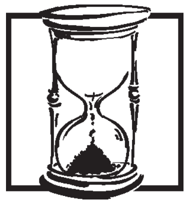

Chapter 1: Geologic History of the South Central US: The Big Picture

Geologic history is the key to this guide and to understanding the story recorded in the rocks of the South Central. By knowing more about the geologic history of our area, you can better understand the type of rocks that are in your backyard and why they are there. We will look at the history of the South Central as it unfolds: as a series of major events that created and shaped the area over the past one billion years. These events will act as the framework for the topics to follow and will shed light on why our region looks the way it does!

The **geologic time scale** (*Figure 1.1*) is an important tool used to represent the history of the Earth—a standard timeline used to describe the age of rocks and **fossils**, and the events that formed them. It spans Earth's entire history and is separated into four principle divisions.

The first of these, the **Precambrian**, extends from about 4.6 billion years ago to 541 million years ago. Little is known about this time period since very few fossils or unaltered rocks have survived. What few clues do exist indicate that life first appeared on the planet some 3.9 billion years ago in the form of single-celled organisms.

The second division, the **Paleozoic**, extends from 541 to 252 million years ago. Fossil evidence shows that during this time period, life evolved in the oceans and gradually colonized the land.

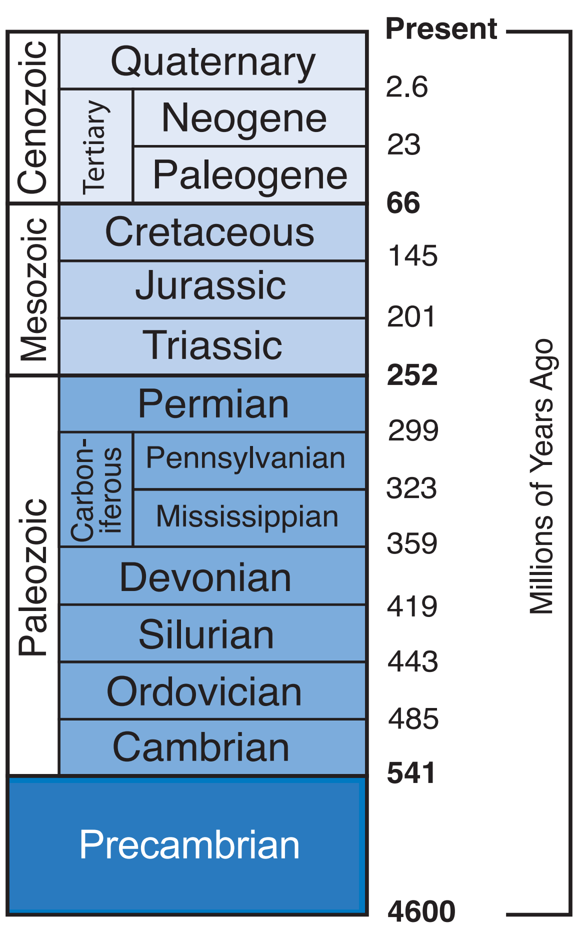

Figure 1.1: The Geologic Time Scale (spacing of units not to scale).

fossil • *preserved evidence of ancient life, including, for example, preserved skeletal or tissue material, molds or casts, and traces of behavior.*

About the Time Scale: *The time scale in* The Teacher-Friendly Guides™ *follows that of the International Commission on Stratigraphy (ICS). The Tertiary period, though it was officially phased out in 2008 by the ICS, remains on the scale in the Guides, since "Tertiary" is found extensively in past literature. In contrast, the Carboniferous and Pennsylvanian & Mississippian periods all enjoy official status, with the latter pair being more commonly used in the US.*

CHAPTER AUTHORS

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1

Geologic History

Geologic Time

dinosaur • *a member of a group of terrestrial reptiles with a common ancestor and thus certain anatomical similarities, including long ankle bones and erect limbs.*

extinction • *the end of species or other taxonomic groups, marked by death of the last living individual.*

plates • *large, rigid pieces of the Earth's crust and upper mantle, which move and interact with one another at their boundaries.*

lithosphere • *the outermost layer of the Earth, comprising a rigid crust and upper mantle broken up into many plates.*

asthenosphere • *a thin semifluid layer of the Earth, below the outer rigid lithosphere, forming the upper part of the mantle.*

volcanic island • *one of a string of islands created when molten rock rises upward through oceanic crust.*

earthquake • *a sudden release of energy in the Earth's crust that creates seismic waves.*

Geologic Time

How did geologists come up with the timeline for the history of the Earth? The geologic time scale was developed over the course of many years and through the combined work of geologists around the world. No rock record in any one place contains the complete sequence of rocks from Precambrian to present. Geology as a science grew as geologists studied individual sections of rock. Gradually, evolutionary successions of fossils were discovered that helped geologists determine the relative ages of groups of rocks. Rock units were then correlated with similarly aged rock units from around the world. The names you see for the different periods on the geologic time scale have diverse origins. Time periods were named after dominant rock types, geography, mountain ranges, and even ancient tribes like the Silurese of England and Wales, from which the "Silurian" period was derived.

The third division, the **Mesozoic** (from 252 to 66 million years ago), is also called the "age of reptiles" since **dinosaurs** and other reptiles dominated both marine and terrestrial ecosystems. It is also noteworthy that during this time the last of the Earth's major supercontinents, **Pangaea**, formed and later broke up, producing the Earth's current geography.

***Pangaea*, meaning "all Earth," began to assemble over 300 million years ago and lasted for almost 150 million years. All of the Earth's continents were joined as one to form a giant supercontinent.**

The last and current division, the **Cenozoic**, extends from the **extinction** of the dinosaurs, nearly 66 million years ago, to the present. With the demise of the dinosaurs, mammals became dominant and, subsequently, more diverse and highly developed. We humans don't come into the picture until the last two million years. To get some perspective on this, if the entire geologic time scale were reduced to 24 hours, we wouldn't come onto the stage until two seconds before midnight!

The Earth is dynamic, consisting of constantly moving **plates** that are made of a rigid continental and oceanic **lithosphere** overlying a churning, plastically flowing **asthenosphere** (*Figure 1.2*). These plates are slowly pulling apart, colliding, or sliding past one another with great force, creating strings of **volcanic**

islands, new ocean floor, mountains, and **earthquakes**. The continents are likewise continuously shifting position relative to each other. This not only shapes the land, but also affects the distribution of rocks and **minerals**, natural resources, **climate**, and life.

Rocks and sediments are indicators of past geologic processes and the environments in which those processes took place. In general, **igneous rocks**, created through tectonic activity, reflect past **volcanism**. By looking at both their texture and chemistry we can determine the tectonic setting and whether or not the rocks formed at the surface or deep underground. Likewise, **metamorphic**

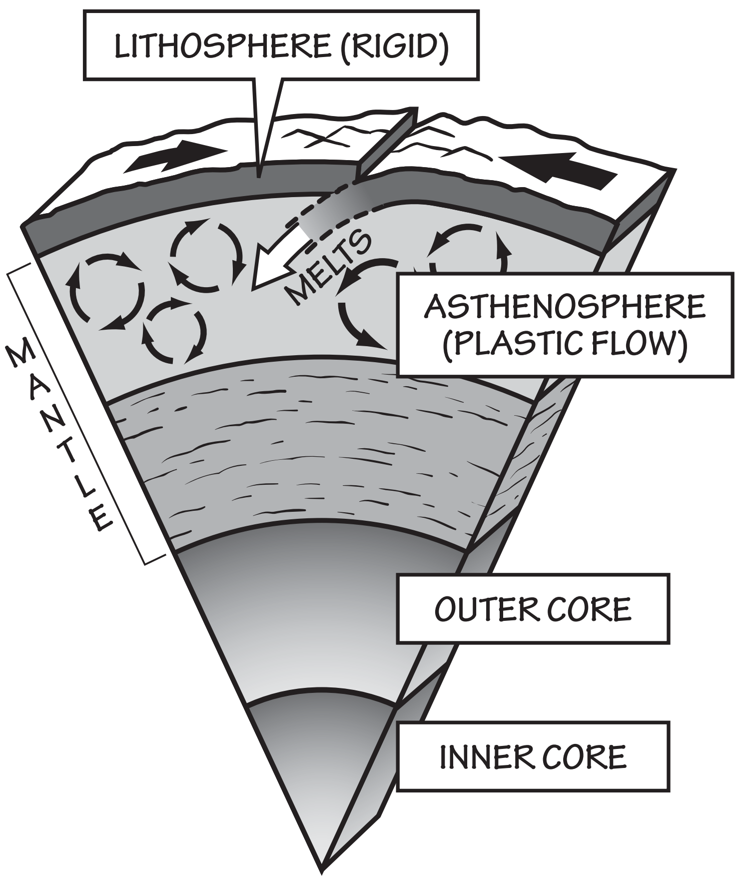


Figure 1.2: The layers of the Earth include the rigid crust of the lithosphere, which is constantly moving over the plastically flowing asthenosphere.

rocks, created when sediment is subjected to intense **heat** and pressure, provide important clues to past mountain-building events, and geologists often use them to map the extent of now-vanished mountain ranges. **Sedimentary rocks** tell perhaps the most comprehensive story of the Earth's history, as they record characteristics of far-away mountain ranges, river

See Chapter 2: Rocks to learn more about different rocks found in the South Central.

