Slater Museum of Natural History Script:

Leaves of Change – Reading the Fossil Record

Total time: 270 minutes
Three 1.5-hour lessons

If you need to shorten the Leaves of Change Lesson, we recommend skipping over Day 1 entirely and only teaching the lessons from days 2 &3.

Day 1: Learning about types of fossils & how they're made!

Introduction to the Fossil Lessons (2 min.)

This week, we are studying ancient life - fossils! What is the name of a scientist that studies fossils? Yes, paleontologists study fossils and what they tell us about the earth's past, such as differences in environments and organisms and how they have changed.

Today we are going to learn about different types of fossils, and later we will practice being paleontologists and see what we can learn by comparing plants we see today to plant fossils from 110 million years ago.

Earth Timeline Activity (20 minutes)

How old do you think the earth is? Scientists estimate that the earth is about 4.6 billion years old. But, interestingly humans have only been around for a small fraction of that time. To get a better idea of how old the earth actually is, and how many different events have occurred, I need a volunteer to hold this end of the string and walk all the way to the back of the classroom.

> *Have a student volunteer and hold the end of the string and walk as far as it goes, while you hold the other end. Throughout the activity, every time you start to discuss a new event, have a student stand and hold the string at that event on the timeline. Eventually most students will be gathered towards the end (modern day) you are holding. Have timeline PowerPoint on the screen to show the students (something visual). Ask students if they know what BYA stands for? MYA? KYA?*

"Student" represents 4.6 billion years ago, this is when the earth was formed. At their point, the earth was pretty much a big chunk of rock circling the sun. Can I have another volunteer? (Volunteer stands and holds the next colored part of the string). A little bit more than 1 billion years later, 3.5 billion years ago, is when we see the oldest geological evidence of life – single, celled organisms, similar to modern bacteria. Can I have somebody else hold the next colored section of our timeline? Shortly after our last event, 3.4 billion years ago, is when we see cyanobacteria appear. Cyanobacteria are also called blue-green algae, and they use photosynthesis. Can anybody tell me what photosynthesis is? Yes, it is how plants make their food, a process in which they convert sunlight into energy, they produce sugar and give off oxygen as a waste product. Another volunteer? About a billion years later, 2.4 billion years ago, we see a shift in the atmosphere. What do cyanobacteria give off to the atmosphere? OXYGEN! Yeah, the bacteria have been giving oxygen off as a waste product. And we finally have an atmosphere that has breathable air! The next major event happens 2 billion years ago, where we see the first evidence of eukaryotes. Eukaryotes are cells that are more complex than bacteria – they are what we are made of! A billion years later, around 1 billion years ago, we see the first evidence of multicellular organisms – species that are made up of more than just once cell. But they are not big or complex yet; we do not see many large animals in the fossil record until about 540 million years ago. 540 million years ago an event that scientists call the Cambrian Explosion, where suddenly we see a huge increase in the diversity of life - many of the main groups of animals we still see today appear during this time. During this time, we mostly see small creatures, relatives of crustaceans, sea stars, sponges, worms, and algae. Fish-like vertebrates did not appear until 480 million years ago, what is special about vertebrates? They have backbones. About 5 million years later, 475 million years ago, we see the first evidence of land plants. Now, at this time do you expect to see very big and complex plants? NO! At this time, we see moss and fern, very small and simple land plants.

Animals do not move onto land until 75 million years later, about 400 million years ago. That is when we see arthropods on land – insects and their relatives, spiders, and millipedes. Why do you think arthropods were the first animals to colonize land, and not vertebrates? Why bugs and not fish? Yes, their exoskeleton (skeleton on the outside) is probably what gave arthropods and advantage to come on land earlier than vertebrates. Their hard outer covering provided them with protection.

About 374 million years ago, vertebrates moved onto land. This is when 4-limbed vertebrates evolve, which then help them give rise to many of the animals we see today. About 50 million years later, 320 million years ago, we entered the "Dawn of the reptiles." Reptiles evolve and quickly dominate land – why do you think reptiles become dominant and not amphibians? Yes, it has to do with their eggs, since reptiles don't need to lay their eggs in water like most frogs and salamanders do, they could move away from waterside habitats and colonize dry land.

300 million years ago Pangea was formed. Anybody know what Pangea was? Yeah, it was a supercontinent. Do continents move? Yes, they do. The continents shift around because of something called plate tectonics. These plates lay on the surface of the Earth and constantly move, a few centimeters a year. 300 million years ago, the continents were all combined to form Pangea. The continents stayed together for about 100 million years, then began to break apart. While Pangea was still together, mammals evolved! About 220 million years is when we see the first mammals – small, shrew like animals. Shortly after, 200 million years ago is when dinosaurs evolved and diversified, they became the dominant land animals and grew to huge body sizes. They stay dominant even while evolving, which is about 160 million years ago. And are still around when flowering plants evolve about 130 million years ago. Up until then, moss and ferns made up most of the plants around. Now, 65 million years ago a huge asteroid hit the Yucatan

Peninsula, which is modern day Mexico today. The impact of the asteroid caused a huge dust cloud that could have lasted from one to ten years, which blocked sunlight and prevented plants from undergoing photosynthesis. The impact also caused megatsunamis and firestorms. All of these effects combined to cause a mass extinction of non-avian dinosaurs, pterosaurs, and giant marine reptiles. Birds, nonavian dinosaurs, and mammals, however, survive. Where do you think these animals went to survive such a tough environment to live in? Burrows underground! With the demise of the dinosaurs, mammals and birds can diversify and dominate the landscape.

About 7 million years ago is when we see evidence of the oldest known hominid to walk upright, on two legs. But modern humans, our species Homo sapiens, do not appear until 200 thousand years ago. And our last event we are covering today happened 10,000 years ago, this is the latest ice age. Do you notice that out of the entire history of earth, all 4.6 billion years ago, humans only appear in this last small chunk of time?!

