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Kansas Physiographic Regions — Bird's-eye Views

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Cover: Buffalo grazing range in Smoky Hills upland at Maxwell Wildlife Refuge. McPherson County, September 2007.

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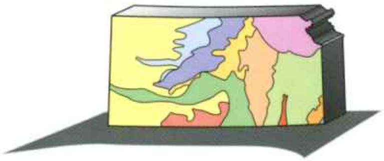


Introduction

Kansas is located in the central Great Plains region of the United States. When first organized in the 1850s, the Territory of Kansas was carved from the Louisiana Purchase of 1803 and the Texas Annexation of 1845. The territory stretched westward from the junction of the Kansas and Missouri rivers to the Continental Divide in the Rocky Mountains (fig. 1). However, the western third of this territory was removed when Kansas became a state in 1861. The state boundaries correspond approximately to latitudes 37°N and 40°N and longitudes 94.6°W and 102°W. Kansas is nearly rectangular, with the northeastern corner cut off by the Missouri River. Overall dimensions are approximately 400 miles (640 km) east to west by 205 miles (330 km) north to south.

The subtle landscapes and perceptions of Kansas as a flat state mask reality. Elevations range from just below 700 feet (215 m) in the southeast to more than 4,000 feet (1,220 m) along the western edge (fig. 2). Specifically, the lowest point is 679 feet where the Verdigris River exits Montgomery County into Oklahoma and the highest is 4,039 feet at Mount Sunflower in Wallace County near the Colorado border. Thus, the total change in topographic relief of the state is 3,360 feet (~1,025 m) between the highest and lowest points. A straight-line distance of 375 miles between these localities has an average gradient of 9 feet per mile. However, the landscape of Kansas is broken by numerous hills and valleys, which include locally steep slopes and relief up to 300 feet (90 m). The shape, or lay, of the land is influenced by three primary factors:

- Geologic foundation: the nature of solid materials—bedrock and sediment—that form the surface and subsurface, including their composition, texture, fabric, architecture, mechanical strength, and other physical attributes.
- Process: the physical, chemical, biological, or human actions that shape the surface into landforms. Broadly speaking, processes are either depositional (constructive) or erosional (destructive).
- Time: both the rate at which a process modifies the surface and the length of time that a process has operated at a site.

Static landscapes do not exist; all land surfaces are subject to diverse processes that operate at greatly varying rates on different geologic foundations. All landscapes undergo constant modification, which may take place gradually, rapidly, or even instantaneously. The active processes also change through time, so that every landscape is subject to continual evolution. Kansas is no exception to these conditions, which explains its variety of landforms.

The landscapes of Kansas cover an underlying geologic foundation that consists

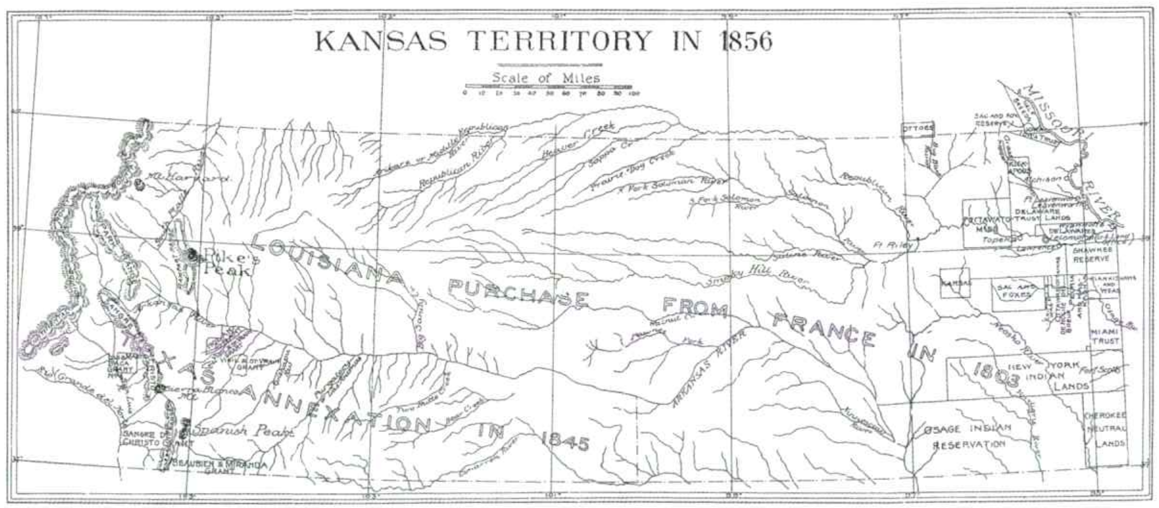


FIGURE 1—Kansas Territory in 1856. The eastern boundary was defined by the junction of the Kansas and Missouri rivers and the western boundary was the Continental Divide.

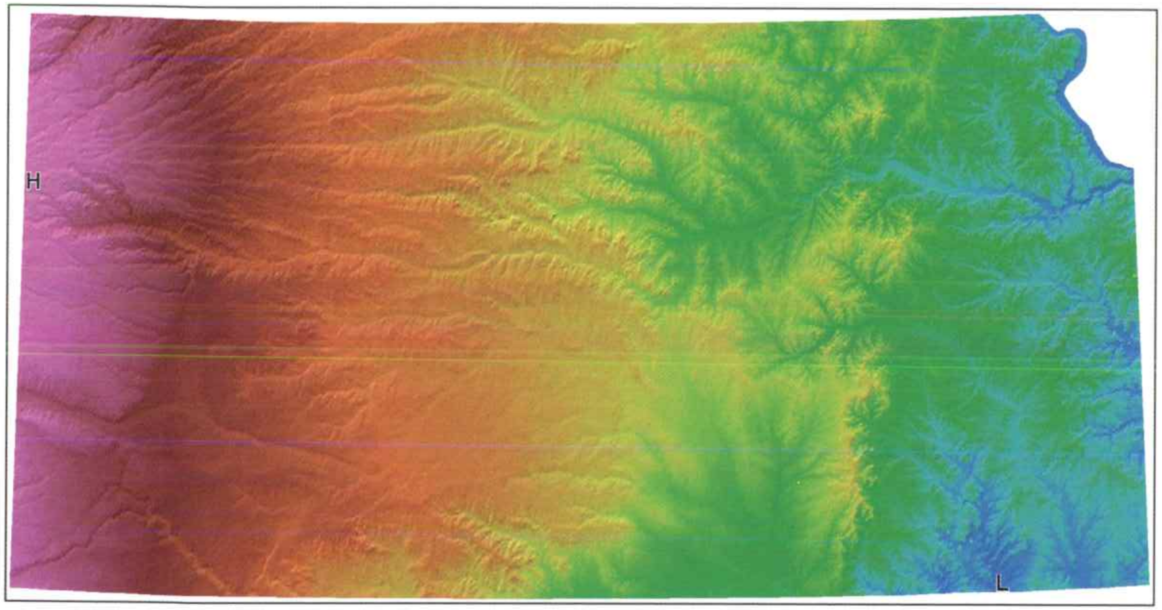


FIGURE 2—Generalized elevation map of Kansas. Elevations range from less than 1,000 feet in the east (blue) to locally over 4,000 feet along the western edge (purple = 3,000 feet). H = highest elevation of 4,039 feet in Wallace County; L = lowest elevation of 679 feet in Montgomery County. Image derived from USA 30-second digital elevation dataset; highest and lowest elevations from U.S. Geological Survey.

of a thick sequence of sedimentary layers resting nearly horizontally on ancient crystalline basement rock composed mainly of granite. The basement rock is not exposed at the surface anywhere in the state. The sedimentary strata were deposited in various marine and terrestrial environments. In the realm of geologic time, sedimentary rocks of Kansas include Paleozoic (old-age), Mesozoic (middle-age), and Cenozoic (young-age) layers spanning nearly 600 million years. The oldest rock exposed at the surface, deposited about 340 million years ago, is Carboniferous (Mississippian Subperiod) limestone (mid-Paleozoic) in the southeastern corner of the state. Toward the west, surface rocks become generally younger in geologic age and higher in elevation.

As Wilson (1978) suggested, this might be likened to the torn pages of an old ledger in which the oldest rock layers are the back pages and younger rock layers are the torn pages toward the front of the book (fig. 3). Portrayed in another way, a traveler moving across the southern margin of the state—from the Mississippian bedrock in the southeastern corner to the modern sand dunes along the Arkansas River near the Colorado border—would pass through strata spanning 340 million years of geologic time. That means the surface rock is an average of 850,000 years younger per mile from east to west. Of course, like an old book with torn or lost pages, the geologic record of Kansas also has many gaps or missing intervals, known as unconformities, which give rise to abrupt breaks in the geology and landscapes of the state.

To a considerable extent, the economic vitality of Kansas depends upon its geologic resources for both agriculture and industry. Land use is dominantly agricultural interspersed with small towns and large urban centers. Wheat fields, cattle ranches, grain elevators, oil and gas fields, and railroads are iconic symbols of human life in Kansas. Agriculture depends on rich soils. In the eastern part of the state, ample rainfall allows dryland farming and waters tallgrass prairie for cattle grazing. Westward, rainfall diminishes and ground water is essential

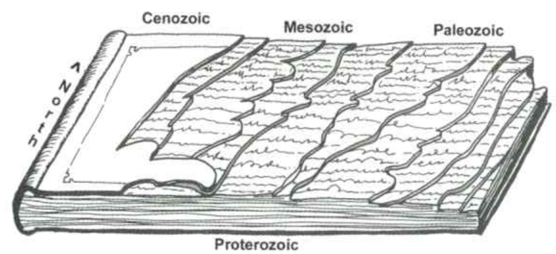


FIGURE 3—Kansas geology depicted schematically as the torn and eroded pages of a book. The bottom cover represents the Proterozoic crystalline (granite) basement. The pages and top cover symbolize sedimentary layers that rest in near-horizontal position. Geologic ages of sedimentary strata are given across the top—oldest to east and youngest to west. Adapted from Wilson (1978, fig. 2).

for human settlement, irrigated crops, cattle feedlots, and ethanol production.

Kansas has significant energy resources, particularly oil and natural gas, along with coal, coal-bed methane, and wind power. Other important geologic resources include salt, gypsum, limestone, sand and gravel, and lamproite. Kansas is emerging as a destination for ecotourism based on the tallgrass prairie of the Flint Hills, the wetlands of Cheyenne Bottoms and Quivira in the central part of the state, and other natural attractions.

Landscape Photography

The Great Plains region is often overlooked by landscape photographers in favor of more obvious mountains, seacoasts, deep canyons, and tall forests. However, the seeming simplicity of the Great Plains contains rich and diverse environments. Natural habitats include prairie, woodland, and wetland. From the oak forest along the rugged Missouri River bluffs to playas and shortgrass prairie of the High Plains, Kansas spans major environmental transitions. All of these settings give rise to ample opportunities for creative and resourceful photographers.

Over the years, the scenic wonders in Kansas have been photographed many times, but mainly from a *frog's-eye* view at ground level. For example, in 1935 the Kansas Geological Survey first published Kenneth K. Landes' booklet *Scenic Kansas,* which featured ground views of several locations represented in this book. From our *bird's-eye* view, however, those sites are presented from an entirely different perspective.

Aerial photographs reveal spatial patterns and relationships that are difficult, if not impossible, to see from the ground. They allow people to recognize the geologic resources upon which much of their livelihood depends and help the public to appreciate the importance of maintaining natural areas and a sustainable environment. Kansas offers much exciting content for visually stimulating aerial photography.

Aerial views of the earth's surface may be acquired from high-flying airplanes and satellites orbiting in space, but a closer perspective also is possible. Small-format aerial photography (SFAP) was the primary method used to capture the pictures in this book. SFAP involves using 35- and 70-mm film cameras or compact digital cameras to take low-height airphotos from manned or unmanned platforms (Warner et al., 1996). Manned platforms include small airplanes and helicopters, ultralight aircraft, gliders, and hot-air balloons. Unmanned platforms in common use are balloons, blimps, model aircraft, and kites. SFAP has become widely employed in recent years for documenting all manner of natural and human resources (Bauer et al., 1997), including geology (Hamblin, 2004). The method is relatively low in cost, highly portable, and quick to utilize in the field.

Aerial photographs in this book were acquired with kites (Aber et al., 1999) and a small helium blimp (Aber, 2004) equipped with various types of film and digital cameras. They were taken from 100 to 500 feet (30–150 m) above the ground using radio-controlled camera rigs (figs. 4 and 5). The camera could be tilted (vertical to horizontal) and rotated (360°) to provide all possible viewing angles in relation to the ground target. These techniques bridge the gap between ground photography and conventional aerial photography and satellite imaging. Manned airplanes and helicopters normally are restricted to heights above 500 feet in the countryside and 1,000 feet in urban areas. SFAP images with large-scale and exceptionally high spatial resolution that are created using unmanned kites below 500 feet depict ground features in surprising detail.

Successful photography depends upon camera techniques combined with aesthetics. Artistically attractive imagery is a powerful means to display the beauty and complexity of the earth's natural and cultural environments. SFAP provides a real bird's-eye view that is impossible to capture by any other means.

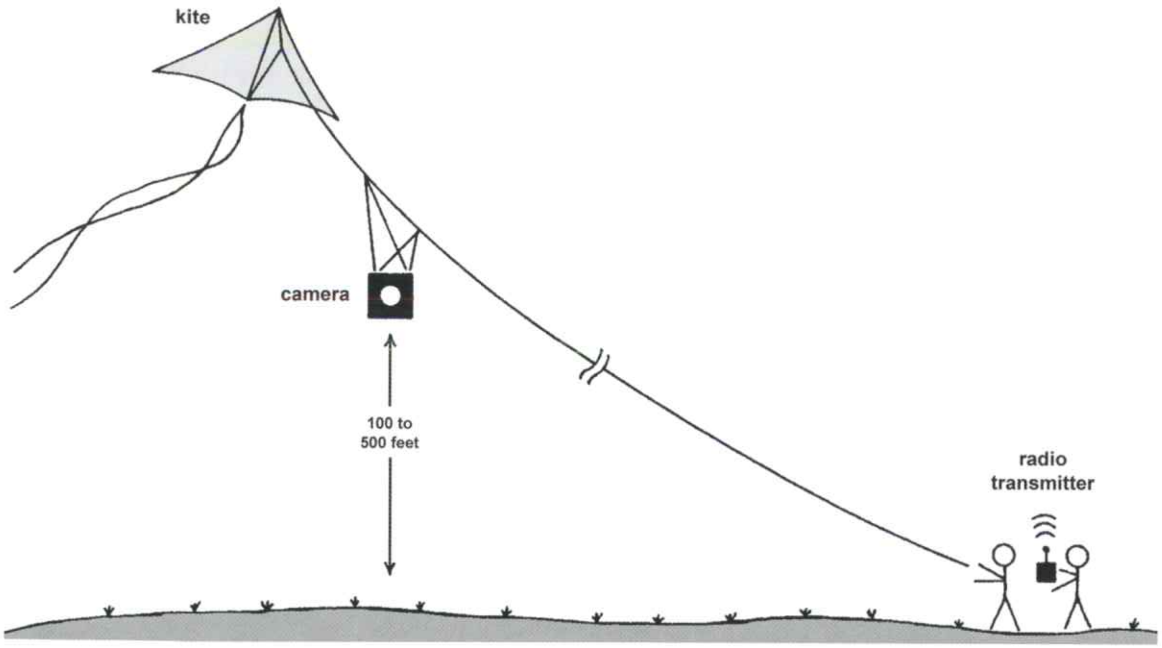


FIGURE 4—Basic setup for kite aerial photography. The camera rig, controlled by a radio transmitter on the ground, is attached to the kite line. Not to scale. Adapted from Aber et al. (2003, fig. 1).

Physiographic Regions

From the High Plains in the southwest to the Glaciated Region of the northeast, the state contains a rich variety of geologic and geographic features, which were recognized by early explorers and geologists. The physiography of Kansas was described in some detail in the late 19th century by State Geologist Erasmus Haworth (1896, 1897), who emphasized the influence of bedrock characteristics on the development of surface landscapes and river systems. In 1902 G. I. Adams published a map of Kansas and northern Oklahoma that divided the state into several physiographic regions, or provinces, along lines generally followed by later geoscientists (fig. 6).

FIGURE 5—Canon S70 digital camera rig for kite or blimp aerial photography. The seven-megapixel camera has a wide-angle lens and is radio-controlled from the ground. It can pan (0–360°) and tilt (0–90°) to provide views in all orientations. T = tilt servo, S = shutter microservo, P = pan servo.

Physiographic provinces are defined primarily on the basis of underlying geology and secondarily by topographic conditions, vegetation cover, and human land use. Some, such as the Flint Hills and Smoky Hills, have high relief and steep slopes compared to the lowlands and plains throughout much of the state. In general, physiographic provinces of eastern and south-central Kansas are underlain by well-consolidated sedimentary rocks of late Paleozoic ages, which are primarily Carboniferous (Pennsylvanian Subperiod) and Permian (fig. 7). In contrast, much of central and western Kansas is covered by poorly consolidated to loose sediments of Mesozoic (mainly Cretaceous) and Cenozoic (Neogene and Quaternary) ages.

The surface landscape and drainage of Kansas were affected substantially during the Ice Age in the Glaciated Region and High Plains when an ice sheet entered the northeastern corner of the state and glacial meltwater from the Rocky Mountains swelled rivers flowing across the High Plains. The

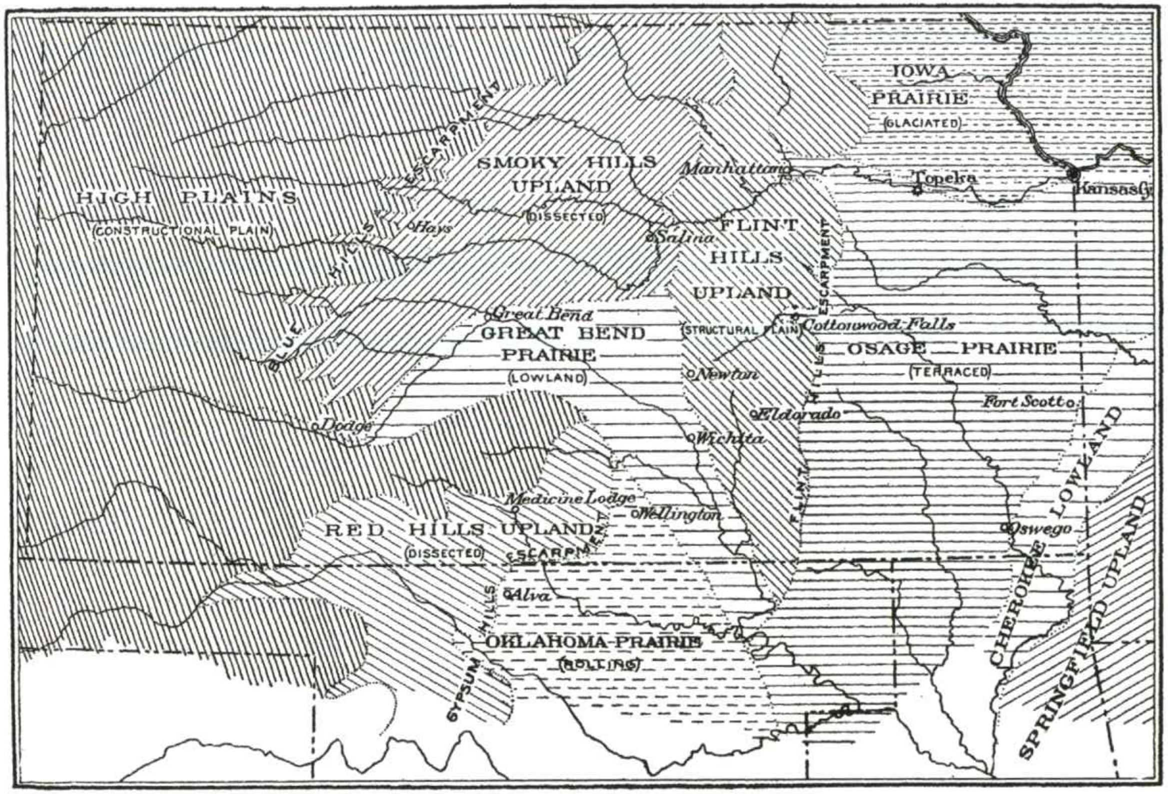


FIGURE 6—1902 map showing physiographic regions of Kansas and northern Oklahoma. From Adams (1902, fig. 2).

topographic relief of Kansas was increased significantly by a combination of erosion and deposition related to glaciation (Frye and Leonard, 1952). Wind also played a prominent role, creating sand dunes and depositing loess (silty sediment) in several regions of the state. Thus, the older bedrock is mantled in many places by relatively young glacial, fluvial, and eolian sediments. In all of the physiographic regions, human activities have altered the landscape, primarily through agriculture and the growth of industry and cities. We have imposed distinctive geometric patterns, such as center-pivot irrigation and road networks, on the underlying geologic foundation of Kansas.

