Supergroup.

Explain what the color variations and composition of each of these layers tells us about how the atmosphere has changed over time.

- Specimen #17, pyrite-bearing conglomerate:

(Answer: This quartz-pebble conglomerate is from one of the oldest layers of the Huronian Supergroup. It formed as a gravel bar in a river, perhaps during a flood. The rock contains the heavy minerals pyrite [called "fool's gold"] and uraninite [a uranium mineral], which were originally particles carried by the river. These minerals could not have survived in the presence of oxygen. They are part of the evidence for an oxygen-poor atmosphere 2.5 billion years ago.)

- Specimen #18, gray-white quartz:

(Answer: This quartzite formed in a riverbed, as indicated by the well-developed cross-bedding [sedimentary layers at angles to the main horizontal layers]. Its buff to gray color is typical of the oldest rocks of the Huronian Supergroup. The color suggests deposition when the atmosphere contained no free oxygen.)

- Specimen #19, red quartzite:

(Answer: The rocks in the upper part of the Huronian Supergroup are red-brown, like this quartzite specimen. The color is due to the presence of small quantities of iron oxide minerals (rust), and indicates deposition when the atmosphere contained oxygen.)

What clues about the conditions on the early Earth are found in rocks like the Huronian Supergroup?

(Answer: Many geologists believe that this sequence of rocks records a change from an oxygen-free to an oxygen-bearing atmosphere.)

ANSWER KEY

b. Observe specimen #16, the oldest fossil.

What was the Age of Microbes and what was its importance to the evolution of life on Earth?

(Answer: From 3.9 to about 1.2 billion years ago, life was confined to microbes, or single-celled organisms. During this time, the microbes prospered, gradually altering their surroundings. The conditions they created made the environment hospitable for the emergence of more complex life-forms, beginning about 1.2 billion years ago. Geochemical evidence, in the form of traces of organic carbon in rocks, suggests that life existed nearly 3.9 billion years ago.)

Describe the specimen and explain how the presence of fossil bacteria supports the idea that the Earth's atmosphere was evolving. How does the presence of these fossil bacteria support the idea that Earth's atmosphere was evolving?

(Answer: This 3.5-billion-year-old black chert from the Warrawoona Group of Western Australia contains microscopic forms believed by some scientists to be fossil bacteria. If these are actually fossils, they are the oldest-known examples of life. The microfossils resemble modern light-sensitive bacteria, and the rocks in which they are found formed near the surface of a shallow sea. It is thus likely that organisms employing photosynthesis – the use of sunlight for food and energy – were providing oxygen for an evolving atmosphere.)

2 Why is the Earth Habitable?

One of the simplest definitions of a life-form is: anything with the capacity to reproduce and regulate itself. Before life began, the complex organic, or hydrocarbon-bearing, molecules that make up RNA and DNA, the building blocks of life, must have formed. No one knows exactly how life formed from these molecules, but many ideas have been put forward.

As you enter this area, go toward the large video screen on the right and explore the “Life at the Hydrothermal Vents” label deck.

Some scientists theorize that life began at deep-sea vents. Find three lines of evidence to support this claim.

(Answer: Some of the thermophilic, or heat-loving, vent microbes are the most primitive organisms known on Earth. They include Archaea, which belong to a third domain of life and are as different from bacteria as bacteria are from all other organisms. Second, complex organic molecules, the building blocks of life, are found at the vents. Third, the deep ocean was one of the few places on the early Earth that was protected from frequent meteorite bombardments and lethal radiation.)

Explain how sulfide chimneys can support life without the presence of sunlight.

(Answer: Hot, mineral-rich fluids supply nutrient chemicals. Microbes, some of which eat these chemicals, form the base of the food chain for a diverse community of organisms. These vents are the only places on Earth where the ultimate source of energy for life is not sunlight but Earth itself.)

ANSWER KEY

3 How has the Earth Evolved?

a. Observe specimen #14, stromatolite and the illustrated label deck “How Do We Know About the Earth’s Early Atmosphere?”

What are stromatolites?

(Answer: Mats of bacteria that trap and precipitate sediments or colony of microbes piled on one another over time, forming semi-rigid, upward-pointing, and branching columns.)

What was their role in the oxygenation of Earth’s early atmosphere?

(Answer: These bacteria produced oxygen through photosynthesis.)

Why did they flourish when shallow seas became more extensive?

(Answer: Because the atmosphere during much of the Precambrian had little oxygen, there was no protective ozone layer, and life could prosper only in water of just the right depth – shallow enough for sunlight to penetrate, but deep enough to block out the Sun’s harmful ultraviolet radiation.)

b. Observe specimen #15, banded iron (also see specimen #23 around the corner) and the illustrated label deck “How Do We Know About the Earth’s Early Atmosphere?”

Describe the bands and explain how they formed.

(Answer: The dark layers are mainly composed of magnetite (Fe_3O_4) while the red layers are chalcedony, a form of silica (SiO_2) that is colored red by tiny iron oxide particles. Some geologists suggest that the layers formed annually with the changing seasons.)

When and why did banded iron formations stop forming?

(Answer: About 1.7 billion years ago, banded iron formations – sedimentary rocks consisting of iron-rich layers alternating with iron-poor ones – stopped forming. By this time, photosynthesis had supplied enough oxygen to entirely deplete the oceans of their iron.)

