BACKGROUND MATERIAL

Excerpts from: National Science Foundation,
Teaching About Evolution and the Nature of Science,
National Academy Press, 1998, ISBN 0-309-06364-7,
USGS Website, Geological Resource Division of the National Park Service

Nature of Science

Teaching about evolution has another important function. Because some people see evolution as conflicting with widely held beliefs, the teaching of evolution offers educators a superb opportunity to illuminate the nature of science and to differentiate science from other forms of human endeavor or and understanding. However, it is important from the outset to understand how the meanings of certain key words in science differ from the way that those words are used in everyday life.

Think for example, of how people usually use the word "theory." Someone might refer to an idea and then add, "But that's only a theory." Or someone might preface a remark by saying, "My theory is . . .." In common usage, theory often means "guess" or "hunch." In science, the word "theory' means something quite different. It refers to an overarching explanation that has been well substantiated. Science has many other powerful theories besides evolution. Cell theory says that all living things are composed of cells. The heliocentric theory says that the earth revolves around the sun rather than vice versa. Such concepts are supported by abundant observational and experimental evidence that they are no longer questioned in science.

Sometimes scientists themselves use the word "theory" loosely and apply it to tentative explanations that lack well-established evidence. But it is important to distinguish these casual uses of the word "theory" with its use to describe concepts such as evolution that are supported by overwhelming evidence. Scientists might wish that they had a word other than "theory" to apply to such enduring explanations of the natural world, but the term is too deeply engrained in science to be discarded.

Glossary of Terms Used in Teaching About the Nature of Science

Fact: In science, an observation that has been repeatedly confirmed.
Law: A descriptive generalization about how some aspect of the natural world behaves under stated circumstances.
Hypothesis: A testable statement about the natural world that can be used to build more complex inferences and explanations.
Theory: In science, a well-substantiated explanation of some aspect
of the natural world that can incorporate facts, laws, inferences, and tested hypotheses.

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alternative theory in light of new and compelling evidence.

The geocentric theory that the sun revolves around the earth was replaced by the heliocentric theory of the earth's rotation on its axis and revolution around the sun. However, ideas are not referred to as "theories" in science unless they are supported by bodies of evidence that make their subsequent abandonment very unlikely. When a theory is supported by as much evidence as evolution, it is held with a very high degree of confidence.

In science, the word "hypothesis" conveys the tentativeness inherent in the common use of the word "theory.' A hypothesis is a testable statement about the natural world. Through experiment and observation, hypotheses can be supported or rejected. At the earliest level of understanding, hypotheses can be used to construct more complex inferences and explanations.

Like "theory," the word "fact" has a different meaning in science than it does in common usage. A scientific fact is an observation that has been confirmed over and over. However, observations are gathered by our senses, which can never be trusted entirely. Observations also can change with better technologies or with better ways of looking at data. For example, it was held as a scientific fact for many years that human cells have 24 pairs of chromosomes, until improved techniques of microscopy revealed that they actually have 23. Ironically, facts in science often are more susceptible to change than theories, which is one reason why the word "fact" is not much used in science.

Finally, "laws" in science are typically descriptions of how the physical world behaves under certain circumstances. For example, the laws of motion describe how objects move when subjected to certain forces. These laws can be very useful in supporting hypotheses and theories, but like all elements of science they can be altered with new information and observations.

Those who oppose the teaching of evolution often say that evolution should be taught as a "theory, not as a fact." This statement confuses the common use of these words with the scientific use. In science, theories do not turn into facts through the accumulation of evidence. Rather, theories are the end points of science. They are understandings that develop from extensive observation, experimentation, and creative reflection. They incorporate a large body of scientific facts, laws, tested hypotheses, and logical inferences. In this sense, evolution is one of the strongest and most useful **scientific** theories we have.

GEOLOGIC BACKGROUND FOR PIKES PEAK AREA

Plate Tectonics
The action is at the edges!

If you are lucky enough, or sometimes, unfortunate enough to live where two plates meet, you've probably had first-hand experience with moving plates! That's because many potentially catastrophic geologic phenomena, such as earthquakes, volcanic eruptions, and tsunamis originate at the narrow boundary zones between plates.

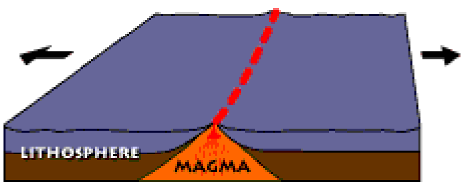
There are three basic things that can happen where the edge of one plate meets another. The plates can push against each other, producing a convergent plate boundary, the plates can move apart, forming a divergent plate boundary, or the plates can slip past each other side to side, which geologists call transform plate boundaries. Wherever plates grind against each other, you can expect earthquakes.