Since the publication of Adams' 1902 map, several other versions of a Kansas physiographic map have been produced. State Geologist R. C. Moore's elegant map from 1930 featured the Osage Plains, Cherokee Lowland, Flint Hills, Great Bend Prairie, Cimarron Breaks (Red Hills), Smoky Hills, Blue Hills, and High Plains (fig. 8).

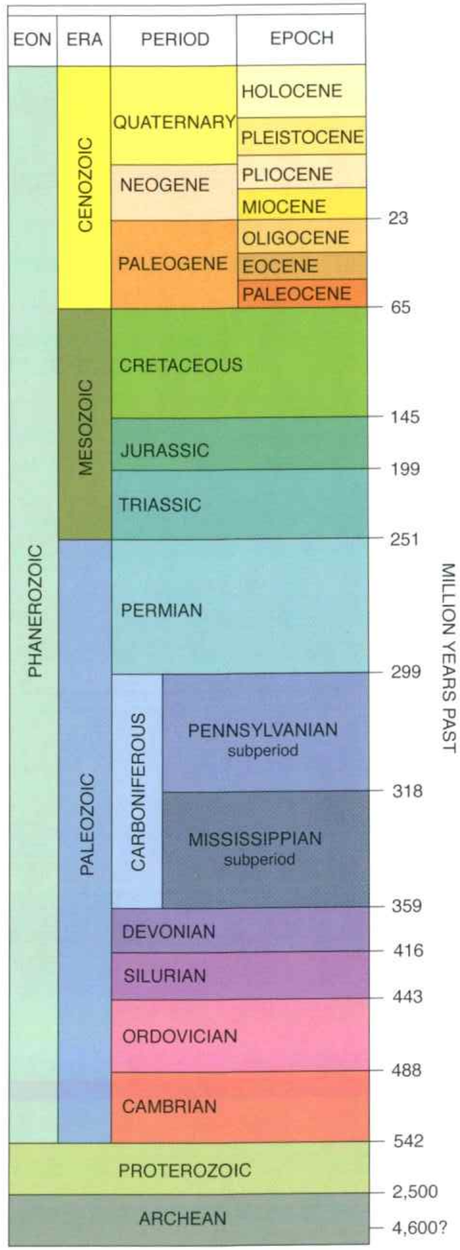


FIGURE 7—Geologic timetable. Adapted from Kansas Geological Survey (2007).

Elaborating on Moore's general scheme in 1949, Walter Schoewe added the Glaciated Region (till plains), Ozark Plateau, and Chautauqua Hills (fig. 9). Schoewe also introduced the Arkansas River Lowlands with four subregions: Finney, Great Bend, McPherson, and Wellington. In 1953, Grace Muilenburg presented a simplified physiographic map of the state that combined the Blue Hills into the Smoky Hills, omitted the Ozark Plateau and Chautauqua Hills, formed a Red Hills–Wellington area, and did not include the western (Finney Lowlands) portion of the Arkansas River valley in the Arkansas River Lowlands, which she labeled the Great Bend Prairie (fig. 10).

These efforts culminated with a *Generalized Physiographic Map of Kansas* (fig. 11) published in Frank Wilson's *Kansas Landscapes: A Geologic Diary* in 1978 and subsequently reproduced in many Kansas Geological Survey publications. Wilson included 11 physiographic regions and generally followed Schoewe's interpretation with a couple of noticeable exceptions. He made the Wellington–McPherson Lowlands distinct from the Arkansas River Lowlands

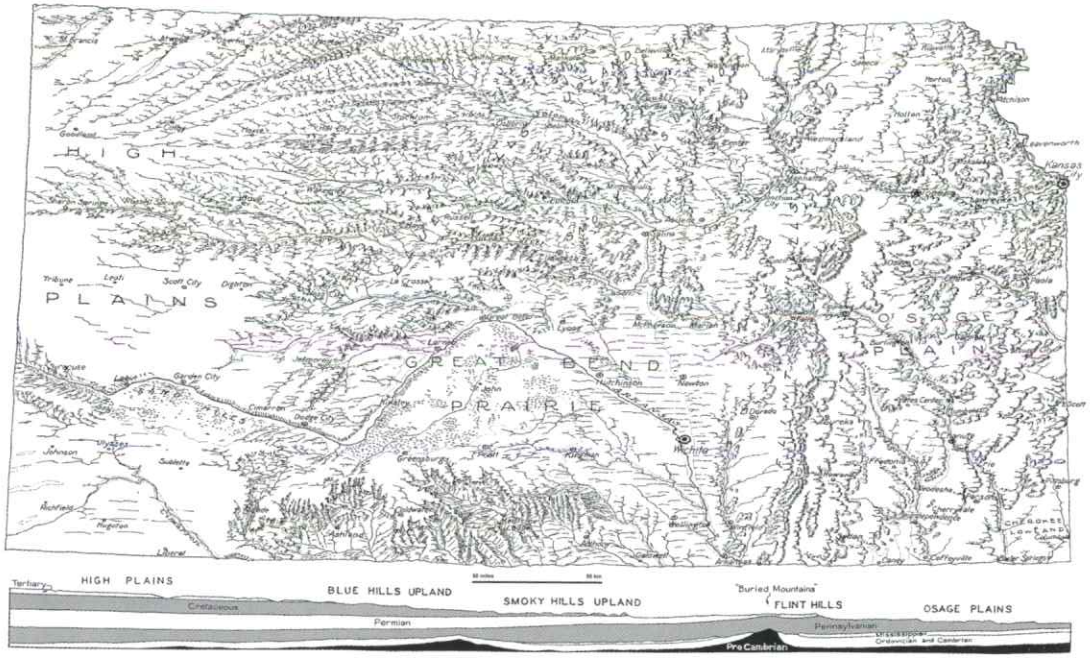


FIGURE 8 (above right)—1930 map showing surface features of Kansas within the major physiographic provinces with underlying geologic cross section. Adapted from Moore (1930).

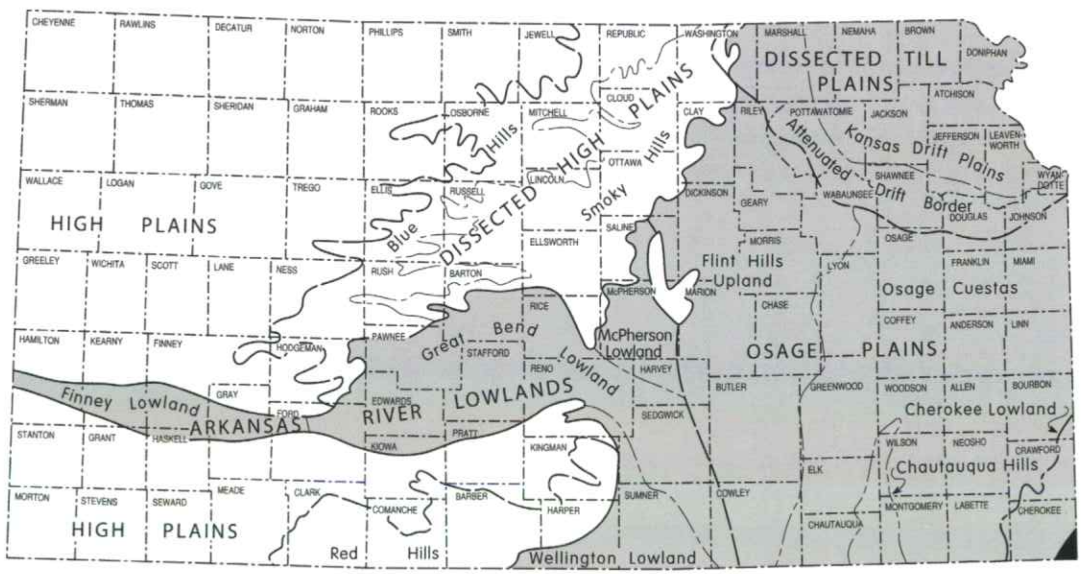
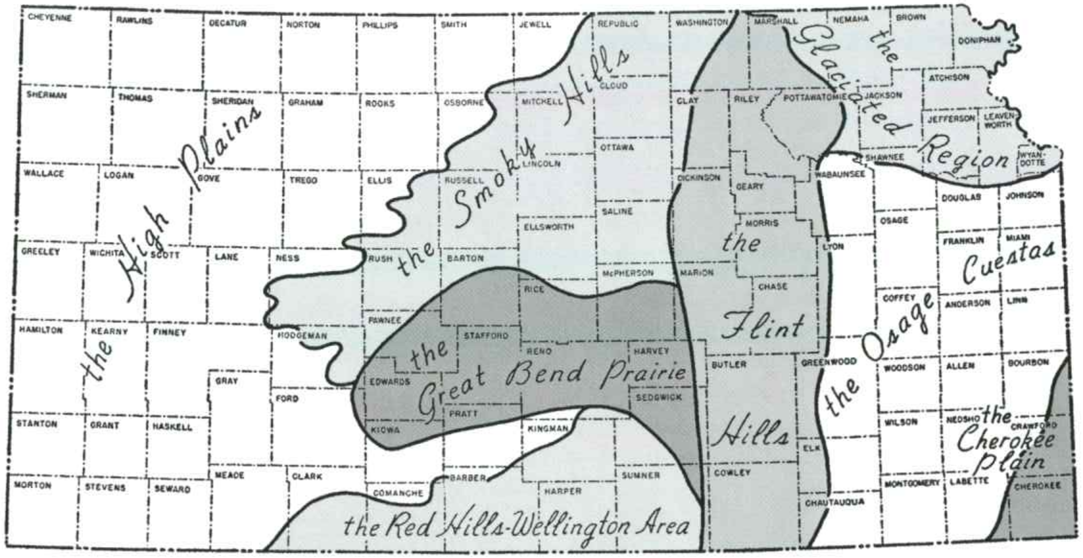


FIGURE 9 (right)—1949 map showing physiographic regions and subregions of Kansas. Ozark Plateau depicted in black. Adapted from Schoewe (1949, fig. 22).

and incorporated the Blue Hills and part of the High Plains into a large Smoky Hills region.

Although Wilson's map remains the official version of physiographic regions for the Kansas Geological Survey, in this book we have combined and made minor modifications to Schoewe's and Wilson's maps for the purpose of presenting our aerial views. In our map of physiographic regions (fig. 12), we set apart the Blue Hills and Chalk Buttes as distinct subregions of Wilson's large Smoky Hill region. Wilson recognized them as subregions in his writing but did not distinguish them on his map. Following Schoewe, we lumped the Wellington and McPherson lowlands into the Arkansas River Lowlands region on our map. In the text, we describe them as separate sections of the Arkansas River Lowlands along with the Finney and Great Bend lowlands.

In the course of taking aerial photographs, we have toured and observed many portions of the state with an eye toward recognizing the diagnostic features that characterize each physiographic region or subregion. Primary factors used to define physiographic regions



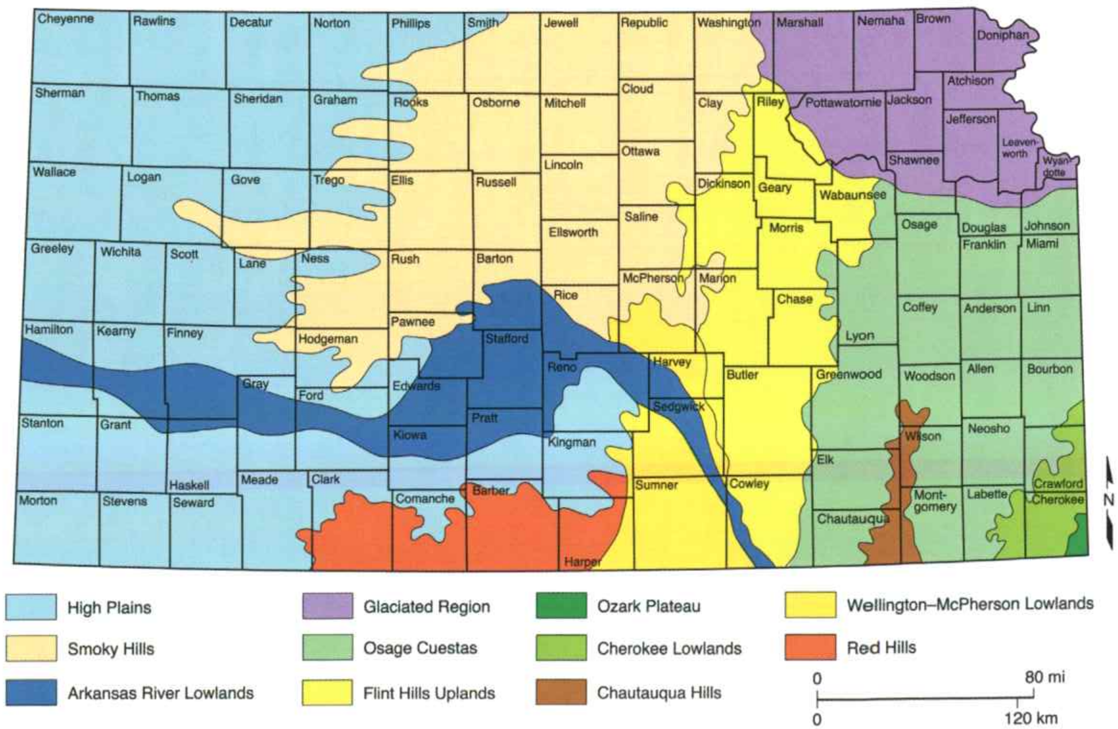


FIGURE 10 (above right)—1953 map showing simplified physiographic regions of Kansas. Adapted from Muilenburg (1953).

FIGURE 11 (right)—Map showing generalized physiographic regions recognized by the Kansas Geological Survey. Based on Wilson (1978, fig. 8).

are underlying bedrock, surficial sediment and soils, distinctive landforms, general relief, and surface drainage; secondary factors include vegetation, climate, and typical human land use. The latter often involves extracting subsurface resources such as ground water, oil and gas, salt, and coal. Physiographic regions correspond closely in many places with ecoregions of Kansas defined on the basis of abiotic and biotic criteria (Chapman et al., 2001).

The basic characteristics of the physiographic regions of Kansas are summarized in table 1. Some of the regions, such as the High Plains and Osage Cuestas, are large and relatively homogeneous. Others, such as the Ozark Plateau and Chautauqua Hills, are relatively small but quite distinctive in character. Some have subtle subregions, such as the four in the Arkansas River Lowlands introduced by Schoewe and noted above. In the following chapters, each physiographic region is described and illustrated by small-format aerial photographs taken from a unique bird's-eye view.

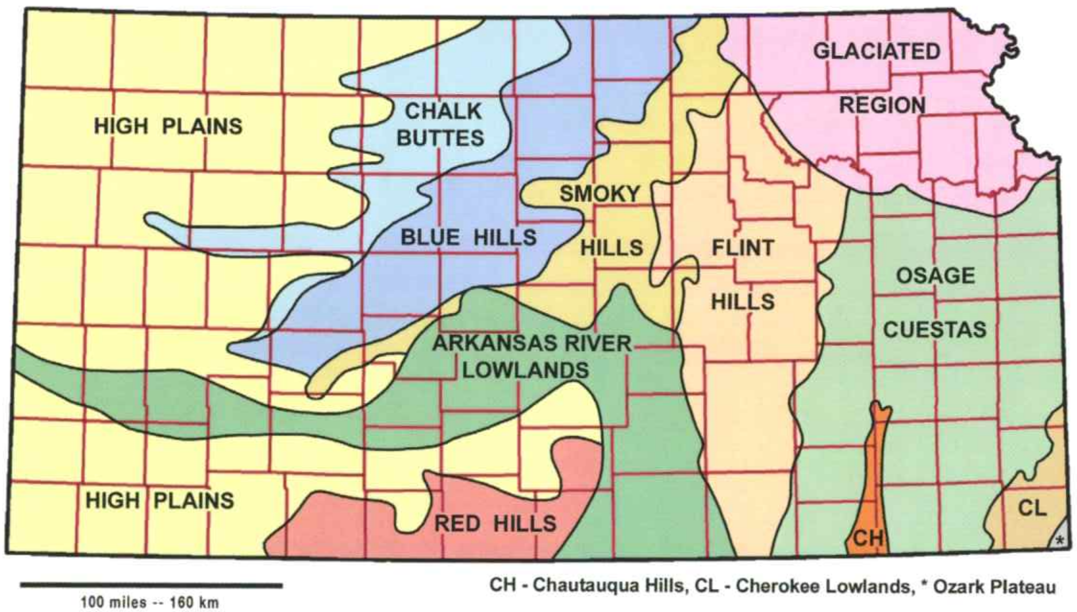


FIGURE 12—Map showing modified physiographic regions and subregions of Kansas featured in this book. Based generally on the Schoewe and Wilson maps (see figs. 9 and 11) with modifications of some region boundaries and names. Limit of glaciated region from Aber (1991a). See table 1 for general characteristics of each region.

TABLE 1—General characteristics of the physiographic regions featured in this book.

