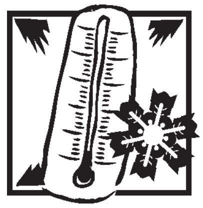

Chapter 6: Glaciers in the South Central US

Most people may not picture the South Central as an area that once contained **glaciers**, but the northern parts—northern Kansas and Missouri—were reached by the most extreme glacial advances of the late **Pleistocene** (*Figure 6.1*), and **weathering** and deposition indirectly associated with glaciation have occurred in other parts of this area. During the **Quaternary** period, which began just 2.6 million years ago and extends to the present, ice at times extended southward from the Hudson Bay area and over the northern United States. These **ice sheets** scraped away and ground up whatever rock was at the surface. When the ice finally retreated, it deposited the rock and dirt it had been carrying, influencing the landscape long after the ice was gone. Because glaciers affected the South Central in ways that do not directly correspond with bedrock in its different regions (which is not to say that bedrock is irrelevant), this chapter is instead organized according to the geographic areas associated with glacial processes.

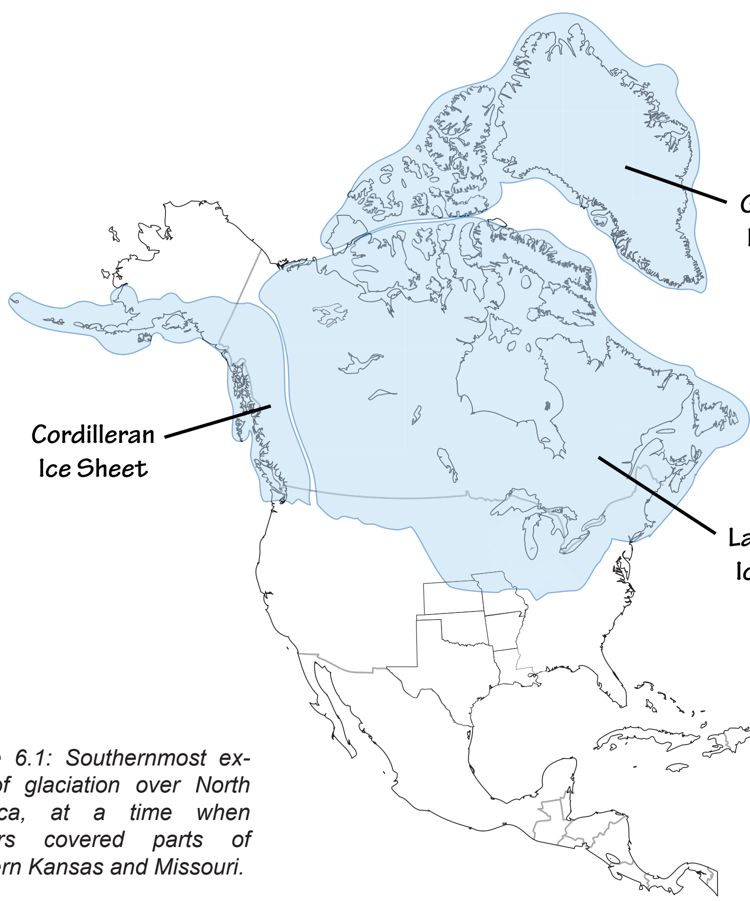

Figure 6.1: Southernmost extent of glaciation over North America, at a time when glaciers covered parts of northern Kansas and Missouri.

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

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

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

Quaternary • *a geologic time period that extends from 2.6 million years ago to the present.*

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).*

CHAPTER AUTHOR

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6 Glaciers

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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).*

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

firn • *compacted glacial ice, formed by the weight of snow on top.*

ablation zone • *the front part of a glacier, where ice is lost due to melting and calving.*

calving • *the process by which ice breaks off from the end of a glacier.*

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

What is a glacier?

A glacier is a large mass of ice (usually covered by snow) that is heavy enough to flow like a very thick fluid. Glaciers form in areas where more snow accumulates than is lost each year; a cold **climate** and sufficient moisture in the air for the precipitation of snow are both necessary factors that permit at least some snow to last year round. As new snow accumulates, it buries and **compresses** old snow, transforming it from a fluffy mass of snowflakes into ice crystals with the appearance of wet sugar, known as **firn**. As this firn is buried deeper, it coalesces into a mass of hard, dense ice that is riddled with air bubbles. Much of this transformation takes place in the high part of a glacier where annual snow accumulation outpaces snow loss—a place called the **accumulation zone**. At a depth greater than about 50 meters (165 feet), the pressure is high enough for plastic flow to occur. Ice flow is driven by gravity, and it causes movement downhill and out from the center (*Figure 6.2*). Once the ice becomes thick enough, it flows outward to the **ablation zone***,* where ice is lost due to melting and **calving**. The boundary between these two zones, the equilibrium line, is found where annual ice accumulation equals annual ice loss. Because the altitude of this line is dependent on local temperature and precipitation, glaciologists frequently use it to assess the impact of **climate change** on glaciers.

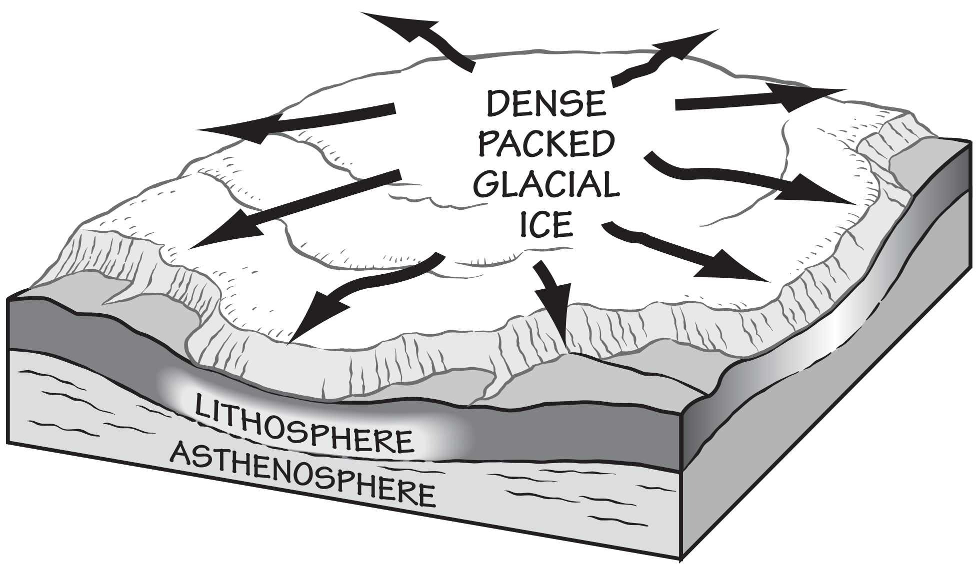

Figure 6.2: As dense glacial ice piles up, a glacier is formed. The ice begins to move under its own weight and pressure.

Most broadly, there are two types of glaciers: smaller alpine glaciers and larger continental glaciers. Found in mountainous regions, alpine glaciers have a shape and motion that is largely controlled by **topography**, and they naturally flow from higher to lower altitudes. Alpine glaciers may fill part of a single valley, or they may cap an entire mountain range.