Geologic Time

mineral • *a naturally occurring solid with a specific chemical composition and crystalline structure.*

climate • *a description of the average temperature, range of temperature, humidity, precipitation, and other atmospheric/hydrospheric conditions a region experiences over a period of many years (usually more than 30).*

igneous rocks • *rocks derived from the cooling of magma underground or molten lava on the Earth's surface.*

volcanism • *the eruption of molten rock onto the surface of the crust.*

metamorphic rocks • *rocks formed by the recrystallization and realignment of minerals in pre-existing sedimentary, igneous, and metamorphic rocks when exposed to high enough temperature and/or pressure.*

sedimentary rock • *rock formed through the accumulation and consolidation of grains of broken rock, crystals, skeletal fragments, and organic matter.*

1 Geologic History

Geologic Time

system • *a set of connected things or parts forming a complex whole.*

lithification • *the process of creating sedimentary rock through the compaction or sementation of soft sediment.*

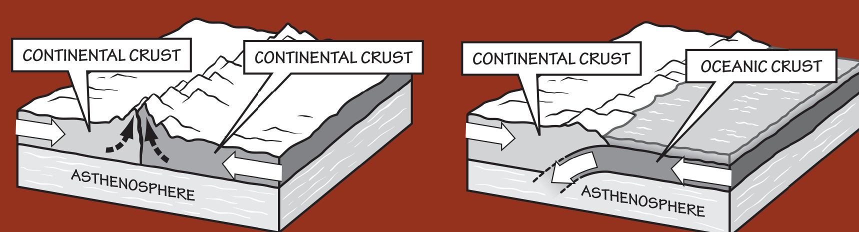
erosion • *the transport of weathered materials.*

glacier • *a body of dense ice on land that does not melt away annually and has sufficient mass to move under its own weight.*

ripple marks • *surface features created when sediment deposits are agitated, typically by water currents or wind.*

Continental and Oceanic Crust

The lithosphere has two types of crust: continental and oceanic. Continental crust is less dense but significantly thicker than oceanic crust. The higher density of the oceanic crust means that when continental crust collides with oceanic crust, the more dense oceanic crust will be dragged (or subducted) under the buoyant continental crust. Although mountains are created at these oceanic/continental crust collisions due to the compression of the two plates, much taller ranges are produced by continental/continental collisions. When two buoyant continental crusts collide, there is nowhere for the crust to go but up! The modern Himalayas, at the collision site of the Asian and Indian plates, are a good example of very tall mountains formed by a collision between two continental crusts.



systems that transported the sediments, and the final environment in which the sediments accumulated and **lithified**. The size and shape of sediments in sedimentary rocks, as well as the presence of fossils and the architecture of sedimentary rock layers (sedimentary structures), can help us infer how the sediments were transported and where they were finally deposited. However, because rocks are often reformed into different rock types, ancient information is lost as the rocks cycle through the igneous, metamorphic, and sedimentary stages.

Fossils indicate both the type of life that once flourished in an area and the kind of climate in which that life existed. Paleontologists use groups of fossils found in the same place to construct pictures of entire ecosystems. These ecosystems of the past are matched to similar present-day ecosystems, whose climate conditions are then used to infer what sort of climate the fossilized organisms lived in. Unfortunately, few organisms are easily preserved as fossils, and many environments also do not lend themselves to preserving organisms as fossils. As a result, the clues that fossils give provide only glimpses of the ancient world, with many important details missing.

Geologic History 1

Precambrian

Landscapes and geologic structures are also indicators of past geologic processes and the environments in which they occurred. For instance, the shape of a valley reflects the forces that carved it. Valleys with V-shaped profiles tend to be the products of stream **erosion**, whereas U-shaped valleys are more likely to have been carved by **glaciers**. Layers of intensely folded rock indicate a violent past of tectonic plate collisions and mountain building. Sedimentary structures, such as **ripple marks** or **cross-bedding**, can demonstrate the direction and energy level of the water that moved the sediment. Although landscapes tell us much about the geologic processes that created them, they inevitably change over time, and information from the distant past is overwhelmed by the forces of the more recent past.

See Chapter 3: Fossils for more information about the South Central's prehistoric life.

Ultimately, geologists rely upon the preserved clues of ancient geologic processes to understand Earth's history. Because younger environments retain more evidence than older environments do, the Earth's recent history is better known than its ancient past. Although preserved geologic clues are indeed fragmented, geologists have become increasingly skilled at interpreting them and constructing ever more detailed pictures of the Earth's past.

See Chapter 4: Topography for more detail about the landscapes found in the South Central States.

cross-bedding • *layering within a bed in a series of rock strata that does not run parallel to the plane of stratification.*

Canadian Shield • *the stable core of the North American continental landmass, containing some of the oldest rocks on Earth.*

compression • *flattening or squeezing as a result of forces acting on an object from all or most directions.*

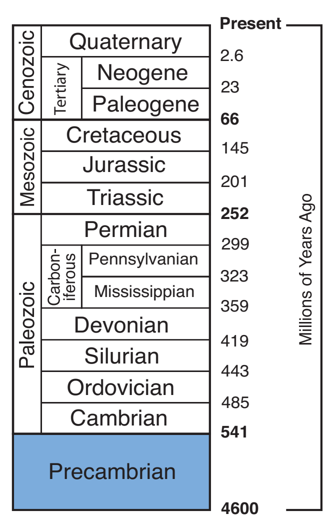
Precambrian Beginnings:
Roots of the South Central

The Earth is estimated to be approximately 4.6 billion years old. Rocks dating to 4 billion years old are found on almost every continent, but the oldest rocks known are 4.3-billion-year-old greenstone beds found along the eastern shore of Hudson Bay in northern Quebec. These are part of the **Canadian shield**, the ancient core of the North American continental landmass.

The Canadian shield has experienced very little tectonic activity (faulting and folding) for millions of years. Shields, or cratons, are the stable cores of all continents and are often covered by layers of younger sediments.

The oldest known materials in the world are 4.4-billion-year-old zircons from Western Australia.

The shape and position of North America has changed dramatically over the last billion years, and geologic processes continue these changes today. **Compression** from



1 Geologic History

Precambrian

weathering • *the breakdown of rocks by physical or chemical means.*

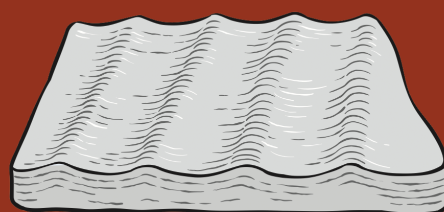
basement rocks • *the foundation that underlies the surface geology of an area, generally composed of igneous or metamorphic crystalline rock.*

magma • *molten rock located below the surface of the Earth.*

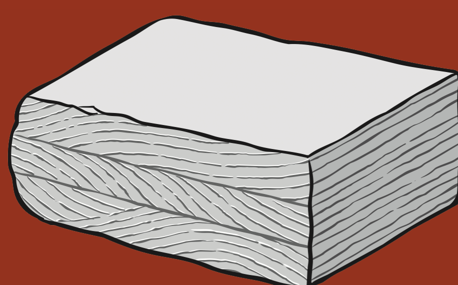
mantle • *the layer of the Earth between the crust and core.*

Sedimentary Structures

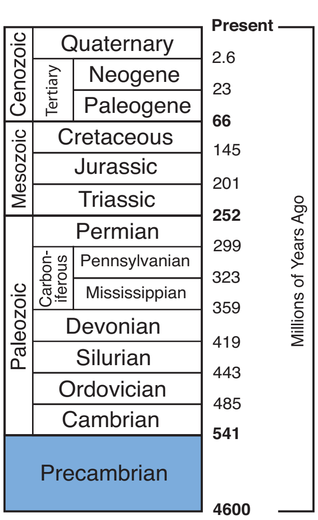
Sedimentary rocks often reveal the type of environment in which they formed by the presence of structures within the rock. Sedimentary structures include ripple marks, cross-beds, mud cracks, and even raindrop impressions. Consider the type of environments in which you see these sedimentary structures today in the world around you.



Ripple marks suggest the presence of moving water (though wind can also create ripples and even dunes). Mud cracks indicate that the sediment was wet but exposed to the air so that it dried and cracked.



Cross-beds form as flowing water or wind pushes sediment downcurrent, creating thin beds that slope gently in the direction of the flow as migrating ripples. The downstream slope of the ripple may be preserved as a thin layer dipping in the direction of the current, across the natural flat-lying repose of the beds. Another migrating ripple will form an additional layer on top of the previous one.



colliding plates, tension from plates pulling apart, the addition of land to North America, **weathering**, and erosion have combined to slowly sculpt the form of the continent. More than a billion years ago, narrow strips of land collided with and compressed one another to form the Precambrian beginnings of the North American continent, also called Laurentia. From this proto-North America, sediment was eroded and transported by rivers and streams across the ancient continental margins and then into the adjacent oceans. The sediment deposited in the ocean waters on the eastern margin of Laurentia composes what is presently called the Grenville Belt.

Geologic History 1

The South Central States are divided up into five different geologic provinces or regions (*Figure 1.3*): the Central Lowland (1), Interior Highlands (2), Coastal Plain (3), Great Plains (4), and the Basin and Range (5). Among these regions, Precambrian-aged rock is exposed in only a few discrete places in Texas, Oklahoma, and Missouri, although it underlies larger swaths of the area. Much of the **basement rock** here is a remnant of volcanic islands and an associated submarine mountain range that formed about 1.4 billion years ago as **magma** welled up from the **mantle** and cooled into **granite** or erupted, forming **rhyolite**. These islands later collided with other **microcontinents** to form the bedrock of the proto-North American continent.

The oldest exposures in the South Central are found within the Saint Francois Mountains of the Interior Highlands. Granitic and rhyolitic igneous rocks represent the remains of a **Proterozoic** mountain range dating to nearly 1.5 billion years ago, and they form the core of the Highlands today. Further south, the Central Texas Uplift of the Great Plains province contains **gneiss** and granite that formed between 1.3 and 1 million years ago. The Franklin Mountains near El Paso, Texas, part of the Basin and Range province, also contain Precambrian-aged rock.