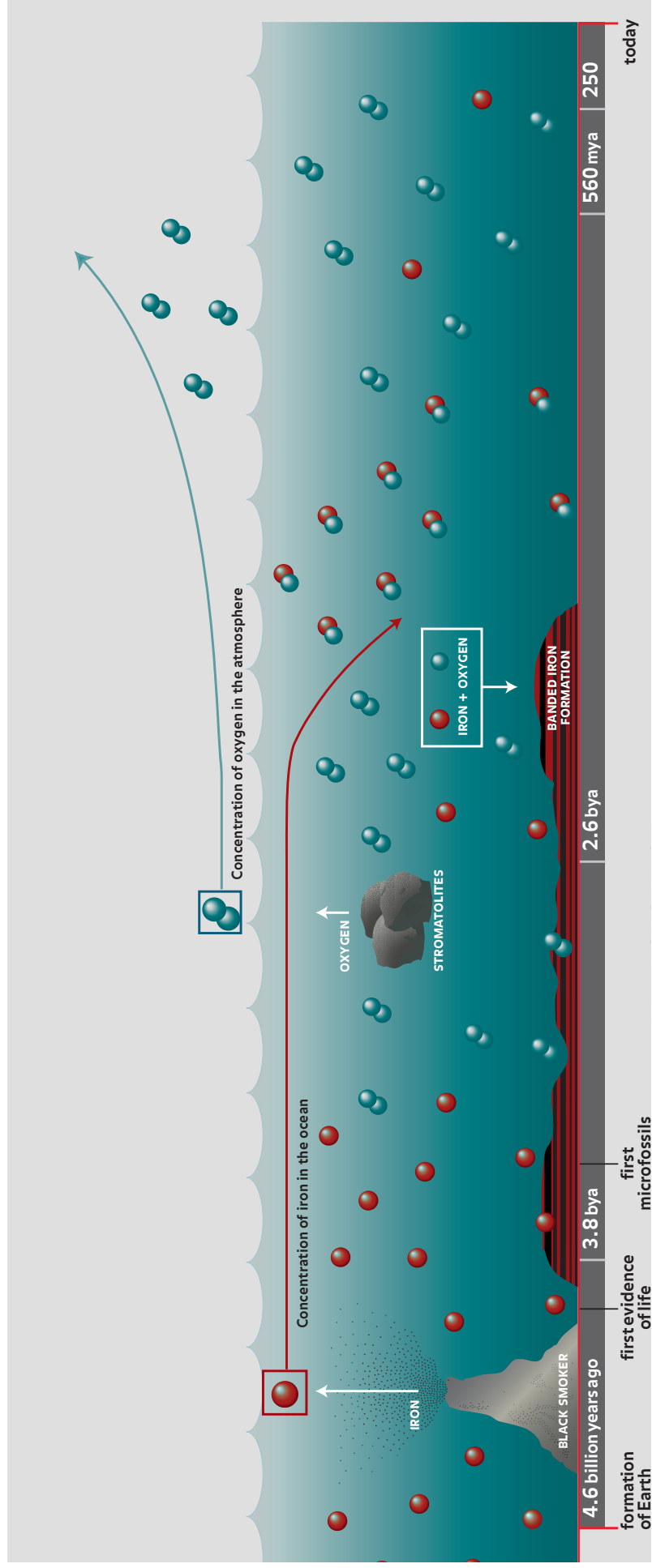
What does the presence of banded iron formations tell us about conditions in the early atmosphere and oceans?

(Answer: They show that the atmosphere and ocean once had no oxygen. Photosynthetic organisms were making oxygen, but it reacted with the iron dissolved in seawater to form iron oxide minerals on the ocean floor, creating banded iron formations.)

NOTE: Photos of the specimens that you examined in the hall are available at amnh.org/rose/hope.

Student Handout

How do we know about the early atmosphere?



Student Writing Guidelines

Based on the reading, your visit to the Gottesman Hall of Planet Earth and your discussions, write an illustrated essay in which you describe how Earth's systems and life on Earth co-evolved to create an oxygen-rich atmosphere.

Be sure to include:

- how this evolution can be seen in the Huronian Supergroup
- the role of black smokers, banded iron formations and stromatolites in atmospheric oxygenation

Support your discussion with evidence from the reading and the information gathered using the Gottesman Hall of Planet Earth worksheet.

Use this checklist to ensure that you have included all of the required elements in your essay.

- ☐ I introduced the topic of Earth systems and life on Earth co-evolving to create an oxygen-rich atmosphere.
- ☐ I clearly described how Earth's systems and life on Earth co-evolved to create an oxygen-rich atmosphere.
- ☐ I only included relevant information about the role of black smokers, banded iron formations and stromatolites in atmospheric oxygenation.
- ☐ I used information from "Footprints of the Air" to explain the topic in detail.
- ☐ I used information from the Gottesman Hall of Planet Earth to explain the topic in detail.
- ☐ I used academic, non-conversational tone and language.
- ☐ I included a conclusion at the end.
- ☐ I proofread my essay for grammar and spelling errors.