Physiographic Region	Bedrock Age and Type	Surficial Sediment	Landforms	Relief	Drainage	Natural Vegetation	Land Use	Special Conditions
High Plains	Neogene silt, sand, gravel, mortar beds	Sand, loess, valley alluvium	Broad and flat plain, sand dunes	Low	Intermittent to ephemeral	Shortgrass prairie	Irrigated and dry cropland	Irrigation, oil and gas
Red Hills	Upper Permian shale, sandstone	Alluvium in valleys	Buttes, sinkholes, natural bridges	Moderate	Perennial to intermittent	Mixedgrass prairie	Dry, mixed agriculture	Red beds, salt, gypsum, caves
Arkansas River Lowlands	Quaternary silt, sand, gravel	Sand, loess	Dunes, channels, floodplains	Low	Perennial to intermittent	Mixedgrass to shortgrass prairie	Irrigated and dry cropland	Gravel, salt, irrigation
Chalk Buttes	Upper Cretaceous chalk	Alluvium in valleys, loess	Buttes, gentle hills, badlands	Moderate	Intermittent streams	Mixedgrass to shortgrass prairie	Dry, mixed agriculture	Vertebrate marine fossils
Blue Hills	Upper Cretaceous shale, thin chalk	Alluvium in valleys	Gentle hills	Moderate	Intermittent streams	Mixedgrass to shortgrass prairie	Dry, mixed agriculture	Fencepost limestone
Smoky Hills	Lower Cretaceous shale, sandstone	Upland gravel, valley alluvium	Rugged hills	High	Perennial streams	Mixedgrass prairie	Dry, mixed agriculture	Oil production, concretions
Flint Hills	Permian shale, limestone, chert	Upland chert, valley alluvium	Escarpments, rugged hills	High	Perennial streams	Tallgrass prairie	Cattle grazing, military training	Oil and gas, caves, earthquakes
Glaciated Region	Pennsylvanian and Permian, Lower Cretaceous	Till, loess, valley alluvium	Spillways, buried valleys	High	Perennial large rivers	Oak-hickory forest, prairie	Dry, mixed agriculture	Erratic boulders, earthquakes
Osage Cuestas	Pennsylvanian limestone, shale	Loess, gravel, valley alluvium	Escarpments	Moderate	Perennial large rivers	Oak-hickory forest, prairie	Dry, mixed agriculture	Oil and gas
Chautauqua Hills	Pennsylvanian sandstone, shale	Alluvium in valleys	Rugged hills	High	Perennial streams	Scrub oak forest, prairie	Dry, mixed agriculture	Oil production
Cherokee Lowlands	Pennsylvanian sandstone, shale	Alluvium in valleys	Low plain	Low	Perennial streams	Oak-hickory forest, prairie	Dry, mixed agriculture	Coal mining
Ozark Plateau	Mississippian limestone, chert	Alluvium in valleys	Plateau	Low	Perennial streams	Oak-hickory forest	Dry, mixed agriculture	Lead-zinc mines, caves

High Plains

The High Plains make up the largest physiographic region, occupying most of the western third of Kansas and extending into central Kansas south of the Arkansas River Lowlands. Most of the region is a ramp sloping gently upward to the west that ranges in elevation from about 1,475 feet (450 m) in Reno and Kingman counties of south-central Kansas to above 4,000 feet (1,220 m) near the Colorado border in Wallace County. The High Plains appear to be flat and nearly featureless across long distances. In part this is due to a lack of trees and the ability to see to the far horizon. The High Plains are not entirely featureless, however. Steep slopes and rugged terrain are found locally where small streams have entrenched valleys and ravines into the plains upland, such as along Buckner Creek in Hodgeman County, Ladder Creek in Scott County, Bluff Creek in Clark County, and the Arikaree Breaks in Cheyenne County.

The High Plains physiographic region corresponds to the Western High Plains and western portions of the Central Great Plains ecoregions (Chapman et al., 2001). Native vegetation is dominated by mixedgrass prairie to the east and shortgrass prairie to the west. The western portion lies in the rain shadow of the Rocky Mountains and typically receives less than 20 inches (50 cm) of precipitation per year. Land use depends to a considerable extent on the availability of water and type of soil. A mixture of dryland and irrigated crops is grown in loess soils that cover much of the uplands, and cattle are grazed where the soil is thin or slopes are too steep for cultivation (fig. 13). Cities of the High Plains include Goodland, Colby, Scott City, Liberal, Meade, and Greensburg.

A blanket of alluvial sediment deposited by a network of braided rivers flowing out of the Rocky Mountains during the late Miocene and early Pliocene is the geologic foundation of the High Plains (Gutentag et al. 1984). The Ogallala Formation, the main source of ground water in western Kansas, is composed of this sediment—sand and gravel made up of quartz, feldspar, and granitic rock fragments washed out of the Rockies. The sediment buried pre-existing Mesozoic bedrock, which consists mainly of chalk, shale and sandstone,

FIGURE 13—Dry rangeland near Wagon Bed Spring. View toward the southwest. Grant County, June 2006.

built alluvial fans, and coalesced into a plain extending from the Rockies to as far eastward as the Flint Hills. After deposition, the sediment covering the bedrock was subjected to weathering and soil-forming processes. Soluble carbonates leached from the surface were precipitated in the subsurface and formed weakly cemented zones known as mortar beds. These beds crop out in several locations, including Scott State Park (fig.14). In other places, green-colored sandstone beds were cemented by opal. For the most part, however, the Ogallala Formation remains unconsolidated.

When first formed, the alluvial plain had little local relief and streams shifted across its surface frequently. Sediment accumulated under humid conditions of a subtropical savanna (Gutentag et al., 1984). Eventually sediment buildup ended, and streams began to entrench valleys into the alluvial plain. The midcontinent region underwent a dramatic uplift following the Miocene. The entire southern Rocky Mountains and Colorado Plateau have been raised several thousand feet (Matthews et al., 2003), and the mountains are still rising today. The High Plains were tilted upward to the west, which increased stream gradients eastward and influenced the modern elevation and slope of the High Plains upland. At the same time, sea level lowered worldwide as polar glaciation increased and the climate became cooler and drier.

These factors in combination led to increased erosion of the High Plains by rivers that etched their valleys across the region. The Cimarron, Arkansas, Smoky Hill, Republican, and other river valleys came to resemble their current expression in the landscape (fig. 15). On the eastern edge of the plains, the Ogallala Formation was completely removed by erosion, exposing the underlying Cretaceous and Permian bedrock in the Red Hills, Chalk Buttes, Blue Hills, Smoky Hills, and Flint Hills regions. The modern High Plains region is, thus, a mere remnant of what was once a much larger Miocene–Pliocene plain.

FIGURE 14—Mortar beds at Scott State Park. Resistant layers of mortar beds crop out on the sides of Ladder Creek valley. View northward. Scott County, May 2006.

During the Pleistocene, glaciation waxed and waned several times in the Rocky Mountains (Richmond, 1965, 1986). With each glacial expansion, torrents of meltwater flushed sediments into rivers across the High Plains. Freshly deposited outwash was easily eroded by glacial winds, which carried dust far and wide. The accumulation of dust through several millennia during and after Pleistocene glaciations built up the loess blanket on the High Plains uplands eastward from the Rocky Mountains (Gutentag et al., 1984; Matthews et al., 2003). Loess in northwestern Kansas is now 100 feet (30 m) deep in many places, and thick loess also covers parts of southwestern Kansas (Muilenburg, 1961). Soils formed in the High Plains loess are some of the most productive in the world.

In some areas, sandy sediment was exposed to wind erosion and sand dunes were created. The dunes are mostly stabilized by vegetation cover now and are used for grazing (fig. 16). Active dune formation is relatively recent throughout most of the Great Plains (Swinehart, 1990). Several episodes of dune activity and severe drought took place during the Holocene between 9,600 and 6,500 years ago, between 4,500 and 2,300 years ago, and most recently, between 1,000 and 700 years ago (Miao et al., 2007).

The semiarid climate of the High Plains means that surface water is generally lacking away from the major rivers draining the Rocky Mountains. In the uplands between major river valleys, surface water is particularly scarce. At least 2,000 playa basins are found in the southwestern portion of the High Plains in Kansas (Steiert and Meinzer, 1995). These shallow depressions are dry more often than not but may contain water following heavy rains or snowmelts (fig. 17). Many opinions have been advanced concerning the origin of playa depressions, ranging from subsurface dissolution to wind erosion and buffalo wallows. The area between Scott City and Garden City contains several enclosed drainages, such as White Woman Basin and the basin of Dry Lake (fig. 18), that may contain streams and lakes during wet years.

Widespread ground water beneath the High Plains was first indicated by the numerous springs draining along valleys incised into the plains and along the eastern margin of the plains (Haworth, 1897). The High Plains aquifer extends from Texas to Nebraska and beyond. Part of the aquifer, including much of the Kansas portion (fig. 19), has been exploited since the 1950s as the use of center-pivot irrigation spread rapidly. In some places, the rate of ground-water extraction exceeds the rate of recharge, which amounts to ground-water mining. In other

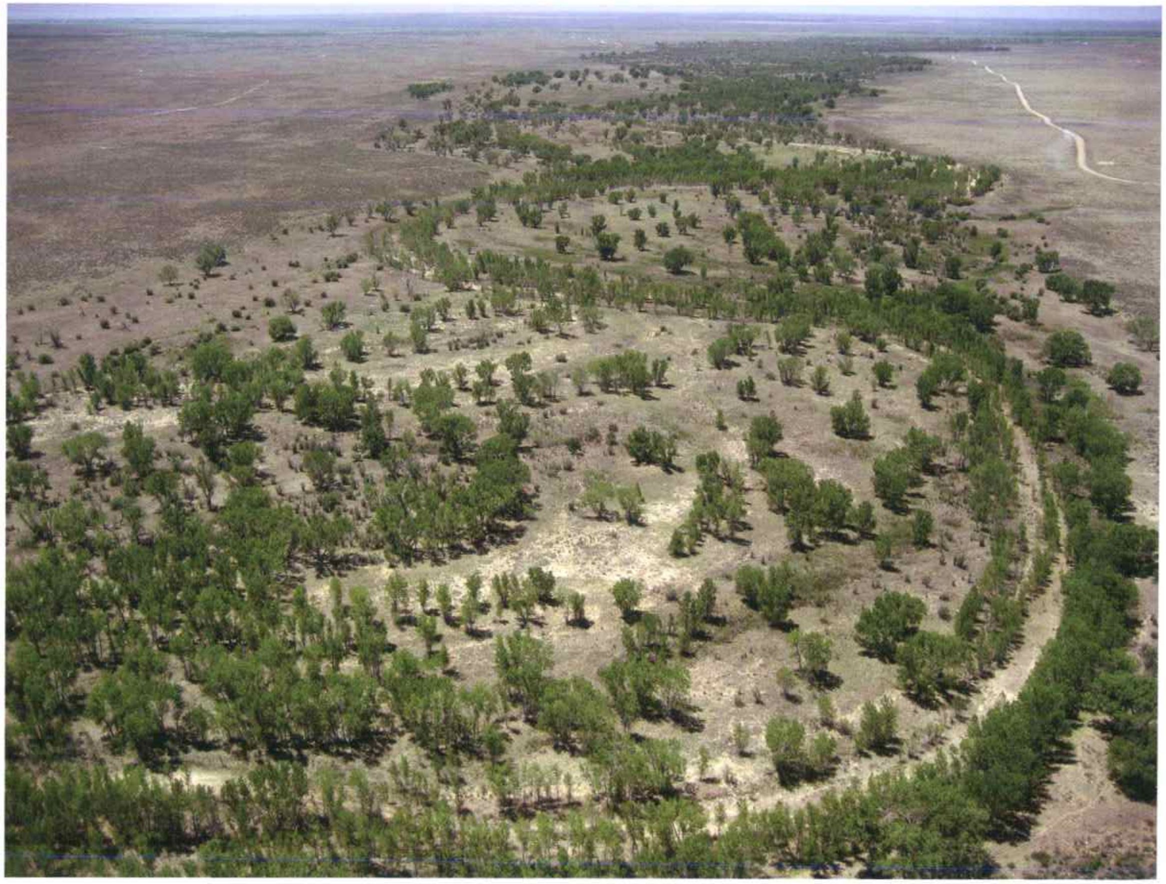


FIGURE 15—Dry channel of Cimarron River at Point of Rocks. Note the symmetrical S-shaped meanderings of the tree-lined channel. Outside the valley, shortgrass prairie covers the upland surface of the High Plains. View toward the southwest. Morton County, June 2006.

FIGURE 16 (left)—Sand hills stabilized by vegetation and used for cattle grazing. Sagebrush grows on the dunes, and green shortgrass prairie fills the swales between dunes. The kite flyers are standing in front of the barn at the abandoned farmstead. View toward the southeast. Scott County (foreground) and Finney County (beyond road), May 2007.

FIGURE 17 (below)—Ephemeral lake in a playa basin during a wet year. Winter wheat and fallow fields surround the water, and an abandoned county road runs across the far end of the lake. View toward the northwest. Scott County, May 2007.

FIGURE 18—Dry Lake. Views toward the southwest. Scott County. **Left:** Wet phase, May 2007. Wind-driven waves stir up suspended sediment from the lake bottom and shore, and a small boat is overturned on the shore to lower left. The line of trees along the edge marks the high-water stage. **Below:** Dry phase, May 2008. Salt crust surrounds a central mudflat on the lake floor.

areas, particularly around sand hills, recharge may be adequate to maintain ground-water reserves. Several Groundwater Management Districts now control the development and promote conservation of this valuable resource in the High Plains region.

To a large extent, the economic vitality of the High Plains depends upon its geological resources. Southwestern Kansas is underlain by the vast Hugoton oil and gas field, one of the largest natural gas fields in the world. In addition to natural gas, helium is produced from the Hugoton and several other gas fields. Raw helium is piped eastward to production plants at Otis and Bushton, making Kansas one of the most important helium producers in the world (National Academy of Sciences, 2000). Where present, irrigation supports an intensive grain and animal-feeding industry, particularly in southwestern Kansas. Producing biofuels and harvesting wind power also add to the potential for economic growth in the High Plains of Kansas (fig. 20).

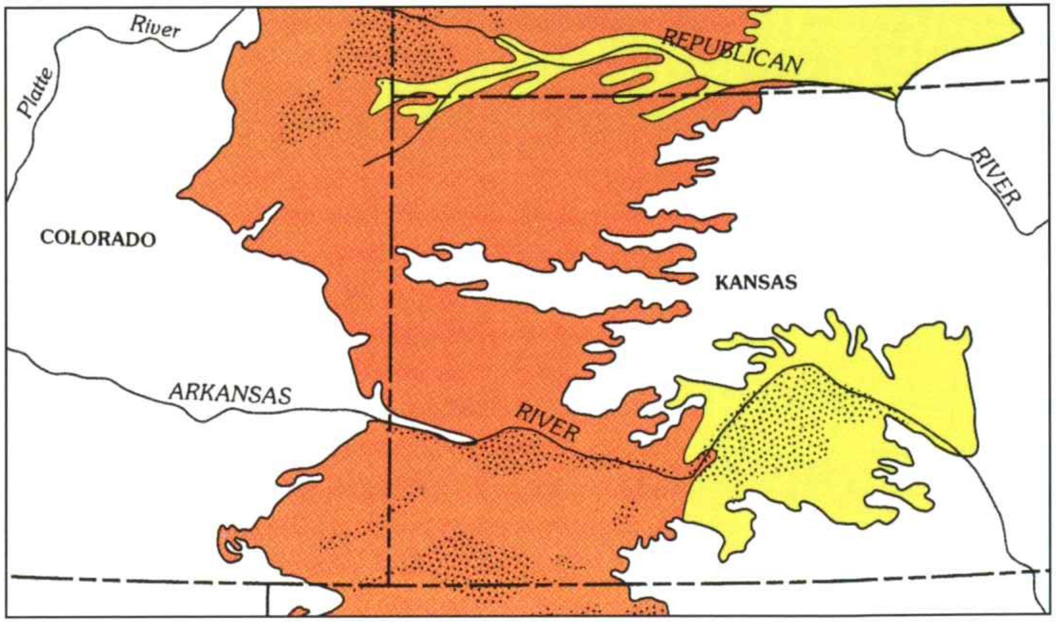
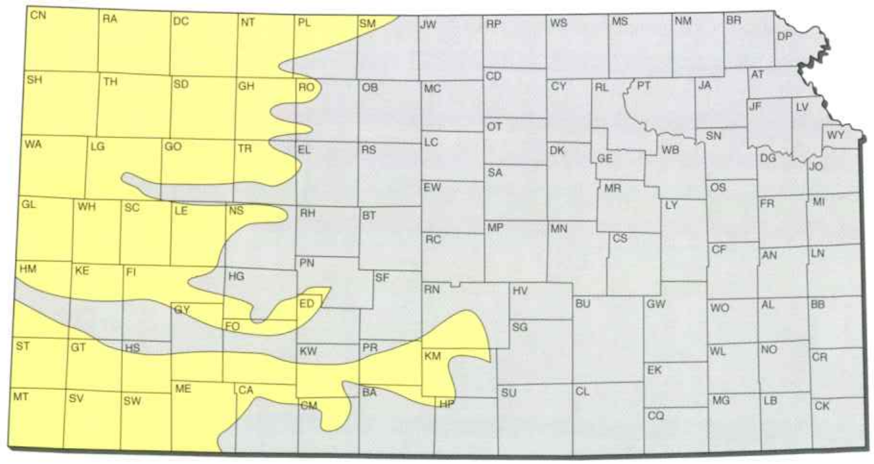


FIGURE 19—Portion of the High Plains aquifer in Kansas and surrounding states. Most of the aquifer consists of the Ogallala Formation (orange); in central Kansas, younger Quaternary sediment (yellow) forms the aquifer. Sand hills areas are indicated by the dotted pattern. Adapted from Weeks et al. (1988, fig. 1).

FIGURE 20—Gray County Wind Farm near Montezuma. The farm has 170 wind turbines that can generate up to 110 megawatts of power, or enough for 33,000 households annually. The turbines stand 295 feet (90 m) tall, are nearly silent in operation, and are positioned along field boundaries. The alternate-year fallow-cropping pattern seen here is used to grow winter wheat without irrigation in the semiarid climate. View toward the northeast. April 2006.



Counties in the High Plains

The High Plains region covers all of Cheyenne, Rawlins, Decatur, Sherman, Thomas, Sheridan, Wallace, Greeley, Wichita, Scott, Stanton, Morton, Stevens, and Seward counties; portions of Norton, Phillips, Graham, Rooks, Logan, Gove, Trego, Lane, Ness, Hamilton, Kearny, Finney, Hodgeman, Gray, Ford, Edwards, Grant, Haskell, Kiowa, Pratt, Reno, Kingman, Meade, Clark, and Comanche counties; and small parts of Smith, Ellis, Pawnee, Barber, and Harper counties.

Red Hills

Red bedrock, soil, and stream sediment are the most obvious defining features of this physiographic region in south-central Kansas. The Red Hills are bounded to the east by the Wellington Lowland section of the Arkansas River Lowlands and to the north and west by the High Plains. Sometimes known as the Gyp Hills for the gypsum found in the area, the Red Hills exhibit a colorful and rugged landscape unlike any other region in Kansas. The region is part of the Southwestern Tablelands ecoregion, characterized by subhumid grassland and semiarid prairie (Chapman et al., 2001). Cities of the Red Hills include Kingman, Medicine Lodge, Coldwater, and Ashland.

