SMITHSONIAN

IN YOUR CLASSROOM

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PREHISTORIC CLIMATE CHANGE

AND WHY IT MATTERS TODAY

Smithsonian Institution

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NATIONAL STANDARDS
The lesson in this issue addresses NAS National Science Content Standards for ecosystems and Earth's history and NCTM National Mathematics Standards for the use of mathematics to solve problems.

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BACKGROUND

A BASIN FILLED WITH TIME

THROUGHOUT HIS CAREER, SMITHSONIAN paleontologist Scott Wing has been digging for early-Cenozoic fossils in the Bighorn Basin of north-central Wyoming. The Cenozoic era, which began with the extinction of the dinosaurs, has been called "the age of mammals." With the giant reptiles out of the way, mammals began exploring new niches and taking the first steps to becoming species that we know today. Wing's interest, though, is in the plant life of the time, particularly how it related to climate.

"When I entered paleontology I never expected my work to be especially relevant to human concerns," he says. "But over the last fifteen years or so I have become convinced that it is."

During the first epoch of the Cenozoic, the Paleocene, the earth's average temperature was warmer than today's by about nine degrees Fahrenheit, more or less as it had been in the days of the dinosaurs. And then suddenly—suddenly, that is, as paleontologists reckon things—a warm world got much warmer. Within ten thousand years at the start of the next epoch, the Eocene, the temperature rose by at least another nine degrees. Since the early 1990s, science has known that this rapid additional warming, called the Paleocene-Eocene Thermal Maximum (PETM), had to do with a release of carbon dioxide in the atmosphere, whether from volcanoes or some other source. In recent years, those studying our own climate have turned to paleontologists like Wing for an understanding of what might lie ahead for us.

The lesson in this issue introduces the subject of climate change, past and future. Students examine fossils of tree leaves that Wing and other scientists discovered in the Bighorn Basin. The leaves are from two times in the early Cenozoic: just before the PETM, about 55.85 million years ago, and during its height, about 55.75 million years ago. Students use the leaves in a mathematical formula to determine temperature differences between the two times, thus doing much of the same work as the scientists. They go on to consider the causes and implications of the carbon in our own atmosphere.

With the new "relevancy" of Wing's work has come an increasing sense of the importance of sharing it with the Smithsonian's audience, particularly with students.

"We have become a geological force in the way we alter the atmosphere, oceans, climate, sediment cycle, and biosphere," he says. "Even earth scientists have been slow to appreciate this." His hope is that students "understand the new world they are creating, and feel a sense of responsibility toward it that is commensurate with their power to change it."

THE BASIN

If a time traveler arrived in Wyoming's Bighorn Basin in the early Cenozoic, the landscape would be recognizable as earthly, though of a different part of the earth. What now looks like the setting of a big-sky western, where only sagebrush flourishes in the arid summers and subzero winters, would have then looked more like coastal South Carolina, with swampy lowlands inhabited by soft-shelled turtles, alligators, and the ancient relatives of palmettos and bald cypresses. In this, there was nothing unique about the Bighorn Basin. The earth was a virtually ice-free planet. Palm trees grew as far north as Canada and alligators swam in Arctic swamps.

But the Bighorn is a special place to paleontologists like Scott Wing. It is surrounded by ranges of the Rocky Mountains, which were still rising in the early Cenozoic. As the mountains rose, they also eroded, burying the basin's dead plants and animals in mud. As mud hardened to rock, this life was preserved as fossils. Millions of years later, the basin itself eroded into hilly badlands, leaving the fossils within reach of pick and shovel. The Bighorn, as Wing puts it, is a "basin filled with time."

THE FIND

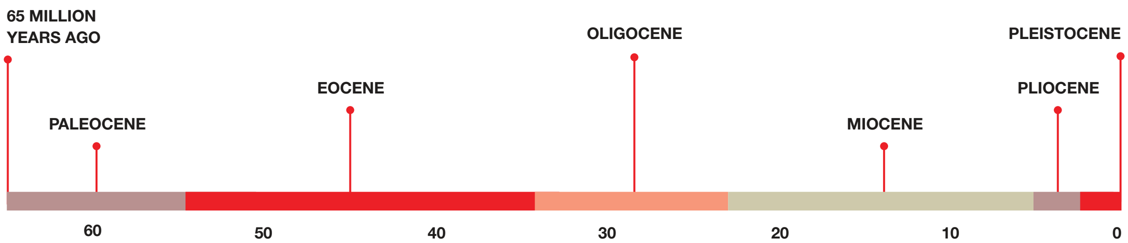
The Bighorn Basin has been the scene of remarkable discoveries of mammals from the early Cenozoic. Lemur-like primates appeared in North America during this time, along with an early version of an animal that would come to symbolize the American West, the horse. The first horses were leaf-eating forest creatures that were only slightly larger than house cats. They would develop their size and speed in cooler times millions of years later, as forest gave way to open grassland. They would then disappear from the Americas during the ice ages, returning only with the Spanish explorers.