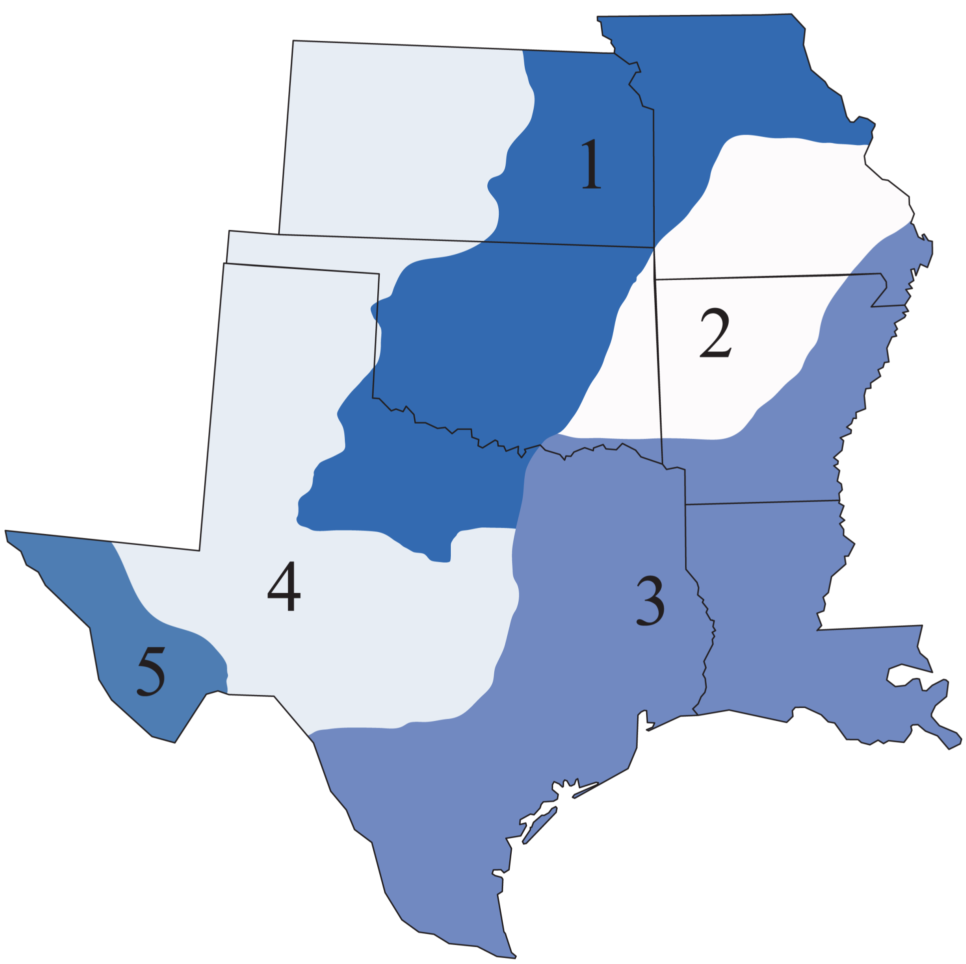


Figure 1.3: Geologic regions of the South Central.

Precambrian

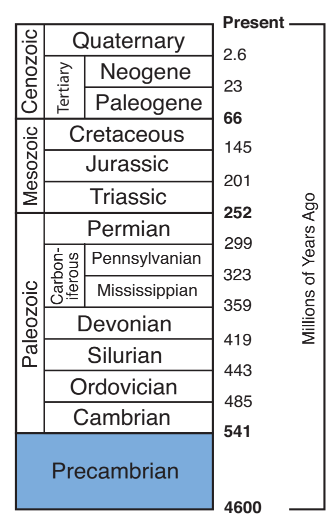
granite • *a common and widely occurring type of igneous rock.*

rhyolite • *a felsic volcanic rock high in abundance of quartz and feldspar.*

microcontinent • *a piece of continental crust, usually rifted away from a larger continent.*

Proterozoic • *a geologic time interval that extends from 2.5 billion to 541 million years ago.*

gneiss • *a metamorphic rock that may form from granite or layered sedimentary rock such as sandstone or siltstone.*



Rodinia • *a supercontinent that contained most or all of Earth's landmass, between 1.1 billion and 750 million years ago, during the Precambrian.*

rift • *a break or crack in the crust that can be caused by tensional stress as a landmass breaks apart into separate plates.*

crust • *the uppermost, rigid outer layer of the Earth, composed of tectonic plates.*

inland basin • *a depression located inland from the mountains, and formed by the buckling (downwarping) of the Earth's crust.*

During the next several tens of millions of years, parts of these mountains were buried in sediment that originated on Laurentia's northeastern portion. The resulting sedimentary rock was subsequently metamorphosed, and it is now exposed at the Llano Uplift in a ring surrounding the previously mentioned older portion.

The remainder of the Precambrian period saw the formation of the supercontinent **Rodinia** about 1.1 billion years ago (*Figure 1.4*), along with its eventual breakup about 750 million years ago. The tectonic activity that generated the formation and breakup of Rodinia may have contributed to the metamorphism evident in the older rocks mentioned above. As Rodinia broke up, a **rift** began to form in what is now southwest Oklahoma. Magma rising near the surface cooled to form parts of the Wichita Mountains. The rifting eventually failed, but not before the **crust** had thinned sufficiently to create a series of **inland basins** in southwestern Oklahoma and western Texas.

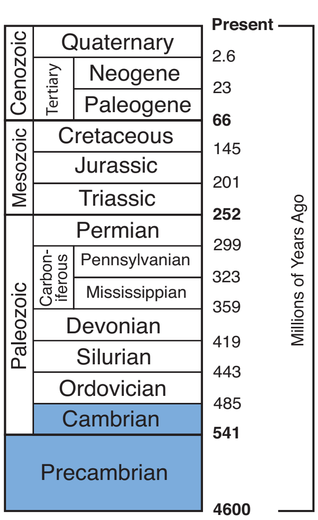
A *rift* occurs when tectonic plates move away from each other. Magma rises up into the margin, cooling to produce new oceanic crust. The resulting action is similar to two conveyor belts moving away from each other. A *failed rift* occurs when the existing crust is stretched thin and magma begins to well up, but the plate is never completely broken.

By the close of the Precambrian, very little existed of the South Central as we know it today. Deposition of sediments within shallow seas during the Paleozoic and Mesozoic, followed by deposition from the eroding Rocky Mountains and Interior Highlands during the Cenozoic era, would later form the South Central familiar to geologists today.

Seas and Mountains:
Sediments of the Midcontinent

During the Paleozoic, extensive deposition occurred in the South Central as shallow **inland seas** spread across the interior of the continent, covering North America's Precambrian shield. Across the Interior Plains, which include significant sections of Kansas, Missouri, Oklahoma, and Texas, a sequence of sediments 1500 to 3000 meters (5000 to 10,000 feet) thick was deposited during the Paleozoic and much of the Mesozoic. In many areas of the Interior Plains, these sediments are found only at depth, with younger sediments from streams and other sources overlaying them at the surface.

Beginning in the **Cambrian** period, about 545 million years ago, the southern portion of the region was persistently submerged (*Figure 1.5*), and a further rise in sea level caused nearly the entire region to be inundated during the late



Geologic History

1

Seas & Mtns

inland sea • *a shallow sea covering the central area of a continent during periods of high sea level.*

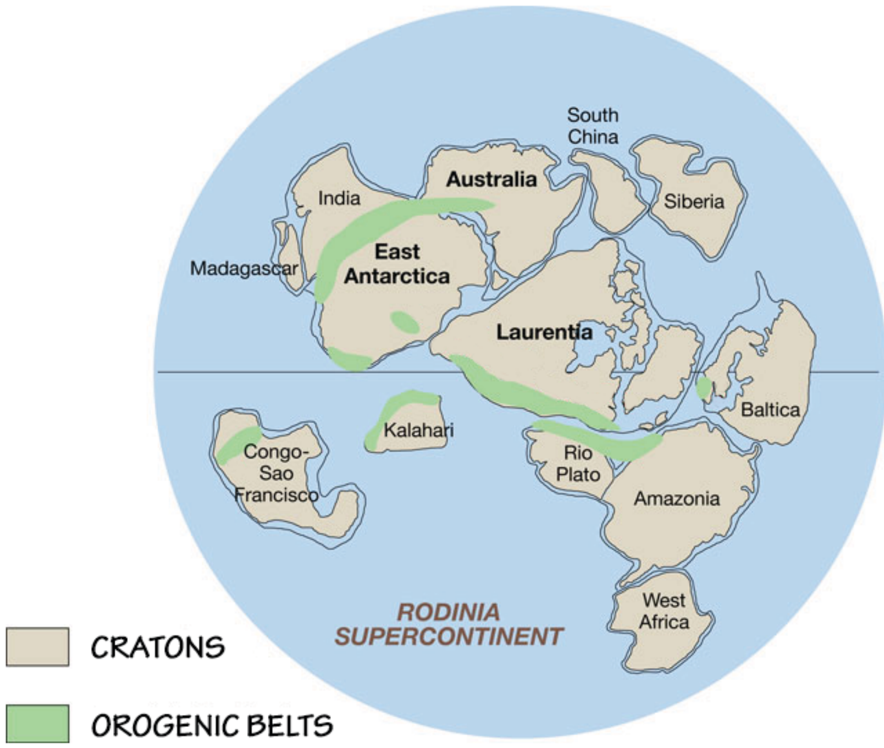


Figure 1.4: The supercontinent Rodinia, circa 1.1 billion years ago. Laurentia represents proto-North America. (See TFG website for full-color version.)

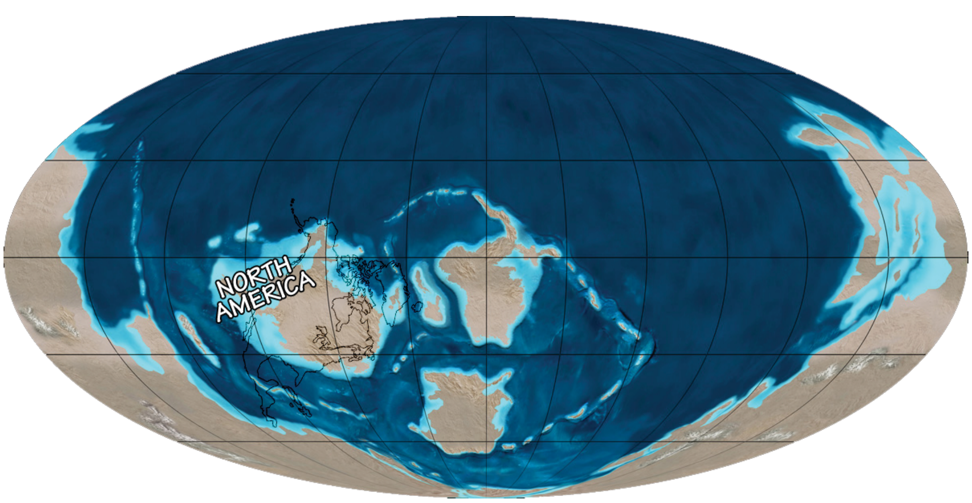
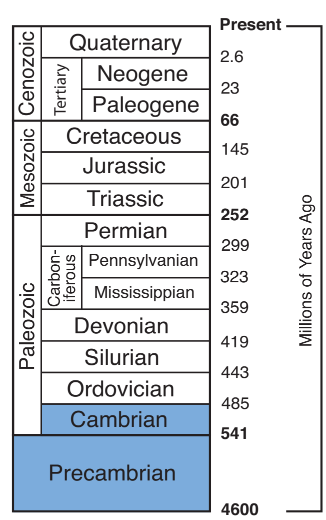


Figure 1.5: Earth during the early Cambrian, around 545 million years ago. (See TFG website for full-color version.)