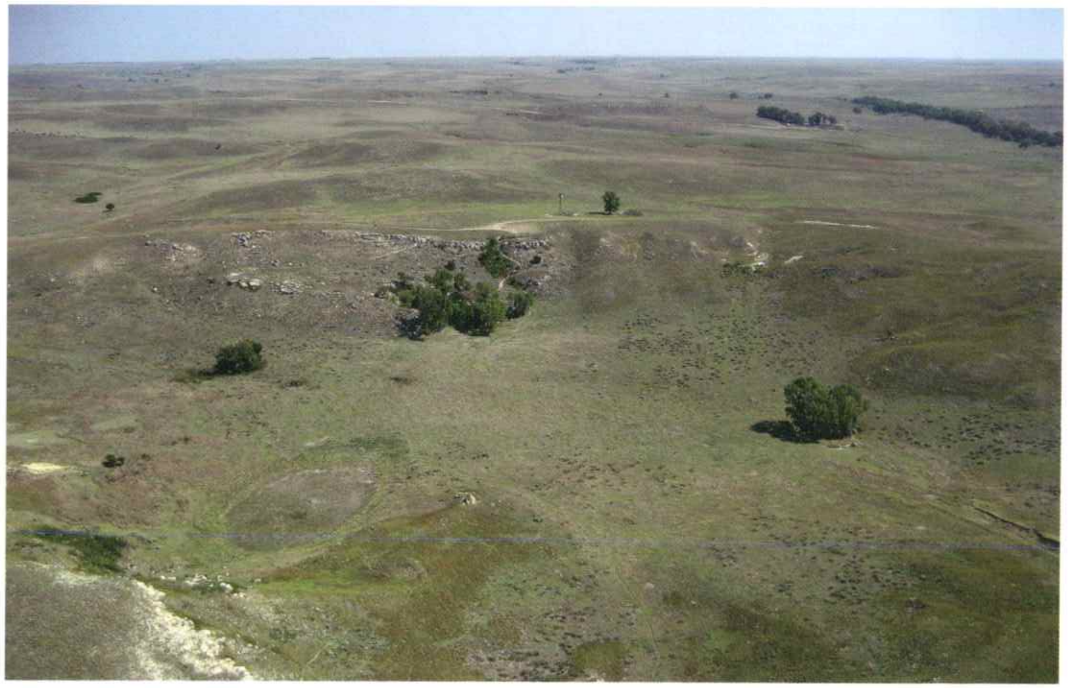
In contrast to adjacent, relatively flat regions, the Red Hills display substantial relief as a consequence of widespread stream and gully erosion. Lowest elevations are about 1,400 feet (425 m) along the Chikaskia River valley in southeastern Kingman County; highest elevations reach 2,400 feet (730 m) in southeastern Meade County. Much of the Red Hills region consists of ravines, gullies, small channels, and valleys that display intricate drainage patterns. Isolated buttes and mesas may stand 100 to 200 feet (30–60 m) above the surrounding terrain (fig. 21). In many ways, the Red Hills resemble parts of the Colorado Plateau or Arizona Painted Desert.

The Red Hills derive their color from Permian bedrock that consists of poorly consolidated shale, siltstone, and sandstone stained rust red by iron oxide. These sediments were deposited as terrestrial alluvium in an ancient desert that extended across what is now the southern Great Plains region from the Rockies in New Mexico and Colorado to the Ouachita Mountains in eastern Oklahoma. Interbedded with the red strata are beds of dolomite and soluble minerals, namely gypsum, anhydrite, and salt deposited from evaporating seawater. Several Lower and Upper Permian formations crop out in the Red Hills, of which the Blaine Formation is most prominent. It contains thick layers of white gypsum and, in the subsurface, salt. Gypsum beds are sufficiently resistant to erosion in the relatively dry climate of the region, so they form conspicuous rimrocks and caprocks, particularly in western Barber County.

Underground dissolution of thick salt and gypsum layers has led to surface collapse in many places. Big Basin and Little Basin are well-known sinkholes in Clark County (fig. 22). Big Basin occupies about one square mile (2.6 km^2) and is more than 100 feet (30 m) lower than the surrounding upland. Little Basin is equally deep but much smaller in area. A perennial pool, known as St. Jacob's Well, is located in Little Basin. The Englewood–Ashland Lowland in southern

FIGURE 21—Red Hills terrain southwest of Medicine Lodge. Red shale and siltstone are eroding to form badlands in the foreground. The light-colored butte, center, is capped with gypsum. Abundant eastern red cedar (*Juniperus virginiana*) grow mainly on gullied terrain. View toward the northeast. Barber County, June 2006.

FIGURE 22—Large sinkholes in Upper Permian red beds in western Red Hills. Clark County, June 2006. **Left:** Big Basin is the large depression in the center-left distance. Only the north half of the basin is visible in this view toward the northwest. **Below:** Little Basin, foreground, contains St. Jacob's Well, a perennial spring located in the center clump of trees beneath the windmill.



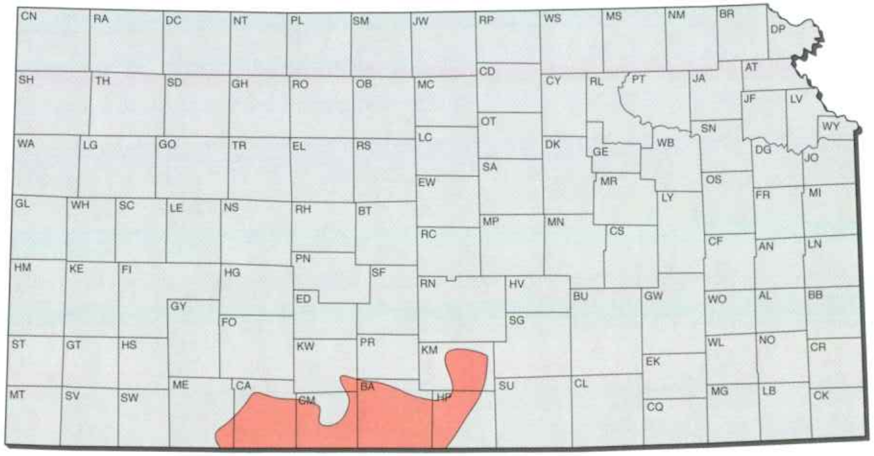
Clark County is thought to be a still larger example of surface collapse by underground dissolution (Wilson, 1978).

Ground water dissolved soluble beds in the Red Hills to create more than 400 caves, the most known caves of any physiographic region in Kansas (Young and Beard, 1993). Most of these caves are young, small, and short-lived, however, because continuous dissolution causes them to collapse within a few millennia. This frequency of collapse suggests that geomorphic change is relatively rapid in the Red Hills due to a combination of subsurface dissolution and surface erosion of soluble and poorly consolidated rock. One of the most famous landmark natural bridges south of Sun City in western Barber County broke down in 1962, although human intervention may have been a contributing factor in that collapse (fig. 23).

Surface water is relatively scarce in the Red Hills. Smaller streams are intermittent; larger perennial streams include the Cimarron River, Medicine Lodge River, and Chikaskia River. A few small, humanmade lakes exist, but no large reservoirs have been constructed in this region. Likewise, ground water is not abundant apart from alluvial aquifers in the larger river valleys. Scarcity of water resources has limited most land use to pasture and grazing. Numerous oil and gas fields have been discovered beneath the Red Hills, especially in Barber County (fig. 24), and gypsum is mined near Sun City to produce drywall and other plaster products.

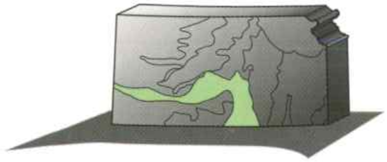
FIGURE 23—Red Hills natural bridge in western Barber County. **Upper:** In 1952 (photo by H. A. [Steve] Stephens; courtesy of Stan Roth). **Lower:** In 1962 when rubble was all that remained after the natural bridge collapsed due to erosion by an intermittent stream (photo by Stan Roth).

FIGURE 24—Small oil field in Red Hills southwest of Medicine Lodge. Note the intricate erosion patterns in the red shale badlands. View toward the northwest. Barber County, June 2006.



Counties in the Red Hills

The Red Hills region covers most of Barber County; portions of Kingman, Harper, Comanche, and Clark counties; and small corners of Kiowa and Meade counties.



Arkansas River Lowlands

The Arkansas River courses through southwestern and south-central Kansas. The adjacent lowlands range from a few miles wide on the Colorado border where the river enters the state (fig. 25) to scores of miles across at the Oklahoma border where it exits. Near the Colorado border, the elevation of the Arkansas River Lowlands peaks at about 3,380 feet (1,030 m); near the Oklahoma border, it reaches its lowest point of about 1,030 feet (315 m).

The Arkansas River Lowlands region, as defined here, encompasses the McPherson and Wellington lowlands as well as the Finney and Great Bend lowlands that Schoewe included on his map (fig. 9, p. 6). It borders the High Plains, Smoky Hills, Blue Hills, Flint Hills, and Red Hills physiographic regions. Terraces, old stream channels, and sand hills locally give some topographic relief to an otherwise flat landscape within the region.

The region cuts across the Western High Plains and Central Great Plains ecoregions (Chapman et al., 2001). The former is composed of the Rolling Sand Plains, Moderate Relief Rangeland, and Flat to Rolling Cropland subregions. The latter includes the Wellington–McPherson Lowland, Great Bend Sand Prairie, and Rolling Plains and Breaks subregions. Cities of the Arkansas River Lowlands include Garden City, Dodge City, Great Bend, Hutchinson, McPherson, Wichita, Wellington, and Arkansas City.

In most places, the Arkansas River Lowlands are lower in elevation than adjacent upland regions. However, the northeastern corner is actually higher in elevation than the Smoky Hills and Flint Hills where the McPherson Lowlands forms a north- and east-facing escarpment in McPherson and Marion counties. Most of the Arkansas River Lowlands region is underlain by stream-deposited sand and gravel of Quaternary age. Some of this sandy sediment has been blown into dunes, particularly along the southern margin of the Arkansas River. The Great Bend section contains one of the largest sand dune terrains in the United States, covering parts of Barton, Stafford, Pawnee, Edwards, Kiowa, Pratt, Rice, and Reno counties (Muilenburg, 1961). Most of the dunes are stabilized by sand-sage prairie vegetation, but active dunes are present near Syracuse in Hamilton County. The Wellington Lowland section, in contrast, is an eroded surface on Permian shale with little alluvial sediment cover (fig. 26).

Displaying a distinctive route across the state, the Arkansas River flows generally east-southeast from the Colorado border to near Dodge City, where it turns abruptly northeast. At Great Bend it turns eastward and curves southeast and south for the remainder of its path across south-central Kansas. The Great Bend Lowland section is unusually wide south of the river, which suggests the Arkansas River has migrated northward a considerable distance during its evolution (Haworth, 1897).

At the northernmost edge of the Great Bend Lowland, Cheyenne Bottoms is a large natural depression that is the terminal point of an enclosed drainage basin in Barton County. It covers about 64 square miles (166 km^2) and has a flat floor with elevation around 1,800 feet (550 m), which is 20 to 40 feet lower than the Arkansas River valley at Great Bend (fig. 27). Cheyenne Bottoms is famous for great flocks of migrating waterfowl and shorebirds, including many rare and endangered species. It is often considered

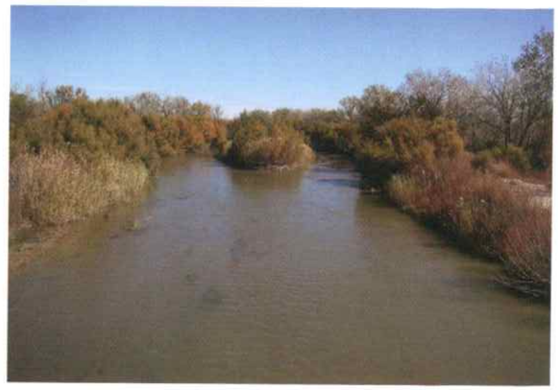


FIGURE 25—Arkansas River where it enters the state from Colorado near Coolidge. The brushy green trees along the banks are salt cedar (*Tamarix*), an invasive species considered a threat to habitat and ground water throughout the southwestern United States (Aber et al., 2005). Downstream (eastward) view. Hamilton County, October 2006.

the single most important site for migrating birds in North America (Zimmerman, 1990) and has been designated as a Ramsar wetland of international importance. Surface water there varies substantially from year to year, depending on drought and flood cycles (fig. 28).

The basin developed in Cretaceous bedrock overlying Upper Permian salt-bearing strata. The cause of sinking at Cheyenne Bottoms is likely due to deep-seated structural subsidence (Bayne, 1977), perhaps accompanied by subsurface salt dissolution and rock-salt creep (Keiswetter et al., 1995). Wind erosion during repeated drought periods may have further scoured the basin. However, the geological origin of this huge elliptical depression remains problematic. Cheyenne Bottoms appears to be the focal point for regional crustal tilting in central Kansas, as evidenced by northward migration of the Arkansas River and the anomalous bend of the river in this vicinity.

Another well-known wetland in the Great Bend Lowland is Quivira National Wildlife Refuge in Stafford County. At Quivira, Rattlesnake Creek feeds a series of saline marshes (fig. 29). Salt is derived from subsurface dissolution of Upper Permian bedrock and transported by ground water to the surface where it emerges in saline springs that feed area streams. As the water moves through the marshes, evaporation leads to increased salinity of seawater character. Similar high-salinity ground water is found along the upper Ninnescah River and lower Arkansas River valleys (Buddemeier et al., 1995). Hutchinson, 30 miles (48 km) east of

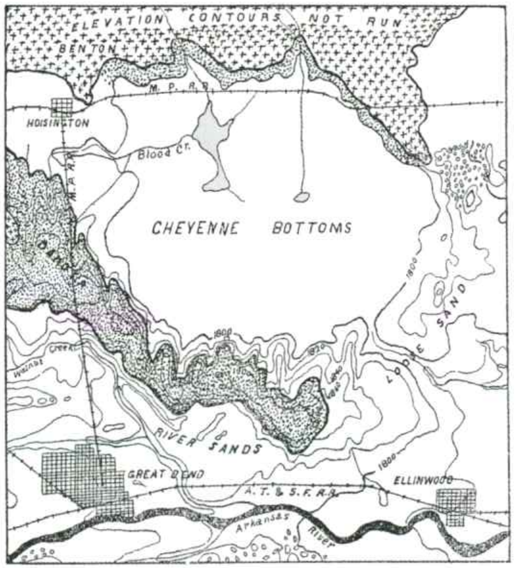


FIGURE 26 (above)—Ninnescah River in the Wellington Lowland section. The biological field station of Wichita State University is visible on the river bank in the lower left corner. Green winter wheat fields are evident in the background of this spring view. Sedgwick County, April 1999.

FIGURE 27 (left)—Cheyenne Bottoms in Barton County. The Blood Creek vicinity in the northwestern portion of the basin is shown in fig. 28. Adapted from Haworth (1897, fig. 1).

Quivira, has a long history of underground salt mining, which continues to be an important part of the local economy.

Several cities grew up along the banks of the Arkansas River, which provided water for early settlement and agricultural development. It was considered navigable as far upstream as Kinsley in the mid-1800s, although that is no longer the case. In the late 19th century, the supply of water was considered unlimited, and numerous canal-and-ditch systems were constructed to divert water from the river for farmland irrigation in the Finney Lowland section. Some of these systems are still in operation today, namely in the vicinity of Lakin and Garden City (fig. 30). The risk of flooding is slight in western

FIGURE 28—The Nature Conservancy marshland in northwestern Cheyenne Bottoms near Hoisington. Views northward. **Above:** Dry marsh during a drought period in October 2006. Note tractor mowing dead cattail thatch left of center. **Right:** The same marsh flooded after heavy rains in May 2007. Water levels reached historic highs in the spring and summer of 2007.

Kansas but increases in central Kansas, as exemplified in Great Bend and Hutchinson in 2007. Most of the Arkansas River Lowlands, except for the Wellington Lowland section, is underlain by the High Plains aquifer (fig. 19, p. 15). Ground water is abundant and has been exploited increasingly for agriculture, industry, cities, and recreation (fig. 31). Three Groundwater Management Districts have been established for portions of the Arkansas River Lowlands to regulate extraction and promote sustainable use of this crucial resource.

FIGURE 29—Quivira National Wildlife Refuge, Stafford County. **Above:** Little Salt Marsh. A levee and drainage structures are used to control water level. Rattlesnake Creek exits the marsh upper right and flows into Big Salt Marsh a few miles north. View toward northwest, May 2003. **Right:** Big Salt Marsh. The square structure in foreground marks the site of a former oil well. View toward southeast, May 2008.

FIGURE 30—Water diversions near Lakin during a drought year. Kearny County, October 2006. **Left:** Lake McKinney, a storage point for water diverted from the Arkansas River west of Lakin via the Amazon Ditch. From Lake McKinney water is transported via the Great Eastern Ditch to northwest of Garden City. The road runs along the dam and Lakin is in the distance. The band of rust-colored vegetation is curly dock (*Rumex crispus* L.). View toward the southwest. **Below:** Water flowing through a control structure in the Amazon Ditch with an oil well in the background.

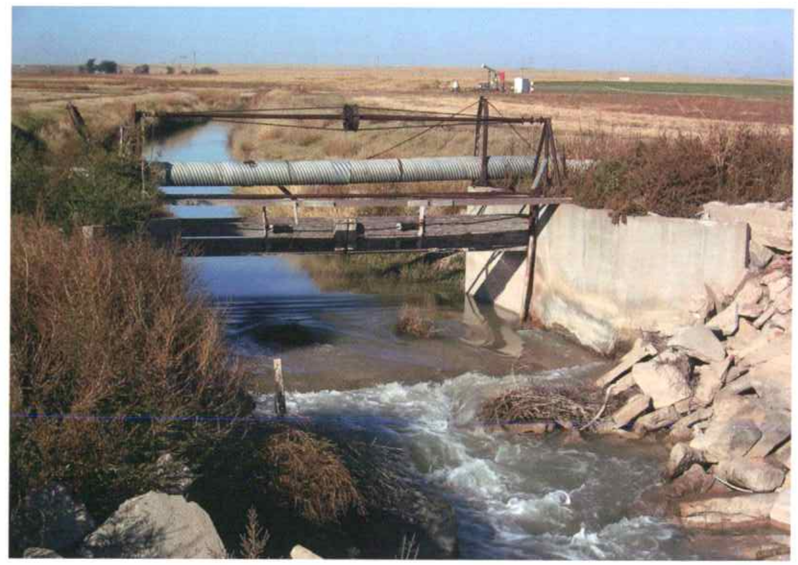
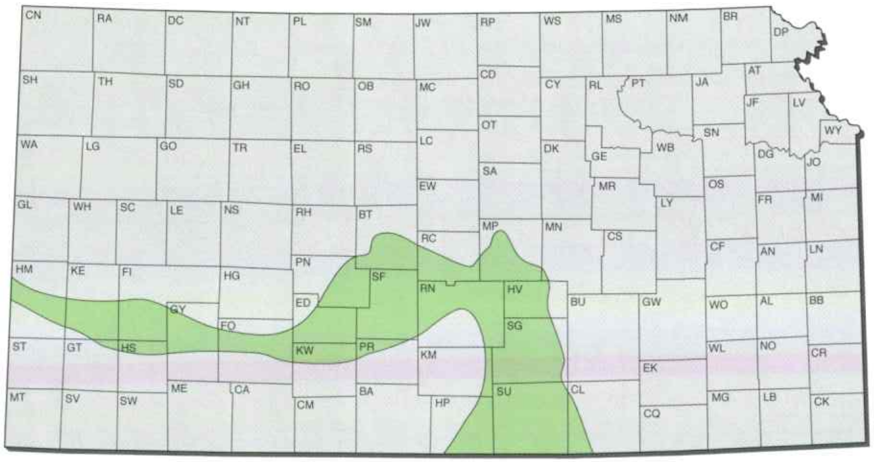
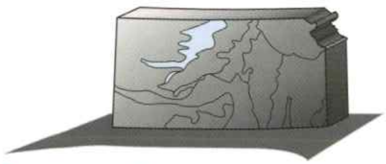


FIGURE 31—South Wind Country Club in sand hills terrain south of Garden City. Sand-sage prairie covers the rough areas between fairways. Ground water is used for fairway irrigation and adjacent suburban housing. View northward. Finney County, May 2002 (Aber et al., 2003).