In the early 1990s, paleontologists working in the Bighorn Basin collaborated with oceanographers to present evidence that the appearance of these animals precisely coincided with worldwide warming during the PETM period. The picture of the PETM world, however, was still quite incomplete. No fossils of PETM plants had been discovered, not in the Bighorn or anywhere else.

By then, Scott Wing had been digging for plants for nearly twenty years, and had covered most of the promising areas of the basin's four thousand square miles. He had found plants from before the PETM and from after it, but comparisons of the fossils indicated no great change of climate. From the botanical point of view, it was as if the whole thing never happened.

In parts of the basin, the strata of the PETM period are visible as bands of rust-laden rock, as though the hills were marked—in bright red, no less—to show where a fossil hunter should look. But plant fossils are much more difficult to find than animal fossils, for the simple

THE CENOZOIC ERA



WHAT NOW LOOKS LIKE THE SETTING OF A BIG-SKY WESTERN . . . WOULD HAVE THEN LOOKED MORE LIKE COASTAL SOUTH CAROLINA.

reason that plants decompose more rapidly in soil than do bones and teeth. As climate scientists were beginning to turn their attention to the PETM, there was nothing for Wing to do but embark on the most hopeless kind of searching—he retraced his steps.

The search went on for another ten years. The discovery came with the turn of a shovel. In the summer of 2003, at a site in the remote badlands, a young field assistant heard a surprising sound coming from a hole where Wing was digging. It was the sound of a grown man crying.

"It's O.K., I'm not crazy," Wing told him. "It's just that I've been looking for this since you were ten years old."

He had found a fossil of a tiny tree leaf embedded in rock. More and more leaves showed themselves as he continued to dig. The site turned out to be a paleontologist's goldmine, yielding two thousand specimens from thirty species. It was enough to fill in a missing piece of the puzzle.

WHAT THE LEAVES SAY ABOUT THE PETM

Before this discovery, it was clear from the mammal fossils that life was on the move during the PETM. But mammals, because they can regulate their body temperature, do not respond as directly to climate change as do plants. What Wing's leaves showed was a complete change of landscape in the ten thousand years of the warm-up.

Paleontologists, who deal in tens of millions of years, tend to think of a period like ten thousand years as a mere moment in time. If a time traveler stood in Wyoming and saw things accelerated in that way—the PETM in a moment—it would be like watching South Carolina fly off to the north and southern Mexico sweeping in to take its place. The ancient relatives of southeastern American plants would give way to ancient relatives of subtropical species like acacias, mimosas, and poinsettias.