__sandstone__ • sedimentary rock formed by cementing together grains of sand.

__carbonate rocks__ • rocks formed by accumulation of calcium carbonate, often made of the skeletons of aquatic organisms.

__shale__ • a dark, fine-grained, laminated sedimentary rock formed by the compression of successive layers of silt- and clay-rich sediment.

__plate tectonics__ • the process by which the plates of the Earth's crust move and interact with one another at their boundaries.

Cambrian. During the Paleozoic, even the high areas of northwestern Texas and the Ozarks of Missouri were occasionally underwater. The basin that had formed in Oklahoma as Rodinia broke up (see *Precambrian Beginnings*), along with much of the southern portion of the South Central, contains rocks from this time, some of which preserve the region's oldest fossils in what are now Oklahoma's Wichita Mountains and Missouri's Saint Francois Mountains. The Saint Francois Mountains are the core of the Ozarks, and represent the exposed portion of a Precambrian, igneous mountain chain. As the tallest point of the Ozarks, the Saint Francois Mountain range is thought to represent the only area of the central US to have never been submerged by the shallow seas of the Paleozoic and Mesozoic eras.

See Chapter 4: Topography to learn more about the Ozarks and Saint Francois Mountains.

Ordovician-aged rocks in southern Missouri and northern Arkansas show sequences of **sandstones**, **carbonates**, and **shales**, which are indicative of fluctuating sea levels and shifting shorelines. Invertebrate fossils are not uncommon in these rocks. In Missouri, a layer of **clay** formed of **volcanic ash** hints at tectonic activity far off to the east. During the Ordovician, the South Central was rotated roughly 90º clockwise relative to its current position (*Figure 1.6*). New England, now located northeast of the South Central, was actually forming to the *south*east at that time.

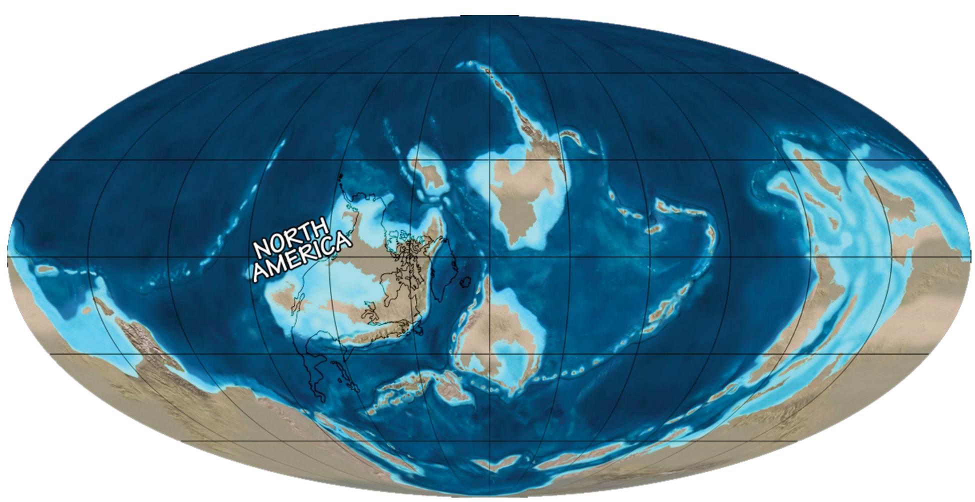
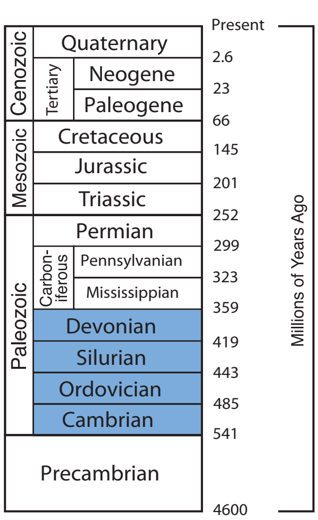


Figure 1.6: Earth during the late Ordovician, around 450 million years ago. (See TFG website for full-color version.)



During the **Silurian** and **Devonian** periods, the South Central again saw the sea advance over the entire region, and then retreat to what is now its southeastern third. Very little bedrock is preserved from this time. During the **Carboniferous**, however, **plate tectonics** led to the initial stages of Pangaea's assembly (*Figure 1.7*). As North America collided with **Gondwana** (a southern supercontinent), both the Appalachian Mountains and the South Central's Interior Highlands were

Seas & Mtns

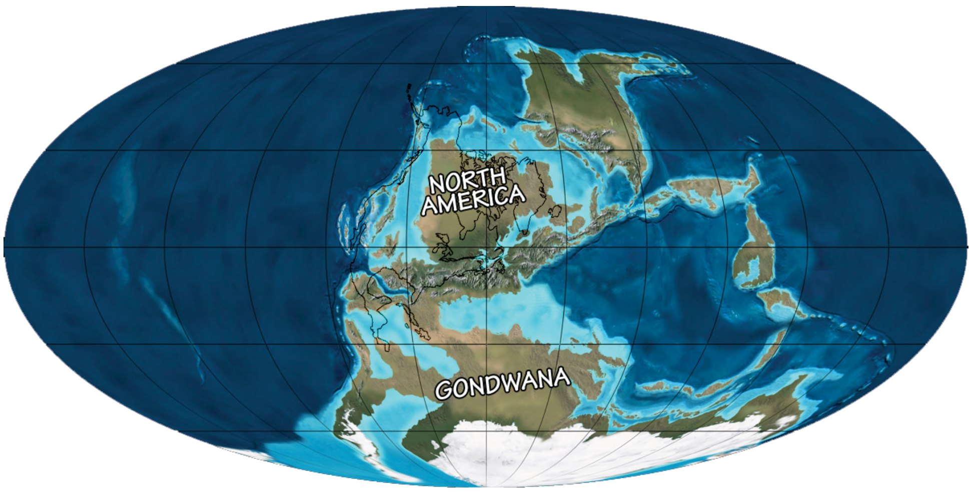


Figure 1.7: Initial formation of Pangaea during the late Carboniferous, around 300 million years ago. (See TFG website for full-color version.)

formed. The Highlands can be divided into two distinct sections: the Ouachita Mountains to the south (west central Arkansas, southeastern Oklahoma, and, beneath the surface, significant parts of central Texas), and the Ozark Uplift to the north (southern Missouri, northern Arkansas, and northeastern Oklahoma). After their **uplift**, erosion shaped the Ozarks into a series of plateaus capped by more resistant layers that are cut extensively by stream and river valleys.

As the landmasses collided, ancient seafloor was compressed into a series of folds and **faults**, producing the Ouachita Mountains. Since the collision occurred in a north-south direction, these folds extend in an east-west direction. Once established, these mountains began to erode, filling the submarine basins that had formed in western Texas as Rodinia broke up. By the **Permian**, these basins were full of rich organic material. Today, they are collectively called the Permian Basin, an area famous for its **petroleum** production.

See Chapter 7: Energy for more about the formation of petroleum resources in the South Central.

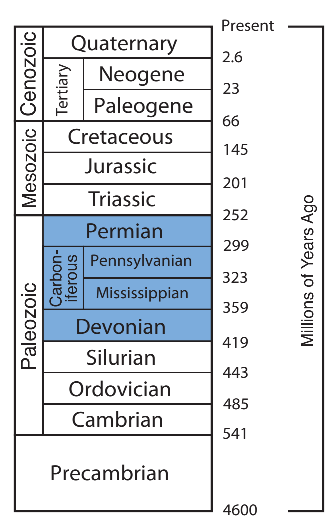
By the Permian, the assembly of Pangaea was essentially complete (*Figure 1.8*). Most of the South Central was above sea level at the dawn of the Mesozoic, partly due to regional uplift. Moreover, the arrangement of most of the land into a supercontinent resulted in a relatively low sea level. When the continental plates are amassed, they take up a comparatively smaller area on the surface of the Earth, and oceanic crust takes up a greater area. This means there are likely to be fewer rifts on Earth's surface, and therefore fewer mid-oceanic ridges (underwater mountain ranges that can displace huge volumes of water). Because in this arrangement there is, on average, more distance for oceanic crust to cover before it **subducts** below a continent, it spends more of its time on the surface, allowing it to cool, condense, and sink. Therefore, overall, the seafloor is "lower," and the sea level is subsequently lower near

Gondwana • *the supercontinent of the Southern Hemisphere, composed of Africa, Australia, India, and South America.*

uplift • *upward movement of the crust due to compression, subduction, or mountain building.*

fault • *a fracture in the Earth's crust in which the rock on one side of the fracture moves measurably in relation to the rock on the other side.*

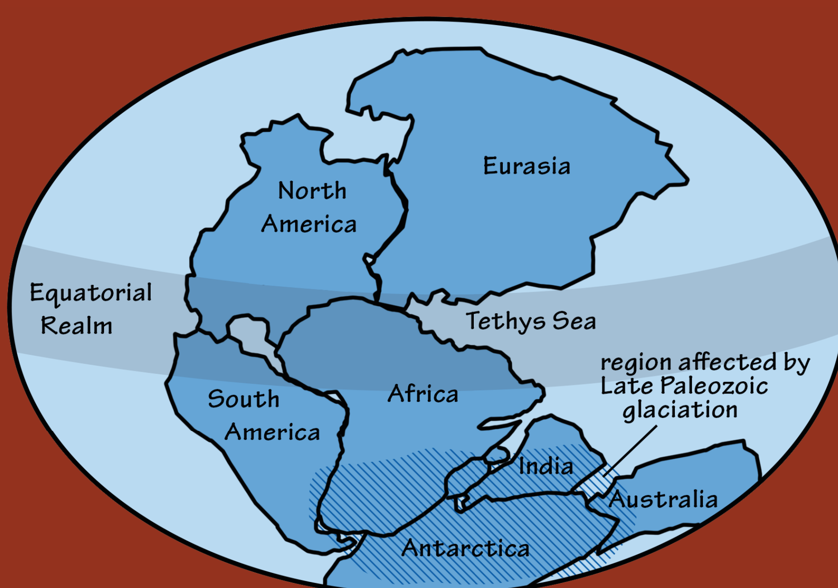
petroleum • *a naturally occurring, flammable liquid found in geologic formations beneath the Earth's surface.*



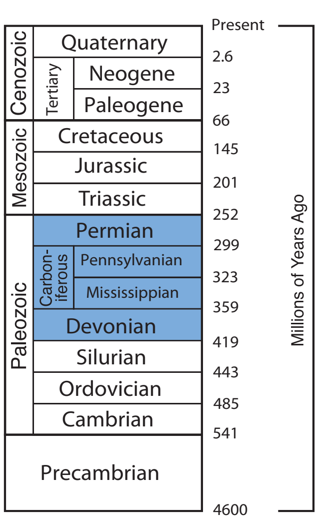
Geologic History

Evidence for Pangaea

How do we know that Pangaea existed 250 million years ago? Fossil evidence and mountain belts provide some of the clues. For example, the Permian-age fossil plant *Glossopteris* had seeds too heavy to be blown across an ocean. Yet *Glossopteris* fossils are found in South America, Africa, Australia, India, and Antarctica! The mountain belts along the margins of North America, Africa, and Europe line up as well and have similar rock types, an indication that the continents at one time were joined as Pangaea. Despite the discovery of *Glossopteris* and other geologic evidence, the theory of continental drift was not accepted for decades, until the mechanisms of continental movement were discovered and reformulated under the modern theory of plate tectonics. The supercontinent Pangaea existed for approximately 100 million years, reaching its largest size during the Triassic period. During the Jurassic, the landmass began to fragment into the modern continents, which slowly moved toward their present-day positions over the following 150 million years.