Divergent plate boundaries

One young divergent plate boundary that you'll recognize is actively forming the **Red Sea**. Although the Arabian Peninsula and Africa were once linked to form a single continent, they are now being ripped apart. The white arrows show the directions the two plates are moving. You can see that a new ocean, the Red Sea is being formed as they separate.

What's going on inside?

Geologists still have a lot to discover about the Earth's deep interior. Evidence we have today suggests that divergent boundaries form above temperature instabilities near the boundary between the core and mantle. Just above the core hot blobs of mantle begin to move slowly upward, eventually forming conveyor belt-like convection currents within the semi-fluid asthenosphere.



Convection currents diverge where they approach the surface. The diverging currents exert a weak tension or "pull" on the plate above it. Tension and high heat weakens the floating plate and it begins to break apart. The two sides move away in opposite directions, creating a divergent plate boundary.

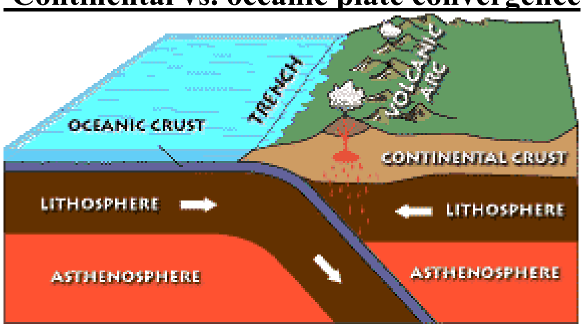
The weaknesses between the diverging plates fill with molten rock from below. Seawater cools the molten rock, which quickly solidifies, forming new oceanic lithosphere. This continuous process builds a chain of volcanoes and rift valleys called a **mid-ocean ridge** or **spreading ridge**.

Little by little, as each batch of molten rock erupts at the mid-ocean ridge, the newly created oceanic plate moves away from the ridge where it was created.

Convergent plate boundaries

Convergent plate boundaries come in several flavors, but they share one thing in common - plate collisions! Take a look at the differences between the three examples on this page.

Continental vs. oceanic plate convergence



In a contest between a dense oceanic plate and a less dense, buoyant continental plate, guess which one will sink? The dense, leading edge of the oceanic plate actually *pulls* the rest of the plate into the flowing asthenosphere and a **subduction zone** is born! Where the two plates intersect, a deep **trench** forms.

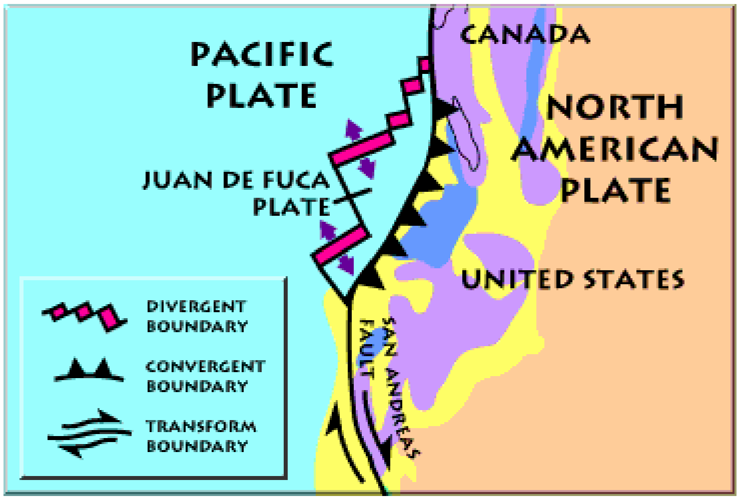
Geologists aren't sure how deep the oceanic plate sinks before it completely melts, but we ***do*** know that it remains solid far beyond depths of 100 km beneath the Earth's surface.

When the subducting oceanic plate sinks deeper than 100 kilometers, huge temperature and pressure increases make the plate 'sweat'. Well, not exactly, but the uncomfortable conditions force minerals in the subducting plate to release trapped water and other gasses. The gaseous sweat works its way upward, causing a chain of chemical reactions that MELT THE MANTLE above the subducting plate.

This hot, freshly melted liquid rock (magma) makes its way toward the surface. Most of the molten rock cools and solidifies in huge sponge-like magma chambers far below the Earth's surface. Large intrusive rock bodies that form the backbones of great mountain ranges such as the Sierra Nevada form by this process.

Some molten rock may break through the Earth's surface, instantly releasing the huge pressure built up in the gas-rich magma chambers below. Gasses, lava and ash explode out from the breached surface. Over time, layer upon layer of erupting lava and ash build volcanic mountain ranges above the simmering cauldrons below.