1. How Fossilization Occurs? (10 minutes)

We have just learned that the earth is really old and clearly a lot has happened! But how can scientists figure out what the earth was like billions of years ago? How do we know when certain animals and plants appeared? That is right! – scientists use fossils! But what exactly is a fossil, and how do they form?

A fossil is anything that was alive or related to something that was once alive. And it has to be at least 10,000 years old. Do you know what we call scientists who study fossils? Paleontologists! –study fossils and what they can tell us about the earth's past – different environments and different organisms, and how they have changed over time. What sorts of items do you think can become fossils; Yeah, fossilized flowers, leaves, bacteria, bones!

Next we will learn how fossils are formed. Raise your hand if you think it is easy to become fossilized? Hard? Interesting, let's look at a short video that shows us how fossils are formed and maybe that will change your mind. Now, the video showed us how fossils are formed. Becoming a fossil is quite difficult because there are several steps that have to happen quickly and very gently. Firstly, something has to die, then it has to be covered by mud or sediment. Once buried, the soft parts (like organs and skin) will decompose and the hard parts (like teeth and bones) will decompose more slowly. Over time, water seeps through those hard parts. As the water seeps in, it very slowly dissolves the bone and leaves behind minerals. The minerals replace the organic material left behind from the animal or plant, and it becomes a rock-like fossil. Essentially, the organism turns into stone! Most dinosaur fossils are formed this way, as well as petrified wood, and organisms' shells. This type of fossil formation is called "***Permineralization"***, it is the most common way in which a fossil is formed.

**Show class the petrified wood and dinosaur bones*

There are several different ways a fossil can form. Another type of fossil formation is called **"Unaltered Preservation**." This is the rarest type of fossilization. What does alter mean? To change something- Good! So unaltered, means not changing. Organisms that undergo this type of preservation do not change, do not decay. Some examples of this are insects that get trapped in amber, or a mammoth getting completely frozen in an ice block.

A third type of fossil preservation is called, "**Authigenic Preservation**." This happens when an organism is completely destroyed or dissolved, and all that is left is the impression it left behind in the sediment (like mud).

**Show class the shell conglomerate example. Conglomerate means held/clamped together.*

2. Fossil Types (10 minutes)

We just went over some of the different ways in which a fossil can be formed. There are many different types of fossils too! There are four types of fossils that we will be talking about and looking at up close. Some fossils are ***body fossils***, these are the remains of an organism, it can be the whole organism or parts of it, like fragments. We have already looked at some examples of body fossils, they include dinosaur bones, petrified wood, and fossilized coral. These are body fossils because they are all part of the organism, some complete, some only parts of the organism.

**Show fossilized coral*

Another type of fossil is ***trace fossils***. These types of fossils show that an organism was present, but they were never actually part of the animal or plant. Can you think of anything that an organism might have left behind that would make a good trace fossil? Yeah- dung, the scientific word for that is coprolite, let's try to use this word instead just like paleontologists call it. Other things include footprints and worm burrows.

**Show dinosaur track*

Lastly, we have what we call ***Cast and Mold fossils***. When the organism decays completely, it leaves behind a cavity, or empty space, in the rock - this is the exact same size and shape of the organism. This is a mold fossil. If that mold gets filled in with sediments, then it becomes a cast. The cast fossil looks just like the outside of the organism. Even though there is no original material, no part of the organism left, the sediment/rock/sand is evidence that the plant or animal once existed.

*Show the shell conglomerate (again) and point out the cast and mold. This conglomerate has a variety of shell fossils.

3. Fossil Identification Activity (20 minutes)

Hand out Naturalist Tool Kits (plastic bags with magnifying glasses, pencil, colored pencils, ruler), and a Fossil Identification Activity Sheet (provided in the General Supplies box).

Now we are going to practice identifying different types of fossils. I am going to give every group a fossil. For two minutes, I want you to talk about what type of fossil you think it is – a body fossil, a trace fossil, or a cast/mold. Write down the answers you come up with as a table on your fossil activity sheet. After two minutes, I will call "Switch fossils!" and we will very carefully pass our fossils to the next group. Remember, these are fossils which means they are extremely old and delicate! If a fossil breaks I will not be able to replace it. Next, I will pick one member from each group to be the "passer" so when I call "Switch fossils!" only the passer is going to carefully pass the fossil to the next group. I will pass around the worksheet that the recorder will be filling out, you will decide what type of fossil you are looking at (body/trace/cast/mold) and take a guess of what has become fossilized. After every group sees each fossil, we will talk about them as a class and you can see if you were right!

> *Place students in 6 groups. Designate a recorder and passer in each group. Pass out fossils in each class. Give students two minutes to study the fossil in their group, and decide what type of fossil it is. Have one student in each group write down what type of fossil it is, then after two minutes, ask groups to switch fossils. Only the passer can get up and bring the fossil to the next group. Repeat until all groups have seen all six fossils.*

Okay, every group has seen every fossil, correct? Which group has "Fossil A"? Tell me what kind of fossil do you think you have - body, trace, or cast-mold? And what is your fossil of? Great! –Fossil A is a body fossil; since it is the shell of the original organism. And this fossil is of an ammonite- extinct group of marine molluscs.

Ask the other groups to share their answers to the fossil they have on their table. KEY BELOW.

Fossil Letter	*Fossil type*	*Fossil belongs to…*
A	*Ammonite*	*Body*
B	*Brachiopods*	*Body*
C	*Coprolites*	*Trace*
D	*Shark teeth*	*Body*
E	*Trilobite*	*Body*
F	*Shell conglomerate*	*Cast and Mold*

Okay, can I have the passer carefully stand up and bring all the fossils up here to me?