Assessment Rubric

Scoring Elements		1 Below Expectations	2 Approaches Expectations	3 Meets Expectations	4 Exceeds Expectations
RESEARCH	Reading	Attempts to present information in response to the prompt, but lacks connections to the texts or relevance to the purpose of the prompt.	Presents information from the text relevant to the purpose of the prompt with minor lapses in accuracy or completeness.	Presents information from the text relevant to the prompt with accuracy and sufficient detail.	Accurately presents information relevant to all parts of the prompt with effective paraphrased details from the text.
	AMNH Exhibit	Attempts to present information in response to the prompt, but lacks connections to the Museum exhibit content or relevance to the purpose of the prompt.	Presents information from the Museum exhibit relevant to the purpose of the prompt with minor lapses in accuracy or completeness.	Presents information from the Museum exhibit relevant to the prompt with accuracy and sufficient detail.	Accurately presents information relevant to all parts of the prompt with effective paraphrased details from the Museum exhibit.
WRITING	Focus	Attempts to address the prompt, but lacks focus or is off-task.	Addresses the prompt appropriately, but with a weak or uneven focus.	Addresses the prompt appropriately and maintains a clear, steady focus.	Addresses all aspects of the prompt appropriately and maintains a strongly developed focus.
	Development	Attempts to provide details in response to the prompt, including retelling, but lacks sufficient development or relevancy.	Presents appropriate details to support the focus and controlling idea.	Presents appropriate and sufficient details to support the focus and controlling idea.	Presents thorough and detailed information to strongly support the focus and controlling idea.
	Conventions	Attempts to demonstrate standard English conventions, but lacks cohesion and control of grammar, usage, and mechanics.	Demonstrates an uneven command of standard English conventions and cohesion. Uses language and tone with some inaccurate, inappropriate, or uneven features.	Demonstrates a command of standard English conventions and cohesion, with few errors. Response includes language and tone appropriate to the purpose and specific requirements of the prompt.	Demonstrates and maintains a well-developed command of standard English conventions and cohesion, with few errors. Response includes language and tone consistently appropriate to the purpose and specific requirements of the prompt.
SCIENCE	Content Understanding	Attempts to include science content in explanations, but understanding of the topic is weak; content is irrelevant, inappropriate, or inaccurate.	Briefly notes science content relevant to the prompt; shows basic or uneven understanding of the topic; minor errors in explanation.	Accurately presents science content relevant to the prompt with sufficient explanations that demonstrate understanding of the topic.	Integrates relevant and accurate science content with thorough explanations that demonstrate in-depth understanding of the topic.

EDUCATOR'S GUIDE



Gottesman Hall of PLANET EARTH



INSIDE:

- Suggestions to Help You **Come Prepared**
- **Essential Questions** for Student Inquiry
- Strategies for **Teaching in the Exhibition**
- **Map** of the Exhibition
- **Online Resources** for the Classroom
- Correlation to **Framework**
- **Glossary**



ESSENTIAL questions

The hall poses five essential questions. Use them to connect the hall's themes to your curriculum.

How has Earth evolved?

Four and a half billion years ago our solar system formed. Along with all the other planets, Earth was created from clouds of dust orbiting our infant Sun. Molten at first, the planet differentiated into a molten iron **core** and a silicate outer layer – within a few tens of millions of years. Shortly thereafter the Moon formed, possibly from material ejected when a Mars-sized object smashed into early Earth. As Earth's surface cooled enough for a new **crust** to solidify, **water vapor** and other gases were driven from the interior to form an ocean and **atmosphere**. By at least 3.5 billion years ago, photosynthetic bacteria had evolved and began introducing oxygen into the ocean and atmosphere. After approximately 1.8 billion years, the atmosphere and ocean were saturated with oxygen.

Why are there ocean basins, mountains, and continents?

Earth's solid **mantle** ceaselessly churns. **Convection** transports heat from the deep interior to the surface as hot, buoyant rock rises and cooler rock sinks. This churning drives plate tectonics (the movement of rocky **plates** that make up the solid shell of the planet), which forms ocean basins, shifts **continents**, pushes up mountains, and causes **volcanoes** to erupt. Most **earthquakes** occur along the margins of these plates. Wind and water also shape Earth's surface. Over millions of years they wear down mountains and redeposit them as sediments, carving the landscapes we live in.

How do scientists read the rocks?

All over the world, from ocean trenches to roadside **outcrops** and from riverbeds to mountaintops, geologists collect **rocks**. They observe their mineralogy and texture, and measure their composition to find out where and how the rocks formed. To determine their relative age, they observe sequences of layered rocks, and identify the fossils found in **sedimentary** rocks. Some rocks can be dated radiometrically, which gives their absolute age. All this information, combined with **geologists'** observations of processes operating today, makes it possible for them to reconstruct geologic history in order to deduce what happened long ago.

What causes climate and climate change?

The Sun's energy drives **climate**. Because Earth is a sphere, more heat falls on equatorial regions than on the poles. This uneven distribution drives winds and ocean currents that transport heat from the tropics to the poles. Many components of the Earth system (amount of sunlight, composition of the atmosphere, ocean composition and circulation, location of continents, extent of ice sheets, and life itself) interact to regulate climate. Scientists study the record of past climate, which is preserved in **glaciers**, in land and ocean sediments, in corals and trees, and, for the distant past, in rocks. This record tells us that climate has changed throughout Earth's long history, sometimes suddenly and sometimes gradually. Human activity, particularly burning **fossil fuels**, is now causing atmospheric CO₂ content and global average temperatures to rise at a rapid pace. The effects on climate include more intense **weather** events, such as droughts and storms, and rising sea levels.

Why is Earth habitable?

Life on Earth is possible because it is the right distance from the Sun for liquid water to exist on its surface. Early life, which may have begun in the ocean, evolved with the planet over huge stretches of time. Energy and the elements necessary for life circulate through the biosphere (the living portion of our planet), the atmosphere, the ocean, and the solid Earth. Key biogeochemical cycles include the **water cycle**, **carbon cycle**, and **rock cycle**. Because of this cycling, there is oxygen in the air to breathe, an **ozone layer** to help block ultraviolet radiation, and a surface temperature much lower than it would otherwise be.



The Grand Canyon tells a story of erosion by water and wind, with steep walls of hard rock and slopes of softer, more easily eroded sedimentary rock.