Continental glaciers are much larger, and they are less controlled by the landscape, tending to flow outward from their center of accumulation. It is not surprising that today's continental glaciers, also called ice sheets, are found in the high latitude polar regions of Greenland and Antarctica where temperatures are low most of the year. Keep in mind that there must be landmasses at high latitudes for continental glaciers to occur, as by definition they cannot form over open water. While persistent sea ice can and does form, the fact that it floats prevents it from flowing as a glacier does. The glaciers that stretched over northern North America as recently as 20,000 years ago were primarily continental ice sheets.

While only the two broadest categories of glaciers are discussed here, glaciers exist in a variety of forms. Even these broadest of distinctions are not quite so clear-cut (e.g., continental glaciers often have tongues that feed into valleys, which may become alpine glaciers).

In summary, glaciers grow when it is cool enough for an ice sheet to accumulate snow more quickly than it melts. As they grow, ice sheets become so massive that they flow outwards, covering an increasing area until melting at the margins catches up to the pace of accumulation. Glaciers that reached the South Central states of Kansas and Missouri flowed from centers of accumulation far to the north (in what is now Canada), and glacial growth southward through the Midwest was more a result of this lateral flow than of direct precipitation from falling snow. By 18,000 years ago, the ice was in retreat due to a slight warming of the climate—it was not actually flowing backwards, but melting faster than it was accumulating and advancing.

Glacial Landscapes

The interaction of glaciers with the landscape is a complex process. Glaciers alter landscapes by **eroding**, transporting, and depositing rock and sediment. **Scouring** abrades bedrock and removes sediment, while melting causes the ice to deposit sediment. Glacial features like **moraines**, **drumlins**, and **kettles** occasionally break the pattern of gently rolling hills found in most of the Midwest north of Kansas and Missouri (*Figure 6.3*). Even in areas where glaciers did not reach, glacial runoff changed the landscape—meltwater loaded with abrasive sediment carved the landscape, making it more rugged.

See Chapter 4: Topography to learn more about the marks glaciers left on the South Central's landscape.

Continental glaciers also affect the landscape by depressing the Earth's **crust** with their enormous mass, just as a person standing on a trampoline will cause the center to bulge downwards. The effect is quite substantial, with surfaces being lowered by hundreds of meters. Of course, this means that when the glacier retreats and the mass is removed, the crust will rise to its former height

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

erosion • *the transport of weathered materials.*

scouring • *erosion resulting from glacial abrasion on the landscape.*

moraine • *an accumulation of unconsolidated glacial debris (soil and rock) that can occur in currently glaciated and formerly glaciated regions.*

drumlin • *a teardrop-shaped hill of till that was trapped beneath a glacier and streamlined in the direction of the flow of the ice moving over it.*

kettle • *a lake formed where a large, isolated block of ice became separated from the retreating ice sheet.*

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

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

__reef__ • a feature lying beneath the surface of the water, which is a buildup of sediment or other material built by organisms, and which has positive relief from the sea floor.

__plucking__ • process in which a glacier "plucks" sediments and larger chunks of rock from the bedrock.

__frost wedging__ • weathering that occurs when water freezes and expands in cracks.

__sand__ • rock material in the form of loose, rounded, or angular grains, and formed as a result of the weathering and decomposition of rocks.

__clay__ • the common name for a number of very fine-grained, earthy materials that become plastic (flow or change shape) when wet.

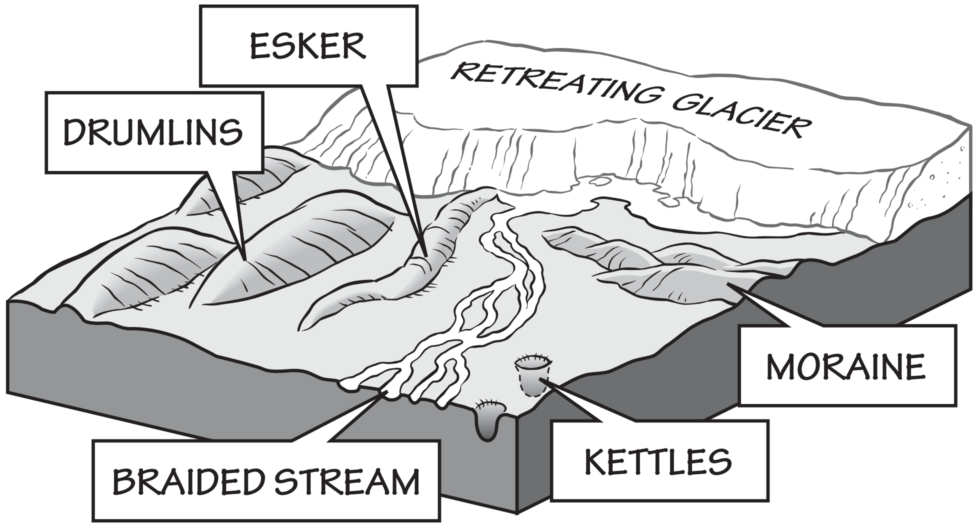

Figure 6.3: Common glacial landscape features.

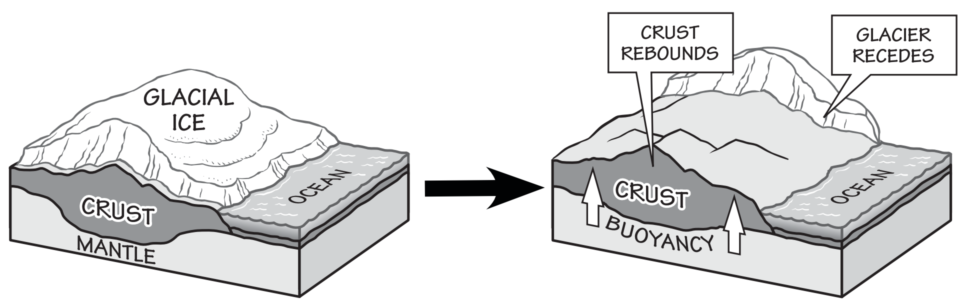

Figure 6.4: Isostatic rebound resulting from glacial retreat.

in a process known as **isostasy** (*Figure 6.4*)**.** Dramatic results include marine **reefs** lifted high above sea level and marine sediments composing coastal bluffs.

Erosion

Thousands of years of scraping by ice can have dramatic, and sometimes dramatically varied, effects on a landscape. Glaciers erode the land they flow over via abrasion and **plucking**. Harder bedrock will be scratched and polished by sediment stuck in the ice, while **frost wedging**, when water freezes and expands in cracks, can eventually break chunks of rock away. Softer bedrock is much more easily carved and crushed. Abrasion, or scouring, occurs when rock fragments in the ice erode bedrock as the glacier moves over it. Plucking involves glaciers literally pulling rock from underlying bedrock. The flowing ice cracks and breaks rock as it passes over, pieces of which become incorporated in the sheet or bulldozed forward, in front of the glacier's margin. The less resistant rock over which glaciers move is often eroded and ground-up into very fine **sand** and **clay** (called **rock flour**). Once eroded, this material is carried away by the ice and deposited wherever it melts out.