4. What can we learn from fossils? (10 minutes)

Now that we know what fossils are, how they are formed, what kind of information do you think paleontologists can learn from the different types of fossils we mentioned?

Body fossils can tell us about what an animal looked like and how it might have moved. Trace fossils can give us information about that animal's behavior and movement. Remember, trace fossils are things like traits, footprints, burrows, and nests. What do you think coprolites can tell us? The droppings of an animal can tell us about its diet, what it is eating, and its habitat, where it was getting its food.

5. Are there limits to the fossil record? (15 minutes)

We can learn a lot from the fossil record, but there is also a lot it does not tell us. How often do you think something becomes a fossil? Do we have fossils of every single species, every single type of animal or plant that ever lived? We are going to do a quick activity to see the probability, or likelihood, that an animal or plant becomes a fossil. Imagine everyone here was an organism living thousands of years ago and then you died. I am going to give everyone a card that says what their fate was when they died. We will take turns and everyone can read aloud their card. I will be keeping track of how many of you become fossils on the board.

> *Pass out fossilization probability cards face down. One by one, have students flip over their card and read what it says. Record how many students do and do not become fossils on the board in two columns. Very few students will become fossils, illustrating the rarity of fossilization.*

We have just seen how becoming a fossil is actually pretty rare. Only a couple of you become fossils! Fossilization needs a very specific set of circumstances, like we talked about. An animal must be buried quickly, so it does not get eaten by scavengers. The animal could be buried by a mudslide or volcanic ash. Water also needs to help bury the animal, but not so much water that the animal falls apart and is carried away! Soft parts then have to decay, while sediment presses down on the hard parts and they turn to stone over a long period of time. All of these things need to happen just right – which is very rare!

Next, I would like to show you some rare fossils you have not seen today, such as this crab concretion. Concretions are compacted minerals like calcite that collect around the center, often something that was once alive like a leaf or mussel, or even a piece of shell. Without concretion forming, it would be extremely rare to find a fossilized crab shell because they are so delicate. Another rare event is when the soft parts are compressed and only the carbon is left behind, an event called carbonization. This is usually seen in plant fossils, but occasionally in vertebrates too like this fish – Notice the scales and vertebra!

Because of how rare it is for things to become fossilized, our view of the fossil record and the history of life on earth is incomplete. Scientists use evidence like fossils and knowledge of modern biology, chemistry, and geology to reconstruct a picture of what earth was like over the years. Today, we can use our knowledge of animals and plants to make educated guesses and attempt to fill the gaps of the fossil record, and think about how extinct animals and plants lived millions of years ago.

Conclusions (3 minutes)

Now that we are expert paleontologists- we know what fossils are, some of the different kinds of fossils, how they form, what we can learn from them, and how rare they are, we can begin to think how studying fossils can tell us a lot about past environments, temperature, and climate conditions. For the next two days, we are going to study modern plants and compare them to fossil plants and see what we can learn about life in Washington 110 million years ago.

Homework Assignment: In order to do that please bring a leaf, no bigger than the size of your hand to class tomorrow.

Day 2: Learning about leaves!

Homework Assignment (Assigned the day before this Lesson):

> *Have students bring in a leaf that they found at home, on a walk, or on their way to school. This could also be an assignment students do at the beginning of the lesson, using plants growing around the school although there might be less diversity among the leaves they collect. To help with the lesson, limit students to leaves that are no bigger than one of their hands. It helps to bring in extra leaves in case a student loses or forgets to bring in a leaf.*

Introduction to Botany (5 min.)
Today we are going to practice being botanists! Can anyone tell me what a botanist studies? Bots? Botans? Not quite…Botanists study plants!

Botanists are people who study how plants live in the world and what they can do. But why would a person study plants? Why are plants important?
Plants are some of the most remarkable and most abundant living things on Earth. They live in nearly every ecosystem on the planet – from hot dry deserts to frozen tundra. By mass, plants make up nearly 80% of all living "stuff" on planet Earth!

Not only are plants very abundant, they're also extremely important for ecosystems. Plants, along with seaweed, algae and some bacteria, are the only organisms on Earth capable of photosynthesis. Organisms that use photosynthesis don't ingest food like we do. Instead, they *make* their food by converting light energy from the sun into chemical energy for their bodies. After converting sunlight into food, they release oxygen into the atmosphere. In fact, if it weren't for plants, we would all suffocate and die. Scientists estimate that about 20% of the oxygen we breathe on a daily basis was produced by plants in the Amazon Rainforest alone! Plants are also the source of food for animals- including people. Since we can't make our own food from sunlight, we eat plants which can. We eat plants like fruits, vegetables, and grains and we also eat them indirectly when we eat animals which eat plants.

Even though plants are all around us every day, sometimes we don't notice how cool they are. Our first step as botanists today will be to observe plant leaves and try to notice something new about these important organisms. We are going to observe them in two ways. First, we are going to make rubbings of our leaves using colored pencils and paper to create leaf prints and then we are going to draw our leaves.

1. Discovering Leaf Anatomy (15 min.)

> *Hand out Naturalist Tool Kits (plastic bags with magnifying glasses, pencil, colored pencils, ruler) and Fossil Journals*

Everyone please open your Fossil Journals so we can start observing details about our leaves

We will start by **making a leaf rubbing**. Has anyone ever made a rubbing before?
Place your leaf inside the box on the inside cover of your journal. Choose whichever color colored pencil you like from your Naturalist Kit (note: dark colors work best). Turn your journal page so you are looking at the rubbing box on page 4. Rub your colored pencils gently over the paper until you can see the print of your leaf. Make sure to use the side of the colored pencil or the leaf rubbing won't show up. Also, don't be afraid to color outside the lines- you have to go further than the edge of your leaf to get the whole thing to show up.

> *Demonstrate this on a blank sheet of paper so students understand how to make a rubbing*.

Make sure you can see your entire leaf in your rubbing, including the edges. If you finish early you can use a second color on top.