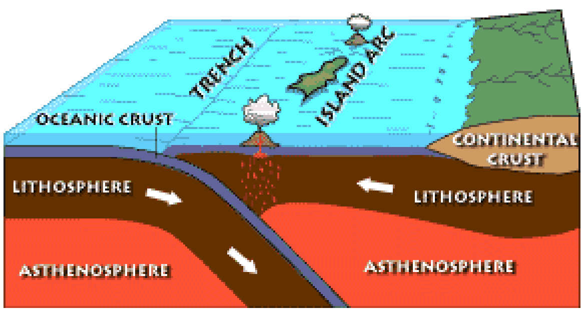
An example of this kind of convergence produces the spectacular volcanic landscape of the



Northwest. Off the coast of Oregon, Washington, Alaska and Canada a small plate, the Juan de Fuci, dives beneath North America. This type of convergent plate boundary, called a **subduction zone**, is known for producing historic earthquakes of great magnitudes.

Oceanic vs. oceanic plate convergence

In a contest between a dense oceanic plate and a less dense, buoyant continental plate, you know that it's the dense oceanic plate that sinks.



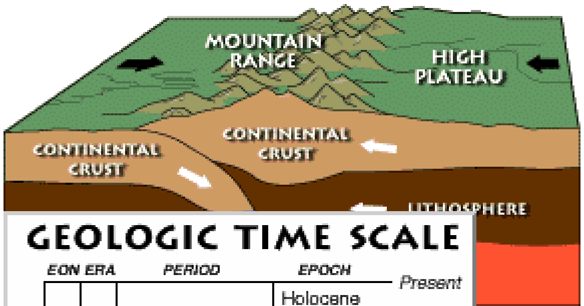
What happens when two dense oceanic plates collide? Once again, density is the key!

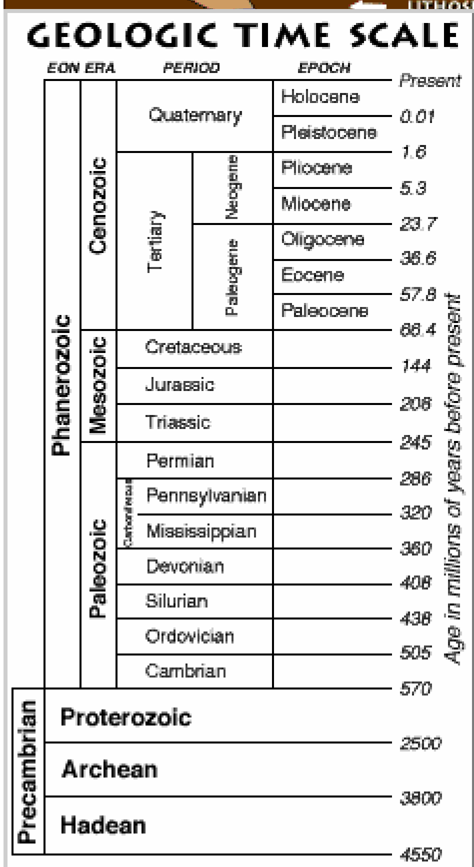
Remember that oceanic plates are born at midocean ridges where molten rock rises from the mantle, cools and solidifies. Little by little, as new molten rock erupts at the mid-ocean ridge, the newly created oceanic plate moves away from the ridge where it was created. The farther the plate gets from the ridge that created it, the colder and denser ('heavier') it gets.

When two oceanic plates collide, the plate that is older, therefore colder and denser is the one that will sink.

The rest of the story is a lot like the continental vs. oceanic plate collision we described above. Once again, a subduction zone forms and a curved volcanic mountain chain forms above the subducting plate. Of course, this time the volcanoes rise out of the ocean, so we call these volcanic mountain chains **island arcs**. The Aleutian Peninsula of Alaska is an excellent example of a very volcanically active island arc.