Creating the Gottesman Hall of Planet Earth

It took three years, dozens of reconnaissance trips, and 28 expeditions to collect the spectacular rocks on display in this hall. Scientific teams have many responsibilities, from figuring out where to look for specific kinds of geologic evidence to transporting specimens across deserts and glaciers, through customs, and safely back to the Museum. The teams returned with a total of 172,000 pounds of rock from as far away as Antarctica and as close as New York's Central Park, from high in the Alps to the Pacific Ocean's Juan de Fuca Ridge.

The youngest is a chunk of sulfur collected just days after it solidified on Indonesia's active Kawah Ijen volcano by scientists wearing masks to protect them from poisonous gases. The oldest is a zircon crystal from Jack Hills, Australia, which at 4.3 billion years is almost as ancient as Earth itself. Some samples were pried loose with a rock hammer, while massive boulders required boom trucks, helicopters, or ocean submersibles.



Kawah Ijen volcano, Indonesia

Then came the labor-intensive process of preparing, mounting, and installing the specimens, some weighing several tons: 168 rock samples and eleven full-scale models of outcroppings from 25 countries, including Australia, Indonesia, Italy, Kazakhstan, Mauritania, Switzerland, and Venezuela – and five regions of the ocean floor. Their stories combine to tell that of our dynamic planet.

Come Prepared

Plan your visit. For information about reservations, transportation, and lunchrooms, visit amnh.org/education/plan.

Read the Essential Questions in this guide to see how themes in the hall connect to your curriculum. Identify the key points that you'd like your students to learn.

Review the Teaching in the Exhibition section of this guide for an advance look at the models, specimens, and interactives that you and your class will be encountering.

Download activities and student worksheets at amnh.org/resources/rfl/pdf/hope_activities.pdf. Designed for use before, during, and after your visit, these activities focus on themes that correlate to the New York State Science Core Curriculum.

Decide how your students will explore the Gottesman Hall of Planet Earth. Suggestions include:

- You and your chaperones can facilitate the visit using the **Teaching in the Exhibition** section of this guide.
- Your students can use the **student worksheets** to explore the exhibition on their own or in small groups.
- Students, individually or in groups, can use copies of the **map** to choose their own paths.

Correlations to Framework for K–12 Science Education

Your visit to the Gottesman Hall of Planet Earth can be correlated to the new Framework for K–12 Science Education from the National Research Council.

Science Practices

Asking questions; Developing and using models; Analyzing and interpreting data; Obtaining, evaluating, and communicating information

Crosscutting Concepts

Patterns; Scale, proportion, and quantity; Systems and system models; Stability and change

Core Ideas

Earth's Place in the Universe: ESS1.C: The history of planet Earth; ESS2.B: Plate tectonics and large-scale system interactions; ESS3.B: Natural hazards; ESS3.D: Global climate change

teaching in the EXHIBITION

This hall uses specimens, videos, models, and interactives to investigate the history and composition of Earth and the ongoing processes that shape it. The **guided explorations** are designed around five themes. The first four themes are below; the fifth is on the insert. (*Answers are in italics.*) The numbers (#) correspond to the specimens. Refer to the map for locations.

1 HOW EARTH FORMED

A Meteorites (#1–3): The most important clues to the composition of the early solar system come from meteorites. Have students observe these three and discuss the evidence about Earth's formation that they contain.

B Four Density Blocks (#4–7): When Earth was forming, heavier materials like iron sank to the center to form the core and lighter ones like silicates rose to the surface. Have students take turns lifting the samples and exploring the diagrams. Ask them to connect this experiment to how Earth's layers are organized.



C Banded Iron (#23, 15) and Stromatolite (#14): Rocks can contain important clues about the atmosphere. In early Earth, metals like iron were released into the ocean from hot springs but remained in solution in the water. When photosynthetic organisms began producing oxygen, it reacted with the iron in the seawater and precipitated as iron oxide to form the banded iron formation. Eventually, oxygen began to accumulate in the atmosphere. Have



students observe both banded iron formations and the stromatolite (the fossilized remains of early oxygen-producing microbes). Ask them to use the "How Do We Know About the Early Atmosphere?" diagram to explore the way these two rocks formed and what this tells us about the early atmosphere.

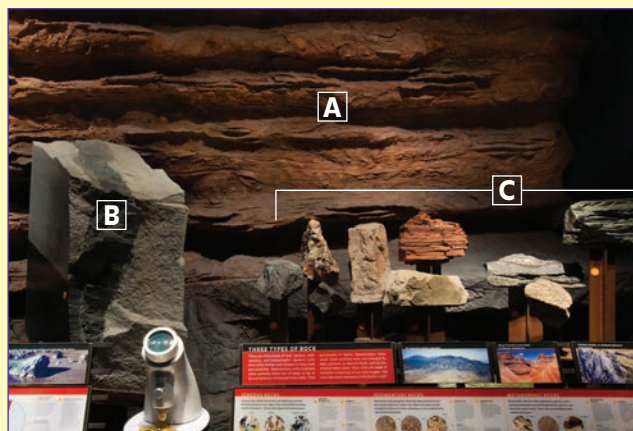
D Sulfide Chimney (#28) and Banded Ore (#26): Chimneys form today when iron and other metals from underwater hot springs react with seawater and precipitate, in this case as sulfide minerals. Walk past the Dynamic Earth Sphere to observe the chimneys at the other end of the hall. Have students examine the "Deep-Sea Vents and Ore Deposits" panel and discuss the way these two very different ore deposits formed.