> *Take a few minutes to discuss the leaf anatomy diagrams on page 5 with your class; relate what they saw in their rubbings to the diagrams. Point out important features, like margins and veins. Note that each picture in the diagram is <u>one leaf</u>; even a compound leaf counts as only one leaf.*

Next we are going to **sketch our leaves**. On page 6 there is space for you to make a scientific drawing of your leaf. There are three things your drawing needs in order to be a *<u>scientific</u>* drawing: 1. Labels on important features, 2. Measurements and a scale bar, 3. Detail. How do you make a detailed drawing of your leaf, not just a drawing that could be any leaf? Careful observation.

> *Review with your class how to use centimeters to measure their leaves. Scale bars are good to explain, but not totally necessary.*

Now, let's talk about what we observed in our leaves. What do you notice about the shape of your leaf? Compare it to the leaves of the other students at your table. How are the leaves in the classroom similar or different from each other? What parts of the leaf show up in the rubbings- color? edges? veins?

> *You should be guiding students to notice that leaves can have different kinds of margins (i.e. edges) but you can talk about all the differences students observed (eg. color, shape, number of leaflets, length of stem, vein pattern, etc).*

Now that you have noticed all these things about your leaves, we are going to **sort the leaves**. See if you can guess how I am sorting them. Try to guess what single feature is different between the two piles.

> *Sort the leaves into two piles based on leaf margin. One pile will be smoothed margined leaves and the other toothed margin leaves. There will likely be some leaves which are not as easy to place in one category or the other, you could place these in a third pile and ask students what they think once they have figured out the two categories. (Examples are on the next page)*

I have two piles of leaves on my desk that only I can see. I will take volunteers to come up and guess which pile their leaf goes in- I'll let you know whether it's the right pile or not.

Leaf Examples

Untoothed Margin

Toothed Margin

Now for a tricky one:

This leaf is serrate in some places and smooth in others.
It is a difficult leaf to figure out. For our purposes,
we will call it toothed because it does have some teeth.

Now that you have all seen the two piles of leaves, can anyone guess what is different about them?

Spread out the leaves or pick up an example from each pile so that students can see them.

Try and name something that is true of all the leaves in one pile and none of the leaves in the other pile. Size? No. Color? No. Smooth margins? Yes! In one pile the leaves have jagged, rough edges and in the other pile the leaves have smooth edges. Botanists call the outer edge of the leaf its **margin.** Smooth edges are called **entire margins** and jagged edges are called **serrate margins.** This can get much more complicated than it sounds so we're going to use paleobotanist terms and call them **Toothed or Untoothed.**

Pick a few leaves to make sure students understand the difference. Use the terms "toothed" and "untoothed"

So what type of margin does this leaf have? And this one?

This part could be expanded to explain simple and compound leaves by making another two piles or by separating the compound leaves and talking about them, but unless you will be doing further work with plants, this might confuse the important point.

Margin type is very important and can tell us a lot about a plant. In particular, plants with toothed margins tend to be found in colder climates. Those jagged teeth along their perimeter are actually an adaptation for growing faster during the cold months of spring. And if a plant can grow faster at the beginning of spring, it will be bigger and stronger when the untoothed leaves of other plants begin to grow later in the spring. However, the reverse happens in warmer climates, like tropical rainforests, because the toothed leaves no longer have an advantage.

If students want their leaves back they can tape them in the box on page 6 now or at the end of the lesson.

2. Plant Communities and Climate (2 min.)

In addition to plants being easy to study, abundant, and extremely important for life on Earth, they also can tell us a lot about local climate. In fact, the leaf margin types we just learned about can tell us about climate.

Plants, just like animals, are specially adapted for living in certain environments. For example, any creature that lives in the Sahara Desert must have special adaptations, traits or characteristics, for dealing with the intense heat and for conserving water. Desert rodents do this by sleeping through the heat of the day, foraging for food at night. Similarly, desert plants like cacti and yucca have adapted to "sleep" in the daytime, opening their pores to take in C02 only at night when it's cooler so they'll lose less water. Desert plants are also often succulent –which means they are specially adapted to store water in thick, squishy leaves or stems– to help deal with the dry climate and hot temperatures.
We can use this connection between climate and the adaptations of plant communities to estimate annual rainfall, average annual temperature, and even the latitude of any ecosystem on Earth.

Margin type can tell us a lot about a plant. In particular, plants with toothed margins tend to be found in colder climates. Those jagged teeth along their perimeter are actually an adaptation for growing faster during the cold months of spring. And if a plant can grow faster at the beginning of spring, it will be bigger and stronger when the untoothed leaves of other plants begin to grow later in the spring. However, the reverse happens in warmer climates, like tropical rainforests, because the toothed leaves no longer have an advantage. But you shouldn't just take my word for it. Let's see if we can do the research to show a relationship between leaf margins and the climate of a place.

3. Leaf Communities (10 min.)

Break students into (five) groups of no more than six students each and pass out Plant Community cards so that all members of a group have a different Plant Community.

You are all now groups of Botanists studying leaves in different regions of the country and world. You will use leaves from your area of study to determine what leaf margins can tell us about Mean Annual Temperature for that region. Everyone should now be looking at the leaf picture side of the laminates (not the map side). Good. Now I want everyone to take the next five minutes to examine your leaves. I need you all to **count the number of plants with toothed margins, the number of plants with untoothed margins, and the total number of plants in your community. Record these numbers on the top of page 7 in your Fossil Notebook.** Remember, we're counting the number of plant types or species on your sheet, not the individual leaves or leaflets. Raise your hand if you need some help. And remember, this is NOT a talking exercise. Silent voices please!

Check your students' answers (Correct answers in table below). Go over some of the trickier leaves if students had difficulties (wavy margins vs. toothed, leaves vs. leaflets, etc.), and make sure everyone can confidently identify leaf margins BEFORE continuing.