Counties in the Arkansas River Lowlands

The Arkansas River Lowlands region covers all of Stafford and Sumner counties; portions of Hamilton, Kearny, Finney, Haskell, Gray, Ford, Edwards, Kiowa, Pawnee, Barton, Pratt, Rice, Reno, McPherson, Harvey, Sedgwick, Kingman, Harper, and Cowley counties; and small corners of Grant and Marion counties.



Chalk Buttes

The Chalk Buttes form a northeast-trending band between the High Plains and the Blue Hills with a long finger extending westward into the High Plains along the Smoky Hill River valley. Not recognized before as a separate physiographic region, the Chalk Buttes have most often been included in the High Plains (Moore, 1930; Schoewe, 1949; Muilenburg, 1953). Wilson (1978), however, identified this area as the "Niobrara chalk country" and placed it in the Smoky Hills. Because the underlying geology and surficial landforms are considered sufficiently distinct, the Chalk Buttes area is designated herein as a subregion of the Smoky Hills. The Chalk Buttes lie within the Central Great Plains ecoregion, particularly the Rolling Plains and Breaks subregion (Chapman et al., 2001). Hays is the largest city in the region, located at its eastern margin in Ellis County. Other cities include Stockton, Osborne, and Smith Center.

Lowest elevations in the region are about 1,750 feet (535 m) near Mankato in Jewell County, and highest elevations are around 2,750 feet (840 m) at the tip of its western extension along the Smoky Hill River valley in Logan County. Upland areas, such as in the vicinity of Smith Center, comprise subtle hills and undulating plains in which local relief is generally less than 50 feet (15 m; fig. 32). But where small streams dissect the upland, relief may be as much as 100 feet (30 m). The greatest local relief, exceeding 200 feet (60 m), is found in the Smoky Hill River valley where small tributaries have cut numerous steep-sided ravines and eroded badlands along the sides of the main valley in Logan, Gove, Trego, and western Ellis counties (fig. 33). In this area, the Smoky Hill River has excavated one of the deepest valleys in the state with little accumulation of alluvial sediment (Haworth, 1897).

The Chalk Buttes subregion is characterized by the Upper Cretaceous

FIGURE 32—Slightly undulating upland and shallow channel of Paradise Creek at Plainville Township Lake. The kite line is on the right. View toward north. Rooks County, May 2008.

Niobrara Chalk, which is composed of chalk, shaly chalk, and chalky limestone beds some 500 to 750 feet (150–230 m) thick (O'Connor, 1968). This chalk originated in a shallow, inland, tropical sea and is comparable to chalk that forms the White Cliffs of Dover in England and similar chalk cliffs in Denmark (fig. 34). The Niobrara Chalk has been world famous for its vertebrate and invertebrate fossils since the late 19th century when early collectors scoured the region for spectacular mosasaurs, plesiosaurs, fish, sharks, giant turtles, flying reptiles, aquatic birds, ammonites, squids, and giant clams (Everhart, 2005). Logan, Gove, Lane, Trego, Ellis, and Rooks counties, in particular, have yielded many thousands of specimens over the years. Although the Upper Cretaceous strata are best known for marine fossils, remains of terrestrial dinosaurs (Liggett, 2005) and petrified wood also have been found. Badlands in the Chalk Buttes region are considered among the most important sites in the world for collecting mosasaurs (Everhart, 2005), and the search for remarkable fossils continues today.

Where the Smoky Hill River valley was deeply eroded, chalk remnants in the form of buttes, towers, and pinnacles were left behind in several places, particularly in Gove County. Among the best-known geologic landmarks in Kansas are Castle Rock and Monument Rocks. At Monument Rocks, the residual chalk stands as narrow partitions or walls rising above the surrounding shortgrass prairie like ruins of an ancient fortress (fig. 35). This site has been used for movie sets, as it captures the public imagination of the

FIGURE 33—Chalk badlands near Castle Rock. Such badlands are prime areas for fossil collecting. Agricultural crops grown in thin loess soil can be seen on the upland in the background. View toward southwest. Gove County, April 2007.

FIGURE 34—Stevns Cliff in eastern Denmark. The lower white portion is Upper Cretaceous chalk; the upper gray ledge is Paleocene (Paleogene) limestone. This cliff is the worldwide reference section for the Cretaceous/Paleogene boundary (see fig. 7, p. 5). Note the people standing at base of cliff for scale.

"wild west." Unfortunately, the soft chalk is gradually weathering and eroding away, which has led to collapse of several famous landmarks (fig. 36). Both the "Cobra" near Castle Rock and the "Sphynx" at Monument Rocks disappeared in this manner during the past few decades (Charlton and Merriam, 2003). Because of its prominence and widespread distribution, chalk has been proposed as the state rock (Muilenburg, 1961). However, Kansas has never adopted an official state rock, mineral, gemstone, or fossil.

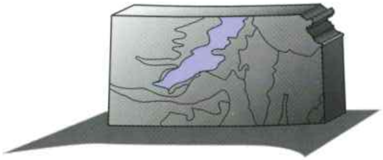
As in the Blue Hills subregion, ground water is scarce and surface water in rivers and lakes is subject to recurring drought in the Chalk Buttes. Cedar Bluff Reservoir on the Smoky Hill River is the most sizable water body, although it is full only in exceptionally wet years. Webster and Kirwin are other notable reservoirs dammed respectively on the South Fork Solomon and North Fork Solomon rivers in Rooks and Phillips counties. The City of Hays, at the eastern margin of the region, has perennial water shortages because of insufficient surface-water and ground-water supplies, which have placed limits on economic development. Like the Blue Hills, the Chalk Buttes region is situated above the Central Kansas uplift in which numerous oil fields are located. When energy prices are high, exploration and development of oil fields are renewed in the region.

FIGURE 35—Monument Rocks in the Smoky Hill River valley. Gove County, May 2006. **Above:** The cluster of chalk buttes, one with an arch, is surrounded by shortgrass prairie. Individual buttes stand 25 to 30 feet (8–10 m) high. The chalk knob in the upper right corner is the eroded stump of the Sphynx, a former pinnacle. View toward the northwest. **Right:** Light comes through the arch in the butte wall at lower left and the shadow of the photographer (SWA) can be seen beside the rocks (marked with arrow in detail at right).

FIGURE 36—Ground views of Castle Rock. Gove County, in 1941 **(left)**, 1997 **(middle)**, and 2001 **(right)**. The gradual collapse of the central towers and overall reduction of butte mass are evident in these photographs taken from the same vantage point. Adapted from Charlton and Merriam (2003; used with permission).

Counties in the Chalk Buttes

The Chalk Buttes region covers portions of Jewell, Smith, Phillips, Osborne, Rooks, Graham, Ellis, Trego, Gove, Logan, and Ness counties, and small pieces of Norton, Lane, and Finney counties.



Blue Hills

The Blue Hills in north- and west-central Kansas between the Smoky Hills and Chalk Buttes have long been recognized as a unique physiographic area of the state (Moore, 1930; Schoewe, 1949; Johnston, 1964; Buchanan and McCauley, 1987). However, Muilenburg (1953, 1961) combined it into the Smoky Hills and Wilson (1978) considered it a subdivision of the Smoky Hills, which he called the "Fencepost limestone country." Here we consider the Blue Hills as a subregion of the larger Smoky Hills province. The Blue Hills are part of the Central Great Plains ecoregion, specifically the Smoky Hills and Rolling Plains and Breaks subregions (Chapman et al., 2001). Cities in the Blue Hills include Belleville, Beloit, Russell, La Crosse, and Jetmore.

Elevations range from lows around 1,440 feet (440 m) in the Saline River valley to a high of more than 2,600 feet (790 m) at the subregion's boundary with the High Plains in northeastern Finney County. Most of the Blue Hills consists of gently rolling hills and undulating plains with slight local relief (fig. 37). However, a steep escarpment marks the eastern margin of the Blue Hills in places, such as northeast of Ellsworth where local relief exceeds 300 feet (90 m). Likewise steep slopes and high local relief are found on the edges of some river valleys that are incised into the Blue Hills, such as along the Smoky Hill River in Russell and Ellsworth counties and Buckner Creek in Hodgeman County.

The Blue Hills are underlain by Upper Cretaceous marine shale, chalky shale, and thinly bedded chalky limestone. Formations from the bottom up include the Graneros Shale, Greenhorn Limestone, and Carlile Shale. The blue-gray color of the latter is probably the origin of the name for this region (Buchanan and McCauley, 1987). Undoubtedly the most famous geologic feature is the Fencepost limestone bed that marks the top of the Greenhorn Limestone (Muilenburg, 1953; Muilenburg and Swineford, 1975). This thin, chalky limestone bed was widely quarried in the late 19th and early 20th centuries. A similar fossil-

FIGURE 37—Intensively farmed uplands in the Blue Hills where a thin cover of loess soil supports dryland crops. Winter wheat fields alternate with fallow fields and pastures in a rectangular grid pattern. View toward the west. Rush County, May 2006.

rich limestone bed, called the "shell rock," was quarried from the middle Greenhorn Limestone (Wilson, 1978). Both were used for everything from fenceposts to cathedral-style churches (figs. 38 and 39).

Limestone fenceposts became iconic symbols of early homestead settlement and life in western Kansas (fig. 40). They can still be seen throughout the region even though traditional hand quarrying of "post rock" came to an end in the early 20th century as imported lumber, steel, and other building materials became readily available. Eventually, post rock became popular again and now is being produced mainly for ornamental and decorative purposes. Upper Cretaceous strata of the Blue Hills have yielded many significant fossil specimens, including crocodiles, toothed birds, plesiosaurs, mosasaurs, fish, and large clams (Everhart, 2005).

The Blue Hills span a buried structure known as the Central Kansas uplift, which has been a prolific source of oil production since the mid-20th century. Exploration and development of oil fields in this region, however, has gone up and down with fluctuating energy costs. The Blue Hills have little ground water, and surface-water resources are limited to the major rivers and streams, which are subject to recurring drought conditions. Wilson Lake and Waconda Lake are large reservoirs on the Saline and Solomon rivers, respectively. Finney Wildlife Area, a small reservoir built in the 1930s, is located at the southwestern end of the Blue Hills, but it is dry most years. Nearby, construction is underway for the newest reservoir project in Kansas on Buckner Creek at Horse Thief Canyon in Hodgeman County.

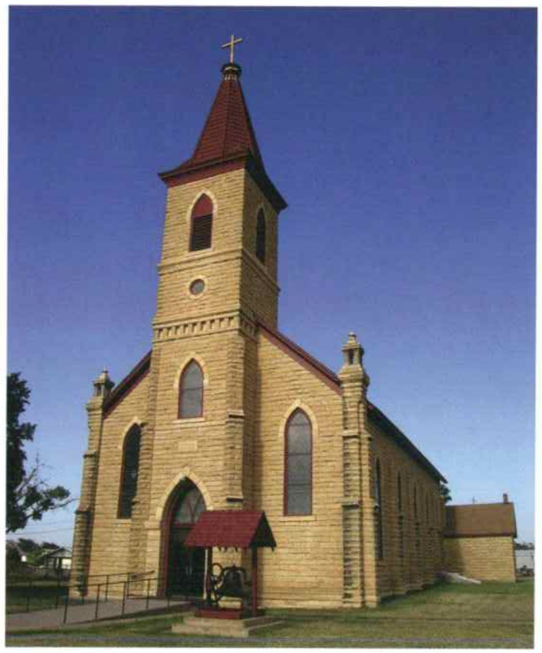
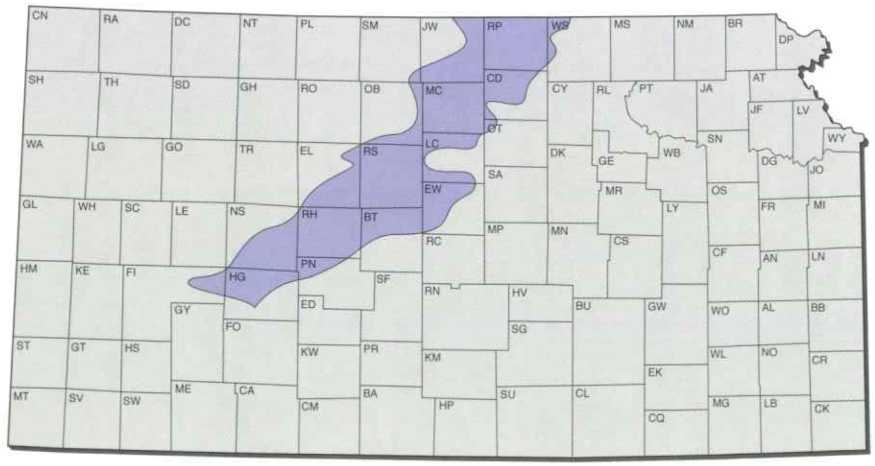


FIGURE 38—Fencepost limestone used for building construction in the Blue Hills. **Left:** Water tower at Paradise built in the 1930s, Russell County. **Right:** St. Anthony's Church in Schoenchen, Ellis County. This is one of several stone churches erected by German–Russian immigrants in the vicinity early in the 20th century. The cornerstone was laid in 1900 and the church dedicated in 1911.

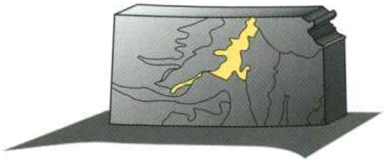
FIGURE 39—Liebenthal. US–183 runs north to south (left to right) and a county road runs eastward into the distance. St. Joseph's Church, built with Fencepost limestone, stands next to the highway on the right, and trees outline the path of the meandering Big Timber Creek in middle background east of town. Rush County, May 2006.

FIGURE 40—Limestone fenceposts at cemetery in Liebenthal. A line of stone fenceposts across the top marks the cemetery parking area about one-quarter mile (0.4 km) west of St. Joseph's Church, seen in fig. 39. Most of the gravestones in the cemetery are imported marble and granite; few are local stone. The kite flyers are in upper right corner. Rush County, May 2006.



Counties in the Blue Hills

The Blue Hills region covers all of Republic, Mitchell, and Russell counties; most of Rush County; parts of Jewell, Washington, Osborne, Cloud, Lincoln, Ellis, Ellsworth, Barton, Ness, Pawnee, Hodgeman, and Finney counties; and small corners of Smith and Ottawa counties.



Smoky Hills

The Smoky Hills form a distinctive region located primarily in north-central Kansas with a southwest extension reaching the High Plains. The Blue Hills and Chalk Buttes, often considered part of the Smoky Hills region, are featured as separate subregions in this book. The Blue Hills lie to the west of the Smoky Hills, the Flint Hills and Glaciated Region lie to the east, and the Arkansas River Lowlands region to the south. Lowest elevations are along the Smoky Hill River valley in Saline County at about 1,240 feet (380 m). The highest elevation, about 2,400 feet (730 m), is on the Ford–Hodgeman county boundary.

Local relief in the region varies from wide valleys to gently undulating plains to rugged hills more than 200 feet (60 m) high (fig. 41). The two most famous vistas are from Coronado Heights in Saline County, supposedly visited by Coronado in 1541, and Pawnee Rock in Barton County, a key landmark on the Santa Fe Trail. The Smoky Hills are in the Central Great Plains ecoregion, specifically the Smoky Hills and Rolling Plains and Breaks subregions (Chapman et al., 2001). Cities in the region include Minneapolis, Salina, Ellsworth, and Larned.

The Smoky Hills are composed of the Cheyenne, Kiowa, and Dakota formations, which consist mainly of shale, siltstone, and sandstone deposited in coastal, deltaic, and shallow-marine environments near the shore of the inland Cretaceous sea. Of these formations, the Dakota is most widespread and characteristic in the southern and eastern Smoky Hills. Within the Dakota, sandstone bodies are distributed in various lenses, channels, and sheets, and local lime and iron cementation of the sandstone is highly variable. Because well-cemented sandstone is more resistant to erosion than poorly consolidated strata, it forms the higher hills and knobs of the region. The patchy distribution of cemented zones in sandstone bodies explains the irregular size, shape, and placement of hills.

Large concretions (fig. 42) are among the most distinctive cemented features within the Dakota sandstone, as at Mushroom Rock

FIGURE 41—Smoky Hill Buttes near Coronado Heights. The hills in the center distance stand more than 200 feet (60 m) above the adjacent terrain. The near pond trapped suspended yellowish-brown sediment from recent runoff, which prevented sediment from entering the next pond downstream. View toward the north. Saline County, May 2007.

FIGURE 42—Rock City near Minneapolis. Ottawa County, April 2007. **Above:** Ground view of sandstone concretions also seen in center of upper right photo. **Upper right:** Most of the large sandstone concretions are nearly spherical; some are joined to create double and triple spheres. The single spheres in this cluster are 15 to 25 feet (5–8 m) in diameter. Vertical closeup view. **Lower right:** The Solomon River valley lies beyond Rock City; the grain elevator at Minneapolis is in the far left background. Superwide-angle overview toward the northeast.

State Park in Ellsworth County and Rock City in Ottawa County. Rock City contains about 200 huge spherical concretions that Wilson (1978) likened to giant bowling balls (fig. 42). Johnston (1964) suggested that concretions may have formed around organic matter buried in the sediment, as decay altered the surrounding chemical environment and led to precipitation of calcium carbonate cement around the organic nucleii. More recently, McBride and Milliken (2006) determined that concretions did not grow outward from central nucleii, but rather the cementation took place throughout the spherical bodies as ground water from different sources mixed in the formation.