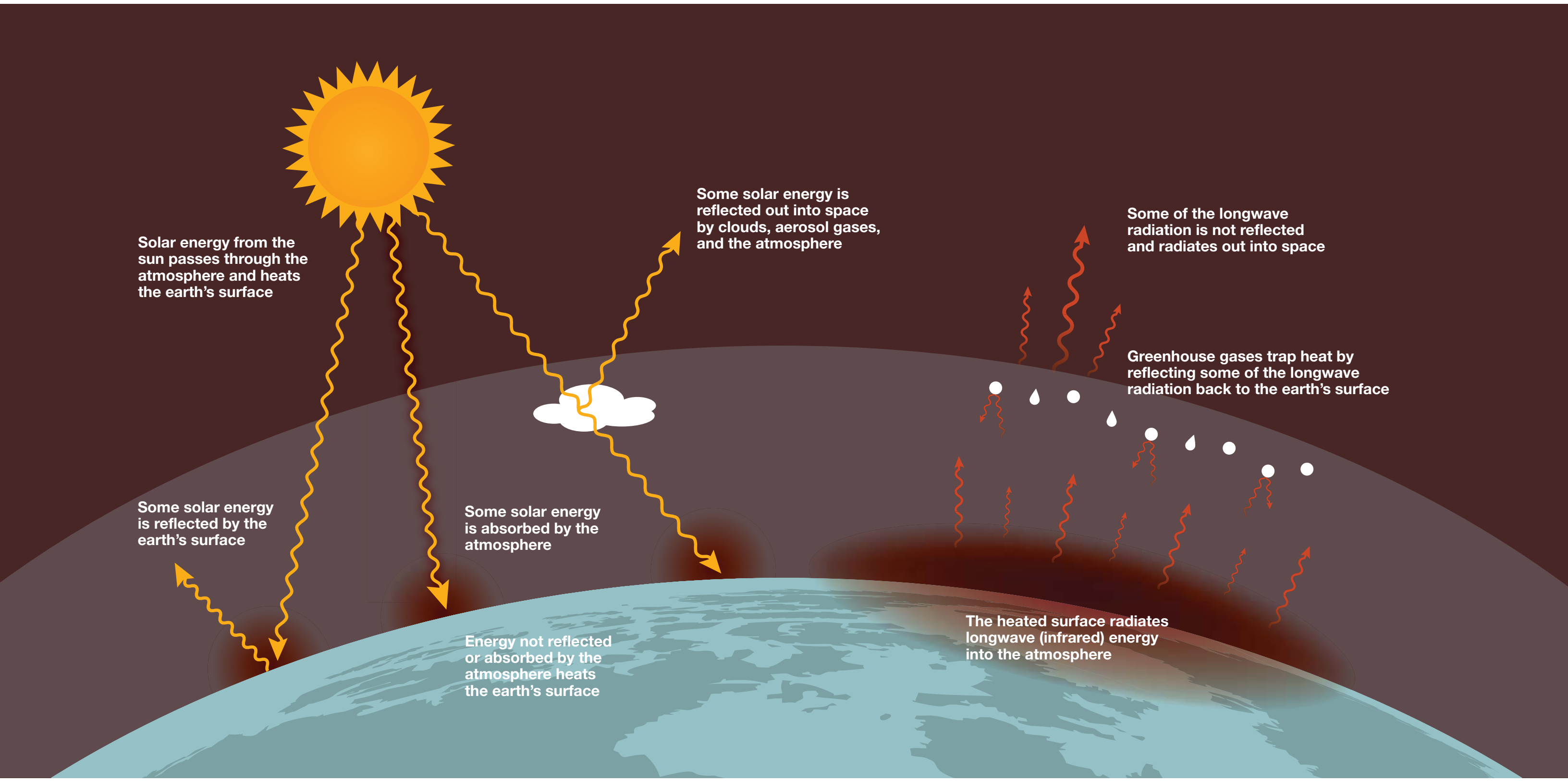
"During the warmest part of the PETM, many species adapted to relatively warm climates would have been able to extend their ranges into middle and high latitudes, and then across Arctic land bridges," says Wing. "Basically climate acted as a pump."

The leaves also gave science a new way of taking the temperature of the PETM. (See the lesson in this issue, page 5.) Prehistoric temperatures are usually measured by ratios of oxygen isotopes in the fossil shells of marine microorganisms called foraminifers. Findings from the newly discovered leaves corresponded with those from the foraminifers—the leaves showed the rapid warming of the PETM, followed by a plateau of heat and a gradual cooling off to pre-PETM conditions.

"It is very exciting," says Wing, "that we have been able to demonstrate with a record from the middle of a continent the same pattern of temperature change."

THE GREENHOUSE EFFECT

Carbon dioxide, water vapor, methane, and ozone are the major greenhouse gases, which keep the earth warm by trapping energy from the sun. Since the mid-nineteenth century, carbon dioxide in the atmosphere has risen by 40 percent.



WHAT THE PETM MIGHT SAY ABOUT THE FUTURE

The fossil record has also reaffirmed the relationship between carbon dioxide and global warming. The warming detected in Wyoming and elsewhere coincides with a widespread dissolving of chalky sediments on the ocean floor, which can only be explained as a result of carbon dioxide entering the ocean. The record also indicates that the planet does not recover quickly from a deluge of carbon: the warm spell of the PETM lasted more than 150,000 years.

When discussing the PETM, Wing tends to put it into terms we might know better. The ten thousand years of initial warming, for instance, is about the same amount of time that has passed since the beginning of agriculture, when humans learned to alter nature for their own advancement. The amount of carbon released during that initial warming is about the same as the amount of carbon in our remaining reservoirs of fossil fuel, 5 to 6 thousand billion tons.