	Sudan	*Tanzania*	*Argentina*	*Kentucky*	*Vermont*	*Alaska*
Untoothed	*5*	*4*	*3*	*2*	*1*	*0*
Toothed	*0*	*1*	*2*	*3*	*4*	*5*
Total	*5*	*5*	*5*	*5*	*5*	*5*
Fraction of Untoothed Leaves	*5/5*	*4/5*	*3/5*	*2/5*	*1/5*	*0/5*

Once you have figured out the number of leaves with toothed and untoothed margins, and the total number of leaves, calculate the Fraction of Untoothed Leaves by putting the number of untoothed leaves in the numerator and the total number of leaves in the denominator. Record this fraction in your journals. What is the relationship between the fraction(or ratio if you're using decimals) and number of untoothed leaves? When the fraction(or ratio) is large, does the plant community have many or few untoothed leaves?

4. Finding your Location's Mean Annual Temperature (MAT) (5 min.)

Please turn over your laminates. You should now be looking at a colorful world map. Can anyone tell me what this diagram is showing us? It's a map of the Earth, yes. What are the colors for? Temperature! Correct. But not just temperature, those colors represent **Mean Annual Temperature** or **MAT**. What does this mean? Mean Annual Temperature? Can anyone tell me what the "mean" is? It's like the average, yes. And "annual" is a synonym for "yearly." So, this is the average yearly temperature. In other words, it's all temperatures for every day of the year averaged to give one number – the MAT. The colors on this map tell us the MAT of a place, using the bar under the graph. For example if my plant community was dark pink, I would estimate the MAT in that area was around -35 degrees C because it's between -30 and -40 degrees C.

Do an example for your students, showing them how to use the bar under the graph to match a color to an MAT. Be sure to use Celsius!

Okay. Now we want to know what the Mean Annual Temperature is in your plant communities. You can figure this out by finding the location of your plant community on the map (it will be one of the arrows on the map), and then finding the color of that area of the map on the bar below the map. If your color doesn't match up perfectly with a number on the bar, make an estimate. Write the location and MAT of your Plant community on page 7 of your journals.

5. Graphing Fractions and MAT (10 min.)

Now we will put the data of all the leaf communities together and see if we can find a relationship between the Fraction(or ratio) of Untoothed Leaves in a plant community and the MAT of the location of that plant community. We will be using data from the whole class, so let's first put it up on the board.

Make a table on the board like the one below. You can include Fractions or Decimals depending on your class's skill level.

		Sudan	***Tanzania***	***Argentina***	***Kentucky***	***Vermont***	***Alaska***
x-axis	***MAT (C)***	30	24	16	12	6	*1*
y-axis	***Fraction of Untoothed Leaves***	*5/5*	*4/5*	*3/5*	*2/5*	*1/5*	*0/5*
Alternate y-axis	*Decimal values for Fractions of Untoothed Leaves*	*1*	*0.8*	*0.6*	*0.4*	*0.2*	*0*

Turn to page 8 in your Journals. You should see a graph with Mean Annual Temperature on the x-axis and Fraction(or Ratio) of Untoothed Leaves on the y-axis.

Enter your whole group's data onto this graph, making a point for each plant community. Then see if you can draw a line through all or most of the points you have made on the graph. What does this line show?

When students have both the Fraction of Untoothed Leaves and the MAT for their Plant Community, have a volunteer from each group put their graph under the document reader. This way you can look at the graph as a class.

Does it look like there is a relationship between Fraction of Untoothed Leaves and MAT? Answer the questions below your graph.

Wrap Up: Review the conclusion that the greater the proportion of untoothed leaves, the greater the MAT.

Right now the MAT of WA is 11.5℃ (52.7 ˚F). Do you think that the temperature around Tacoma has always been 11.5℃ (52.7 ˚F)? Why or why not? It's interesting that as recently as 15,000 years ago, Tacoma was under about 1 km of ice (that's more than half a mile!). What does that suggest about the temperature then? It was a lot colder! In fact the MAT then was 1.1℃ (34 ˚F). How about a million years ago (also 1.1℃)? How about 100 million years ago (when dinosaurs were cruising around) How would we know?

This is what they'll be figuring out, but for reference it was probably around 26℃ (79℉).

How do we try to figure out what the environments were like that long ago? We can't jump into a time machine. Like a detective, we have to rely on clues from the past. The most obvious clues from the past are fossils. What are fossils? Fossils are preserved remains of animals, plants or other organisms from a long time ago. Probably the most famous kinds of fossils are dinosaur fossils, but they are very rare. Plant fossils and shells of sea creatures are way more common. How might you, budding paleontologists, use plant fossils to tell us something about the past? Right! If you can identify types of plants, we know where different kinds of plants live. For instance, if you saw a lot of palm tree leaves would you think it was a warmer or colder environment than now? Yes! Warmer.

6. Formulate a Hypothesis (5 min.)

Before we take a look at our fossil specimens, we are all going to make a prediction about Washington's ancient leaf communities and its ancient climate. **Do you think Washington was warmer or colder 110 million years ago? How do you think this difference in climate affected the ancient plant communities during this time? Do you think there were more leaves with toothed margins, or more leaves with untoothed margins? (review their finding from above) Will the Fraction (or Ratio) of Untoothed Leaves (of Washington) be higher or lower than it is now?**

Give students a minute to write their predictions in their Journals.

That's all for today- next time we will look at the evidence and see what we find.

Day 3: Extant & Extinct Leaves of Washington!

> ***Important Note:*** *there are replicates of each specimen box (Green, Blue, and Red). These replicates contain the exact same specimens and will allow for data-checking when you gather results as a class. Instruct your students not to open the boxes quite yet.*

Last time, we talked about plants- what did we learn? And what did you predict about Washington 110 million years ago?