Major rivers—the Republican, Solomon, Saline, and Smoky Hill—cross the Smoky Hills region. These rivers have migrated back and forth, eroding wide valleys as they cut down into relatively soft, shaly bedrock, but steep bluffs and cliffs remain where cemented sandstone is present. Crops are grown in fertile alluvial soils in the valleys and on low terraces (fig. 43), whereas the uplands are used mainly for grazing pasture (fig. 44). Surface water is relatively abundant, and the Smoky Hill River in Ellsworth County was dammed to form Kanopolis Lake. Ground water is found in alluvial aquifers of the larger valleys and in uplands where sandstone bodies are present in the shallow subsurface. However, little irrigation is practiced in this region, as summer precipitation is normally adequate for crops. Flooding is a recurring event in the valley bottomlands, as seen at Salina in 2007.

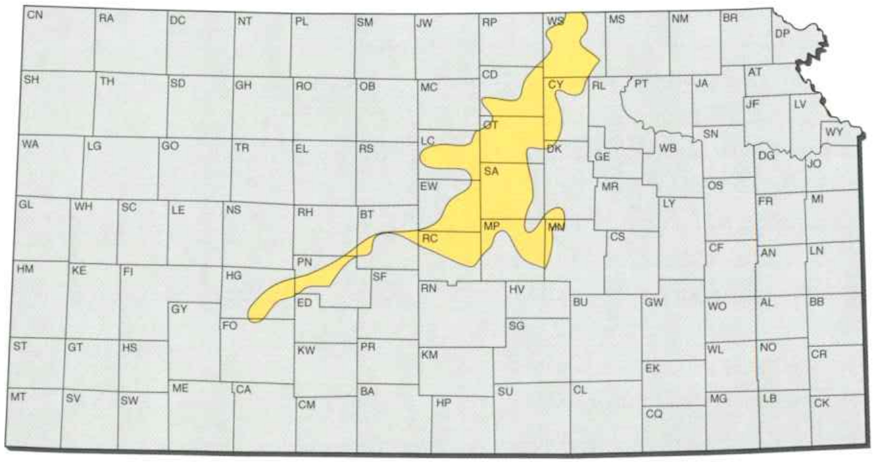
FIGURE 43—Crop fields on low terraces on the eastern side of the Smoky Hill River valley. An old Union Pacific railroad grade curves across at right. View toward northeast. Saline County, September 2007.

Fossil sharks, rays, fish, turtles, crocodiles, plesiosaurs, several dinosaur specimens, various invertebrates, and thousands of leaf impressions have been found in the Dakota Formation since the mid-1800s (Landis, 2005; Liggett, 2005). The Kiowa Formation has yielded rare finds of amber, a type of fossil resin now classified in the cedarite group because of its similarity to specimens from Cedar Lake, Alberta, Canada (Aber and Kosmowska–Ceranowicz, 2001). Small caves are present in Dakota sandstone, and petroglyphs (rock carvings) made by Native Americans are preserved on cliffs and in caves.

Clay and shale of the region have proved to be excellent raw materials for bricks, tiles, and other ceramic products, and lignite (brown coal) was mined for fuel in the past. Underneath the Cretaceous strata, Upper Permian salt beds are mined in the vicinity of Kanopolis and Lyons. Hollowed-out caverns in the salt beds are used for storage of natural gas produced in the Hugoton gas field of southwestern Kansas and other fields. In Saline County, the open prairie landscape is favorable for military training at the Smoky Hill Air National Guard Range (fig. 45).

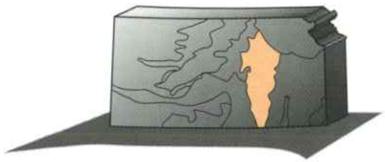
FIGURE 44—Buffalo-grazing range in Smoky Hills upland at Maxwell Wildlife Refuge. Trees line the small stream valleys, and several ponds are visible in the distance. View toward the north. McPherson County, September 2007.

FIGURE 45—Cattle grazing (center) with Smoky Hill Air National Guard Range in the far background. View toward the northwest. Saline County, May 2007.



Counties in the Smoky Hills

The Smoky Hills region covers portions of Washington, Clay, Cloud, Ottawa, Lincoln, Saline, Ellsworth, Marion, McPherson, Rice, Barton, Pawnee, and Hodgeman counties; and small areas of Dickinson, Rush, and Ford counties.



Flint Hills

The Flint Hills region, one of the most distinctive and picturesque areas in Kansas, extends as a belt of hills from the edge of the Glaciated Region southward to Oklahoma, a north-south distance of about 175 miles (280 km). The widest portion, just south of the Kansas and Smoky Hill rivers, is about 70 miles (110 km) across from east to west. Tapering off toward the south, the region is only a few miles wide at the Oklahoma border. Elevations range from below 920 feet (280 m) on the Kansas River in Wabaunsee County to above 1,640 feet (500 m) on the Flint Hills crest in Chase, Greenwood, and Butler counties. These are the highest elevations in the eastern third of the state. Local topographic relief exceeds 300 feet (90 m) in many places. Cities within the Flint Hills include Manhattan and Junction City in the north and El Dorado and Winfield in the south. The physiographic region corresponds closely with the Flint Hills ecoregion, although the latter extends slightly farther east based on tallgrass prairie (Chapman et al., 2001).

The eastern margin of the Flint Hills is a steep, rugged escarpment that rises abruptly above the Osage Cuestas to the east. In contrast, the western side of the Flint Hills is a broad cuesta that slopes gradually downward toward the Smoky Hills and Arkansas River Lowlands. Thus, the crest of the Flint Hills stands higher than terrain on either side. The Flint Hills are deeply dissected by numerous stream valleys. In the northern and central Flint Hills, the Blue, Kansas, and Neosho–Cottonwood river drainages divide the uplands into several distinct segments. The southern Flint Hills, however, form a continuous ridge along the divide between the Verdigris–Fall drainage to the east and Arkansas–Walnut basin to the west (fig. 46).

The Flint Hills are underlain by Lower Permian limestone and shale. These strata are arranged in repeated layers called cyclothems (fig. 47). Cyclothems in the Flint Hills are remarkably similar to Upper Pennsylvanian cyclothems of the Osage Cuestas region, except that Lower Permian cyclothems have prominent red-shale zones and lack sandstone and coal that are common in Pennsylvanian cyclothems. Limestone beds toward the top of each cyclothem contain abundant chert (flint) in many places (fig. 48). Because chert is resistant to chemical weathering, it accumulates as a residual layer in the soil

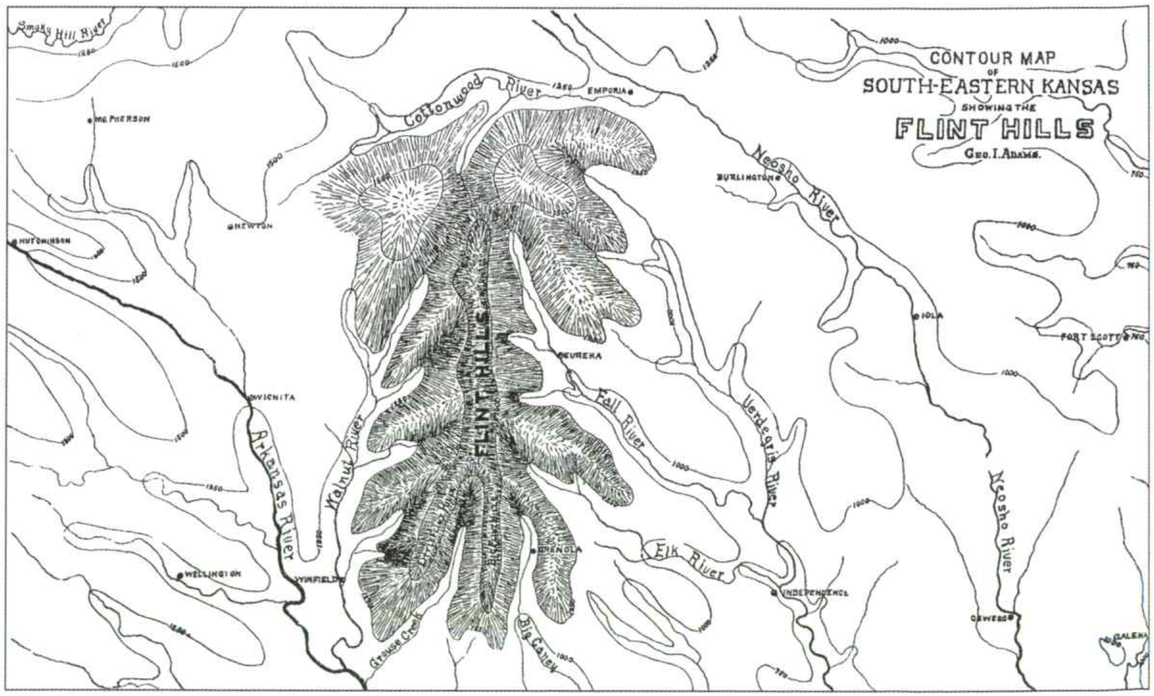


FIGURE 46—Southern Flint Hills south of the Cottonwood River valley. The ridgelike crest forms the drainage divide between the Verdigris–Fall basin to the east and Arkansas–Walnut basin to the west. Adapted from Haworth (1896).

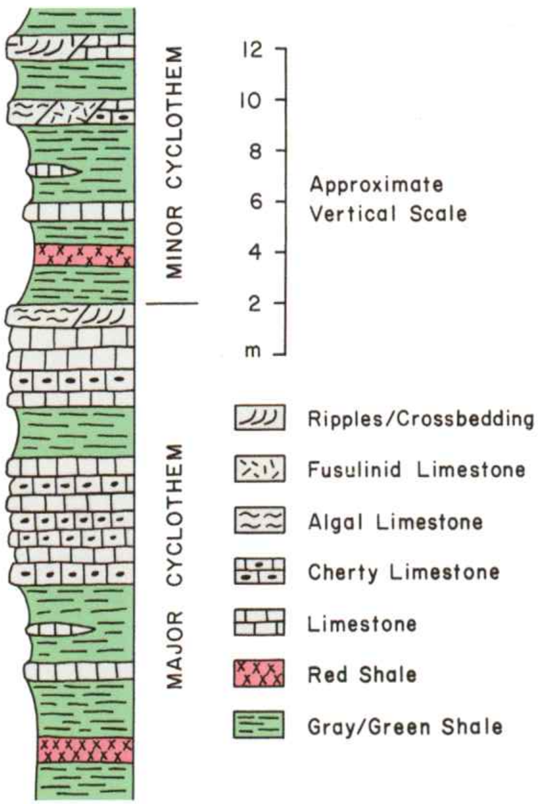


FIGURE 47—Schematic model of Lower Permian cyclothems of the Flint Hills region. Adapted from Aber (1991b).

FIGURE 48—Outcrop of the Florence Limestone Member of the Barneston Limestone displaying interbedded limestone, chert, and shaly limestone. Weathering has concentrated chert fragments in residual red soil at the surface. Scale pole marked in feet. Butler County.

when limestone dissolves at the surface. Consequently, the chert creates an armor-like cover that protects the Flint Hills from erosion and preserves the region's relatively high elevation and rugged topography.

Certain limestone layers lack chert, are relatively homogeneous, and form thick beds ideal for quarrying stone blocks (Aber and Grisafe, 1982). Several of these beds have been exploited since the 19th century and used to build stone structures throughout the Flint Hills. Alma and Marion are two local towns well known for their stone architecture. Among the quarried layers, the Cottonwood and Fort Riley Limestone Members are most important. Many famous buildings have been constructed with these stones, including part of the State Capitol in Topeka and the Chase County Courthouse (fig. 49).

Thicker limestone units, especially the Barneston Limestone, have several zones with well-developed karst morphology as a result of underground limestone dissolution. Typical features include sinkholes, disappearing streams, numerous springs, and cave systems (Young and Beard, 1993). Such features are common in central Butler County (fig. 50). Karst landscape is developed in connection with structural domes, upland drainage divides, entrenched stream valleys nearby, and lack of thick surficial cover, such as chert or loess. The combination of these factors enhanced the conditions for vertical drainage of water into highly fractured and soluble rock (Aber, 1992).

During the course of downcutting, streams have left behind evidence of their former channels in the form of chert gravel deposits named the Leon gravel (Aber, 1992), now situated on hilltops and high terraces. In nearly all cases, downward stream erosion has been asymmetric. As a result, older terraces are located only on one side of the valley. In valleys running north to south, older terraces and chert gravels are located primarily on the western sides; valleys extending east to west have preserved terraces and chert gravels mainly on the northern sides. A similar pattern is found to the east in the Osage Cuestas,

FIGURE 49 (right)—Chase County Courthouse in Cottonwood Falls. Completed in 1873 from Cottonwood Limestone Member quarried nearby, it is the oldest courthouse still in use in Kansas.

FIGURE 50 (below)—Sinkhole in Fort Riley Limestone Member in central Butler County. This sink connects directly to Smith Cave in the subsurface. Kansas Academy of Science fall field trip, October 1995.

which suggests that regional crustal tilting may be responsible for streams gradually shifting toward the south and east as they became entrenched (Aber, 1997).

Stream erosion in the Flint Hills has exploited weak zones in the bedrock, namely fracture zones, resulting in a linear network of valleys. Long, straight stream valleys, which are one type of linear surface feature known as lineaments, coincide with fracture sets in surficial bedrock that reflect still deeper fractures within the basement rock of the region (Aber et al., 1997). Such lineaments may continue across adjacent physiographic regions. Among the most prominent lineaments in eastern Kansas is the Neosho River valley that cuts northwest to southeast through the Flint Hills and Osage Cuestas.

The Flint Hills include the largest tract of tallgrass prairie that still exists in the United States. Owing to rocky soils and steep slopes, crop agriculture has been limited to narrow valleys, particularly in the eastern portion. Some crops are grown in thin loess soils that cap uplands in the western portion of the region. Cattle grazing is the primary land use, and ranchers employ controlled burning to maintain the prairie grasses (fig. 51; Hoy, 1993). Based on the relatively unmodified condition of the landscape, The Nature Conservancy has acquired considerable acreage, including most of the Tallgrass Prairie National Preserve and the Konza Prairie. The Flint Hills embody the archetype of the American prairie, and as such, the region has become a destination for ecotourism and scientific research.

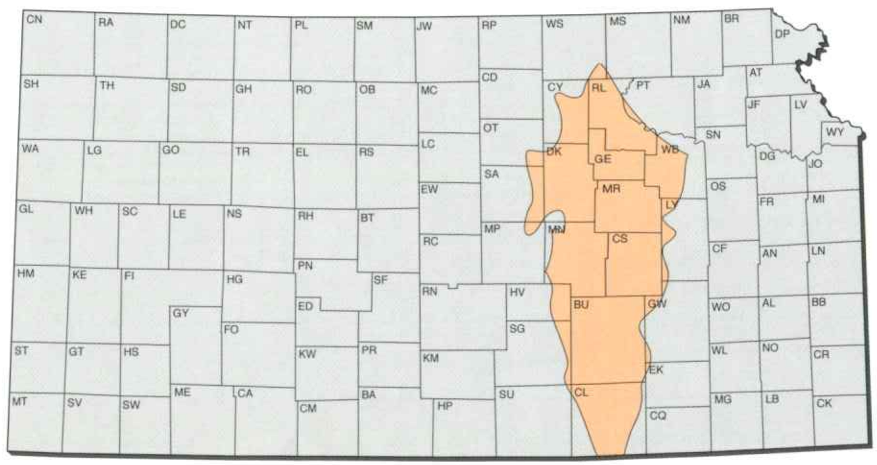
The Flint Hills generally are perceived as little modified by human activity, but in fact, considerable development has occurred. Oil and gas are produced from structures along the buried Nemaha uplift and Humboldt fault zone, particularly in Cowley and Butler counties. The region is crisscrossed with major highways, pipelines, and electrical-transmission lines. Large and small reservoirs have been constructed (fig. 52). Trees and woodlands are encroaching on the grassland as natural fires that would have limited them are kept under control (fig. 53; Applegate et al., 2003; Peterson et al., 2004). Military training takes place at Fort Riley, and a housing boom has been underway in the vicinity of Junction City and Manhattan (fig. 54). Radio and telephone towers cluster on the higher ridges, and, most recently, wind turbines have been constructed to generate electricity. The reality is that few unspoiled prairie vistas remain.

FIGURE 51 (upper left)—Controlled burn maintains prairie-grassland habitat at the Ross Natural History Reservation, Emporia State University. Lyon County, April 2000. From Harrell et al. (2007).

FIGURE 52 (lower left)—Lake Wabaunsee. A small water-supply and recreational resource near Eskridge, the lake is dammed on a tributary of Mill Creek. The road extending from behind the dam into the background serves as both K–4 and K–99. Superwide-angle view toward northwest. Wabaunsee County, June 2006.

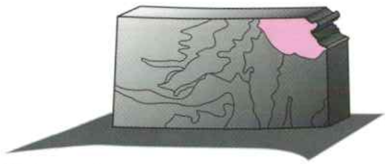
FIGURE 53—Rural Flint Hills vista in central Chase County. In spite of the largely natural character of this late spring prairie scene, encroachment of trees along Rock Creek and its tributary valleys is evident. View toward east. June 2008.

FIGURE 54—Recent housing development in the Flint Hills uplands on the west side of Manhattan. The typical character of the Flint Hills is hardly noticeable in this standard pattern of suburban land use. View toward northeast. Riley County, September 2006.



Counties in the Flint Hills

The Flint Hills region covers all of Geary, Morris, and Chase counties; most of Riley, Butler, Marion, and Dickinson counties; portions of Clay, Wabaunsee, Saline, Harvey, and Cowley counties; and small parts of Marshall, Washington, Pottawatomie, Ottawa, Lyon, McPherson, Sedgwick, Greenwood, and Elk counties.



Glaciated Region

The Glaciated Region covers northeastern Kansas, including most of the area east of the Blue River valley and north of the Kansas River valley. In places the region extends south of the Kansas River valley in Wabaunsee, Shawnee, Douglas, and Johnson counties and west of the Big Blue and Little Blue river valleys in Marshall and Washington counties (fig. 55). This physiographic region is part of the Western Corn Belt Plains ecoregion, which includes the Missouri Alluvial Plain, Kansas Loess Hills, and Loess and Glacial Drift Hills in Kansas (Chapman et al., 2001).

Elevation in the Glaciated Region ranges from about 725 feet (220 m) at the junction of the Kansas and Missouri rivers in Kansas City to more than 1,550 feet (475 m) in central Pottawatomie County. Relief varies from relatively broad and flat uplands with gentle slopes to steep hills and deeply dissected stream valleys (fig. 56). The most rugged terrain is found adjacent to the Missouri River valley in Doniphan, Atchison, and Leavenworth counties, and where the Glaciated Region meets the Flint Hills in Wabaunsee and Pottawatomie counties. Bedrock of the region consists of Upper Pennsylvanian shale, limestone, and sandstone toward the east, Lower Permian shale and limestone to the west, and Cretaceous shale and sandstone in Washington County.

This region was invaded at least twice by broad glacial lobes that extended across the northern Plains from an ice sheet flowing southward out of central Canada. These glacier advances eroded the pre-existing landscape, deposited widespread till, and deformed the underlying bedrock. Glacial meltwater also played a prominent role in shaping the landscape through erosion of spillway channels and accumulation of thick, stratified sediment in glacial lakes and rivers.