Continental vs. continental plate convergence

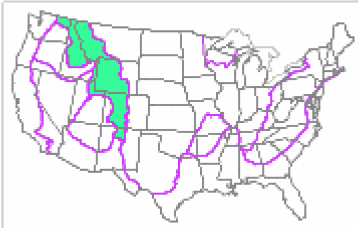




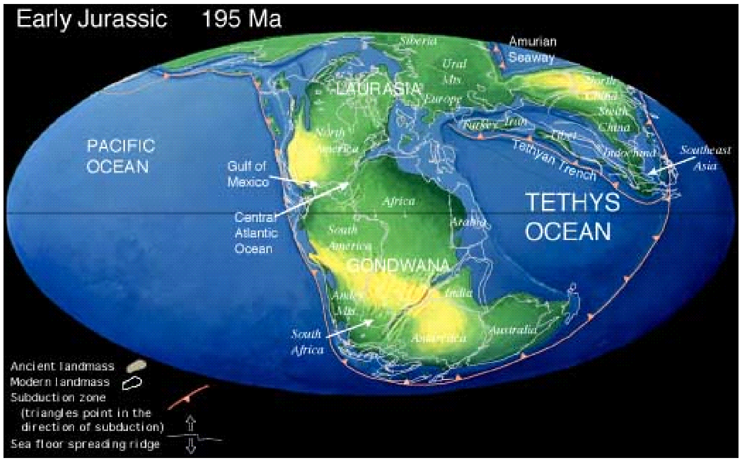
By this time, you understand enough about plates to guess that when the massive bulk of two buoyant continental plates collide there is bound to be trouble!

The Himalayan mountain range provides a spectacular example of continent vs. continent collision. When two huge masses of continental lithosphere meet head-on, neither one can sink because both plates are too buoyant.

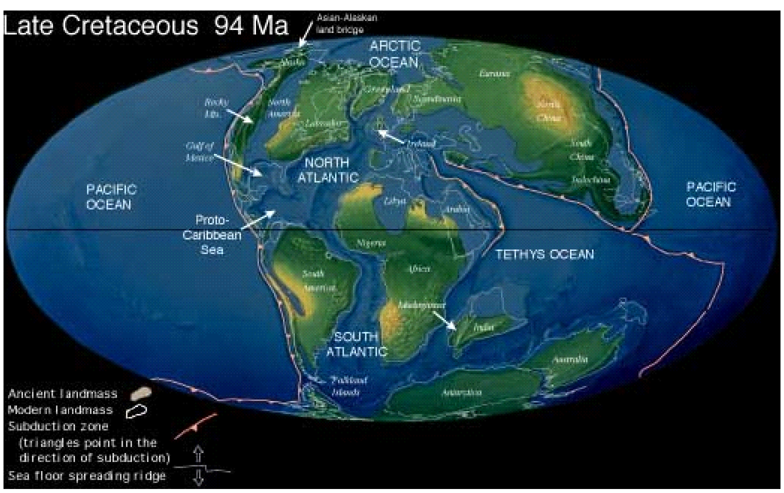
It is here that the highest mountains in the world grow. At these boundaries solid rock is crumpled and faulted. Huge slivers of rock, many kilometers wide are thrust on top of one another, forming a towering mountain range. The pressure here is so great that an enormous piece of Asia is being wedged sideways, slipping out of the way like a watermelon seed squeezed between your fingers.



Northern Rocky Mountains
The Rockies form a majestic mountain barrier that stretches from Canada through central New Mexico. Although formidable, a look at the topography reveals a discontinuous series of mountain ranges with distinct geological origins.



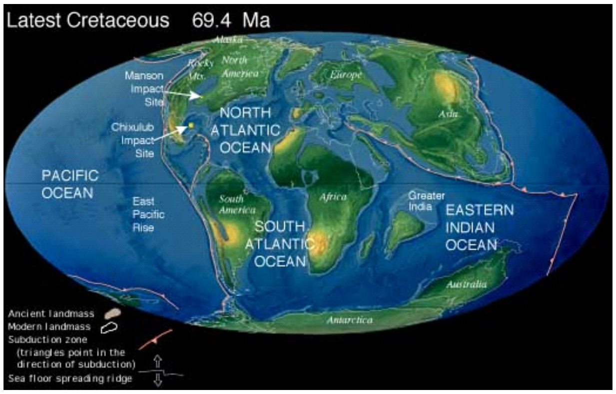
The Rocky Mountains took shape during a period of intense plate tectonic activity that formed much of the rugged landscape of the western United States. Three major mountain-building episodes reshaped the west from about 170 to 40 million years ago (Jurassic to Cenozoic Periods). The last mountain building event, the Laramide orogeny, (about 70-40 million years ago) the last of the three episodes, is responsible for raising the Rocky Mountains.



Setting the stage

During the last half of the Mesozoic Era, the Age of the Dinosaurs, much of today's California, Oregon, and Washington were added to North America. Western North America suffered the effects of repeated collision as slabs of ocean crust sank beneath the continental edge. Slivers of continental crust, carried along by subducting ocean plates, were swept into the subduction zone and scraped onto North America's edge.