> *Review leaf margins and Mean annual temperature. Ask students to share their hypotheses and encourage them to propose a research project. Encourage them to conclude the Fraction of untoothed leaves should be observed in a fossilized Washington plant community and a modern Washington plant community and that this data should be plotted on the graph made last lesson to find MAT and compare the current MAT to 110 million years ago.*

Remember we said that plants make up 80% of living things on earth. With this in mind, do you think it's easier to find plant fossils of dinosaur fossils? Right, plant fossils! You will all get the chance to look at plant fossils today.

7. Specimen handling instructions (5 min.)

Each person should now have a Naturalist Tool Kit and each group should have a specimen box on their table. Does everyone have all these materials? Good. Now before we open these boxes, I need to give you all some very important instructions. So I need **everyone's eyes on me, mouths quiet, and ears listening**! The specimens we are going to use today are from the Slater Museum of Natural History. They do not belong to me, they do not belong to you – they belong to the Museum and they are *not* toys. I expect you to treat these objects with the utmost respect. That means I don't want to see you playing with them, spinning them, bending them, etc. I have absolutely *no tolerance* for disrespecting museum specimens. If I see you misbehaving I will take your specimens away from you and you will *not* be able to participate in science for the rest of the day. **That is rule number one. Respect the specimens**. **Rule number two is keep the specimens on your desk as much as possible**. The easiest way to break a specimen is by accidentally dropping it. So please keep the specimens on your desk whenever you are not looking at them up-close. Okay? **Rule number three is also extremely important: stay in your seats!** We will have the chance to see all the specimens at the end of the lesson, but for right now, I need you all to stay in your seats! When students get up and start wandering around, specimens get accidentally bumped off tables, fall to the ground and break. So please, please, please stay in your seats at all times!
Can anyone recite all three rules for me?

> *Reviewing the Specimen Handling Instructions should be the last thing your students do before opening their specimen boxes. Pass out boxes to each table and Naturalist Tool*

Kits to each student (plastic bags with colored pencils, magnifying glass, ruler, pencil) as they are reciting rules.
Reminder: *You will need at least three groups, but no more than six. Each group should have no more than five students).* ***Note that there are replicates of each specimen box (Green, Blue, and Red).*** *These replicates contain the exact same specimens and will allow for data-checking when you gather results as a class.*

Data Collection: Extant Leaves
Great. So first, we are going to take a look at some extant leaf specimens from around the Puget Sound and use these leaves to estimate the Mean Annual Temperature of Western Washington, just like we would with fossil leaves. Before you open your boxes, I want to remind you that these are *real leaves*, and they are very fragile. Please do not bend the paper or squish the leaves. You *will* break them!
Okay, now everyone open your boxes and take out the leaf specimens. **Just the leaf specimens please! Do not touch the fossil bags quite yet!**

8. Record Margin Types (5 min.)

We are going to **fill out the table** on page 9. First I want everyone to write your group's color on the line above the table.

Go around the room and give a couple examples, "This group is a green group – they have a green box," etc.

Okay, now every person in your group needs to have a chance to see each extant leaf in your box. You will have one minute to decide whether the leaf you are looking at has toothed or untoothed margins. The first leaf will be easy because you already decided what type of margins it has while you were sketching it. Go ahead and **write the leaf's number in the column on the left**. **Then put an X in the box to indicate which type of margin your leaf has**.

Set-up an example table on the board. Using a random, 3-digit number in the "Leaf #" column, fill out the first row for a hypothetical leaf. Make sure all your students understand how to fill out the table.

Okay, does everyone have their first leaf written on the table? Good, now I want you to pass your leaf to the group-member to the right of you. Everyone should now have a *new* leaf. **You have one minute to write the leaf # and decide what kind of margin it has**. When I say, "switch," you will pass the leaf to the right. Ready? Okay start writing! Remember, this is a quiet task! No talking please!

Give your students about a minute to decide what type of margins their leaf has. Go around the room to judge how quickly they will complete this task. Once they all seem to be done with one leaf, they will switch and have about a minute to complete another.

Switch! Everyone pass your leaves to the person on your right! Does everyone have a new leaf? Okay, one more minute to fill in the row for this leaf.

> *Continue this process until all students have filled-out the table for their group's set of five extant leaf specimens. They need to have recorded data for all five leaves before continuing.*

Data Collection: Fossil Leaves

Okay, now I need everyone to put the leaves back into the box. Once your table has done this, put your pencils down, and put your eyes and ears on me. I need to give you some very important instructions before we continue. Is everyone ready? All leaves back in their boxes? Good.

Now we are going to be observing our fossil specimens. Don't touch anything yet! Eyes on me please! Each bag contains one fossil specimen, and just like the leaves there are five at each group. Remember, **everyone will have a chance to see all the fossils at your table,** so please be gentle and patiently wait your turn. Before we can open up these bags let's go over the three rules again.

9. Review Specimen Handling Instructions. (5 min.)

What was rule number one? Yes. Respect the specimens and handle them gently. These fossils are **literally 110 million years old! They are irreplaceable**. That means, if you break one, we will **never** be able to find a new one to replace it. They might look just like rocks, but these are fragile, ancient leaves fossilized in stone. They are still extremely fragile and **they WILL break if you drop them**. Which brings us to rule number two, which is…? Yes. Rule number two is, "**leave the specimens on the desk as much as possible**." And lastly, who can remember what rule number three is? Yes. **Stay in your seats**. Okay are we ready to take a look at our fossils? Everyone select one fossil bag and **gently** examine your fossil.