2 THE ROCK RECORD

A Cast of Rock Outcrop from Scotland: One way geologists learn about Earth's history is to interpret the structure of rock formations. In general, sedimentary rocks are deposited in horizontal layers, and younger beds lie atop older ones. Have students examine this cast. Ask: What two main types of rock do you see? What do you observe about each section? (*Top section is dark red, and made of horizontal beds of sandstone. Bottom section is blocky gray slate in vertically-oriented layers.*) Ask: What do you think this tells us about how this part of Earth's crust formed? (*The gray slate, which had been deposited in water, must have been uplifted, tilted, eroded, and submerged again. The red sandstone layers were deposited above the slate. This discontinuity reflects processes that occurred over long periods of time.*)

B Dike in Granite (#3): Dikes are planar bodies of once-molten rock that intruded across the layering of older rocks. Have students examine this sample and identify which rock formed first. (*The lighter one, the granite, is older than the gray-black basaltic rock.*)

C Three Types of Rocks (#4–12): Geologists use different characteristics to categorize rocks. Have students read about sedimentary, igneous, and metamorphic rocks on the panel and connect these characteristics to what they observe about the rocks on display.



The dike in granite [B] and three types of rocks [C] are silhouetted against a cast of the famous Scottish outcrop [A] known as Hutton's Unconformity.

- D Gabbro and Vials (#16):** Geologists can date some rocks radiometrically by chemically analyzing them



in the lab. Have students examine the mineral grains in the vials and the related panel to learn about half-life and radioactive dating techniques.

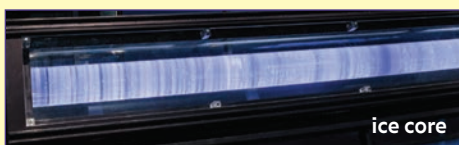
- E Grand Canyon Section:** Geologists construct maps to understand how the Grand Canyon and other Earth features formed. Have students look at the large geologic map on the left. Ask them to examine the cross-section views on the right to explore what they tell us about rock formations and age. Then have students observe the rocks (#18-22) and correlate them to the cross-sections in the “Building the Canyon’s Layers” diagram. Help them infer that the location of different types of rocks and structures can reveal the story of the Grand Canyon’s formation.

- F Granite (#15), Claystone (#16), Gneiss (#17), and Rock Cycle Diagram:** Rocks form and transform, some many times over vast expanses of geologic time. Help students connect the characteristics of the three types of rocks (see 2C) to processes at work in the rock cycle.

3 CLIMATE & CLIMATE CHANGE

- A Weather and Climate Section:** The complex interaction of many factors – the amount of sunlight, the condition of the atmosphere, the ocean, the solid Earth, the ice sheets, and life itself – regulates climate and causes it to change. Have students explore the area to learn about the relationships between the atmosphere, ocean, climate, and weather. Then have them investigate greenhouse gases and the role of carbon in the climate system.

- B Ice Core, Deep-Sea Sediment Core (#8), and Tree Ring Section (#13):** Climate changes over time. This record is preserved in glaciers, in lake and ocean sediments, in corals and trees, and in rocks. After watching the video, have students explore how scientists use different types of evidence to learn about past climate. Encourage students to use the ice core inter-



- C Carbon Cycle Diagram and Fossil Fuel Interactive:**

The amount of CO₂ in the atmosphere strongly influences climate. Have students explore how carbon moves through Earth and describe the different roles of short- and long-term reservoirs (e.g. the ocean versus the mantle and crust).

4 NATURAL RESOURCES

- A Groundwater Video:** One of the most important processes in the formation of Earth’s resources – from oil and gas to metal ores and freshwater – is the flow of fluids through rock. Have students watch the videos to learn why and how scientists model groundwater flow.

- B Ore Specimens (#1-8, 18-25):**

Have students explore this group of specimens, which illustrates how ores form. Ask students to select one specimen and explain what resource it provides.



Ore samples [B] loom above the groundwater video [A] and line the passageway to the right.

- C Water Cycle Diagram:** Water is part of Earth, its atmosphere, and all of its living organisms. Have students identify groundwater and discuss its role in creating Earth’s resources.

Our Dynamic Earth Today

- **Dynamic Earth Sphere:** Suspended from the ceiling, it recreates a view of Earth from space. Watch the layers of clouds, vegetation, ice, and ocean peel away to reveal the underlying rocky surface.
- **Earth Bulletins:** The large video screen and computer kiosks describe recent earthquakes, volcanic eruptions, and major storms, and present current Earth science research.
- **Bronze Earth Globe:** This is an accurate model of the solid Earth, with vertical measurements exaggerated by a factor of 22.5.

ONLINE resources

Gottesman Hall of Planet Earth

amnh.org/rose/hope/

The Museum's detailed website about the hall. Includes scientist profiles, fun facts, and extensive resources.

Earth OLogy

amnh.org/ology/earth

Hands-on activities and interactives for kids 7 and up, including "If Rocks Could Talk" and "Edible Earth."

Science Bulletins: Earth

amnh.org/sciencebulletins/

Videos, essays, and data visualizations about current research in Earth Science.

Earth: Inside & Out

amnh.org/resources/rfl/web/essaybooks/earth/

Fifteen lively case studies, from historic figures to geologists at work today.

Discover the Hall of Planet Earth

amnh.org/resources/rfl/pdf/discover_earth.pdf

A two-page printable activity sheet designed to be completed by kids with a chaperone during a visit.

Grand Canyon Geology Lesson Plans

nps.gov/grca/forteachers/upload/Geology-3.pdf

Comprehensive lesson plans created by the National Park Service. Topics range from rock identification to making fossils and creating a Grand Canyon geologic timeline.

Water Cycle Game

response.restoration.noaa.gov/watercyclegame

Students role-play the complex journey of a water molecule as it travels through the water cycle.

Investigating El Niño Using Real Data

datainthe classroom.org/content/el-nino/

Five activities that use real data from NOAA.