More resistant **igneous** and **metamorphic rock** is often polished and scratched by the grinding action of sediments trapped in the glacial ice. Streams of meltwater from the glacier, frequently gushing and full of sediment, cause significant amounts of scour as well. The abrasive sediments in the flowing water create **potholes** in the bedrock and **plunge pools** at the base of waterfalls. At the edge of the sheet, where the ice at last succumbs to melting, the rock is finally deposited. Piles of this rock form some of the distinctive landforms found in Kansas and Missouri today.

The nature of the glacier causing the erosion is also crucial. Because continental glaciers spread from a central accumulation zone, they cannot go around peaks in their path, so they instead slowly crush and scrape them away. For the most part, this results in flatter landscapes. Conversely, alpine glaciers tend to follow the existing topography, flowing downhill. This frequently causes them to scour existing low points, making them lower still. While this gouging increases the overall **relief** of an area, anything directly in the path of the ice is flattened. For example, a glacier might deepen a valley while surrounding peaks remain high, yet the valley itself, initially cut by a narrow stream into a sharp V-shape, is smoothed into a distinctive U-shape by the wider glacier.

Deposition

As glaciers scrape over the earth, sediment is incorporated into or shoved ahead of the advancing ice. The unsorted mixture of boulders, **gravel**, sand, **silt**, and clay that is picked up and later deposited by glaciers is called **till**. It is important to note that whether a glacier is advancing, in equilibrium, or retreating, its ice is still flowing forward, like a conveyor belt that is constantly depositing till at its margin. In places where a glacier stopped its advance and then melted back, a ridge of till that had been pushed in front of it is left behind, marking the farthest extent of the glacier's margin, or terminus. A ridge of till formed this way is called a moraine, and it may range in length from hundreds to thousands of meters (*see Figure 6.3*). A drumlin is a teardrop-shaped hill of till that was trapped beneath a glacier and streamlined in the direction of the flow of the ice moving over it (*Figure 6.5*). The elongation of a drumlin provides an excellent clue to the direction of flow during an ice sheet's most recent advance.

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

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.*

pothole • *a shallow, rounded depression eroded in bedrock by a glacier.*

plunge pool • *a stream pool, lake, or pond that is small in diameter, but deep.*

relief • *the change in elevation over a distance.*

Figure 6.5: A drumlin field.

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braided stream • *a stream consisting of multiple, small, shallow channels that divide and recombine numerous times, forming a pattern resembling strands of braided hair.*

esker • *a sinuous, elongated ridge of sand and gravel.*

kame • *an irregularly shaped mound made up of sediment that accumulated in a depression on a retreating glacier.*

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.*

Meltwater flowing off a glacier also leaves behind deposits. Unlike till deposits, meltwater deposits are well sorted: large rocks can only be moved by high-energy water, while finer sand and mud are washed downstream until enough energy is lost so that even they are dropped. In other words, the faster the water is moving, the coarser the sediment deposited (*Figure 6.6*). As a glacier melts, streams of sediment-laden meltwater often create networks of **braided streams** in front of the glacier. Streams of meltwater flowing under a glacier can deposit sand and gravel, and when an ice sheet retreats, these snaking ridges of stream deposits, known as **eskers**, are left behind (*Figure 6.7*).

Well-sorted deposits have relatively uniform grain size.

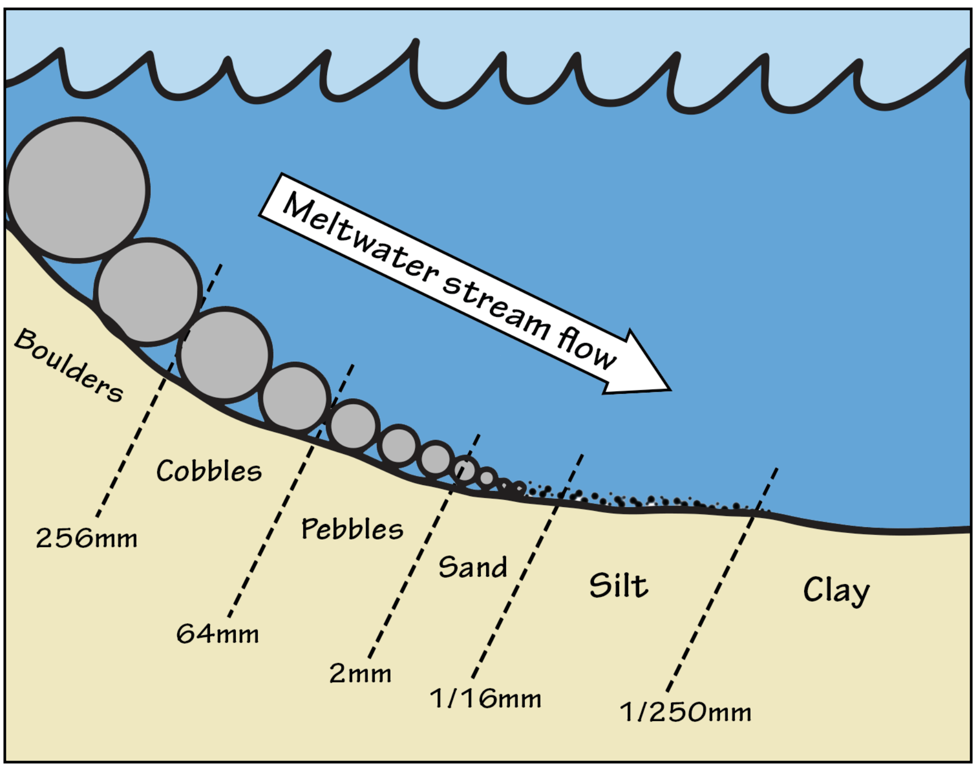

Figure 6.6: Moving water deposits sediment in what is known as a horizontally sorted pattern. As water slows (i.e., loses energy) with decreased gradient, it deposits the large particles first. The sizes in the figure represent the boundaries between categories of sediment type.

Other glacial features include kettles, **kames**, and **erratics**. Kettles are depressions left behind by the melting glacier. Blocks of ice may be broken off from the glacier and buried or surrounded by meltwater sediments (*Figure 6.8*). When the ice eventually melts, the overlying sediments have no support, so they frequently collapse and form a depression that often fills with water to become a lake. Kames are formed in nearly the opposite way: layers of sediment fill in depressions in the ice, leaving mound-like deposits of sorted sediment after the glacier retreats (*Figure 6.9*). Often, kettles and kames occur near one another.

Figure 6.7: Eskers are composed of sand and gravel deposited by streams that flowed under the ice, partially filling the sub-ice channel. When the ice melts, the sinuous deposit remains.