> *Allow the students some time to marvel at their fossils.*

10. Sketch a Fossil. (10 min.)

Alright, I need everyone's attention once again! Hands free, eyes on me? Do I have everyone's attention? Okay, please open your journals to page 10. Just like with the extant leaves, **we are going to sketch our fossils and provide some information about their shape and appearance. Pay close attention to the leaf's margins, venation, and shape.** And remember, most fossils that paleontologists discover are *not* entire specimens. The largest T-rex fossil ever discovered was missing 20% of its bones! But, that won't stop us, right? We can still learn a whole lot from a fragment of leaf! We can still see its margins, we might be able to judge its size, and we can even compare it to other leaves we might know of today. Feel free to use your magnifying glasses to take a closer look at those margins and veins. If you're not sure which leaf in a rock to look at- look for a white dot. You have about five minutes to sketch this leaf. You don't need to add color to this one, since most fossils don't preserve their colors very well. Make sure to include a measurement of the fossil in centimeters.

Give your students between five and ten minutes to sketch their fossil. While they are sketching, go around the room and ask a few students about their fossils. Ask them to describe its shape, margins, vein patterns, and anything else they can about their leaves. Perhaps they recognize their leaf. Perhaps it looks similar to leaves in their backyard. Specifically, using the fossils key in the teaching binder, you should make sure your students are not having trouble identifying leaf margins. Fossil leaf margins are somewhat more difficult to identify than living leaf margins.

Okay, everyone **finish-up your sketches**. Put those finishing touches on your fossil leaves. If you haven't decided what type of margin your fossil leaf has, you have less than a minute to write that down next to your sketch. Ready?

11. Record Margin Types (5-10 min.)

Pencils down, hands free, and eyes on me. Now, just like we did with our leaf specimens, we are now going to **record the margin types for all five fossil specimens in our box**. **We have a table to fill-out, just like last time.** But instead of taking just a minute for each specimen, I'm going to give you guys a bit more time to think about your fossil leaf's margins because some fossil margins are a bit harder to identify than the margins on the living leaves. But before we start, **make sure you have recorded your box color and your first fossil leaf**. The fossil leaf's number is on a tag attached to the fossil bag- make sure to pass the fossil and the bag together. Does everyone have their first row complete? Raise your hand if you need more help.

You can use the key to fossil margins in the teaching binder to identify any tricky fossil margins.

Okay, now SWITCH! You have **two minutes to identify your fossil leaf's margins**. Raise your hand if you are unsure.

Give your students a minute or so to decide what type of margins their fossil leaves have. If they appear to be struggling, you may need to practice with some sketches on the board. Show the difference between wavy and toothed margins. All toothed margins will be plainly obvious, and in general, all the margins that aren't plainly toothed will be considered untoothed. After it appears that everyone has identified their fossil leaf's margins, have your students pass their leaves to the person on their right.

Okay SWITCH. **Pass your fossil to the person on your right**. Gently! Be careful with these specimens! **Remember, they're not just rocks, they're 110 million-year-old fossils!** You now have another two minutes to identify this fossil's margins. Raise your hand if you need some help. Remember this should be a quiet time, not a chatting time!

Continue this process until all students have filled-out the table for their group's set of five extinct leaf specimens. They need to have recorded data for all five fossils before continuing.

Does everyone have all their data recorded for these five fossil specimens? Good. Now I need everyone to put their fossils back into their bags and gently put them back in the specimen box. Once your table has done this, put your pencils down and your eyes on me.

Key to Extinct Leaf Margins

	Red	Green	Blue
Toothed Leaves	1	2	1
Untoothed Leaves	4	3	4

Key to Extant Leaf Margins

	Red	Green	Blue
Toothed Leaves	3	3	4
Untoothed Leaves	2	2	1

12. Compile Class Data (10 min.)

We are now going to trade data with all the other tables to give everyone more data. Why is it important to get more data? Do you think our estimates of temperature would be accurate if we only used five leaves or five fossils? Think what would happen if we wanted to know the eye color for everyone at school and we only chose five people? What if those five people all had brown eyes? Does that mean the whole school has brown eyes? No, we need more data!
With that in mind, we are going to get data from all the other groups to make our conclusions stronger and more accurate.
Everyone open your Paleontology Notebooks to page 11. Here we have three tables – one for each color group.

On the board or under your document reader, draw these three tables and fill them in as you collect data from the class, ensuring everyone has the same information.

Okay, where is the Blue Group?

Remember, there might be two groups of the same color. They should have identical data.

Looking at the extant leaves first, tell me how many of your leaves had untoothed margins? (*Answer: 1*). And how many total leaves were in your box? (*Answer: 5*) Other Blue Group, did you get the same answer? Good. Now, what about the extinct leaves – the fossils? How many of your fossil leaves had untoothed margins? (*Answer: 4*). Other Blue Group, did you get the same answer? Great!

> *Continue this process until all three groups have compiled their data and everyone in the class has filled out the tables on page 11 of their journals.*

Good job. Now we have to do some addition. Who can tell me the sum of all untoothed Extant Leaves for all three groups? (*Blue + Red + Green = 1 + 2 + 2 = 5*). Good. Now can someone find the total sum of all Extant Leaves? (*5 + 5 + 5 = 15*) Good job. Now what is the sum of all untoothed Fossil Leaves? (*Blue + Red + Green = 4 + 4 + 3 = 11*). Great! And how many total fossil leaves did we look at today? (*5 + 5 + 5 = 15)*. Ok, now everyone should have written those numbers beneath your tables on page 11. Does everyone have that information written down? Good. Now it's time to calculate **the mean annual temperature** of Cretaceous and present-day Washington!

Your totals should be:
 # Untoothed Extant Leaves: ____5__   *# Untoothed Fossil Leaves: ____11_____*
 # Total Extant Leaves: _____15___   *# Total Fossil Leaves: _____15_____*

13. Math and Graphing(15 min.)

Now that we have collected all this information about the margins of Washington's extinct and extant leaf communities, what are we going to do with it all? Well, as we discovered before, calculating the ratio of untoothed leaves to toothed leaves can give us an estimate of the temperature of that region. This ratio is the Fraction or Ratio of untoothed leaves. We will now use the extant leaf totals to calculate the Fraction of untoothed leaves for modern-day Washington and the fossil leaf totals for Cretaceous Washington. This is used by paleontologists and botanists to estimate the **Mean Annual Temperature** for a region.