"Comparisons make something else clear," he says. "Should we burn the remaining fossil-fuel reserves in the next few hundred years, we will be releasing carbon into the atmosphere more than ten times faster than it was released during the PETM."

The unknowns about the PETM are what worry scientists the most. For example, they have found no evidence of a single source of the carbon. It seems likely that there was a chain reaction, in which, perhaps, warming from volcanically released carbon dioxide destabilized ocean-floor deposits of methane, an even more powerful greenhouse gas. The methane would have added to the greenhouse effect before being converted into carbon dioxide and water vapor by chemical reactions in the atmosphere. Such a chain reaction has parallels to the worst of the worst-case scenarios for our future, in which, for example, a carbon dioxide–induced warming of the Arctic releases the methane now buried beneath permafrost.

"The central truth about predicting global change is that the systems we are predicting are very complicated and very interconnected," Wing says. "We can make all the supercomputer models we want, but we won't really know how well these models predict the future until we get there. And then it will be too late. The great advantage of the fossil record is that we can study events that have already happened and work out the links."

He puts it another way: "It seems that the least we can do, now that we are modifying the planet we live on, is to read the operator's manual written in its rocks."

LESSON

A FOSSIL THERMOMETER

BY FOLLOWING THE STEPS IN THIS LESSON, students are able to calculate temperatures in the prehistoric world. They use a method called "leaf-margin analysis," which was the primary way that Scott Wing and his team measured PETM warming when they discovered their leaf fossils in the Bighorn Basin.

How does it work? The first requirement is a collection of leaf fossils that represent a large number of tree species from given time and place. One determines the percentage of the species that have leaves with smooth edges, as opposed to toothed, or jagged, edges. This number—the percentage of smooth-edged leaves—goes into an equation that gives the average annual temperature (AAT) in Celsius of the given time and place:

AAT= (0.3006 x percent smooth) + 1.141

Why does it work, this simple process? The reasons are complicated. Teeth allow leaves to begin photosynthesis early in the spring, an advantage in climates with short growing seasons. On the other hand, teeth allow a loss of water vapor, a disadvantage in a warm climate. These tradeoffs lead to a high percentage of smooth-edge species in warm regions, which has been observed in living forests around the world.

In the lesson, students examine two sets of leaf fossils from the Bighorn Basin. The first represents the climate 55.85 million years ago, before the PETM warm-up. The second represents the height of the warm-up, 55.75 million years ago. The sets appear on the front and back of the pullout poster in this issue. Larger versions of the leaf fossils are available for downloading at smithsonianeducation.org.

STEP ONE

Begin with a discussion of the work of the paleontologists studying leaf fossils from the Bighorn Basin. Distribute copies of Handout 1, which should help with the introduction.

STEP TWO

Display the pullout poster, turned to the side marked "Site A." (If downloading the fossil photos, display them in the order in which they appear on the poster.) Distribute copies of Handout 2, which should help introduce leaf-margin analysis.

Working as a class, the students look closely to determine which of Site A's leaves are smooth-edged and which are toothed. (In some cases, fossilized tears and bug bites may appear as teeth. Ask students to look for regular patterns along the edges.)

Students mark the handout's corresponding table with an S for smooth or a T for toothed. When you turn over the poster, they do the same with the leaves from Site B.

Correctly completed, the Site A table would look like this:

1 T	2 S	3 T	4 S	5 T	6 T	7 T	8 S
9 S	10 T	11 S	12 T	13 S	14 S	15 T	16 S

The Site B table would look like this:

1 T	2 T	3 S	4 S	5 T	6 S	7 S	8 S
9 S	10 S	11 S	12 T	13 S	14 S	15 T	16 S

Students now figure the percentage of smooth-edged leaves in each set. Site A has eight smooth leaves and eight toothed, which comes to 50 percent. Site B has eleven smooth and five toothed, which comes to 68.75 percent.

STEP THREE

Distribute Handout 3 and guide students as they use the percentage numbers to calculate the average annual temperature of the time periods of the two sites. Solutions should be rounded to one decimal place.

Site A:
0.3006 x 50 + 1.141 = 16.2 °C

Site B:
0.3006 x 68.75 + 1.141 = 21.8 °C

To get a sense of these climates in more familiar terms, students convert Celsius to Fahrenheit, rounding off results to the nearest whole numbers. Site A's average annual temperature in Fahrenheit is 61 degrees, roughly the same as today's average in Charleston, South Carolina. Site B's average Fahrenheit temperature is 71 degrees, about the same as today's average in parts of the Yucatan Peninsula in Mexico.