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

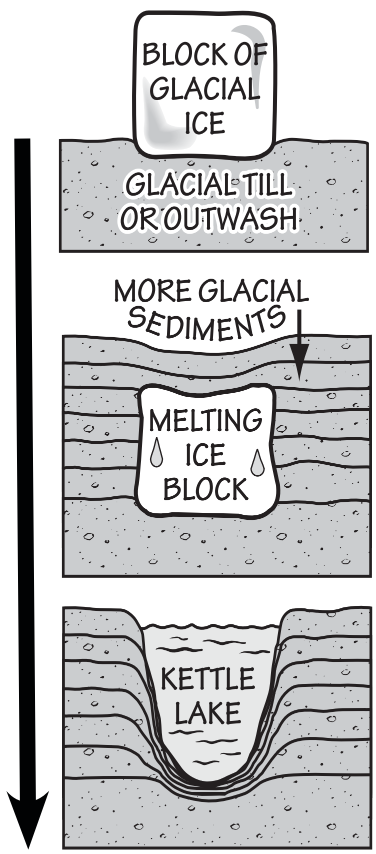
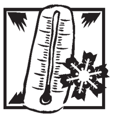


Figure 6.8: Kettle lakes form where large, isolated blocks of ice become separated from the retreating ice sheet. The weight of the ice leaves a shallow depression in the landscape that persists as a small lake.

Erratics are rocks that the ice sheet picked up and transported farther south, sometimes hundreds of kilometers (miles) from their origin. They are often distinctive because they are a different type of rock than the bedrock found in the area to which they have been transported. For example, boulders and pebbles of igneous and metamorphic rocks are often found in areas where the bedrock is **sedimentary**. It is sometimes possible to locate the origin of an erratic if its composition and textures are highly distinctive. The pink-colored Sioux quartzite erratics found across much of northwestern Kansas are one such example; they originated in the area where Minnesota, South Dakota, and Iowa intersect.

Periglacial Environments

Though little of the South Central was covered by ice sheets, much of the area felt their effects. The portion covered by the ice sheet was scoured and covered with glacial deposits, while the



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

permafrost • *a layer of soil below the surface that remains frozen all year round. Its thickness can range from tens of centimeters to a few meters.*

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

fracture • *a physical property of minerals, formed when a mineral crystal breaks.*

joint • *a surface or plane of fracture within a rock.*

talus • *debris fields found on the sides of steep slopes, common in periglacial environments.*

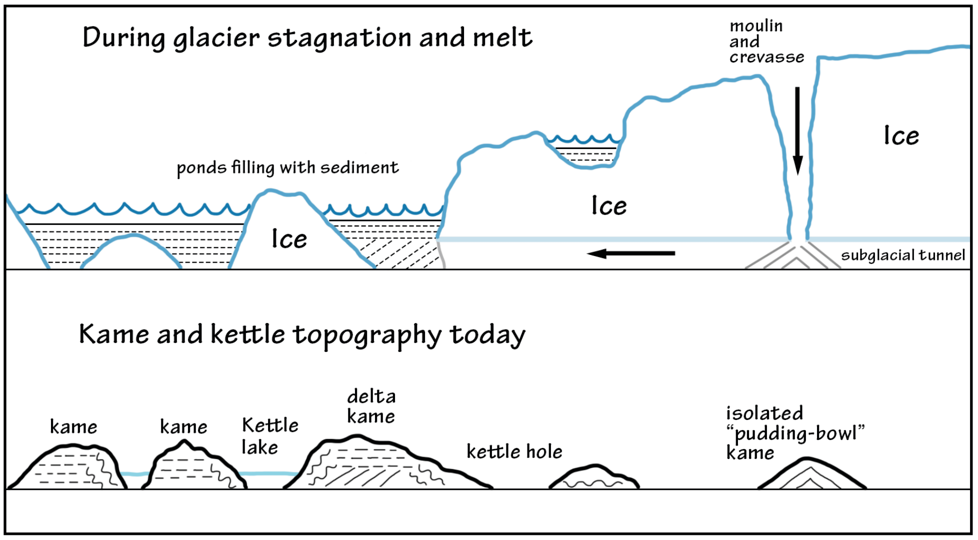

Figure 6.9: Glacial sediment deposits and the resulting hills called kames.

area south of the ice sheet developed its own distinctive landscape and features due to its proximity to the ice margin. This unglaciated but still affected area is called a **periglacial zone**.

The average annual air temperature in a periglacial area is between -12˚ and 3˚C (10˚ and 37˚F). Though the surface of the ground may melt in the summer, it refreezes in the winter.

There are a variety of features associated with a periglacial zone that also provide clues to the extent of the most recent ice sheet. In the tundra-like environment of a periglacial zone, **aeolian**, or windblown deposits, are common. Sand dunes and **wind**-transported sediments are found in former periglacial areas of the South Central.

The **permafrost** associated with the periglacial area, in which the ground is frozen much of the year, can cause mass movement of sediment. When the surface layer of the permafrost ground thaws, it is full of moisture. This water-heavy layer of **soil** may move rapidly down a hill in a process called **solifluction**.

Physical weathering of the bedrock is magnified in the periglacial environment because of the freeze-thaw cycles associated with permafrost. When water enters the cracks and fissures in the ground and subsequently freezes, the ice wedges the cracks farther and farther apart (*Figure 6.10*). Freeze-thaw is important in any climate that cycles above and below the freezing point of water. Because ice takes up more space than water, the pre-existing cracks and **fractures** are widened when the water freezes. Along ridges, rocks are eventually broken off as ice wedges continue to expand in **joints** and fractures. The boulders and blocks of bedrock roll downhill and are deposited along the slope or as fields of **talus**. Frost action also brings cobbles and pebbles to the surface to form nets, circles, polygons, and garlands of rocks. These unusual patterns of sorted rock are known as **patterned ground**. Solifluction and ice wedging are found exclusively where the ground remains perennially frozen yet is not insulated by an ice sheet. Such conditions only occur in areas adjacent to ice sheets. While conditions like these existed in parts of the South Central and must have led to the formation of patterned ground, any evidence has subsequently been covered with glacial sediment or eroded away.

Physical weathering **is the break-up of rock due to physical processes (such as erosion by wind, water, and ice) rather than chemical processes.**

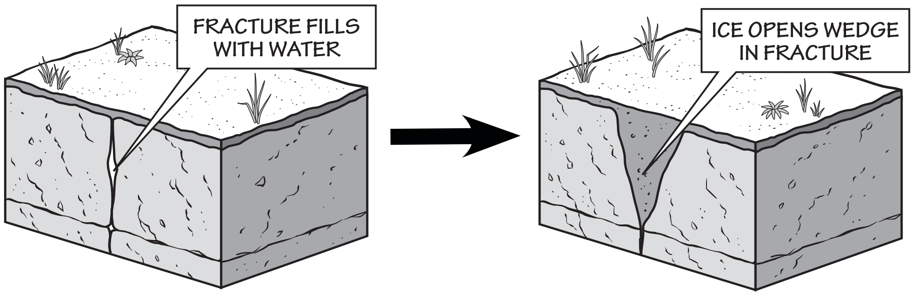

Figure 6.10: Physical weathering from a freeze-thaw cycle.