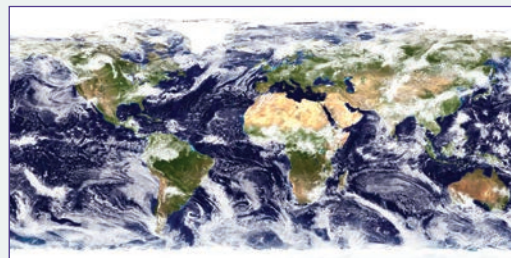
NASA: Earth

www.nasa.gov/topics/earth

Images, video, and stories from the Earth-observing satellite, the ISS, the Atmospheric Infrared Sounder and other NASA instruments that monitor our planet.

Visible Earth

visibleearth.nasa.gov



NASA's catalog of images and animations of our planet.

NOAA

noaa.gov/

The National Oceanic and Atmospheric Administration charts seas and skies, monitors weather, and guides stewardship of marine and coastal resources.

National Earthquake Information Center

earthquake.usgs.gov/regional/neic/

Run by the USGS, this site assesses the location and size of all destructive earthquakes worldwide and maintains a public database dating back to the year 856.

IRIS Seismic Monitor

iris.edu/seismon

Monitor global earthquakes in near real-time, visit seismic stations around the world, and search the web for earthquake- or region-related information.

Learn About U.S. Volcanoes

volcanoes.usgs.gov/about/

Extensive resources published by the USGS. Activities include Wegener's Puzzling Evidence Exercise and Plate Tectonics Tennis Ball Globe.

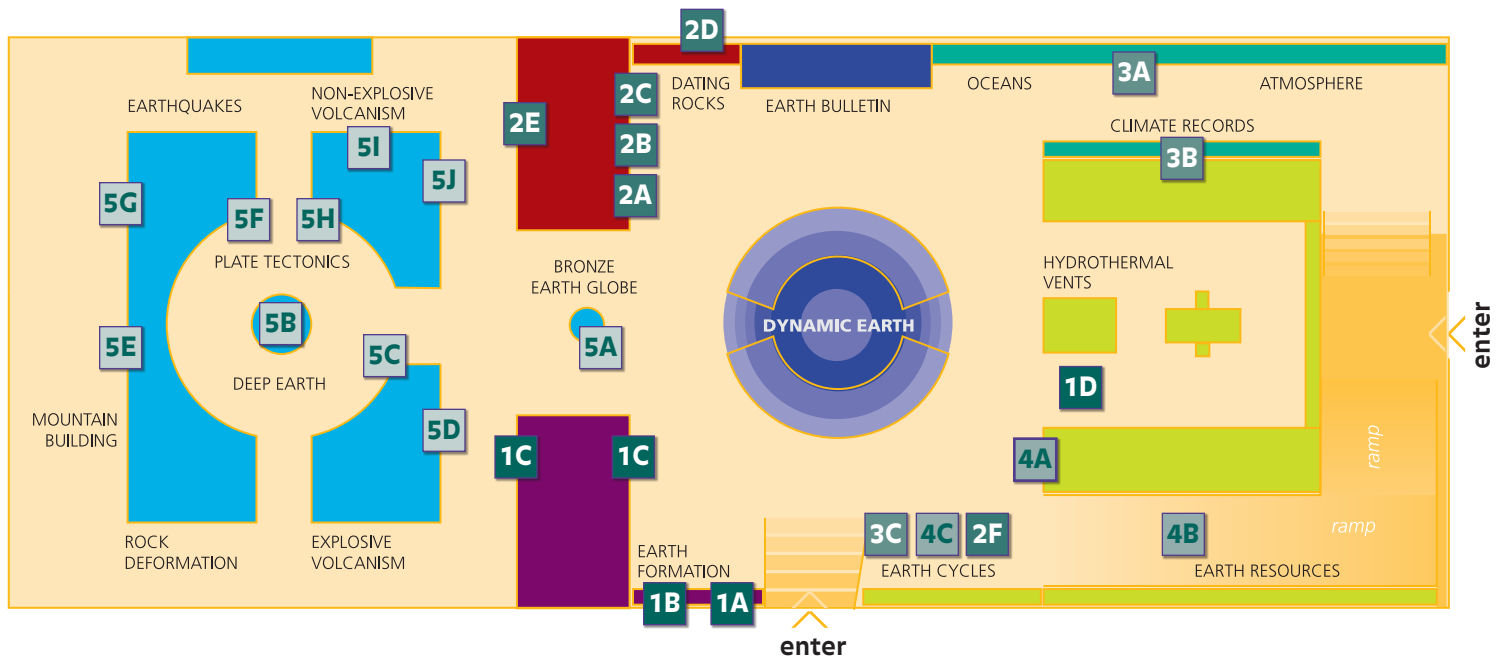
CREDITS

Funding for the Educator's Guide has been provided through the generous support of The Louis Calder Foundation.

Photo Credits

Cover: All photos, © D.Finnin/AMNH. **Essential Questions:** Grand Canyon, © Ashton Applewhite; Kawah Ijen Volcano, © D.Finnin/AMNH; deformed conglomerate, © D.Finnin/AMNH. **Teaching in the Exhibition:** All photos, © D.Finnin/AMNH. **Online Resources:** The Blue Marble, © NASA Goddard Space Flight Center Image by Reto Stockli (land surface, shallow water, clouds). Enhancements by Robert Simmon (ocean color, compositing, 3D globes, animation). Data and technical support: MODIS Land Group; MODIS Science Data Support Team; MODIS Atmosphere Group; MODIS Ocean Group Additional data: USGS EROS Data Center (topography); USGS Terrestrial Remote Sensing Flagstaff Field Center (Antarctica); Defense Meteorological Satellite Program (city lights). **Plate Tectonics Insert:** All illustrations by Eric Hamilton.