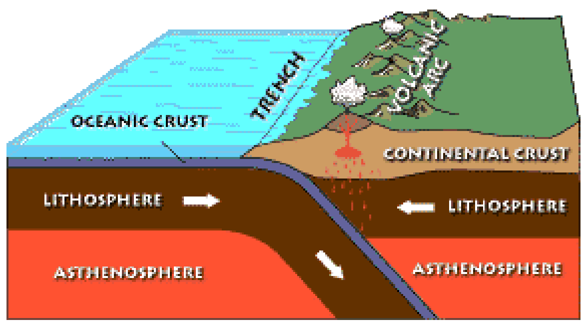
About 200-300 miles inland, magma generated above the subducting slab rose into the North American continental crust. Great arc-shaped volcanic mountain ranges grew as lava and ash spewed out of dozens of individual volcanoes. Beneath the surface, great masses of molten rock were injected and hardened in place.



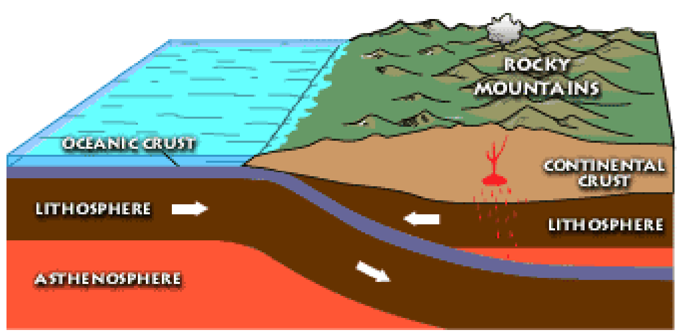
For 100 million years the effects of plate collisions were focused very near the edge of the North American plate boundary, far to the west of the Rocky Mountain region. It was not until 70 million years ago that these effects began to reach the Rockies.

Raising the Rockies

The growth of the Rocky Mountains has been one of the most perplexing of geologic puzzles. Normally, mountain building is focused between 200 to 400 miles inland from a subduction zone boundary, yet the Rockies are hundreds of miles farther inland. What geologic processes raise mountains at this scale? Although geologists continue to gather evidence to explain the rise of the Rockies, the answer most likely lies with an unusual subducting slab.



Sketch of an oceanic plate subducting beneath a continental plate at a collisional plate boundary. The oceanic plate typically sinks at a fairly high angle (somewhat exaggerated here). A volcanic arc grows above the subducting plate.



This sketch shows the plate tectonic setting during the growth of the Rocky Mountains (Laramide orogeny). The angle of the subducting plate is significantly flatter, moving the focus of melting and mountain building much farther inland than is normally expected.

Pikes Peak

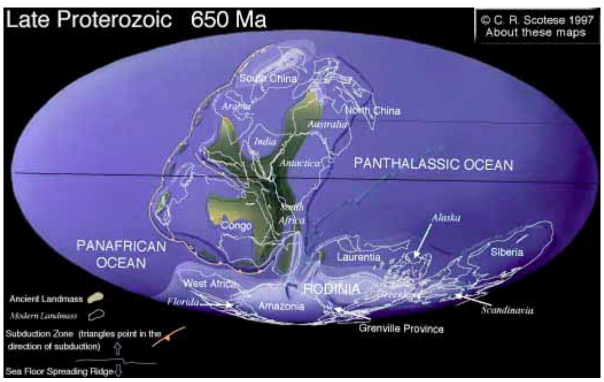
The grandeur of Pikes Peak is the culmination of many geologic events:

- the formation of the rocks through hundreds of millions of years,
- the repeated uplift of the mountains by gigantic tectonic forces, and
- millions of years of erosion by water and ice that sculpted the mountains into their present forms.