Glaciers and Climate

Glaciers are sometimes called the "canary in the coal mine" when it comes to climate change. This is because alpine glaciers are highly sensitive to changes in climate. For instance, a glacier grows (advances) when it accumulates more ice than it loses from melting or calving. Advances tend to happen when cold, wet years dominate the local climate. On the other hand, a glacier will shrink (retreat) during warm, dry periods as it loses more ice than it gains each year.

As discussed in the chapter on climate, for much of Earth's history there have not been persistent ice sheets in high latitudes. Any time that the world is cool enough to allow them to form is called an "**ice age**." Based on this definition, we are living in an ice age right now! The current ice age began about 34 million years ago when ice sheets were first forming on Antarctica, followed by on Greenland at least 18 million years ago, and finally on North America, which defined the beginning of the Quaternary period (about 2.6 million years ago). When most people use the phrase "the ice age," however, they are referring to the **last glacial maximum** during which much of North America and Europe covered in ice thousands of meters (feet) thick and many kinds of large, wooly mammals roamed the unfrozen portions of those continents.

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patterned ground • *patterns and sorting in the soil caused by repeated freezing and thawing, which causes repeated heaving upwards and settling of the rocks and pebbles in the soil.*

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.*

last glacial maximum • *the most recent time the ice sheets reached their largest size and extended farthest towards the equator, about 26,000 to 19,000 years ago.*

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Age of the Quaternary

In 2009, scientists at the International Commission on *Stratigraphy* voted to move the beginning of the Quaternary period to 2.6 million years ago, shifting it 0.8 million years earlier than the previous date of 1.8 million years ago—a date set in 1985. They argued that the previous start date was based on data that reflected climatic cooling that was only local to the region in Italy where it was first observed. In contrast, the 2.6 million year mark shows a global drop in temperature, and it includes the entirety of North American and Eurasian glaciation, rather than having it divided between the Quaternary and the earlier *Neogene* period.

The Quaternary period is divided into two epochs. The earlier Pleistocene encompasses the time from 2.6 million to 11,700 years ago, including all of the Quaternary up until the most recent episode of glacial retreat—the beginning of the **Holocene**. During the Pleistocene, there were several dozen intervals of glaciation separated by warmer **interglacial** intervals characterized by glacial retreat. In North America, these cycles are known as the **pre-Illinoian** (1.8 million–302,000 years ago), **Illinoian** (191,000–131,000 years ago), Sangamonian (131,000–85,000 years ago), and **Wisconsinan** (85,000–11,000 years ago). The Illinoian and Wisconsinian were cooler periods that saw glaciers advance, while the Sangamonian was a warm interglacial period.

The pre-Illinoian glaciation included many glacial and interglacial periods that were once subdivided into the Nebraskan, Aftonian, Kansan, and Yarmouthian ages. New data and numerical age dates suggest that the deposits are considerably more complicated; they are now lumped together into a single period. Most of the glacial features to the north in the Midwest were created during the Pleistocene, while glaciers that extended far enough to reach Kansas and Missouri only occurred during glaciations in the pre-Illinoian period.

Ice on a Schedule

The enormous continental glaciers that define an ice age are so large that their extent is most directly affected by global trends, while mountain glaciers are much more susceptible to local and short-term changes in climate. Continental ice sheets advance and retreat in cycles that last tens of thousands of years and are controlled to a large extent by astronomic cycles.

Scientists continue to debate the particular causes of the onset of glaciation in North America over two million years ago. Movement of the Earth's tectonic **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

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stratigraphy • *the branch of geology specifically concerned with the arrangement and age of rock units.*

Neogene • *the geologic time period extending from 23 to 2.6 million years ago.*

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

interglacial • *a period of geologic time between two successive glacial stages.*

pre-Illinoian glaciation • *a grouping of the Midwestern glacial periods that occurred before the Wisconsinian and Illinoian glaciations.*

Illinoian • *a period of glaciation that occurred during the Pleistocene, 191 to 131 thousand years ago.*

Wisconsinian glaciation • *the most recent interval of glaciation, which occurred during the Pleistocene, 85,000 to 11,000 years ago.*

Astronomic Cycles and Ice Sheets

The cyclical movements of ice sheets seem primarily to be caused by specific astronomic cycles called *Milankovitch cycles*, which change the amount of light the Earth receives, particularly when comparing the summer to the winter. The cycles, predicted through principles of physics a century ago, are related to the degree of tilt of the Earth, the Earth's distance to the sun, and the point in the Earth's revolution around the sun during which the Northern Hemisphere experiences summer. When the cycles interact such that there is milder seasonality (cooler summers and warmer winters) at high latitudes in the Northern Hemisphere, less snow melts in summer, which allows glaciers to grow. The cyclicity of glacial-interglacial advances was about 40,000 years from before the start of the Quaternary until about a million years ago. For reasons that aren't clear, however, the cycles changed to about 100,000 years. If not for human-induced climate change, we might expect glaciers to approach Kansas and Missouri again in about 80,000 years!

the ocean basins. This, in turn, altered oceanic currents. Mountain building, which occurred when continents collided, erected obstacles to prevailing winds and changed moisture conditions. The freshly exposed rock from the rising of the Himalayas also combined with **atmospheric** carbon dioxide through chemical weathering; this consequent decrease in levels of atmospheric carbon dioxide was at least partially responsible for global cooling. Finally, the presence of continental landmasses over one pole and near the other was also a major factor enabling the development of continental glaciers.

Seeking Detailed Records of Glacial-Interglacial Cycles

While glaciers have advanced over central North America and retreated again dozens of times during the Quaternary, each advance scrapes away and reworks much of what was previously left behind, making it difficult to reconstruct the precise course of events.

Therefore, to investigate the details of any associated climate change we must seek environments that record climate change and are preserved in the geologic record. Since the 1970s, the (international) Deep Sea Drilling Project has provided a treasure trove of data on coincident changes in the ocean, preserved in sediments at the ocean bottom (*Figure 6.11*). In the 1980s, coring of ice sheets in Greenland and Antarctica provided similar high-resolution data on atmospheric composition and temperature back nearly one million years

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

atmosphere • *a layer of gases surrounding a planet.*

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__Laurentide Ice Sheet__ • an ice sheet that covered most of Canada during the last major glaciation.

(*Figure 6.12*). The data from these programs have revealed that the Earth experienced dozens of warming and cooling cycles over the course of the Quaternary period. Traces of the earlier and less extensive Pleistocene glacial advances that must have occurred have been completely erased on land, so these advances were unknown before records from deep-sea cores and ice cores revealed them. These glaciations may have had indirect impacts on the South Central, particularly on sea level variations along the Gulf Coastal Plain, but they did not likely reach Missouri and Kansas.