> *Choose one of the below methods based on your class's math skills.*

1). *Required knowledge: fractions (basic), number lines (basic)*

Explain to your students that the fraction they're using is the ratio of untoothed leaves to total leaves. This can be written as a **division problem** or as a **fraction**.

Find 5/15 and 11/15 on the **vertical number line** (y-axis). Using the bold, diagonal line, estimate the MATs (on the **horizontal number line**; x-axis) for each Fraction of untoothed leaves on the vertical number line.

Answers: **≈12˚C (extant MAT)** **≈23˚C (fossil MAT)**

Extensions: Practice converting and simplifying fractions using hypothetical Fractions of untoothed leaves such as 1/2, 1/5, 6/30, etc. Practice graphing skills by finding the MATs for each of these hypothetical P-values. Practice graphing skills and learn about plant communities around the world (geography practice) by working backwards using the MATs from the following countries: Costa Rica = 24˚C; Japan = 9˚C; Iceland = 5˚C; Mali = 28˚C; Portugal = 17˚C.

2). *Required knowledge: division, graphing (basic)*

Explain to your students that the fraction they're using is the ratio of untoothed leaves to total leaves. How can this be written as a division equation? Ask your students to solve for each P-value by **dividing** the number of entire leaves by the total number of leaves. Do this for both the extant leaves and the fossil leaves.

Answers: **0.333 (extant P-value)** **0.733 (fossil P-value)**

Next, using the graph find each Ratio of untoothed leaves on the **y-axis** and estimate its corresponding MAT on the **x-axis** using the bold diagonal line.

Answers: **≈12˚C (extant MAT)** **≈23˚C (fossil MAT)**

Extensions: Practice converting P-values (i.e. fractions) to percentages and percentages to P-values using some hypothetical leaf communities. Practice graphing skills using these hypothetical leaf communities. Practice graphing skills and learn about plant communities around the world (geography practice) by working backwards using the MATs from the following countries: Costa Rica = 24˚C; Japan = 9˚C; Iceland = 5˚C; Mali = 28˚C; Portugal = 17˚C.

14. Conclusions(10-30 min.)

Depending on the time available, these responses could also be written in a short essay format and make for a good writing extension.

Now that we have calculated the Fraction of untoothed leaves for modern-day Washington, and Cretaceous Washington, and we know the MATs for both time periods, we can make some interesting comparisons between ancient Washington and modern-day Washington. Open up your Fossil Notebooks to page 13. Spend the next five or ten minutes answering the question at the top of page 13. **Was Washington colder or warmer 110 million years ago? Be specific! Tell me about how much colder or warmer** Cretaceous Washington was than present-day Washington! Make sure to summarize the trend or connection between the number of untoothed leaves in a location and the MAT of that place.

Give students about five minutes to write one or two sentences about the difference in MAT between Cretaceous and modern-day Washington. While students are writing, be *sure everyone still has their laminated guides to Earth's Climate Timeline. You will be using the map in Box 1 for the following question.*

Wrap up that sentence!

15. Wrap-up(5 min.)

Making comparisons between our extinct ecosystem and a present-day ecosystem (such as a tropical forest in Central America) is an excellent way to wrap-up today's lesson. Explain that paleontologists make similar comparisons in order to learn more about what life was like in the past. However, unlike us, paleontologists would have gathered tons of additional data and information. Ask your students to guess what additional types of data we would need to make a more robust comparison between Cretaceous Washington's plant communities and a present-day plant community. Here is an excellent tie-in for the Variables FOSS lesson. Regardless of what information we are missing, these comparisons using leaf margins do tell us some very valuable things about ancient Washington.

As you wrap-up, encourage your students to never stop asking questions and thinking like a paleontologist. Using data to make comparisons like these that "fill-in the gaps" of our hypotheses is an extremely valuable mode of scientific thought – not only when reading the fossil record, but also in other aspects of science. For example, astronomers use comparisons like these to make hypotheses about newly discovered planets and whether or not they might be capable of supporting life.

Be sure all the fossil specimens are back in their bags, and all the specimens have been returned neatly to their boxes. Collect all Naturalist Kits and laminated sheets. Students should keep their Fossil Notebooks. Ask your students if they have any remaining questions regarding paleontology or leaf fossils. Feel free to write down questions and send them to Slater Museum staff.

Math Extensions

1. MAT and P-values: working backwards (Math, Geography, Critical Thinking)
   Using the MAT map of the world today, estimate the P-value for the following locations:
   a. Japan
   b. The Amazon Rainforest
   c. Uruguay
   d. The Himalayan Plateau

   Using these P-values for each location, estimate the percentage of the plant community that you would expect to have serrate leaf margins.

Writing Extensions

1. Using the geologic timeline of Earth's climate (image 2) on the laminated sheet, make a prediction about the future of Earth's climate. In particular, take note of how often the planet had a "hothouse" climate and how often it had an "icehouse" climate and use this as evidence to support your hypothesis. Finally, predict how this will affect Earth's flora and fauna in 100 million years (consider the flora and fauna of Earth 100 million years ago).
2. Biomes Project:
   Do all areas of Earth with similar MATs have similar climates? What other factors (other than temperature) influence climate? What sorts of affects does this have on the flora and fauna of that region? Compare and contrast two different locations with similar MATs but different climates (e.g. Australia and Brazil, the Gobi Desert and the American Great Plains, etc.).
   Do you think Earth's biomes have changed over time? What biomes would you expect to find in North America 200 million years ago? 300 million years ago?