Gottesman Hall of Planet Earth **MAP**



Essential Questions

- How has Earth evolved?
- Why are there ocean basins, mountains, and continents?
- How do scientists read the rocks?
- What causes climate and climate change?
- Why is Earth habitable?

Teaching in the Exhibition

- | | | | | |
|---|--|---|---|---|
| 1 How Earth Formed <ul style="list-style-type: none"> A Meteorites B Four Density Blocks C Banded Iron and Stromatolite D Sulfide Chimney and Banded Ore | 2 The Rock Record <ul style="list-style-type: none"> A Cast of Rock Outcrop from Scotland B Dike in Granite C Three Types of Rocks D Gabbro and Vials E Grand Canyon Section F Granite, Claystone, Gneiss, and Rock Cycle Diagram | 3 Climate & Climate Change <ul style="list-style-type: none"> A Weather and Climate Section B Ice Core, Deep-Sea Sediment, and Tree Rings C Carbon Cycle Diagram and Fossil Fuel Interactive | 4 Natural Resources <ul style="list-style-type: none"> A Groundwater Video B Ore Specimens C Water Cycle Diagram | 5 Plate Tectonics <ul style="list-style-type: none"> A Bronze Globe and Slice of Crust B Churning Earth C Model of Collision D Explosive Volcanism E Mountain Formation F Model of Slip G Earthquakes Section H Model of Separation I Basalts J Hawaiian Hot Spots |
|---|--|---|---|---|



GLOSSARY

atmosphere: the mixture of gases (78% nitrogen, 21% oxygen, 0.9% argon, and 0.03% carbon dioxide, by volume) that surrounds the Earth

carbon cycle: the continuous flow of carbon through living things (biosphere), the solid Earth (geosphere), the oceans (hydrosphere), and the atmosphere

climate: the weather (including extremes) in a particular region averaged over a number of years

convection: the process by which hotter, less dense material rises and is replaced by colder and denser material

continent: one of Earth's large land masses

core: the mass of metallic iron and nickel at the center of the Earth. The fluid outer core begins at 5100 km below the surface and the solid inner core at 2900 km.

crust: Earth's outermost solid layer, consisting of a continental crust averaging 45 km thick and an oceanic crust averaging 8 km thick

earthquake: a shaking of the ground caused by the abrupt release of accumulated strain when a fault ruptures

erosion: the processes that wear down rocks and transport the loosened sediment

fossil fuels: coal, oil, and natural gas, which formed from the remains of organisms that lived millions of years ago

geologist: a scientist who studies Earth, e.g. its history, composition, structure, and the processes that shape it

glacier: a large, semi-permanent, slowly flowing river of ice formed from compacted snow

igneous rock: rock formed when magma (molten rock) solidifies

mantle: the layer between the core and the crust of the planet. Its properties, such as density and viscosity (resistance to flow), change with depth.

metamorphic rock: rock formed when sedimentary, igneous, or other metamorphic rocks recrystallize into new rock forms, typically under the influence of heat and pressure

mineral: any naturally occurring, inorganic solid with a specific composition and an orderly crystalline structure

outcrop: bedrock exposed at Earth's surface

ozone layer: the region of the upper atmosphere that contains about ninety percent of Earth's ozone (molecules made up of 3 atoms of oxygen)

plates: the blocks that make up Earth's rigid, cold, outermost shell, averaging 100 km thick and consisting of crust and uppermost mantle

radiometric dating: a technique for measuring the age of geologic materials based on the decay of naturally-occurring radioactive isotopes

rock: a naturally occurring aggregate of one or more minerals

rock cycle: the cycle in which sedimentary, igneous, and metamorphic rocks are transformed into other rock types through processes such as melting, crystallization, erosion, deposition, **lithification** (the process by which sediments are turned into rock), and recrystallization

sedimentary rock: rock formed when sediments accumulate and lithify, or when minerals precipitate directly from water

volcano: a vent in Earth's surface through which magma and associated gases and ash erupt. The ejected materials often form a conical structure.

weather: the state of the atmosphere at a specific place and time, characterized by temperature, barometric pressure, wind velocity, humidity, cloud state and precipitation

weathering: the physical and chemical processes that discolor, soften, and break down rocks exposed to air, water, and organic material

water vapor: the gaseous state of water

water cycle: the cycling of water among oceans and lakes, land, living organisms, and the atmosphere



What is Plate Tectonics?

A Bronze Globe & Slice of Crust Model: This globe is a model of the solid Earth: Earth without water. (To help students understand the term “solid Earth,” have them watch the Dynamic Earth sphere overhead and see the liquid slowly drained away from the rocky surface). Have students compare the familiar topography of the continents with the less familiar topography of the ocean basins. Point out the “slice of crust” model hanging overhead. Invite students to use the diagram below to find the region on the globe that’s represented in the model above. Tell them that they’re going to be exploring the ways in which plate tectonics shapes the solid Earth.

B Churning Earth Section: Convection is the main way in which heat is lost from the interior of the Earth. It’s the force that drives the movement of tectonic plates. Have student go to the video kiosk in the circular table and watch scientific models of how the Earth’s core and mantle convect.

When Plates Collide

C Model of Collision: When an oceanic plate meets a continental plate, the oceanic plate descends, or subducts, beneath the continental plate and sinks into the mantle. Have students explore the model and use their hands to simulate this interaction.



model showing an oceanic plate (r) subducting under a continental plate (l)

D Explosive Volcanism Section: Most explosive eruptions occur in volcanoes above subduction zones, where one plate dives beneath another. Have students watch the video and explore samples from Medicine Lake Volcano, California (#5-10).