Handout 3 contains a chart that allows students to check their work by finding the intersections of smooth-leaf percentage and temperature. With very young students, you might bypass the calculations and go straight to the chart.

STEP FOUR

Distribute Handout 4, which contains timeline charts of the PETM warming, along with information on the release of carbon. Students identify the times of Site A and Site B on the charts. When they note the sharp rise of temperature, they speculate on the causes. A class discussion of their ideas might lead to a deeper discussion of current concerns about climate change.

STUDENTS CAN WORK INDEPENDENTLY ON THE LEAF-SORTING AND CALCULATION PORTIONS OF THE LESSON IN AN ONLINE INTERACTIVE SIMULATION. VISIT SMITHSONIANEDUCATION.ORG/CLIMATECHANGE

SITE A

1

2

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10


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7
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16

SITE B

1

2

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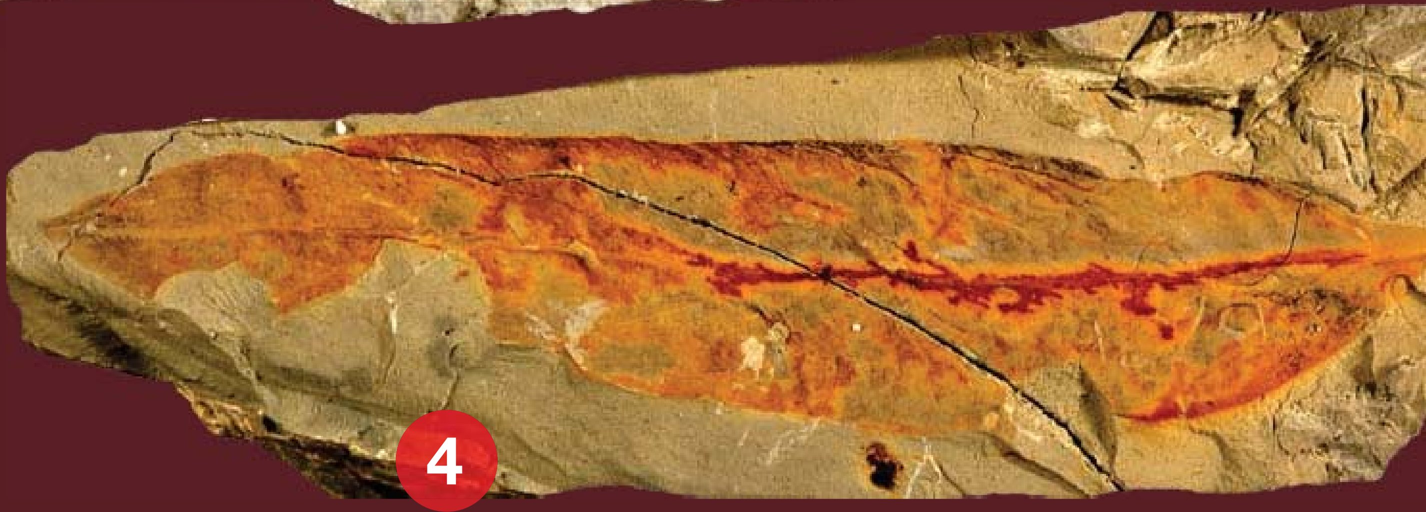
10


3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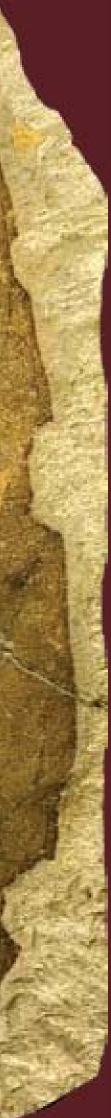