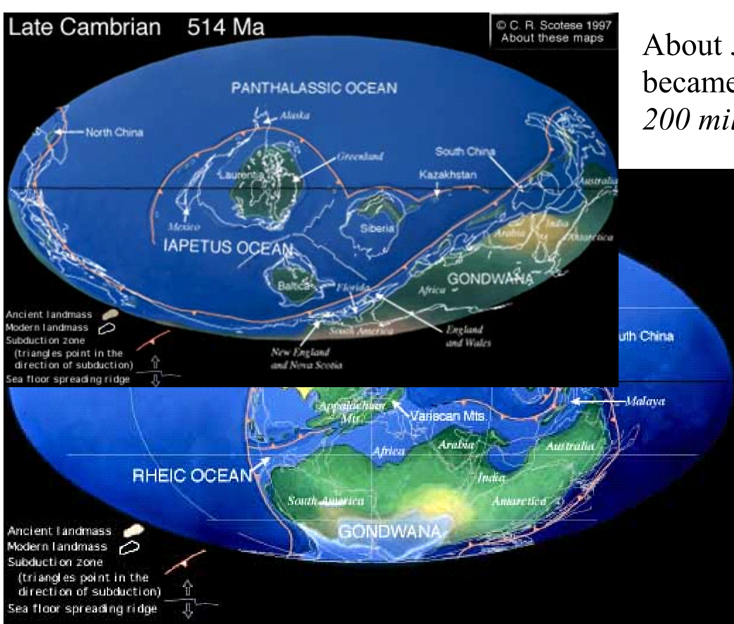
Brief geologic history

Most of the rock in Pikes Peak is granite. The newer rocks of the **Garden of the Gods** are — originally were **shale, siltstone**, and **sandstone**, along with some **volcanic rocks** deposited about *1.8 to 2 billion years ago* in an ancient sea. Between *1.7 and 1.6 billion years ago*, these **sedimentary rocks** were caught in a collision zone between sections of the Earth's crust called **tectonic plates**.

The Pikes Peak granite is a batholith, which extends from near Castle Rock, 40 miles to the north, and southward through the Rampart Range to the southern end of the Cheyenne Mountains. It extends from Colorado Springs westward for more than 40 miles. The **Pike Peak granite** uplifted into the metamorphic rocks about *300 million years* after the formation of the Proterozoic mountains. We do not know what caused this igneous episode.

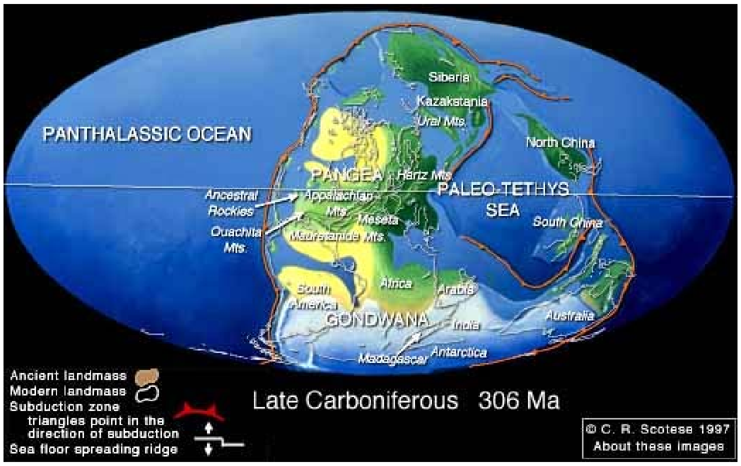


The "ancestral Rocky Mountains" that formed here during Proterozoic time were slowly eroded and reduced to a fairly flat surface, exposing the core of metamorphic rocks and granite. This erosion occurred over a long period, from approximately *1,300 million to 500 million years ago*. Little else is known about the geologic events in this area during this time span because the rocks of that age have eroded away in the region. This lack of stratigraphic information is called an unconformity.



About *500 million years ago*, this relatively flat area became covered with shallow seas. Over the next *200 million years*, several hundreds of thousands of feet of **Paleozoic** sedimentary rocks were deposited on the old Proterozoic surface. During the **middle Pennsylvanian Period**, yet another mountain range was uplifted in this area. From it the Paleozoic Period sediments were eroded.

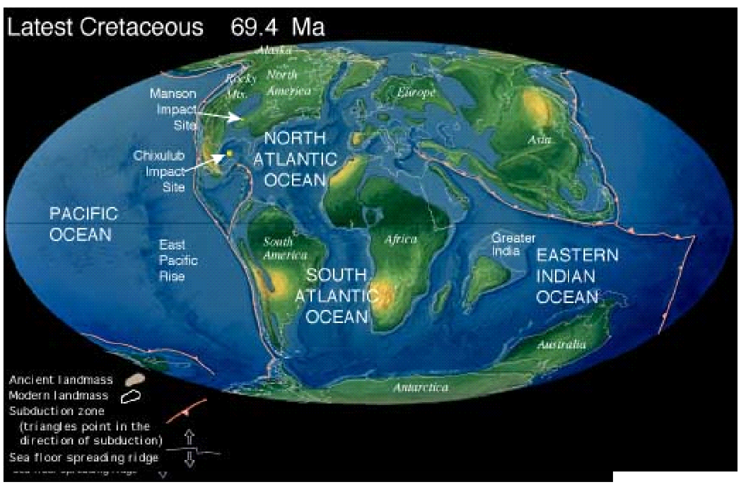
- Sediments shed from these **"ancestral Rocky Mountains"** were deposited along the mountain flanks. Today, these make up the sedimentary formations at the bottom of Pikes Peak.