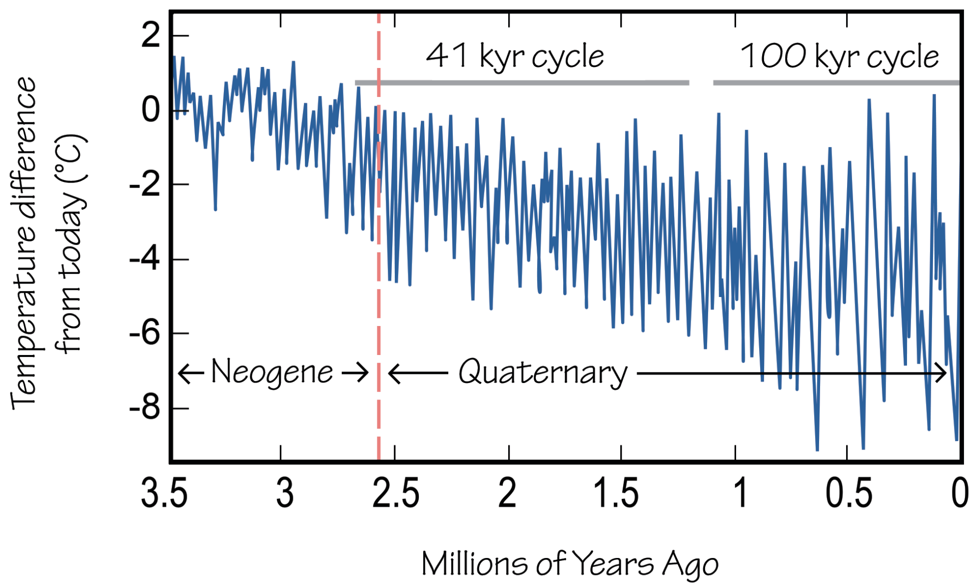

Figure 6.11: Ocean bottom temperatures from 3.6 million years ago to present, based on chemical analyses of foraminifera shells. Notice how the amplitude of glacial-interglacial variations increases through time, and how the length of cycles changes.

The Impact of Glaciation in the South Central

The direct influence of continental glaciers upon the surface of the South Central US is limited because even during the most extreme intervals of Pleistocene glaciation, the **Laurentide Ice Sheet** barely reached as far south as northern Missouri and Kansas (*see Figure 6.1*). Glacial deposits that exist in Missouri and Kansas can be difficult to date to a specific glacial advance and are simply labeled as pre-Illinoian. There were perhaps five pre-Illinoian glaciations in Missouri, representing glaciations as recently as a few hundred thousand years ago, and two in Kansas, the most recent being about 600,000 years ago.

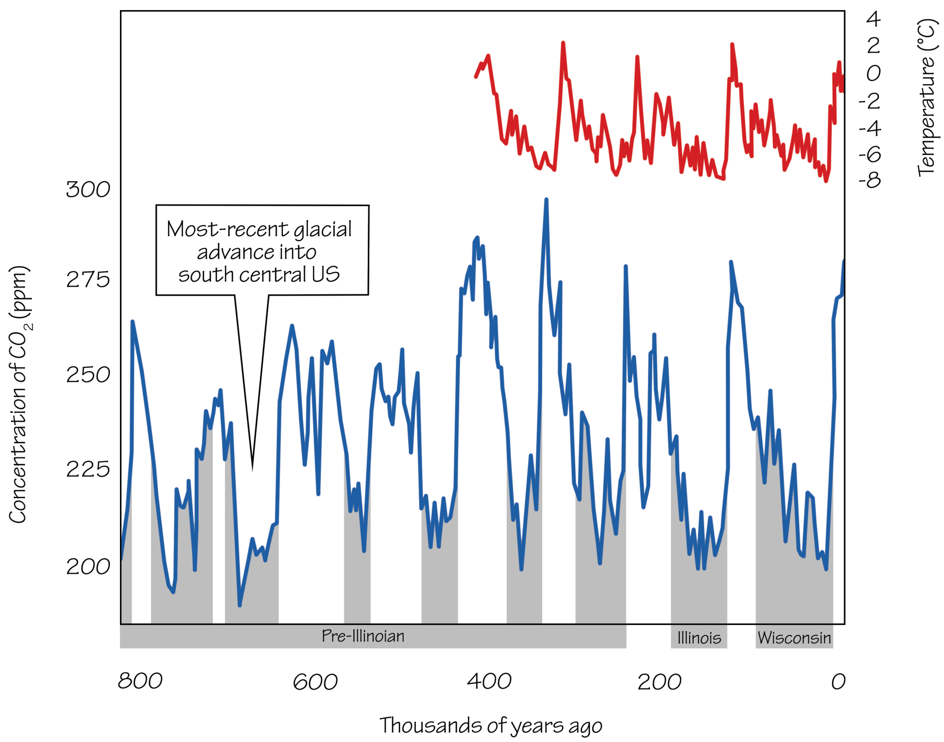

Figure 6.12: Ice core atmospheric temperature and carbon dioxide concentrations from an ice core taken in Vostok in Antarctica along with with CO_2 data from several cores in Greenland give a record of glacial advances over the past 800,000 years. Glacial deposits in the South Central are from pre-Illinoian advances.

Glacial **drift**, including large numbers of rocks from outcrops that occur farther north, is the primary evidence that remains of these glaciers (*Figure 6.13*). Larger glacial landforms that probably existed have since eroded away. Among the most distinctive glacial erratics found in the South Central are quartzite boulders, known as the Sioux quartzite, dragged by glaciers from the area

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drift *• unconsolidated debris transported and deposited by a glacier.*

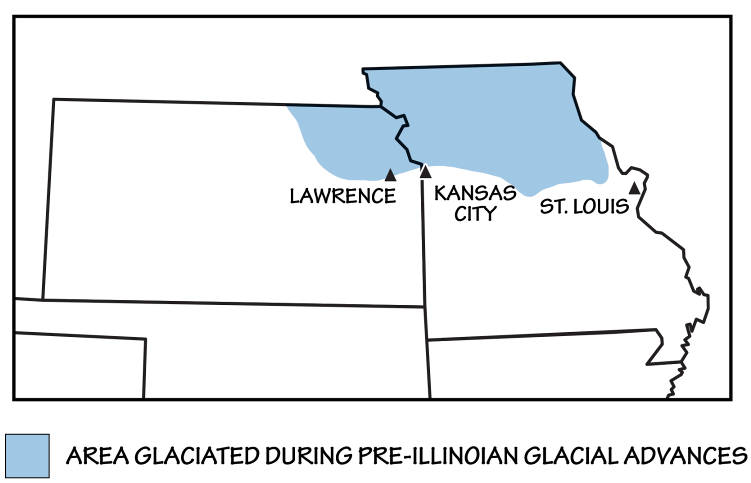

Figure 6.13: The distribution of glacial debris in Kansas and Missouri, marking the southernmost extent of glacial advance into the South Central US.

Review

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

of Sioux Falls, South Dakota (*Figure 6.14*). Perhaps because quartzite is so resistant to erosion, boulder fields of this rock can be especially prominent.

Figure 6.14: This Sioux quartzite erratic is located in the center of Granite Street in McLouth, Kansas. When the town was originally laid out in the 1880s, workers were unable to move the boulder, so they simply paved the road around it.

By 18,000 years ago, the ice sheet was in retreat due to a slight warming of the climate. Though the ice sheet alternately moved forward and melted backward, overall it was on the retreat. Even during glacial advance, the glacier was always melting at its fringes. During times of glacial retreat, the ice sheet was not actually flowing backwards—the glacier continued to flow forward, but it was melting faster than it was advancing.