Pangaea during the late Paleozoic era



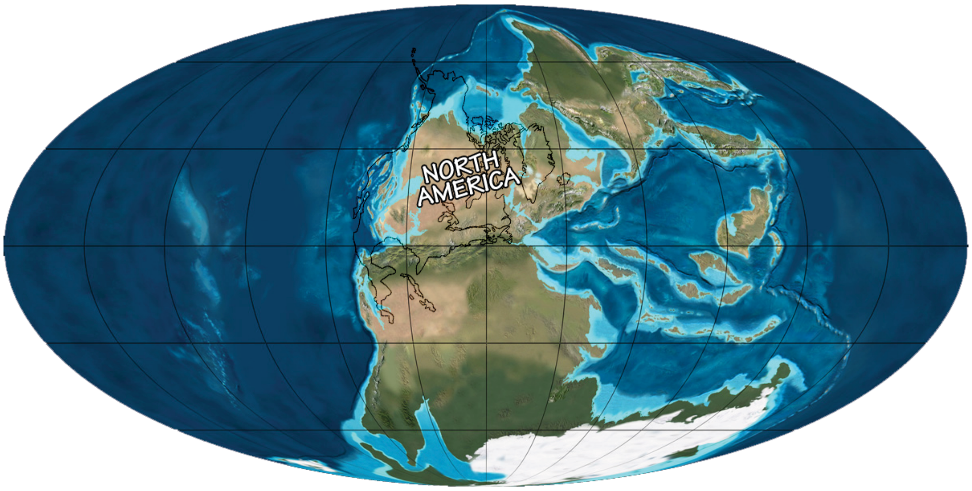


Figure 1.8: Earth during the late Permian, around 260 million years ago. (See TFG website for full-color version.)

the continental margins. As the Permian came to an end, the South Central transitioned to a terrestrial environment—in Texas, rocks from this time include **salt** and **gypsum** that were deposited as the sea retreated.

At the beginning of the Mesozoic, the South Central was a part of Pangaea, which broke up in several phases during this era. The Ouachita Mountains ran from the southwest to the northeast, where they were contiguous with the Appalachian Mountains, forming a huge range that extended from Mexico to Maine. By the end of the **Triassic**, the continental plates began to move apart once again, thinning the crust and causing it to **subside**. During the **Jurassic**, North and South America began to separate. Rifting in the Ouachitas opened up a growing basin between the Yucatan and South Central US that was eventually flooded by water from the Pacific Ocean—effectively creating the Gulf of Mexico. The Louann Salt formation, famous for its **impermeable salt domes**, was deposited in this basin over many millions of years. By the late Jurassic, the spreading rift had produced a substantial amount of oceanic crust, forming a deep and expanding floor to the Gulf and creating a connection with the newly developing Atlantic Ocean (*Figure 1.9*). The Gulf then began to function as a seaway, and the resulting circulation caused the deposition of salt to cease.

See Chapter 7: Energy to learn more about the formation and uses of salt domes in the Gulf.

During the early **Cretaceous**, Pangaea entered its final stages of breakup. Far to the west, oceanic crust had been subducting under western North America for tens of millions of years, causing a series of volcanic island complexes to collide with and become accreted to that margin of the continent. The great weight of the resulting mountains, west and north of the South Central, caused the surrounding crust to sink, creating a foreland basin (*Figure 1.10*). By 115 million years ago, the Arctic Ocean had flooded the basin from the north, eventually reaching the northwestern tip of Kansas (*Figure 1.11*).

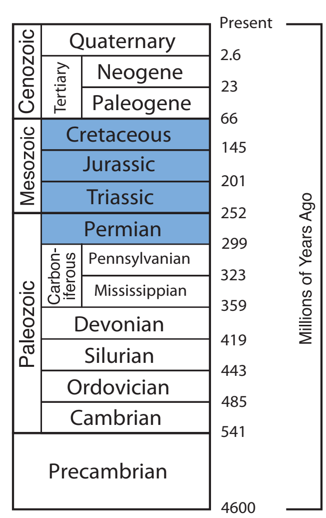
salt • *a mineral composed primarily of sodium chloride (NaCl).*

gypsum • *a soft sulfate mineral that is widely mined for its use as fertilizer and as a constituent of plaster.*

subsidence • *the sinking of an area of the land surface.*

permeability • *a capacity for fluids and gas to move through fractures within a rock, or the spaces between its grains.*

salt dome • *a largely subsurface geologic structure, consisting of a vertical cylinder of salt embedded in horizontal or inclined sedimentary strata.*



Seas & Mtns

hot spot • *a volcanic region thought to be fed by underlying mantle that is anomalously hot compared with the mantle elsewhere.*

Mississippi Embayment • *a topographically low-lying basin in the south-central United States, stretching from Illinois to Louisiana.*

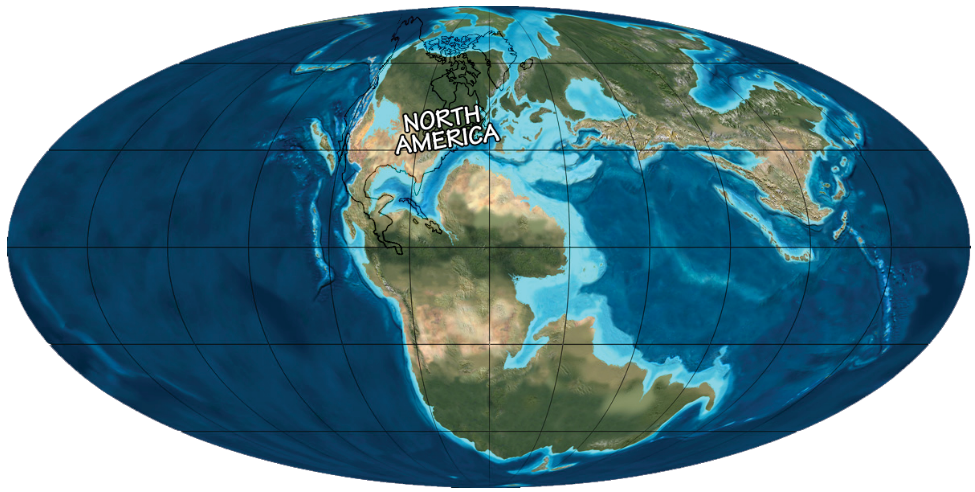


Figure 1.9: Earth during the Jurassic, 170 million years ago. (See TFG website for full-color version.)

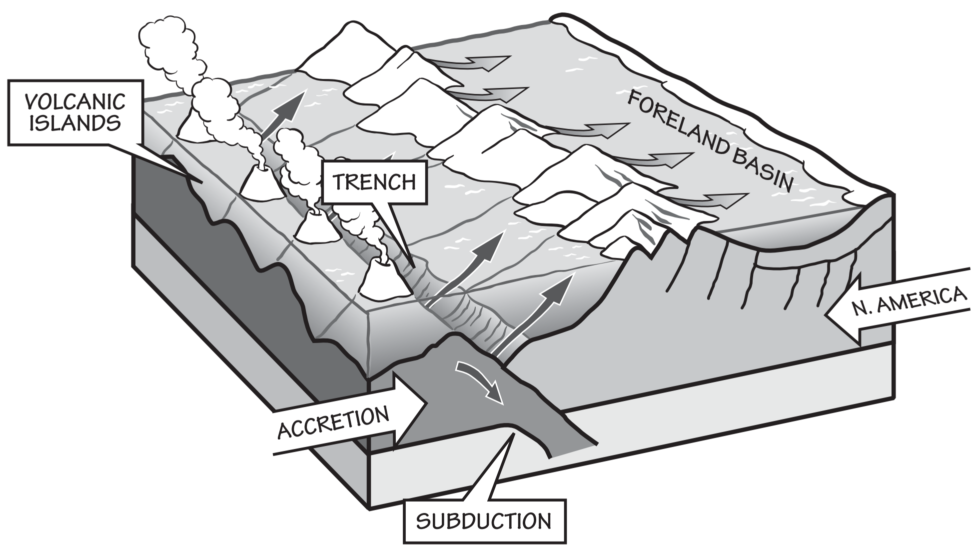


Figure 1.10: Formation of North America's Cretaceous foreland basin.

Era		Period	Millions of Years Ago
			Present
Cenozoic		Quaternary	2.6
Cenozoic	Tertiary	Neogene	23
Cenozoic	Tertiary	Paleogene	**66**
Mesozoic		Cretaceous	145
Mesozoic		Jurassic	201
Mesozoic		Triassic	**252**
Paleozoic		Permian	299
Paleozoic	Carbon-iferous	Pennsylvanian	323
Paleozoic	Carbon-iferous	Mississippian	359
Paleozoic		Devonian	419
Paleozoic		Silurian	443
Paleozoic		Ordovician	485
Paleozoic		Cambrian	**541**
		Precambrian	**4600**

Beginning 95 million years ago, North America passed over a **hot spot** in the mantle. The rising magma uplifted a portion of the Ouachita-Appalachian Mountains, creating an arch and causing the range to be preferentially weathered. After the South Central passed over the hot spot, the crust there had thinned significantly, and it began to cool and subside, eventually forming a basin. As the ocean flooded the area between the Interior Highlands and the Appalachians, what is now the **Mississippi Embayment** was created. The Embayment area today extends from the confluence of the Ohio and Mississippi Rivers in the north, to the Gulf of Mexico in the south. This is the origin of the relatively low, flat area that now separates the Appalachian and Ouachita mountain ranges.