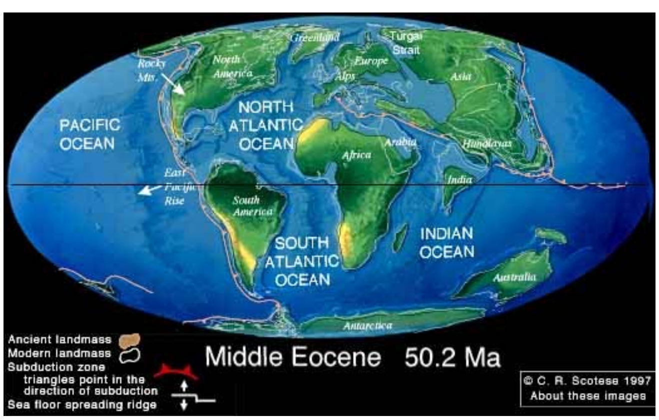
-
- the red rocks in the **Garden of the Gods** near Colorado Springs.

The area that is now Pikes Peak was eroded again and intermittently covered by seas from the middle of the **Permian Period** to the end of the **Cretaceous Period** about *65 million years ago*. Abundant bones and tracks found in sedimentary rocks, like the Morrison formation. They date back to **Jurassic and Cretaceous** times, indicating that **dinosaurs** lived here during those periods.

Major tectonic plates of the Earth's crust began to collide along what was then the western edge of North America about *130 million years ago*. Uplift caused by this collision began to affect the area of the present Colorado Rockies about *70 million years ago*. As the region began to rise, the Cretaceous sea withdrew and the thick layer of sedimentary rocks that had accumulated began to erode. Within a few million years, the sedimentary rocks of the Front Range had eroded away, and the Proterozoic igneous and metamorphic rocks again were exposed to erosion.



As uplift proceeded, deep **fault zones** formed, enormous stresses pulled the Earth's crust apart at what is now the west side of the peak. Between *34-35 million years* ago, the magmas reached the surface and erupted as volcanoes. The tops of the volcanoes stood several thousand feet above the present granitic masses, which since have been eroded to their present size. Extensive **ash beds** from the volcanoes are preserved at Florissant Fossil Beds National Monument.



From the plate collision to the present, rivers and streams have eroded the mountains and transported enormous amounts of sediment to the oceans. By the end of the **Tertiary Period**, the mountains were still fairly high but rounded. The area also was characterized by wide, V-shaped stream valleys.

Then, the Rocky Mountain area saw more drama. About *2 million years ago*, Earth's climate cooled and the **Ice Age** began. Large ice sheets ebbed and flowed across much of the Northern Hemisphere. During several major periods of glaciation—as well as several minor episodes—ice covered much of North America and Europe. The high mountain valleys filled with glaciers.

Pikes Peak felt the effects of the Ice Age. Glaciation in the park probably started about *1.6 million years ago*. Specific evidence of the earliest glaciations doesn't exist because **moraines** formed by the early glaciers were destroyed by glaciers that followed later. Each time glaciers flowed down the mountain valleys they eroded the valley sides and bottoms, helping to straighten and deepen them, removing evidence of earlier glaciations.

There is evidence of the last two major periods of ice accumulation, about *300,000 years ago* and ended about *130,000 years ago*. After the *130,000 years ago* event, came a warmer period that lasted about 100,000 years. The last major glacial episode, called the **Pinedale Glaciation**, began about 30,000 years ago when Earth's climate once again cooled. The Pinedale glaciers reached their maximum extent between 23,500 and 21,000 years ago. Most of the major valleys were filled with glaciers during this time. Between 15,000 and 12,000 years ago, the climate warmed and the glaciers rapidly disappeared. Though glaciers remain in the front range of the Rockies, none of these Alpine glaciers are remnant of Ice Age glaciers.

Some scientists believe that we are living today in a **warming interglacial period**. But they speculate that we could be heading into a period of cooler climate during which glaciers would return.

These explanation are taken from the NPS/USGS website. For lots more on Geology and Paleontology go to:

http://wrgis.wr.usgs.gov/docs/usgsnps/project/home.html
http://www2.nature.nps.gov/grd/
http://www.nps.gov/flfo/mained.htm

Eocene Oligocene Boundary Climate Change

Florissant Fossil Beds National Monument was established in 1969 to protect two types of fossils dating from 34-35 million years ago, lake shale fossils, and permineralized tree stumps. These fossils tell a story about ecosystems quite different from today's enviroment. Many of the plants found in the fossil record reflect a subtropical to warm temperate climate. Florissant presently has a cool temperate climate. Sequoia trees and palms were present at Florissant 34-35 million years, along with insects like the Tsetse fly; all indicators of a warmer enviroment. The follow activities are designed to help students learn to interpret data and propose a hypothesis about the climate change at the Eocene-Oligocene boundary.