In general, till, a mixture of unconsolidated sediment deposited during glaciation, is closely similar in composition

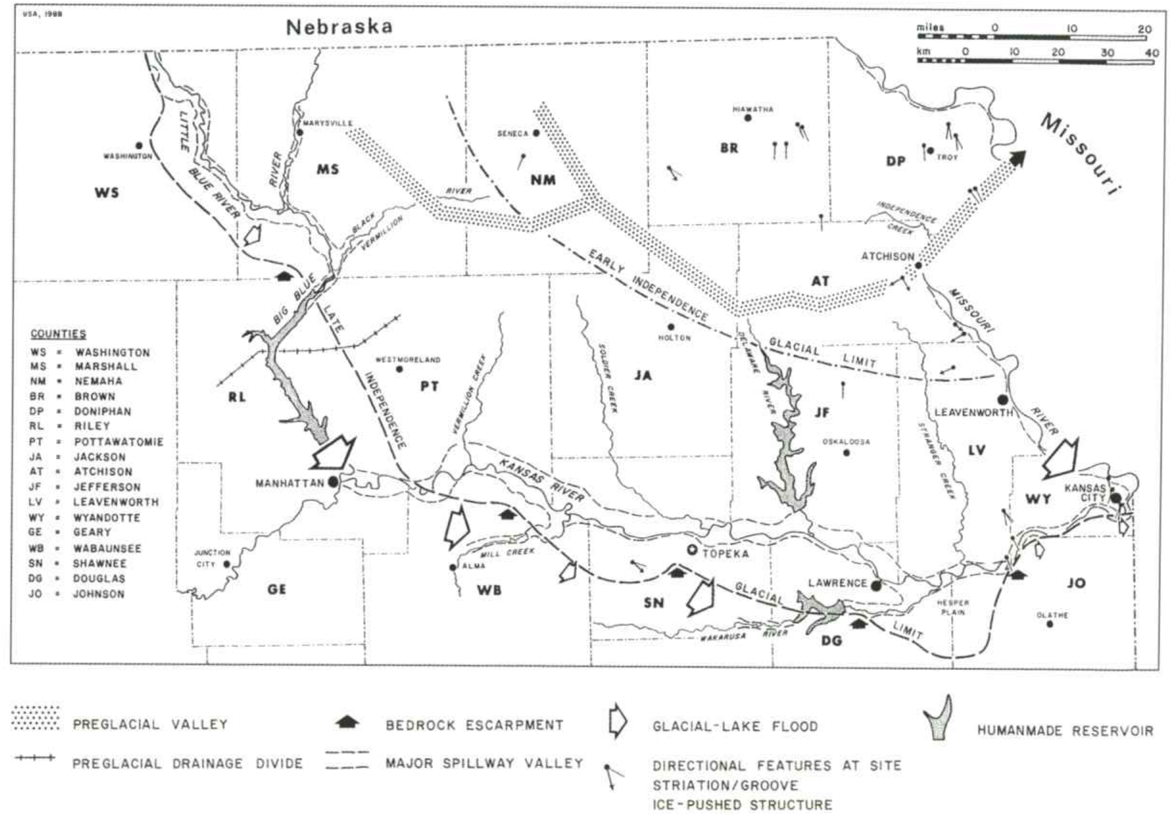


FIGURE 55—Glacial features in northeastern Kansas. Two major ice advances—the early Independence and late Independence—blocked preglacial drainage, dammed proglacial lakes, and caused outburst floods of meltwater that eroded spillway valleys. The maximum glacial limit follows conspicuous bedrock escarpments that blocked ice spreading at the glacier edge. Adapted from Aber (1991a).

FIGURE 56—Glaciated uplands in central Jefferson County. Mixed-agricultural land use and patchy forest cover are characteristic. Lake Perry, a large humanmade reservoir, is visible in the background. The lake is in the Delaware River valley, which was formed by meltwater erosion as a glacial spillway channel. View toward the northwest. June 2006.

to local bedrock. In Kansas, the clay-rich till is derived from abundant shale bedrock. The till also contains anything and everything over which the glaciers advanced on their way to Kansas. Most noticeable are large erratic boulders transported from far-distant bedrock sources (fig. 57). As early as the mid-19th century, Louis Agassiz, the father of the glacial theory, recognized the glacial origin of conspicuous red and pink boulders found throughout northeastern Kansas (Aber, 1984). Most of these are Sioux Quartzite carried from outcrops in southwestern Minnesota and adjacent South Dakota and Iowa. Pipestone, a distinctive blood-red rock carved by Native Americans into smoking pipes and ceremonial objects, comes from the same source area.

Granite, gneiss, greenstone, ironstone, and many other crystalline erratics were transported from the Canadian Shield region even farther to the north. Among the most unusual till components are well-preserved fragments of spruce wood, some as large as fenceposts (Aber, 1991a).

The preglacial landscape included a large, deep valley that extended eastward from Marshall County. Glaciation covered the valley and filled it with sediments that are as much as 400 feet (120 m) thick in places (Denne et al., 1982). This buried valley contains sand and gravel deposits that are an important source of ground water. Blockage of the preglacial drainage caused meltwater to back up along the ice margin in glacial lakes, which accumulated thick, fine-grained sediment. Such glacial-lake sediment is quite abundant in the Manhattan–Wamego vicinity, for example, just beyond the maximum ice limit. The lakes filled rapidly and overflowed, resulting in outburst floods that eroded spillway valleys to the south and east. Most of the modern river and stream valleys of northeastern Kansas were created or modified in this manner, including the Blue, Mill, Kansas, Wakarusa, and Missouri, to name a few. The most enduring legacy of glaciation is the major drainage system, which guided early human settlement and continues to influence economic development of the region. Cities located in or along the main spillway valleys include Manhattan, Topeka, Lawrence, Atchison, Leavenworth, and Kansas City (fig. 58).

In addition to widespread erosion and deposition, glaciation also deformed bedrock in places, creating various shallow folds, faults, and dislocations of rock layers (fig. 59; Dellwig and Baldwin, 1965). Weight from the advancing ice load caused the land to depress. When the glacier receded, the land slowly rebounded. This bedrock disturbance projected deep into the crust and reactivated ancient faults in the basement rock, which may account for historical earthquakes and recent microearthquakes in the region, particularly along the Humboldt fault zone in the Manhattan–Wamego vicinity (Dubois and Wilson, 1978; Aber et al., 1995).

Glacial features in northeastern Kansas have a long and rich history of geological study beginning in the late 19th century (Chamberlin, 1895). Both the glacial episode and deposits were originally called the Kansan stage, but much debate and controversy surrounded the exact definition and meaning of this term, so the name has been abandoned for stratigraphic use (Hallberg, 1986). Aber (1991a) referred to glacial and glacially related deposits in northeastern Kansas as the Independence formation, named for Independence Creek in Atchison and Doniphan counties. The glaciation took place approximately 700,000 to 600,000 years ago and represents the greatest expansion of North American ice sheets during the Pleistocene Epoch.

FIGURE 57—Glacial erratics of Sioux Quartzite. **Top:** Boulders scattered in a pasture near the limit of glaciation. Wabaunsee County. **Bottom:** Boulder placed as a cemetery monument in Emporia about 50 miles (80 km) south of the limit of glaciation. Lyon County.

Glacial deposits and landforms have suffered considerable weathering and erosion and, in places, are buried beneath younger sediment. This is particularly true adjacent to the Missouri River valley in Doniphan, Atchison, and Leavenworth counties and along the northern side of the Kansas River valley in Wyandotte County, where thick loess mantles the landscape. During the last glacial episode, known as the Wisconsinan glaciation, meltwater from ice lobes in the northern Plains swelled the Missouri River valley and laid down outwash sediment about 25,000 to 10,000 years ago. Freshly deposited silt and clay were eroded by wind from the valley and dropped on nearby uplands, forming loess more than 100 feet (30 m) thick in places. Deep-stream erosion has created steeply rolling hills in the loess of Doniphan County, a region known locally as Little Switzerland. Northeastern Kansas, thus, bears direct and indirect imprints of both older and younger Pleistocene glaciations.

FIGURE 58—Kansas City, Kansas, near Kaw Point, the junction of the Kansas and Missouri rivers. Wyandotte County, June 2004. **Upper right:** View northward over the Fairfax Industrial District in the Missouri River valley (Missouri River at right). The floodplain is protected by a stone-faced levee. Valley sides are visible to left and in the far background. **Lower right:** Southward view over Kansas River valley bottomland (Kansas River shown). The floodplain is protected by a stone-faced levee. Circular pools are part of a water treatment plant.

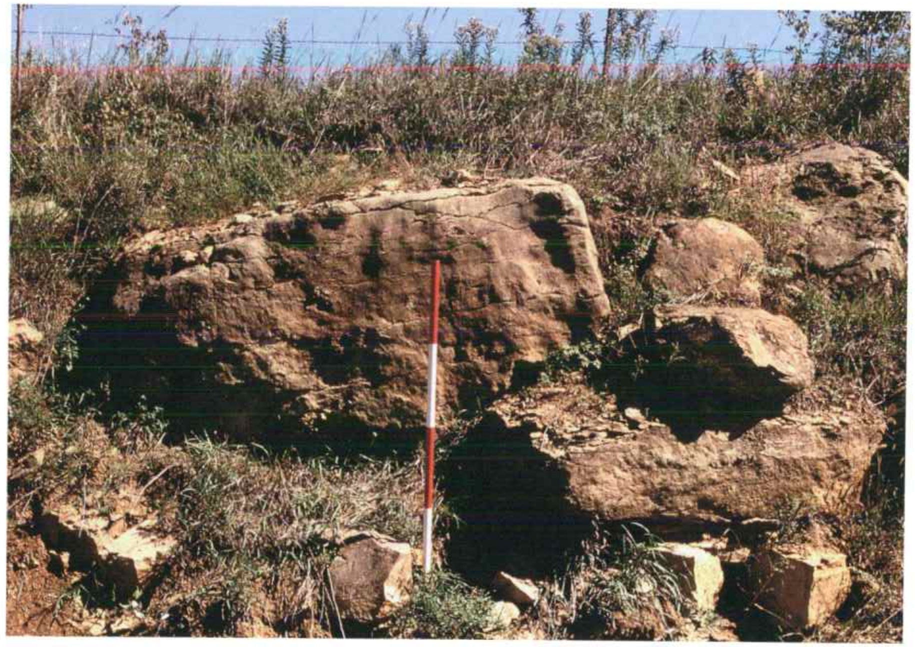
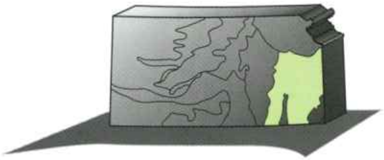


FIGURE 59—Deformation of Upper Pennsylvanian bedrock near Topeka. Limestone blocks are tilted and stacked over each other with glacial gravel packed under and between the blocks. The deformed blocks are part of a large, thin mass of glacially transported bedrock. Scale pole marked in feet. Adapted from Aber and Ber (2007, fig. 7-1).

Counties in the Glaciated Region

The Glaciated Region covers all of Doniphan, Atchison, Brown, Nemaha, Jackson, Jefferson, and Leavenworth counties; most of Marshall, Pottawatomie, and Wyandotte counties; and parts of Johnson, Douglas, Shawnee, Wabaunsee, Riley, and Washington counties.



Osage Cuestas

The Osage Cuestas cover a large portion of eastern Kansas south of the Glaciated Region and east of the Flint Hills, including the Marais des Cygnes, Neosho, and Verdigris drainage basins. Cities in the region include Olathe, Ottawa, Emporia, Chanute, Parsons, and Coffeyville. Elevations range from above 1,300 feet (400 m) in southeastern Lyon County to a low of 679 feet (205 m) where the Verdigris River flows into Oklahoma. This area is part of the Central Irregular Plains ecoregion, which is characterized by a mosaic of tallgrass prairie and oak-hickory forest (Chapman et al., 2001).

Most of the region consists of rolling hills and undulating cuestas of relatively low relief underlain by shale, limestone, and poorly consolidated sandstone (fig. 60). The term cuesta refers to slightly tilted rock layers that form a hill with a gentle slope on one side that is truncated by a steep slope or escarpment on the other side. Johnston (1964) described cuestas in eastern Kansas as a regional trend that occurred when the alternating limestone and shale layers were tilted slightly downward to the west due to uplift of the Ozark Dome in southeastern Missouri. Erosion removed shale more quickly than limestone from the cuestas, which created gentle slopes of resistant limestone layers facing westward and steep slopes of weathered shale facing roughly eastward.

Trending from north-northeast to south-southwest are several narrow escarpments formed on thick, resistant limestone layers (fig. 61). These are present both in the Osage Cuestas and Glaciated Region. Good examples include Hancock Hill at Fort Leavenworth, Mount Oread in Lawrence, Burnett Mound in Topeka, and Table Mound at Elk City Lake. Along such prominent escarpments, local relief may exceed 300 feet (90 m), and landslips may happen on steep shale slopes below the limestone cap.

The Osage Cuestas region is underlain by Upper Pennsylvanian bedrock in which

FIGURE 60—Mixed land use in the Osage Cuestas near Americus. The area is underlain by shale interbedded with thin limestone layers. Pastures, crop fields, wooded tracts, and small ponds (foreground) are typical of upland areas; the Neosho River valley is in the far background. Superwide-angle autumn view toward the northeast. Lyon County, October 2006.

layers are arranged in repeated cycles called cyclothems. The cyclothems in eastern Kansas were made famous by State Geologist R. C. Moore, who described and interpreted these strata and their invertebrate fossils in the mid-20th century (Moore, 1964). The dominant rocks of the Upper Pennsylvanian cyclothems are shale, limestone, and sandstone.

Distinctive elements within these cyclothems include coal beds and black shale. Unlike in the Lower Permian cyclothems found in the Flint Hills, chert is relatively scarce in the Upper Pennsylvanian limestone units, red shale is rarely present, and sandstone is common (fig. 62). The repeated cycles of deposition represent advances and retreats of shallow seas across the region during the Late Pennsylvanian subperiod when North America was situated at the Equator in a tropical climatic zone.

Many explanations for Pennsylvanian and Permian cyclothems of the midcontinent have been offered over the years. These generally fall into three categories—regional crustal movements, local delta-lobe shifting, and global sea-level changes. Frequent fluctuations in sea levels of 80 to 100 or more meters (~260 to 330 feet) were, in fact, worldwide events driven by ice-sheet glaciation (Soreghan and Giles, 1999). The center of glaciation was Gondwana, a megacontinent located on or near the South Pole (Caputo and Crowell, 1985). Most geologists now recognize that Pennsylvanian and Permian cyclothems in Kansas were connected with the late Paleozoic ice age.

Several major tributaries of the Missouri and Arkansas drainage basins cross the Osage

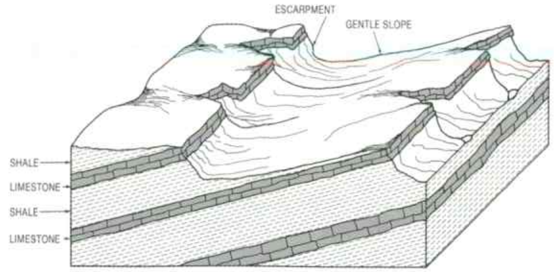


FIGURE 61 (above)—Diagram of cuesta landforms created by differential erosion of gently dipping limestone and shale layers. The landscape resembles giant stairsteps slightly tilted down toward the west (left). Adapted from Wilson (1978, fig. 10).

FIGURE 62 (right)—St. Paul Church built of Pennsylvanian sandstone quarried nearby. Photo by the authors when a new roof was under construction; later the building was damaged by a tornado. Neosho County.

Cuestas. In zones underlain by shale and sandstone, streams have eroded wide valleys with gentle sides and low terraces (fig. 63). However, where rivers cross escarpments of resistant limestone, the valleys are narrow with steep bluffs, as at Elk City Lake in Montgomery County. As streams have cut downward into their modern valleys, they also have migrated sideways. Most rivers flow generally from west to east or northwest to southeast, and through time they have shifted systematically southward. Thus, terraces and old channel gravels are found mainly along the northern sides of valleys.

The gravels in this region are composed primarily of chert derived from the Flint Hills and are similar to the Leon gravel (Aber, 1992). Because the chert gravel is resistant to erosion, today it is found on high terraces, hilltops, and drainage divides up to 250 feet (75 m) above the modern valley floors. The high topographic positions of alluvial chert gravel indicate substantial stream entrenchment and general erosion of the landscape since the oldest and highest gravels were deposited in the late Miocene and Pliocene (Merriam and Harbaugh, 2004). Many of these gravels also contain exotic quartz and quartzite pebbles derived from the High Plains and Rocky Mountains (fig. 64), which indicates the ancestral rivers had headwaters much farther to the west than do modern streams of the region (Aber, 1997).

Most larger cities are located within river valleys because of the proximity to surface water. However, flooding in this region is

FIGURE 63 (above)—Neosho River valley. The Neosho River floodplain appears in the foreground, the city of Hartford is on a low terrace in center background, and John Redmond Lake is on the distant horizon. At this point the Neosho River valley is approximately 4 miles (6 km) wide. View toward the southeast. Lyon County, April 2001.

FIGURE 64 (left)— Exotic pebbles from a single exposure of upland chert gravel. Most are quartzite or quartzose sandstone derived from the High Plains or Rocky Mountains. The various pink, yellowish-brown, and red-purple colors are typical in exotic pebbles throughout southeastern Kansas. Pocket knife for scale.

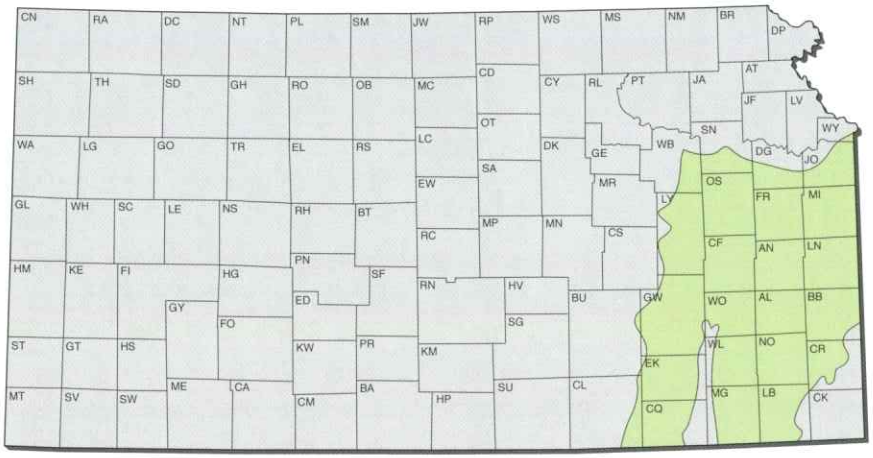
a perennial problem owing to infrequent strong storms and high runoff rates from the mostly shaly uplands. Large reservoirs, such as Fall River and Pomona lakes, have been constructed for flood control, recreation, and water supply (figs. 65 and 66). Thousands of small ponds also have been built throughout the region. In spite of these precautions, flooding remains a danger, as Coffeyville, Iola, and other cities experienced in 2007. In river valleys, alluvial sediment may provide ample high-quality ground water for domestic, agricultural, and city use. In uplands, however, ground water is scarce, hard, or mineralized with iron and manganese.