E Mountain Formation Section: When two continental plates meet, one is thrust over the other to form mountain ranges like the Alps and the Himalayas. Have students watch the video and examine the sand model, and discuss how the model helps scientists understand the way plates interact to form mountain ranges. Then have them observe the rock samples (#1-7) that illustrate the processes (uplifting, folding, crustal thickening, and faulting).

When Plates Move Past Each Other

F Model of Slip: When oceanic or continental plates slide past each other in opposite directions, or move in the same direction but at different speeds, a fault forms. Have students explore the model and simulate this interaction with their hands.

G Earthquakes Section: Earthquakes occur along fault lines (cracks near plate boundaries where the crust on opposite sides moves). Have students explore the earthquake video kiosk and associated text panels. Ask: Why do we monitor them? (*Monitoring helps scientists estimate the odds of an earthquake taking place within a certain period of time.*) Then have students find the faults on the two large casts and the samples (#1-2) and describe what they tell us.

When Plates Separate

H Model of Separation: Most spreading plate boundaries are found in ocean basins. Have students explore the model and use their hands to simulate how plates separate.

I Basalts: Most volcanoes erupt basalt, a fluid lava from the mantle that forms flows. Most basalt erupts from cracks in the seafloor, but some basaltic lava flows occur on continental crust. Have students compare the shapes of the underwater (#9-17) and flood basalts (#18), and discuss their formation.

When Plates Move

J Hawaiian Hot Spots: Basaltic lava also erupts at hot spots, where molten rock, or magma, forms in plumes of hot rock that rise from deep in Earth to penetrate a moving plate above. Have students watch the video and explore the various specimens. Ask: What does the pattern of the Hawaiian island chain reveal about how the Pacific plate is moving? (*The plate is moving slowly over a stationary hot spot in the mantle. The bend records a shift in the movement of the plate 43 million years ago.*)

Wrap Up: Revisit the **Bronze Globe** and ask students to connect specific specimens to places on the globe and to the tectonic processes at work behind them. (*Examples: Collide – Andes and Himalayas; Separate – Mid-Atlantic Ridge; Slip – San Andreas fault*)

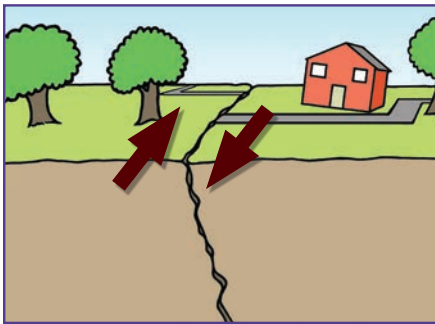
plate **TECTONICS**

Earth's surface may seem perfectly still, but it's actually in constant motion. The planet's thin outer shell is broken into large blocks called tectonic plates, which fit together like a puzzle. They float on Earth's mantle, a really thick layer of hot flowing rock. This flow causes the plates to move in different directions. Even though these massive plates move very slowly (about as fast as your fingernails grow), their motion has a huge effect on Earth. The process of plate tectonics forms oceans, continents, and mountains. It also helps us understand why and where most earthquakes and most volcanic eruptions occur.

When plates meet, four things can happen:

Slip

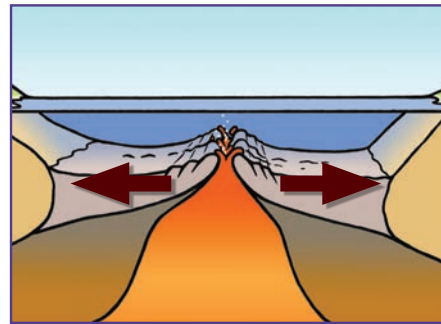
two plates slide past each other



As one plate slides against another, the rocks bend against each other at the fault. When they finally break loose and snap back to their original shapes, the energy is released as an enormous shock wave. That is an earthquake.

Spreading

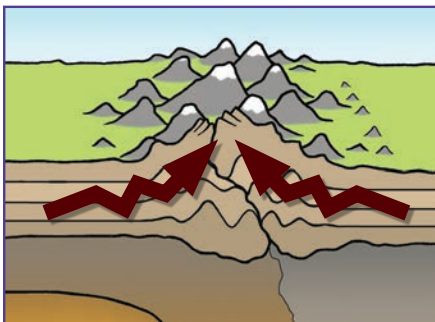
two plates move apart from each other



As two plates slowly move apart, earthquakes occur and magma rises up from the mantle below. The magma erupts from volcanoes that form between the plates, and cools to form new crust.

Collision

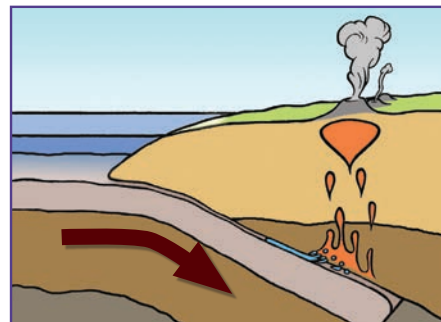
two plates run into each other and fold up



When two continental plates meet, pieces of crust pile atop each other, creating complex patterns of folds and faults. Earthquakes happen and great mountain ranges form.

Subduction

one plate sinks below the other



When a more dense oceanic plate collides with a less dense continental plate, it sinks below the continental plate into the mantle. Earthquakes occur and magma forms and rises to Earth's surface to cause volcanic eruptions.