The Loess Hills

The Loess Hills of extreme western Iowa, extending into northwesternmost Missouri, are named after a glacial deposit formed of windblown rock flour: **loess**. This type of glacial feature is found in significant quantities in only a few places on Earth. These hills form narrow, 320-kilometer (200-mile) long, north-south bands immediately east of the Missouri and Mississippi River **floodplains**, and thinner deposits across Kansas and central Missouri (*Figure 6.15*). They were formed during several glacial/interglacial cycles when glaciers ground down the bedrock. Later, as the ice retreated, meltwater deposited the fine sediments in expansive mudflats. When the mudflats dried, strong westerly winds blew the sand into great dunes, and the finest material (silt and clay) was carried even farther in massive dust clouds. The dunes were eventually stabilized by vegetation and matured into hills, but their loose material is still easily eroded and carved. Slumping, mudslides, and undercutting caused by wind and water have produced steep slopes and a landscape of narrow ridges (*Figure 6.16*).

See Chapter 2: Rocks for a cross-sectional diagram of the Loess Hills.

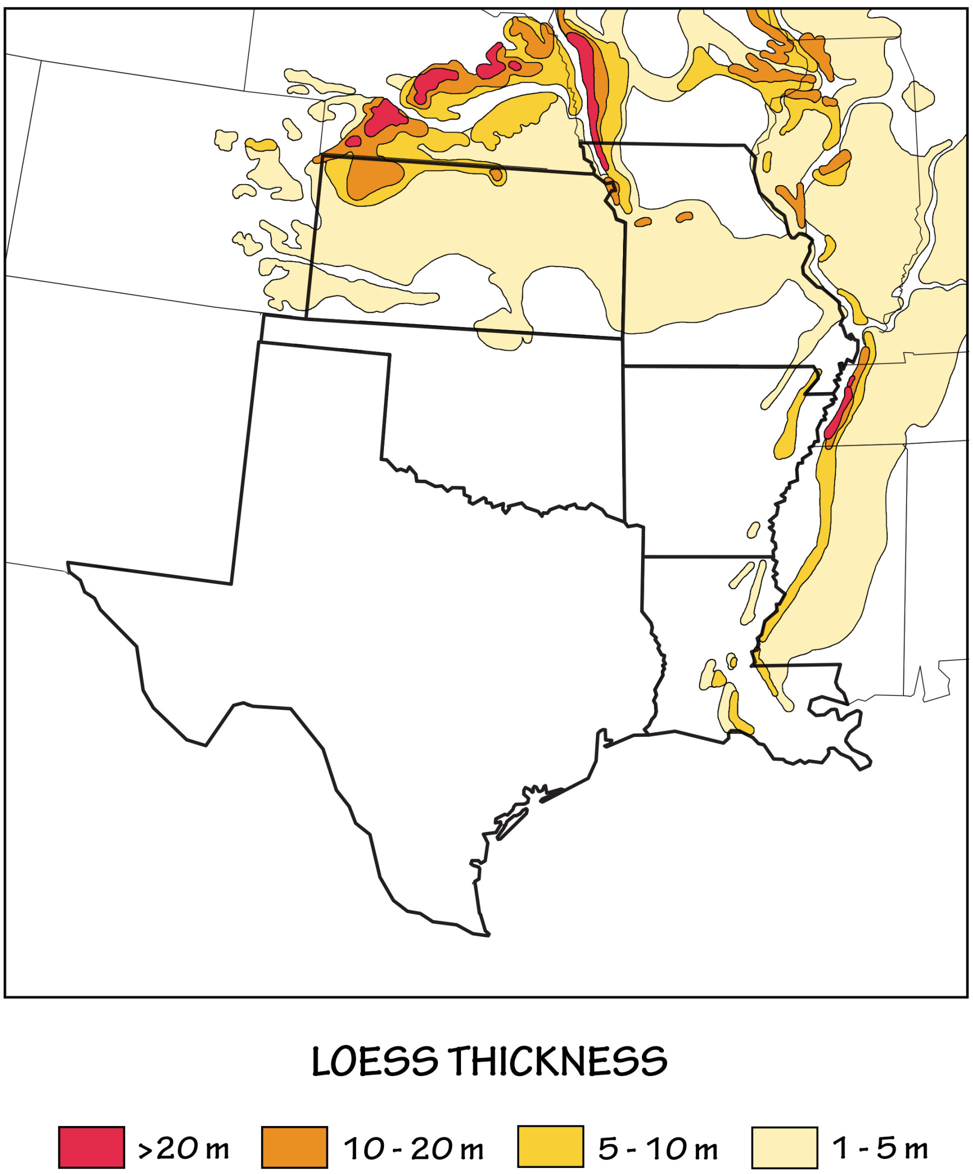

Figure 6.15: Thickness of loess deposits in the South Central US (See TFG website for full-color version.)

Figure 6.16: Landscape of the Loess Hills along the Missouri River in Atchison and Holt Counties, Missouri.

Much of the soil throughout the eastern South Central is composed, in part, of sediment blown from huge mudflats on the banks of the ancient Missouri River, which was a major channel for floods of glacial meltwater. In and around the South Central US, loess deposits occur along the bluffs of the Missouri and Mississippi rivers, and may form hills several hundred meters high. Often, exposed loess will form steep faces of fine silt. The loess can become the base of rich soils and is part of the basis for the "corn belt," an intensively agricultural area spanning much of the Midwest and extending into the Dakotas, Nebraska, Kansas, and Missouri.

See Chapter 8: Soils to learn more about the South Central's rich agricultural soils.

The Coastline and Glaciers

It may seem surprising that the very southernmost part of the South Central US, along the coastline, would be among the areas of the South Central most influenced by glaciers. The reason is not related to the action of the flowing glaciers themselves, but rather the amount of water stored in glaciers globally: during glacial advances, so much water (ultimately evaporated from the surface of the ocean) is trapped in glaciers that sea level can drop by over 100 meters (330 feet). Thus, as recently as 20,000 years ago, what are now bays and river

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mouths along the coast of Texas and Louisiana were dry land many kilometers from the shore, as was much of the continental shelf that rims the coastline (*Figure 6.17*).