7

8

16

HANDOUT 1

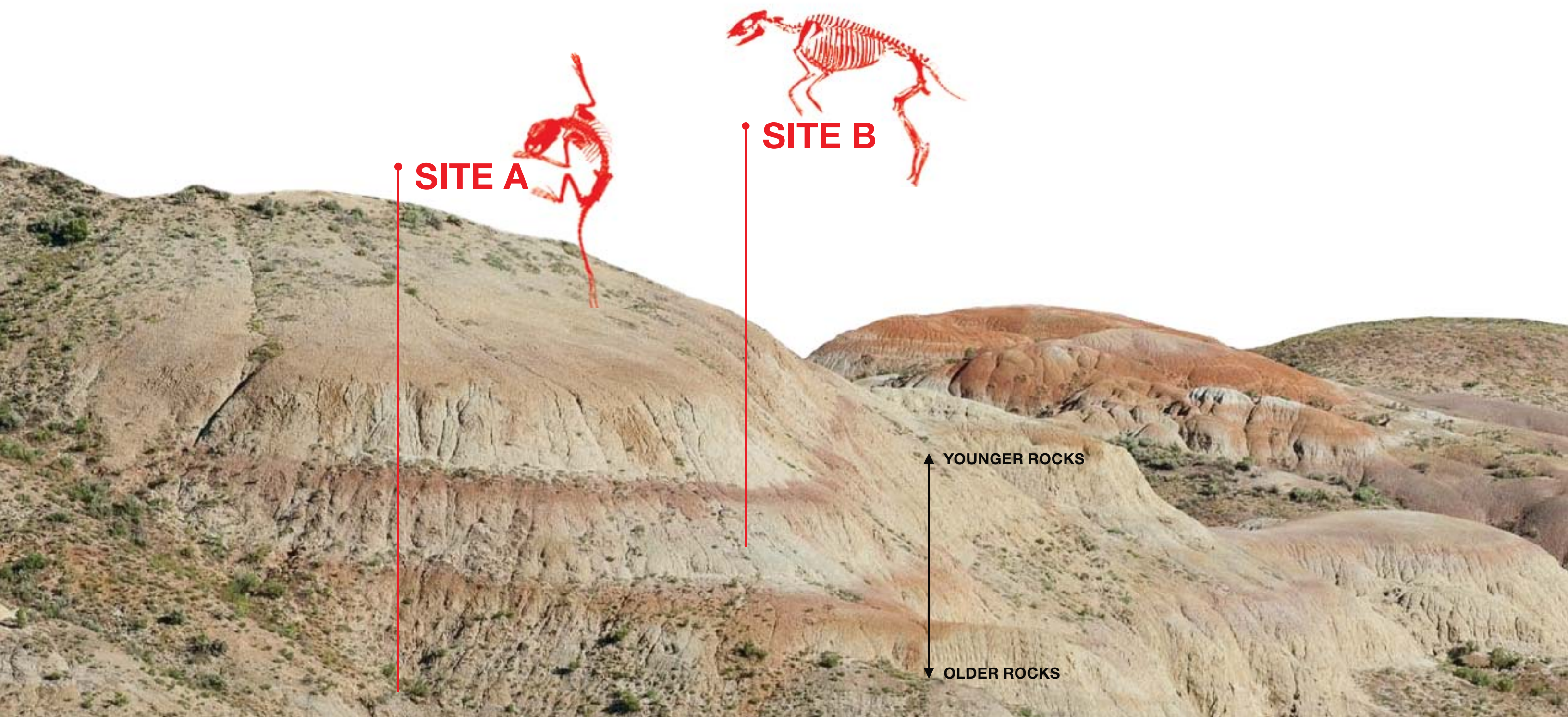
A TEAM OF SMITHSONIAN SCIENTISTS ARE STUDYING PREHISTORIC CLIMATES.

They have just returned from a fossil hunt and have asked your class to help them analyze some of the fossils.

At two dig sites in Wyoming's Bighorn Basin, they found bones of mammals that lived in the early Cenozoic era, about 10 million years after the dinosaurs. At Site A were bones of *Plesiadapis*, an early relative of the primates. At Site B were bones of *Hyracotherium*, a horse that was about the size of a cat.

But the scientists are more interested in something else they found at each site—hundreds of fossils of leaves from prehistoric trees. They know that the primate relative is about 55.85 million years old and that the horse is about 55.75 million years old, so they know the age of the leaves at each site. With the leaves, they can actually read the temperature at each of these times.

And so can you, using a method called "leaf-margin analysis."



HANDOUT 2

LEAF-MARGIN ANALYSIS BEGINS WHEN YOU LOOK CLOSELY AT THE EDGES OF EACH FOSSIL LEAF . . .

to see if it has *toothed edges* or *smooth edges*. Believe it or not, you can tell the average annual temperature of a place millions of years ago by the percentage of fossil leaves that have smooth edges. For this to work, scientists must gather leaves from many different tree species. You will be looking at a very small sample of what the Smithsonian scientists found—sixteen leaves from Site A and sixteen from Site B.

Teeth are little zigzags around the edge of the leaf. They are different from *lobes*. Lobes are formed by big dents in the leaves.