There are many reasons why the climate changes: orbital relationship to the sun, tilt of the earth, plate tectonics, oceanic currents, etc. Some are the proposed hypotheses that may have affected the changes in climate the 34-35 million years ago.

First, what are some of the indicators that tell scientists the climate may have been warmer 34-35 million years ago. A paleobontanist in th 1950s suggested that the plants we find in Florissant's fossil record might have existed at a lower altitude contributing to the types of plant genera that are found. He used the floristic method to determine the paleoelevation. His estimates place Florissant at about 3,000 ft. to 4,000 ft. The floristic method though not totally discounted, does have some weaknesses. It compares these mostly extinct fossil leaf species to modern counterparts. This method relies on accurate identification of fossils, which is sometimes only possible to the genus level, even in the most well preserved specimens. At this level, the widespread distribution of plant genera and families severely limits the ability to accurately assign one particular habitat to plants found in the fossil record. Many of their modern counterparts may have evolved and adapted to new climate conditions. Thus the information about what climate these ancient plants may have lived in may not be entirely accurate.

In the 1970s and 1980s, scientists began to emphasize methods that considered plant characteristics (the physiognomic method), rather comparing genera and species. By studying the modern leaf morphology and anatomy in the context of specific climates, scientists are able to identify climate indicators that did not depend upon identification of taxa, on distribution of modern families, and accounted for some evolutionary adaptation. Some of identifying characteristics of plants that correlated with a climate, such as subtropical are drip tips (pointed apex of a leaf which allows water to drip off), entire margins (smooth margins with no serration), and cordate bases (the base of the leaf has a heart shape). This morphology seems to be consistent with different species in similar climates throughout the world. Several paleobotanists have used this method and published estimates of an elevation very close to Florissant's elevation today (8,400 ft.).

These hypotheses developed by paleobotanists indicate a warmer climate than the one we see today at Florissant. Their research indicates the climate 34-35 million years ago was sub tropical to warm temperate. Today, the climate is cool temperate. But why was the climate warmer? Was it locally warmer? Was it globally warmer? Was Florissant at a lower elevation? Was Florissant closer to the equator? Or are there other events that influenced the change in climate.

MacGinitie in the 1950s suggested that the southern Rocky Mountains uplifted after Florissant, which like the Himalayan uplift, may have contributed to global cooling after 34 million years ago. This also suggests that Florissant may have been at a lower elevation. Some geomorphologists (geologists who study structure movements of the plates and stratigraphic information) support this idea and propose that the tectonic activity continued well past the Eocene/Oligocene boundary. These scientists look at field evidence, which shows a shift in the paleostream drainage and erosion that has taken place since 34-35 million years ago. Some think that structural events could have taken place as little as 5 million years ago.

Much the evidence points to plate tectonics being a major influence in the cooling of the planet at the Eocene/Oligocene boundary. During the Eocene epoch time period Antarctica, the tip of South America, and the Australian Continent were connected. Central America was mostly submerged allowing the warm ocean currents at the equator to flow freely flow from the Pacific into the Atlantic Ocean. Also, the polar ice caps were smaller and more land in general was submerged allowing the oceans of the earth to absorb the heat from the sun. At the beginning of the Oligocene both South America and the Australian Continent broke away from Antarctica. This tectonic movement increased cooling due to convection currents encircling the southern pole and furthered the development of a larger and deeper polar ice cap in Antarctica. The deep ocean currents surrounding Antarctica began to cool and Central America also began to rise out of the water blocking the equatorial currents from the Pacific to the Atlantic. The Pacific current then dropped south and picked up the cooler Antarctica water. The current then brought the cooler water north into the Atlantic Ocean. Scientists think this shift in direction and temperature of deep ocean currents contributed greatly to the cooling of the planet. Other factors could have contributed to this cooling, such as the tilt of the earth toward the sun, or eccentricity (our proximity to the sun). The hypotheses mentioned above are just a few of the put forth by scientist concerning the Eocene Oligocene Boundary Climate Change.

We hope this helps student and teachers begin to understand the processes affecting climate change and science itself. These various studies (at Florissant Fossil Beds National Monument) serve to provide a good applied illustration of the scientific process, wherein hypotheses and results are retested in view of alternative methodologies.[1] Florissant Fossil Beds National Monument was set aside as an important site containing significant fossil resources, though these resources are important, just as important are the questions being raised by the scientists who study them.

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[1] Evanoff, E., Gregory_Wodzicki, K., and Johnson, K., *Proceedings of the Denver Museum of Nature and Science:* Fossil Flora and Statigraphy of the Florissant Formation, Colorado, Series 4, Number 1, 2001