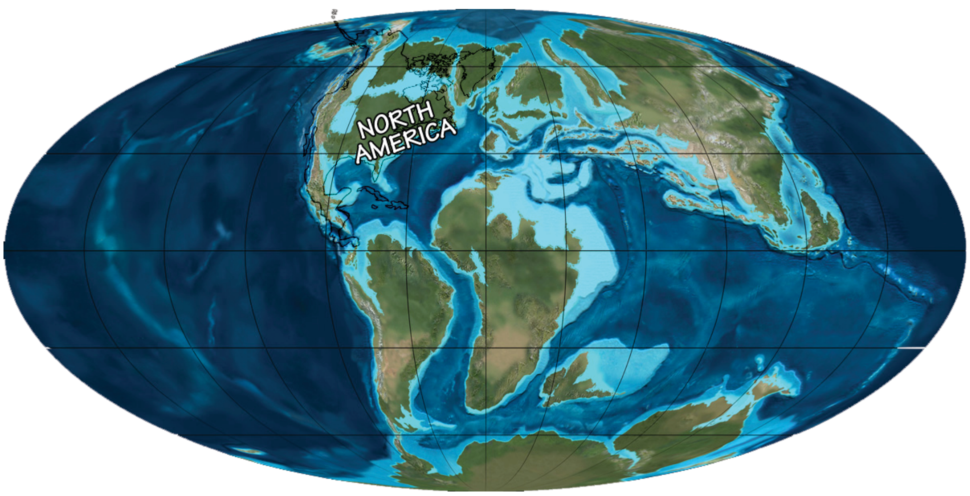


Figure 1.11: Earth during the early Cretaceous, around 105 million years ago. (See TFG website for full-color version.)

Around 85 million years ago, the oceanic crust at North America's western margin (the Farallon plate) began to subduct at an unusually shallow angle. It slid farther inland beneath the continent before finally sinking into the asthenosphere, **downwarping** the western part of the South Central. This created a basin that allowed the waters of the Gulf of Mexico to meet with those in the north, forming the Western Interior Seaway (*Figure 1.12*), which inundated a 1000-kilometer (620-mile) wide swath from Mexico to Alaska. During the very latest stages of the Cretaceous period, around 70 million years ago, the midcontinental sea was displaced by slow uplift of the continent.

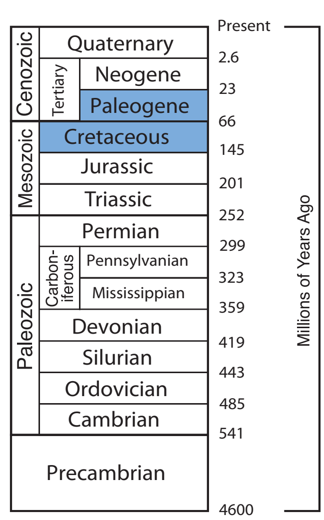
The roots of the *Mississippi Embayment* can be traced as far back as the Precambrian. When the Precambrian super-continent Rodinia broke apart, many smaller rifts in the crust formed adjacent to the major rift that was responsible for the separation of North America. One of the smaller rifts is located beneath the modern Mississippi Embayment. During parts of the Paleozoic era, a proto-Mississippi Embayment existed above the rift. During the Cretaceous, the ocean flooded the embayment; when the sea level fell, the Mississippi River was born.

The Farallon plate continued to collide with western North America, thrusting layers of rock up over each other and causing increasing volcanism to the west of the Western Interior Seaway. The **Laramide Orogeny** of the late Cretaceous and **Paleogene** periods—80 to 55 million years ago—changed the face of the United States. The rising ancestral Rocky Mountains provided sediment that filled the seaway, preserving an amazing variety of the organisms living in the basin. The uplift of the ongoing **orogeny** finally caused the water to split in the Dakotas and retreat south, to survive

downwarp *• a segment of the Earth's crust that is broadly bent downward.*

Laramide Orogeny *• a period of mountain building that began in the Late Cretaceous, and is responsible for the formation of the Rocky Mountains.*

orogeny *• a mountain-building event generally caused by colliding plates and compression of the edge of the continents.*

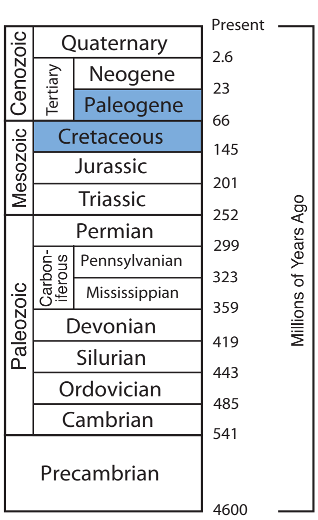


Seas & Mtns

topography • *the landscape of an area, including the presence or absence of hills and the slopes between high and low areas.*

Figure 1.12: The Western Interior Seaway of North America during the Cretaceous period.

in parts of the Mississippi Embayment through the end of the Cretaceous. The now-exposed terrain—the flat floor of the former sea—provided the basis for the **topography** of the Interior Plains. Sediment from the mountains was transported to the coast by rivers and streams, building up successive layers that fanned out onto the continental shelf (*Figure 1.13*). The late Cretaceous was marked by high sea levels worldwide, in part due to the significant increase in plate tectonic activity that followed the break up of Pangaea (*Figure 1.14*). As Pangaea split apart, it changed the shape of the Earth's ocean basins and created underwater ridges such as the Mid-Atlantic Ridge, where new oceanic crust continues to form today. The subsequent displacement of ocean water contributed to higher sea levels, and when sea levels rose, deposition of marine sediment also contributed to the Coastal Plain.



Cenozoic

The coastal plains of south and west Texas formed as sediment washed off the still-growing Rockies. Farther east, **watersheds** originating in the Appalachians deposited sediment on the shores of the Gulf. The Rocky Mountains continued to rise and volcanic activity increased around 50 million years ago, which both produced large quantities of sediment (which was subsequently transported and deposited across the Interior Plains) and **lava** (which covered portions of westernmost Texas).

An *orogeny* is a mountain-building event caused by colliding plates, subduction, and/or compression of the edge of the continents. Orogeny is derived from the Greek word "oro," meaning mountain.

watershed • *an area of land from which all water under or on it drains to the same location.*

lava • *molten rock located on the Earth's surface.*

The Cenozoic:
Sea Level Changes Shape the Continent

The Cretaceous–Paleogene boundary marks one of the most significant physical and biological events in Earth's history. The boundary, which is about 66 million years old, marks the contact between the Mesozoic and Cenozoic

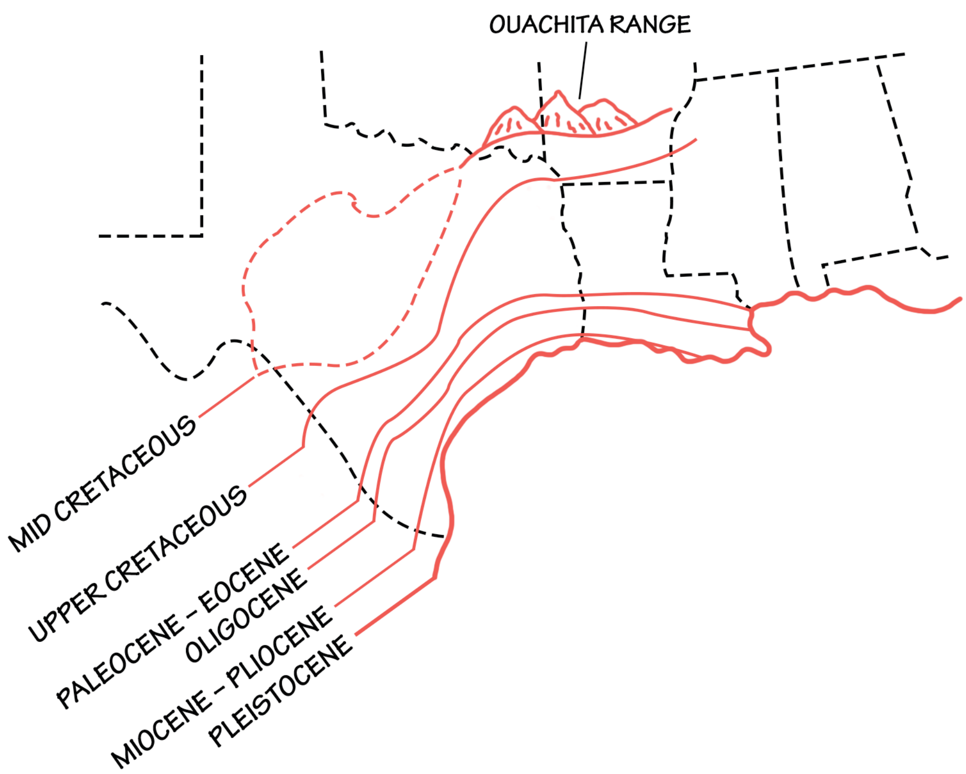
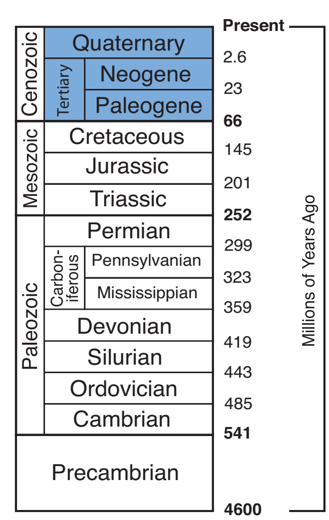


Figure 1.13: Shoreline changes along the Mississippi Embayment during the past 140 million years.