SMOOTH EDGES

TOOTHED EDGES

THIS OAK LEAF IS LOBED BUT HAS SMOOTH EDGES

THIS MAPLE LEAF HAS BOTH LOBES AND TEETH

Record your findings for Site A by filling in the table with “S” for smooth or “T” for toothed.

1	2	3	4	5	6	7	8
9	10	11	12	13	14	15	16

Record your findings for Site B in the same way.

1	2	3	4	5	6	7	8
9	10	11	12	13	14	15	16

How many Site A leaves have smooth edges? ____________________

How many Site B leaves have smooth edges? ____________________

What is the percentage of Site A leaves with smooth edges? ____________________ %

What is the percentage of Site B leaves with smooth edges? ____________________ %

TO FIGURE PERCENTAGES: $\% = \frac{S}{(S+T)} \times 100$

HANDOUT 3

NOW THAT YOU HAVE THE PERCENTAGES . . .

you can put them into an equation that will give you the average annual temperatures (AAT) in Celsius.

HERE IS THE EQUATION:

$$AAT = (0.3006 \times \text{percent smooth}) + 1.141$$

In Celsius, what was the average annual temperature in Wyoming 55.85 million years ago, the date of Site A? ______________ °C

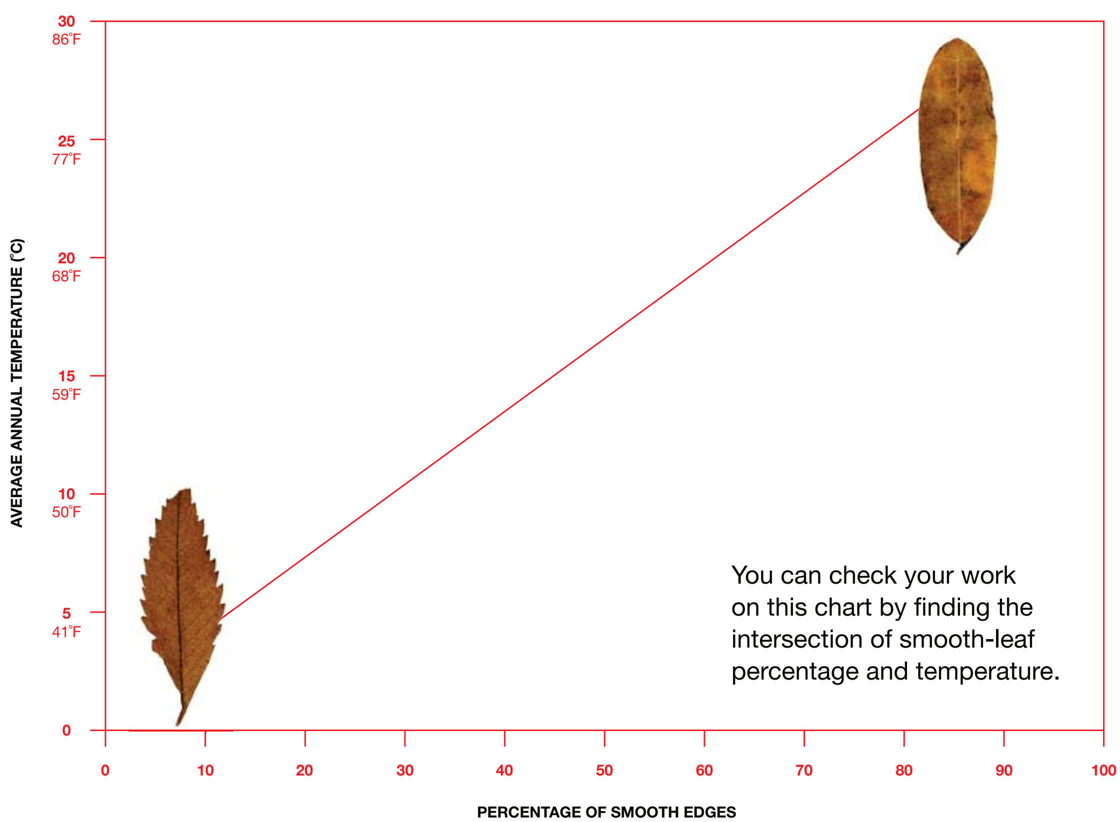
In Celsius, what was the average annual temperature in Wyoming 55.75 million years ago, the date of Site B? ______________ °C