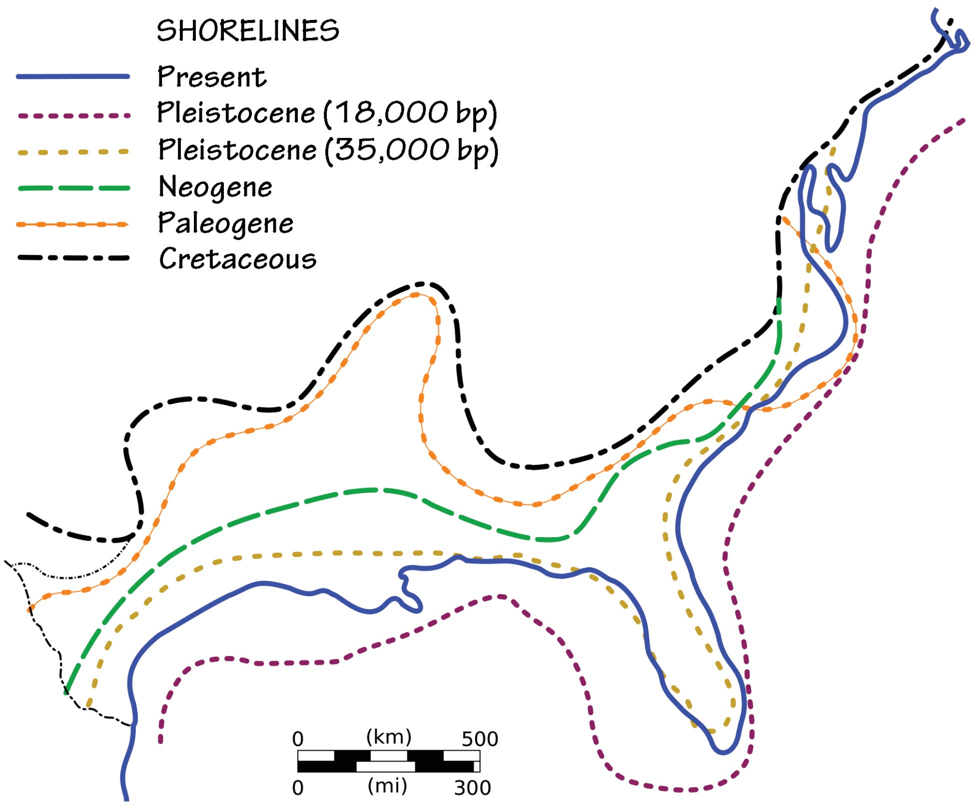

Figure 6.17: The coastline of the South Central US was considerably broader during the Pleistocene, when sea level drop exposed the continental shelf.
(See TFG website for full-color version.)

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

During each interglacial period, as sea level rose, the nature of the coastline was influenced by the erosion that had taken place in the previous glacial period, particularly in river valleys. For example, the Mississippi River cut more deeply into the land and transported more sediment during intervals of lower sea level, and, conversely, slightly higher floodplains from previous interglacial periods can be observed along the edge of the existing Holocene floodplain. The Missouri and Mississippi were conduits for some of the melting of the continental ice sheets; this meltwater contained glacially eroded sediments that contributed greatly to the Mississippi's broad floodplains and **delta**.

As sea level rose to near current levels, it took time for sediments to accumulate just offshore and for the system of barrier islands, lagoons, bays, and estuaries that we know today to develop. The evolution of the coastline and associated changes over the past ten thousand years influenced the history of ecosystems and human settlement of the area.

Resources

Books

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Glaciers in the South Central US

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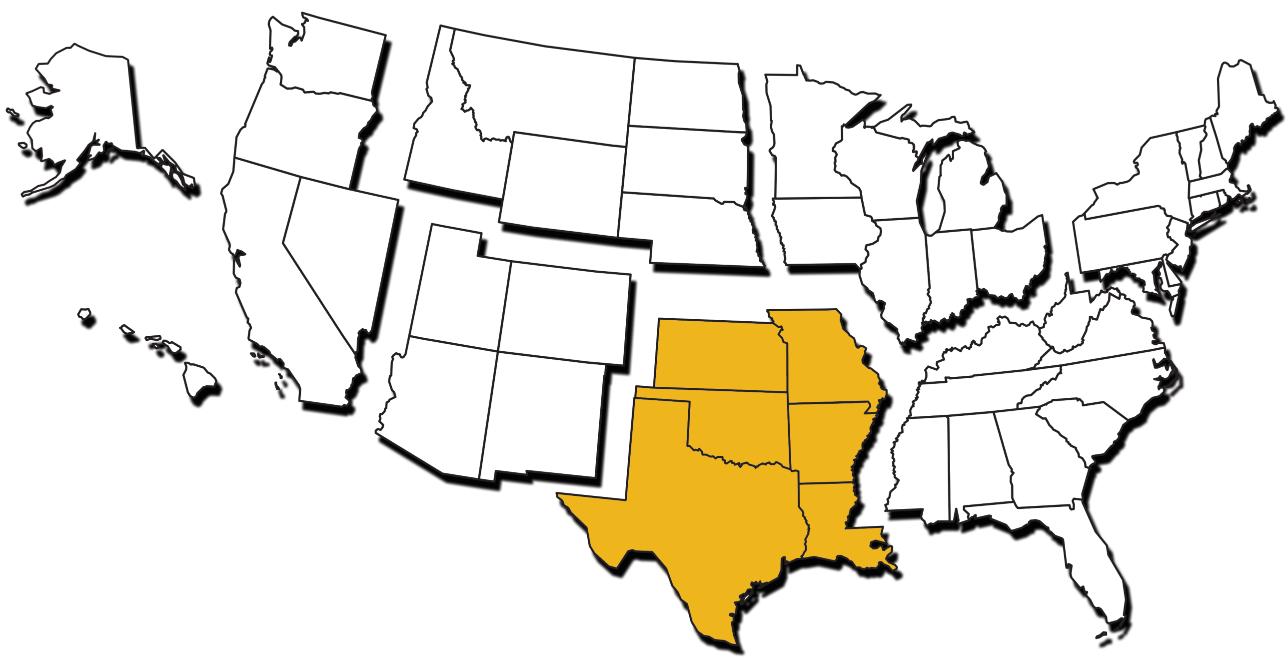
Nagel, T. 2001. *Missouri's Icy Past*. Missouri Department of Conservation. http://mdc.mo.gov/conmag/2001/12/missouris-icy-past?page=0,0.

Activities

Beyond Penguins and Polar Bears, College of Education and Human Ecology, The Ohio State University. (Lesson plans for grades K-5, including topics such as glacial ice, ice movement, and glacial erosion.) http://beyondpenguins.ehe.osu.edu/issue/icebergs-and-glaciers/hands-on-lessons-and-activities-about-glaciers.
Glacier Power, Earth Observing and System Data and Information System (EOSDIS), NASA. (Middle school glacier education resources.) https://earthdata.nasa.gov/featured-stories/featured-research/glacier-power.
Impact of Change in Glacier Ice, Alaska Seas and Rivers Curriculum, Alaska Sea Grant. (Grade 8 lesson plan on glacier retreat.) https://seagrant.uaf.edu/marine-ed/curriculum/grade-8/investigation-2.html.
Learning about Glaciers, Glacier Research Group, Portland State University Geology Department. (High school and college level educational resources.) http://glaciers.us/Learning-About-Glaciers.
Modeling Glacier Dynamics with Flubber, L.A. Stearns, National Association of Geoscience Teachers (NAGT) Teaching Activities, http://nagt.org/nagt/programs/teachingmaterials/11337.html.
National Snow and Ice Data Center (NSIDC) Educational Resources. (High school- and college-level educational resources.) http://nsidc.org/cryosphere/ education-resources/.

The *Teacher-Friendly* Guide™

to the Earth Science of the South Central US



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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.