Cenozoic

eras. It represents a time during which many marine and terrestrial animals and plants, from microscopic varieties to massive dinosaurs, suddenly became extinct. Many scientists accept that the Cretaceous extinctions resulted from the impact of a large meteorite that produced the Chicxulub impact crater along the northern coast of Mexico's Yucatan Peninsula. The extinctions may also have been coupled with the **regression** of shallow seas and massive volcanism in India.

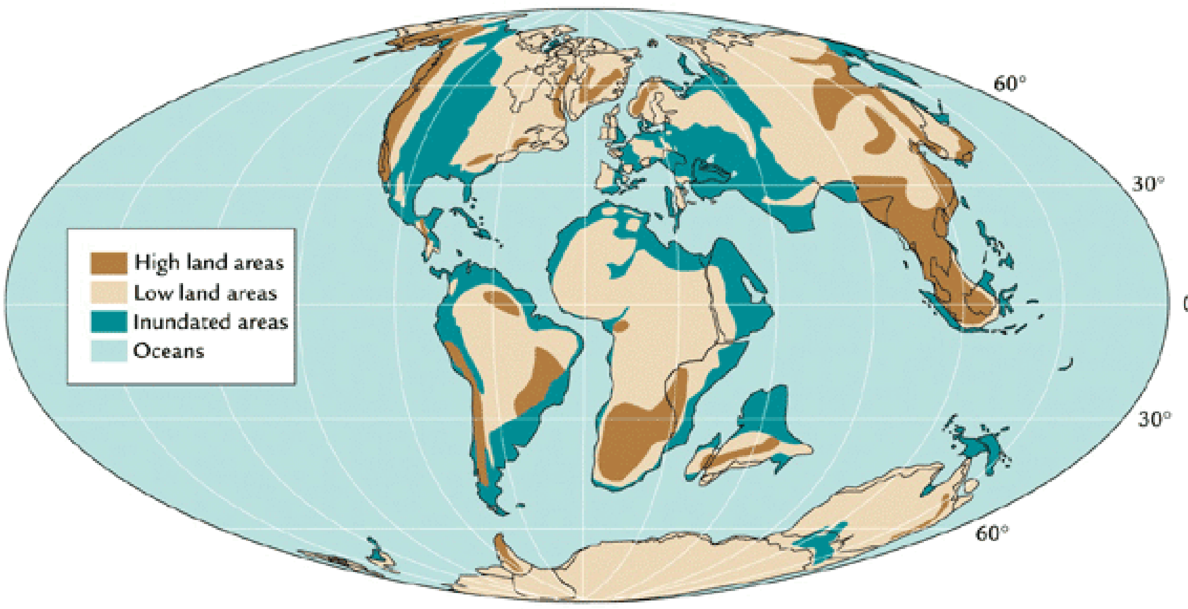
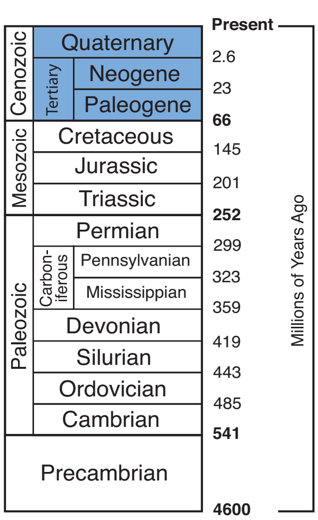


Figure 1.14: Landmasses following the breakup of Pangaea. (See TFG website for full-color version.)



Because the North American plate was (and still is) drifting away from the Mid-Atlantic Ridge during the Cenozoic, mountain building along the plate's eastern margin ceased. Instead, sediment eroding from existing mountains was gradually deposited along North America's **passive continental margin**. Despite minimal tectonic activity in the Coastal Plain area throughout the last 140 million years, the face of the land continued to change significantly due to erosion, deposition, sea level fluctuations, and the **ice age**.

The Coastal Plain of the South Central US is the largest and generally youngest region. Its geology is also relatively straightforward: sediment eroded in the north and west since the Cretaceous has been transported and deposited on the shores of the Gulf of Mexico. In fact, the Coastal Plain's outermost portion marks the approximate shoreline of the Gulf during the Cretaceous. Over the subsequent 70 million years, sediment from the west and north has filled in the Gulf, pushing the shore roughly 300 to 800 kilometers (190 to 500 miles) east and south to its current position, with sediment deposits 15,000 to 18,000 meters (49,000 to 59,000 feet) thick. The depositional settings that formed the Coastal Plain are similar to those seen today, including river, **floodplain**, shoreline, **delta**, and shallow marine environments. The region is still an active environment of deposition, and deposits become increasingly younger toward the Gulf (*Figure 1.15*).

In Texas, the Coastal Plain extends west to the Balcones Fault and Escarpment, commonly regarded as the division between upland and lowland Texas. This relatively low-stress fault is thought to have formed 15 million years ago as a result of the Coastal Plain having "settled" relative to the bedrock of the upland (part of the Great Plains region), but it occasionally still generates small earthquakes. The entire state of Louisiana is found within the Coastal Plain, where Cenozoic deposits formed as the sea advanced and retreated on several occasions. The huge volume of sediment deposited by the Mississippi River helped to build the greatest breadth of the Coastal Plain, which stretches approximately 800 kilometers (500 miles) from southeastern Missouri to the Mississippi Delta.

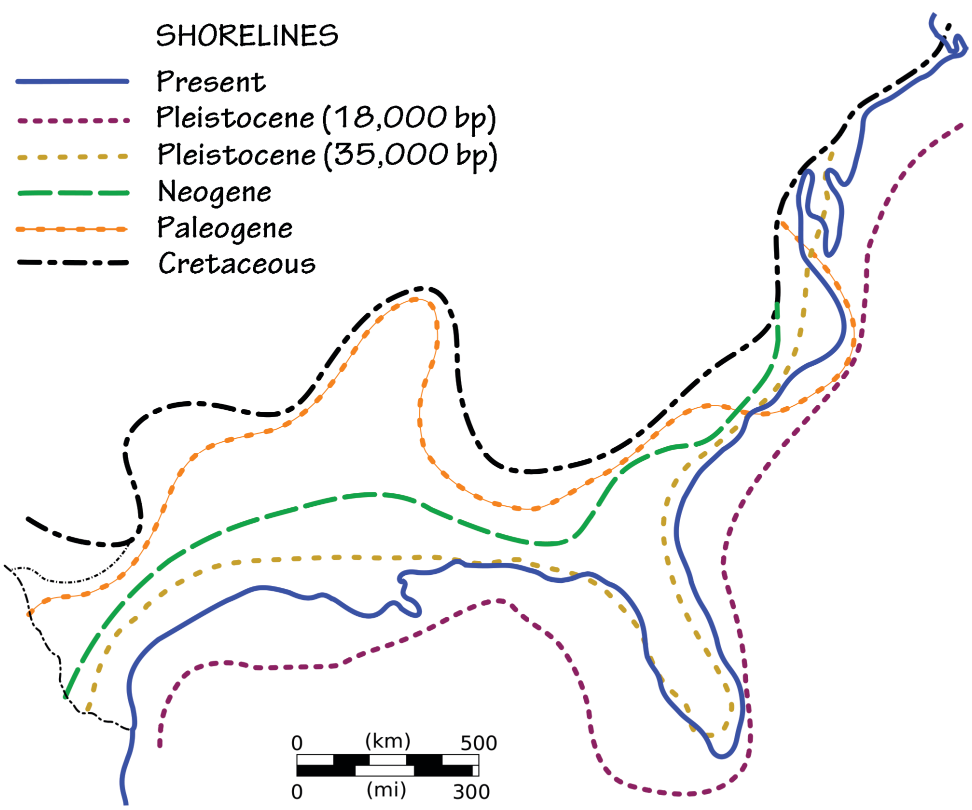


Figure 1.15: Shoreline positions along the Coastal Plain during the past 70 million years. The shoreline reflects the regression that resulted from the last significant glacial advance of the modern ice age. (See TFG website for full-color version.)

Cenozoic

regression *• a drop in sea level.*

passive margin *• a tectonically quiet continental edge where crustal collision or rifting is not occurring.*

ice age *• a period of global cooling of the Earth's surface and atmosphere, resulting in the presence or expansion of ice sheets and glaciers.*

floodplain *• the land around a river that is prone to flooding.*

delta *• a typically wedge-shaped deposit formed as sediment is eroded from mountains and transported by streams across lower elevations.*

Era		Period	Millions of Years Ago
			Present
Cenozoic		Quaternary	2.6
Cenozoic	Tertiary	Neogene	23
Cenozoic	Tertiary	Paleogene	66
Mesozoic		Cretaceous	145
Mesozoic		Jurassic	201
Mesozoic		Triassic	252
Paleozoic		Permian	299
Paleozoic	Carbon-iferous	Pennsylvanian	323
Paleozoic	Carbon-iferous	Mississippian	359
Paleozoic		Devonian	419
Paleozoic		Silurian	443
Paleozoic		Ordovician	485
Paleozoic		Cambrian	541
		Precambrian	4600

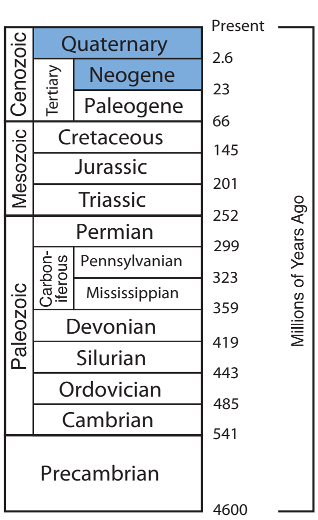
Ice Age

isostasy • *an equilibrium between the weight of the crust and the buoyancy of the mantle.*

ice sheet • *a mass of glacial ice that covers part of a continent and has an area greater than 50,000 square kilometers (19,000 square miles).*

Pleistocene • *a subset of the Quaternary, lasting from 2.5 million to about 11,700 years ago.*

Holocene • *the most recent portion of the Quaternary, beginning about 11,700 years ago and continuing to the present.*



By the **Neogene**, the Farallon plate lay shallowly under the North American plate for hundreds of kilometers eastward of the West Coast. Now situated more fully beneath what are now the South Central, Southwestern, and Rocky Mountain States, this extra layer of crust caused uplift and extension of the region, as the added thickness of buoyant rock (relative to the mantle) caused the entire area to rise **isostatically**. The Farallon plate was subjected to increasing temperatures as it subducted, causing it to expand; as heat dissipated to the overlying North American plate, that rock expanded as well. Finally, the high temperatures in the upper mantle caused the Farallon plate to melt, and the resulting magma was injected into the North American plate, destabilizing it. These processes caused the surface of the North American plate to pull apart and fault into the mountainous blocks of the huge Basin and Range province, a portion of which is found in West Texas.