HERE IS THE EQUATION FOR CONVERTING CELSIUS TO FAHRENHEIT:

$$F = (1.8 \times C) + 32$$

What was Site A's Fahrenheit temperature? ______________ °F

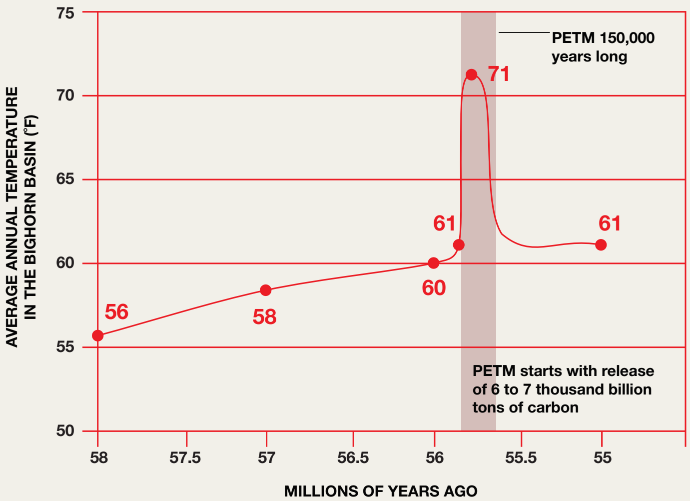
What was Site B's Fahrenheit temperature? ______________ °F

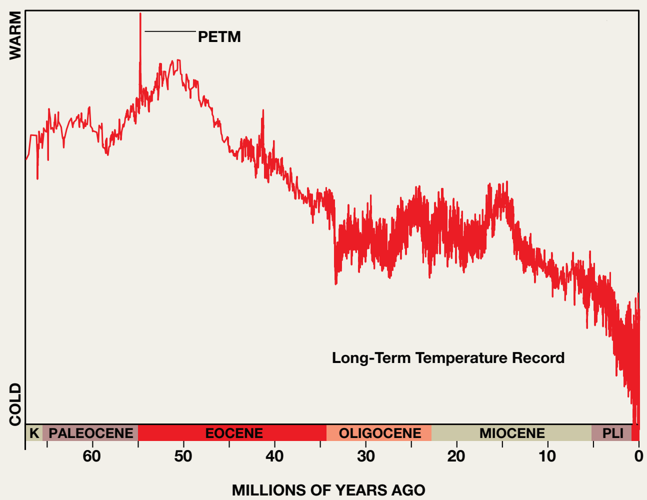


THE SITE B FOSSILS ARE ESPECIALLY IMPORTANT TO THE SCIENTISTS . . .

and you might be able to see why when you find the Site A and Site B times on these charts.

On the chart on the left, mark the two times with X's. Then try to do the same on the next chart, which shows temperature changes throughout the Cenozoic era. The Cenozoic began with the extinction of the dinosaurs, 65 million years ago, and continues today.





PETM stands for Paleocene-Eocene Thermal Maximum. What is happening at this time?

Look again at the charts. Can you find a clue to the causes of the PETM? If so, what is it?

SMITHSONIAN SCIENTIST SCOTT WING TALKS ABOUT THE CHARTS

"The temperature record on the chart on the right comes from chemical measurements of the shells of one-celled sea creatures called foraminifers. The chart on the left shows estimates of temperature made by leaf-margin analysis, the method you've just practiced. The red points show the temperature estimates. The line connecting them is our guess as to how temperature changed between the points. It takes many leaf fossils to get a temperature estimate. Leaf fossils are not common, so we are lucky to have even this many estimates."

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The Smithsonian's web portal for teachers

ONLINE INTERACTIVE

This issue of *Smithsonian in Your Classroom* includes a pullout poster that your entire class can use for the activities in the issue's lesson plan.

Students can also do the activities on their own by using an interactive feature at **smithsonianeducation.org/ climatechange**.

- Gateway to the Smithsonian's art, history, science, and cultural resources
- More than 1,600 Smithsonian resources—websites, lesson plans, activity sheets—searchable by keyword, grade level, subject matter, and alignment to all national and individual state standards
- A rate-and-review feature—like those on book-and-movie-selling sites—where you can share your thoughts with colleagues around the world

Meet Smithsonian scientists, learn about ongoing research, and find educator resources at these sites:

SMITHSONIANSCIENCE.ORG
Science at the Smithsonian, a lively, timely update on current research work, with video and social media features

FORCES.SI.EDU
Forces of Change, a look at the interplay of human life and the natural world from the Smithsonian's National Museum of Natural History