The Ice Age:
Mountains of Ice

At the start of the **Quaternary** period, about 2.5 million years ago, continental **ice sheets** began to form in northernmost Canada. Throughout this period, the northern half of North America has been periodically covered by continental glaciers that originated in northern Canada (*Figure 1.16*). The Quaternary period is divided into two epochs: the **Pleistocene** and **Holocene**. During the Pleistocene, ice sheets advanced south and retreated north several dozen times. The Holocene epoch is the most recent (and current) period of retreat, called an **interglacial** interval. The most recent glacial advance in North America reached its maximum extent 25,000–18,000 years ago, while the beginning of the Holocene is considered to be 11,700 years ago, or about 9700 BCE.

The entire United States was affected by the cooling climate during the most recent ice age. A cooling climate contributes to the growth of continental glaciers: as more snow falls in the winter than melts in the summer, the snow packs into dense glacial ice. In this case, as snow and ice continued to accumulate on the glacier, the ice began to move under its own weight and pressure. The older ice on the bottom was pushed out horizontally by the weight of the overlying younger ice and snow. Glacial ice then radiated out from a central point, flowing laterally in every direction away from the origin (*Figure 1.17*). As a result, the continental glacier that originated in Canada migrated southwards toward the United States.

In the South Central, continental glaciers extended southward into northeastern Kansas and northern Missouri, as evidenced by **quartzite erratics**, **till**, glacial lake deposits, and **loess**. During this time, the ice advanced as far south as the Missouri River, and the meltwater from the glaciers likely cut through the landscape to form the river's original valley. The predominant effects of the Pleistocene ice age on the Coastal Plain were the rise and fall of sea level,

Figure 1.16: Extent of glaciation over North America.

subsequent erosion and deposition, and changes in **weather**, drainage patterns, and the distribution of plant and animal species. At the peak of the **last glacial maximum**, sea level dropped more than 100 meters (328 feet) below the current level (*see Figure 1.15*). Widely fluctuating sea levels drastically affected the erosion and deposition of sediment on the Coastal Plain, creating scarps and river **terraces** and steepening stream gradients, which resulted in more rapid streambed erosion.

Glaciers indirectly affected the majority of the South Central in a variety of ways. Meltwater from the north was filled with sediment that accelerated erosion, carving most of the region's modern river valleys into the landscape. As the flowing water approached the coast and slowed, it dumped its load of sediment, helping to build the Coastal Plain out into the Gulf of Mexico. Quaternary-aged

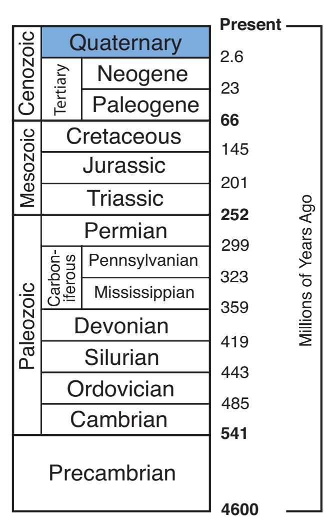
Ice Age

quartzite • *a hard metamorphic rock that was originally sandstone.*

erratic • *a piece of rock that differs from the type of rock native to the area in which it rests, carried there by glaciers often over long distances.*

till • *unconsolidated sediment that is eroded from the bedrock, then carried and eventually deposited by glaciers as they recede.*

loess • *very fine grained, wind-blown sediment, usually rock flour left behind by the grinding action of flowing glaciers.*



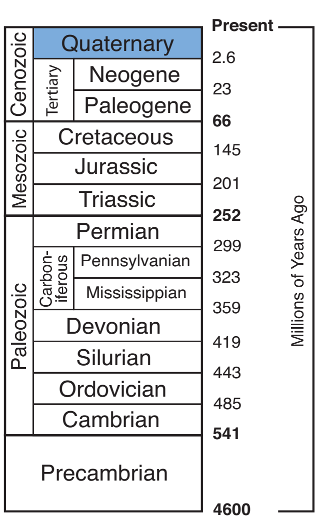
Ice Age

rock flour *• very fine sediments and clay resulting from the grinding action of glaciers.*

wind *• the movement of air from areas of high pressure to areas of low pressure.*

soil *• the collection of natural materials that collect on Earth's surface, above the bedrock.*

Figure 1.17: Continental glaciers originating in Canada spread across North America, including the northern portion of the South Central region, during the Quaternary period.



floodplains along the banks of the Mississippi and Missouri Rivers were also composed of a significant amount of glacial sediment. **Rock flour** from these floodplains was blown by the **wind**, covering much of Missouri and Mississippi in layers of loess. Deposits of this silt provide the foundation for the rich **soils** that exist in much of the central United States. Glacial meltwater and sediment also constructed the outermost 80 kilometers (50 miles) of the Coastal Plain, especially the Mississippi Delta. Nearly all of Louisiana's surface is Neogene- or Quaternary-aged, unconsolidated or semi-consolidated sediment deposited by water.

See Chapter 6: Glaciers to learn more about glaciation and the ways in which the last ice age affected the South Central.

The ice age continues today, but the Earth is in an interglacial stage, since the ice sheets have retreated for now. The current interglacial period has slowed both erosional and depositional processes in the South Central—this and a higher, more stable sea level allowed coastal features such as barrier islands and lagoons to form, resulting in the landscape we know today. The glacial-

Geologic History 1

Ice Age

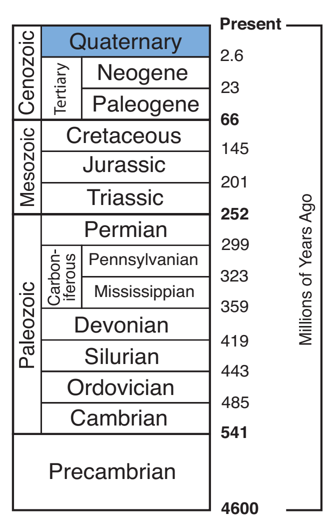
Why was there an ice age?

What led to the formation of large continental glaciers in the Northern Hemisphere 2.5 million years ago? Movement of the Earth's plates may have been a direct or indirect cause of the glaciation. As plates shifted, continents moved together and apart, changing the size and shape of the ocean basins, and altering ocean currents that transported heat from the equator to the poles. Sufficient precipitation in northern Asia and North America also enabled continental glaciers to grow and flow outward. The rise of the Himalayas exposed new rock that trapped carbon dioxide through chemical weathering; in turn, the decreased levels of carbon dioxide led to a global cooling. Finally, the presence of continental landmasses (Antarctica and to some extent Greenland) over or near the poles was also a major factor in the development of continental glaciers, as precipitation could now be deposited on these landmasses.

__climate change__ • See global warming: the current increase in the average temperature worldwide, caused by the buildup of greenhouse gases in the atmosphere.

interglacial cycling of ice ages indicates that the world will return to a glacial stage in the future, but the impacts of human-induced **climate change** might radically shift the direction of these natural cycles.

See Chapter 9: Climate to learn more about how climate change affects the environment.



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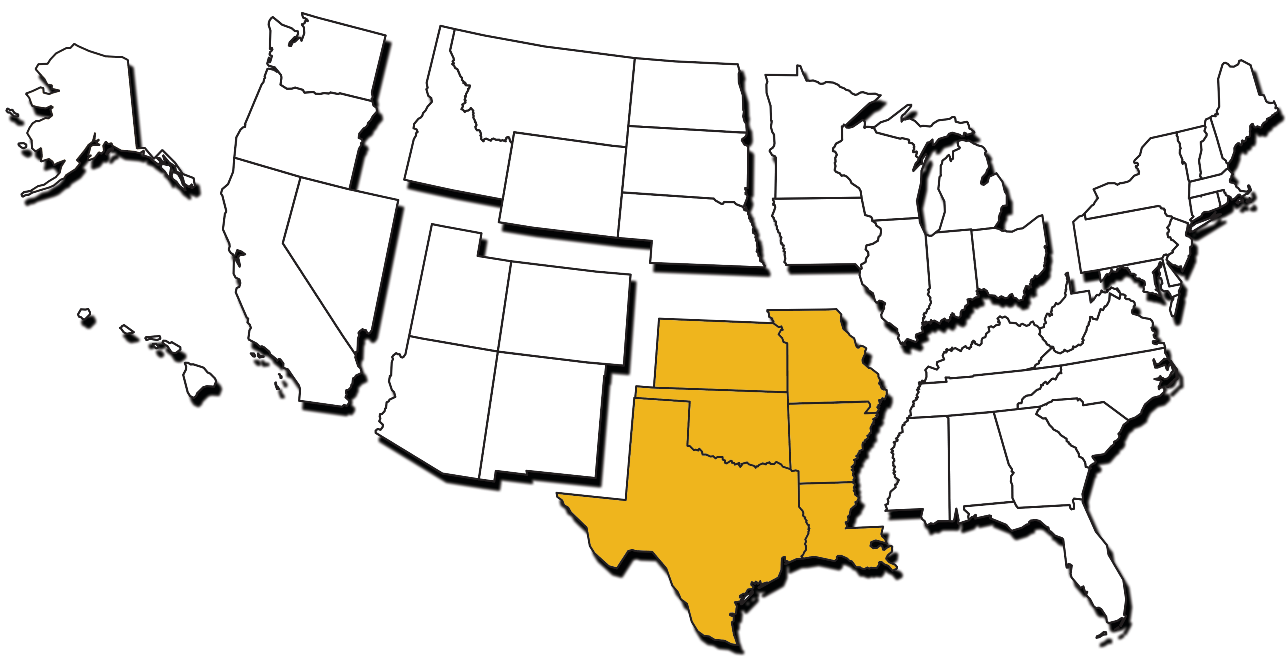

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On the back cover: Blended geologic and digital elevation map of the South Central US. Each color represents the age of the bedrock at the surface. Adapted from Barton, K. E., D. G. Howell, & J. F. Vigil, *The North America Tapestry of Time and Terrain*, US Geological Survey Geologic Investigations Series I-2781, http://pubs.usgs.gov/imap/i2781.