Small oil and gas fields are found throughout the region (fig. 67). Most of these are old and well past their most productive years. In the late 19th and early 20th centuries, an industrial boom took place in southeastern Kansas fueled by natural gas and coal (Clark, 1970). Several dozen brick, tile, cement, glass, and zinc plants were operated using raw materials from the surrounding regions (Wilson, 1978). These industries are largely gone now because the mineral resources and fuels have been depleted. Beginning in the 1990s, coal-bed methane has been tapped for natural gas supplies across the region.

FIGURE 65—Fall River Lake. This reservoir is operated by the U.S. Army Corps of Engineers for flood control, recreation, and water supply. Greenwood County, June 2006. **Above:** View toward the southwest of the dam, reservoir, and State park camping area. **Right:** Spillway at the southwestern end of the dam.

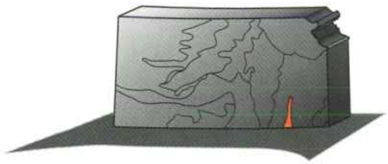
FIGURE 66—Pomona Lake. This reservoir is operated by the U.S. Army Corps of Engineers primarily for flood control as well as recreation and wildlife habitat. Osage County, October 2007. **Above:** View toward east with Dragoon Creek valley in foreground and Pomona Lake in center background. **Right:** View toward northeast of the dam and outlet tower.

FIGURE 67—Cattle pastures, crop fields, ponds, and a wooded stream valley, such as these near Hamilton, are typical in the western Osage Cuestas. The tanks, pumps, buildings, and service roads (foreground) are part of a small oil field. Early spring view toward the northeast. Greenwood County, April 2007.



Counties in the Osage Cuestas

The Osage Cuestas region covers all of Miami, Linn, Franklin, Anderson, Allen, Neosho, Osage, and Coffey counties and parts of Wyandotte, Johnson, Douglas, Shawnee, Wabaunsee, Lyon, Greenwood, Elk, Cowley, Chautauqua, Montgomery, Wilson, Woodson, Labette, Crawford, and Bourbon counties.



Chautauqua Hills

Among the smallest and most distinctive physiographic regions, the Chautauqua Hills form a narrow band within the Osage Cuestas in southeastern Kansas (fig. 68). Elevations range from about 725 feet (220 m) in the Caney River valley at the Oklahoma boundary to above 1,150 feet (350 m) in eastern Elk County. Local relief is typically 100 to 150 feet (30–45 m) and exceeds 200 feet (60 m) in some places. Steep hillsides separate valley bottoms from plateau hill tops. The Chautauqua Hills coincide with the Cross Timbers subregion of the Central Oklahoma/Texas Plains ecoregion (Chapman et al., 2001), named for the oak savanna and dense oak forest that cover most of the area (fig. 69). Caney is the largest city within the Chautauqua Hills. Sedan, Fredonia, and Yates Center are located on the margins of this physiographic region.

Thick Upper Pennsylvanian sandstones within the Douglas Group, namely the Tonganoxie and Ireland Sandstone Members, are the geological foundation of the Chautauqua Hills. Sand was deposited in river and delta channels that drained the continental interior as the sea receded in the late Paleozoic Era. Consequently, marine fossils are scarce, plant fragments and trace fossils are common, and petrified wood is found occasionally. The sandstones are poorly consolidated for the most part, although some portions are solidified by iron oxide cement which accounts for the typical rusty-brown color.

During the middle Cretaceous, about 90 million years ago, igneous pipe structures carried up magma from the earth's mantle and deep crustal rock fragments into the shallow crust of southeastern Kansas. The hot magma metamorphosed adjacent rocks and created ring structures that are reflected by drainage patterns in the modern landscape. Well-studied examples are the Silver City Dome in the Chautauqua Hills and nearby Rose Dome in the Osage Cuestas, both in Woodson County (Wojcik and Knapp, 1990; Aber and Aber, 2001). Similar pipe intrusions

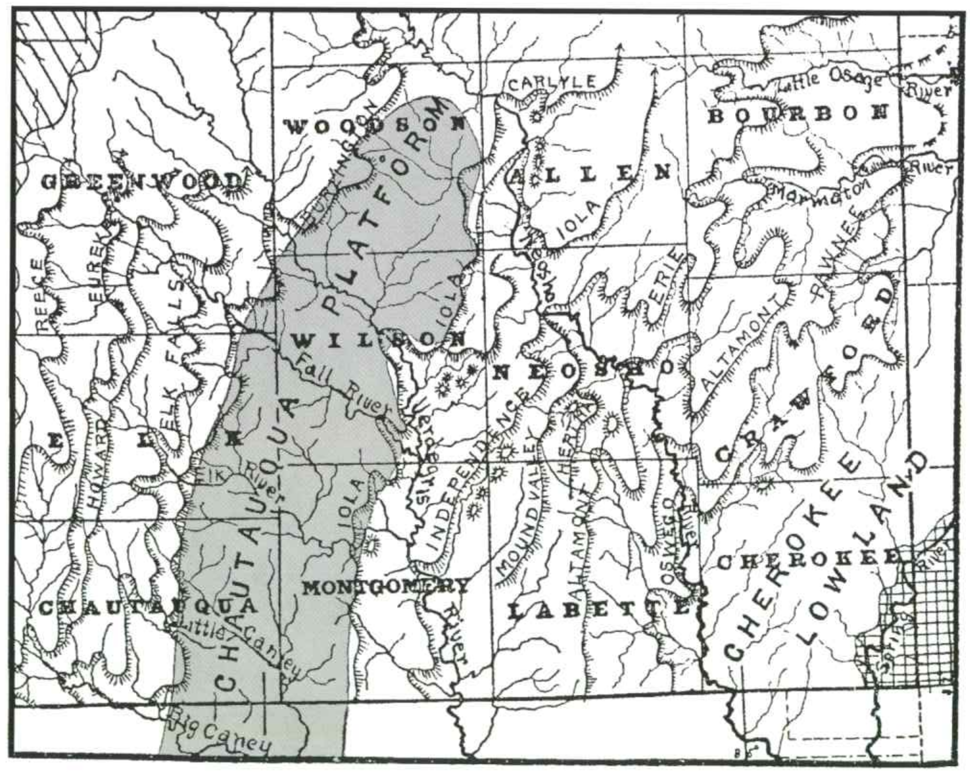


FIGURE 68—Physiographic features of southeastern Kansas, including the "Chautauqua Platform" (gray) and several prominent escarpments in the Osage Cuestas. Modified from Adams (1897–1898, plate III).

FIGURE 69—Woodson County State Fishing Lake and Wildlife Area. November 2007. **Above:** Dense oak forest dominates the eastern side of the lake in this superwide-angle view looking north. **Right:** Close-up view of the picnic area shown in the lower right of photo above.

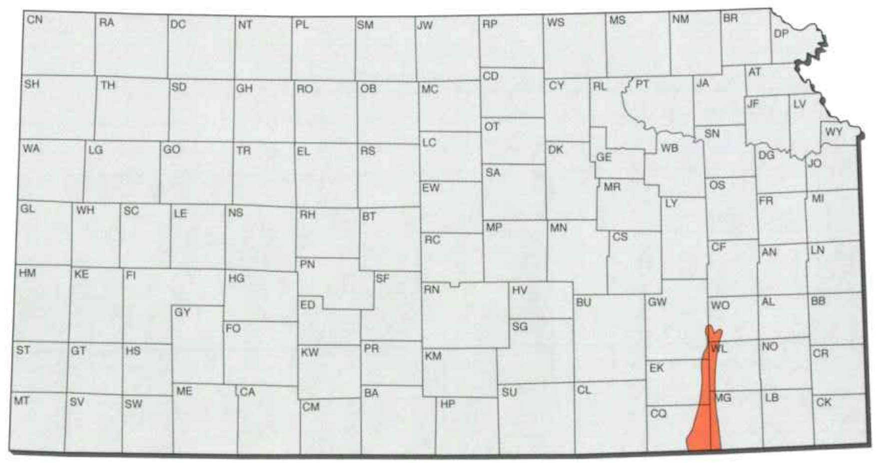
have been found in the Flint Hills in Riley County and the Glaciated Region in Marshall County. Beyond Kansas, similar pipes are found at Crater of Diamonds State Park in Arkansas and along the border of Wyoming and Colorado, where diamonds are mined.

Rainfall is normally adequate to sustain bottomland crops and upland pastures in this relatively humid region and surface water is available. The Verdigris River was dammed to create the large Toronto Reservoir; two smaller lakes are the Yates Center Reservoir

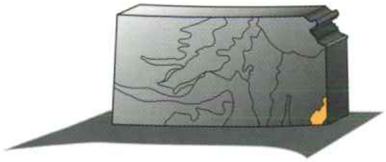
FIGURE 70—Woodson County State Fishing Lake and dam. Toronto Lake is in the far-left background. Note the mixed land cover with forest on the steeper slopes and mowed pasture and crop fields on the upland. Superwide-angle view looking west. November 2007.

and Woodson County State Fishing Lake (fig. 70). Ground water is abundant in the sandstone aquifer but is typically hard with high iron and manganese contents, which limits its usefulness.

Numerous small oil and gas fields exist in the Chautauqua Hills region. Natural gas production helped fuel a regional ceramics industry in the late 19th and early 20th centuries, but the industry died out when the natural gas supply was largely exhausted. The weathered intrusive rock at Silver City Dome is mined for lamproite, which is processed and sold as a cattle-feed additive known by the trade name Micro-Lite.



Counties in the Chautauqua Hills
The Chautauqua Hills region covers portions of Chautauqua, Elk, Greenwood, Montgomery, Wilson, and Woodson counties.



Cherokee Lowlands

The Cherokee Lowlands trend across a portion of southeastern Kansas. Bounded on the east by the Ozark Plateau and the west by the Osage Cuestas, the region has generally low topographic relief composed of poorly drained flat plains, subdued hills, and shallow valleys (fig. 71). Much of the region lies between 850 and 950 feet (260–290 m) elevation. Minimum elevations are slightly below 800 feet (245 m) in the southeastern corner of Bourbon County and in the Neosho River valley on the Oklahoma border; the maximum elevation reaches 1,000 feet (305 m) northwest of the region's principal city Pittsburg. This area is part of the Central Irregular Plains ecoregion, specifically the Cherokee Plains, which is characterized by a mosaic of tallgrass prairie and oak-hickory forest on poor soils (Chapman et al., 2001).

Geologically the region is marked by the Middle Pennsylvanian Cherokee Group, composed of sandstone, siltstone, and shale with thin limestone and coal beds. The latter were of the greatest economic importance. Kansas coal mining commenced in the 1850s with early settlement. The scope of mining expanded dramatically in the 1870s to supply fuel for railroad steam locomotives and for lead and zinc smelting. Both surface and underground mining took place in the Cherokee Lowlands. Underground coal mines also were operated in Leavenworth and Osage counties to the north and northwest. Kansas coal production reached a peak early in the 20th century. Underground mining ended in the late 1950s, but surface strip mining continued in the Cherokee Lowlands until late in the 20th century.

Among several coal beds, the Weir–Pittsburg is thickest at 3 to 5 feet (1–1½ m); it was mined extensively in Cherokee and Crawford counties (Brady and Dutcher, 1974). Most of the other coal seams are less than 3 feet (1 m) thick. Approximately 40,000 acres (~16,200 hectares) of land have been strip-mined in Crawford and Cherokee counties, but today the only active Kansas coal mine is in easternmost Linn County in the Osage Cuestas region. Big Brutus, a huge power shovel that operated in the Pittsburg and Midway mine #19 in Cherokee County in the 1960s and 1970s, is an iconic symbol of Kansas coal mining (fig. 72).

FIGURE 71—Flat landscape near West Mineral. Water channels in the center distance are reclaimed mined land, and an abandoned Missouri–Kansas–Texas Railroad right of way runs diagonally across the foreground. View toward the northwest. Cherokee County, October 2007.

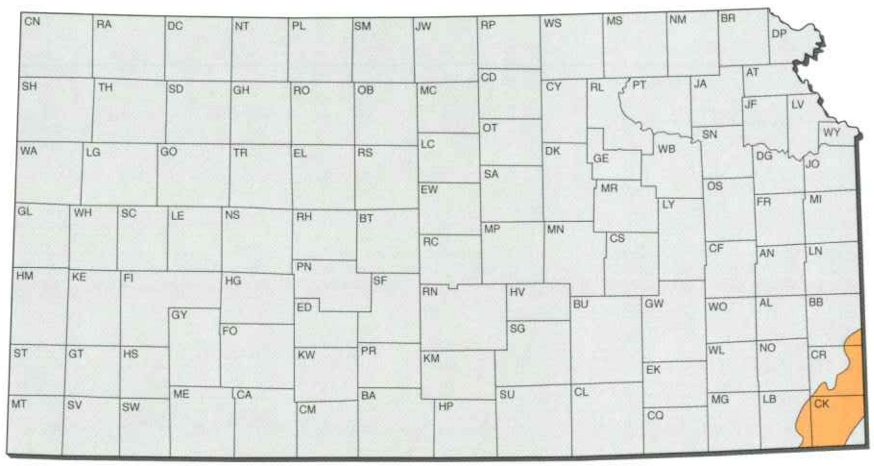
FIGURE 72—Big Brutus restored at the mining-heritage visitors center near West Mineral. The second largest electric shovel in the world, Big Brutus stands 160 feet (50 m) tall with a working weight of 5,500 tons (5,000 metric tons). Cherokee County, October 2007. **Above:** Oblique view looking to the northeast with West Mineral in the left background and reclaimed mined land on right. **Right:** Vertical view with people (upper left) and standard-size shovel (below) for scale.

Prior to 1969, mined land was abandoned and left to overgrow with brush and trees. As an experiment, trees were planted on several thousand acres of mined land in northwestern Cherokee County in the late 1930s (Muilenburg, 1961), and similar revegetation was done in Crawford County. These sites are now wildlife refuges known for excellent deer hunting and fishing. Since 1969, State law requires that mined land be reclaimed for productive agricultural use. The land must be returned to rolling terrain with pasture for grazing or tree cover (fig. 73). Mining activities also have affected surface- and ground-water quality. Acid water

FIGURE 73—Reclaimed mined land near West Mineral. The pastures and water channels in the background and on the left are reclaimed land. Cropland to the right was never mined. View toward the southwest. Cherokee County, October 2007.

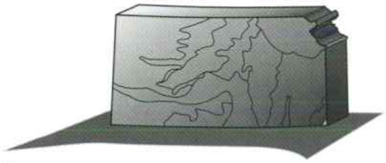
leached from waste-mining debris, known as gob piles, polluted surface and ground water. Streams such as Cow Creek and Shawnee Creek were seriously impacted, and in Cherry and Little Cherry creeks, only the most acid-tolerant organisms survived (Arruda, 1992).

Ground water is produced from alluvial aquifers of the river valleys as well as the Ozark Plateau aquifer system composed of the Springfield Plateau and Ozark aquifers. This system consists mainly of limestone and dolomite that are Mississippian, Ordovician, and Cambrian in age. Although underground in the Cherokee Lowlands, the limestone and dolomite crop out in the adjacent Ozark Plateau of Missouri and extreme southeastern Kansas, with only the Mississippian-age rock cropping out in the Kansas portion. As the bedrock dips westward beneath the Cherokee Lowlands, the aquifers become confined. In recent years, both quantity and quality of water from the Ozark Plateau aquifer system have declined because of increasing regional demand and surface pollution in the recharge area to the east. An interagency coalition has undertaken detailed studies for better management of the water resource (U.S. Geological Survey, 2007).



Counties in the Cherokee Lowlands

The Cherokee Lowlands region covers portions of Bourbon, Crawford, Cherokee, and Labette counties.



Ozark Plateau

The Ozark Plateau, by far the smallest physiographic region in Kansas, covers approximately 55 square miles (145 km^2) in the southeastern corner of Cherokee County. Its elevation ranges from 1,080 feet (330 m) upland to 775 feet (236 m) in valleys. The region is part of the Springfield Plateau of the Ozark Highlands ecoregion (Chapman et al., 2001), and oak-hickory forest is the natural vegetation cover in this relatively warm and humid corner of the state (fig. 74). Although small in size, the Ozark Plateau has some of the most beautiful terrain in the state as well as some of the most serious pollution and geological hazards associated with abandoned mines.

In Kansas, the Ozark Plateau is underlain by Warsaw Limestone and Burlington–Keokuk Limestone, which are thick, cherty, Mississippian limestone beds that total 250 feet (75 m) in thickness. As the limestone dissolved over millennia, chert and insoluble clay accumulated at the surface to form leached, acidic, relatively infertile soils. The region is drained by the Spring River and its main tributary Shoal Creek, which carry clear water over chert gravel beds. Caves, springs, and other karst features are commonplace. Larger caves are found in the Burlington–Keokuk Limestone at or near the valley bottoms, such as the one at Schermerhorn Park on Shoal Creek south of Galena (Young and Beard, 1993).

This region is best known geologically for lead and zinc mining, which began in the 1870s, and is part of the Tri-State mining district that extends into Oklahoma and Missouri. The ore apparently was formed during building of the Ouachita Mountains in Arkansas and Oklahoma in the late Paleozoic when hot, chemically active fluids were squeezed northward into the sedimentary rock sequence (Oliver, 1986). The ore was concentrated in Mississippian limestone along the unconformity with overlying Pennsylvanian shale. Mining in the Galena area reached a peak in the 1890s, but shallow ores were soon exhausted. Mining migrated to deeper strata in the area between Baxter Springs and Treece along the Oklahoma border. Although some of the ore taken from the mines was smelted nearby, much of it was transported out of the region for smelting where fuel was abundant—coal at Pittsburg and natural gas at Iola.

FIGURE 74—Shoal Creek at Schermerhorn Park south of Galena. A forest-covered limestone bluff and upland are to the left, and alluvial bottomland is to the right. Early autumn view toward east. Cherokee County, October 2007.

The legacy of mining remains quite apparent today; large areas are covered with barren fields and piles of chat, a miner's term for waste rock derived from the word chert. In the vicinity of Galena, chat piles have been removed for use as railroad ballast all over the United States, and the terrain has been smoothed and revegetated (fig. 75). To the west along the Kansas–Oklahoma border, chat piles remain (fig. 76).

Acidic water draining from the old mines, chat piles, and smelting sites pollutes the region's surface and ground water. Water quality in the Spring River and its tributaries is heavily impacted by runoff from abandoned mines, agricultural activities, and municipal wastewater discharge (Arruda, 1992). Empire Lake, dammed at the confluence of the Spring River and Shoal Creek, provides cooling water for a coal-fired power plant at Riverton. Substantial sedimentation has taken place in the lake, and it appears to be a sink for pollution derived from upstream (Chambers et al., 2005). Several State and Federal agencies are working to stabilize the geologic and hydrologic situations and to remediate environmental problems associated with past mining and other human activities in the region.

FIGURE 75—Northwest view from Schermerhorn Park. Kansas Highway 26 leads to Galena in the right background. The reddish-brown patches in the distance are former lead and zinc mines that have been smoothed and vegetated. Cherokee County, October 2007.

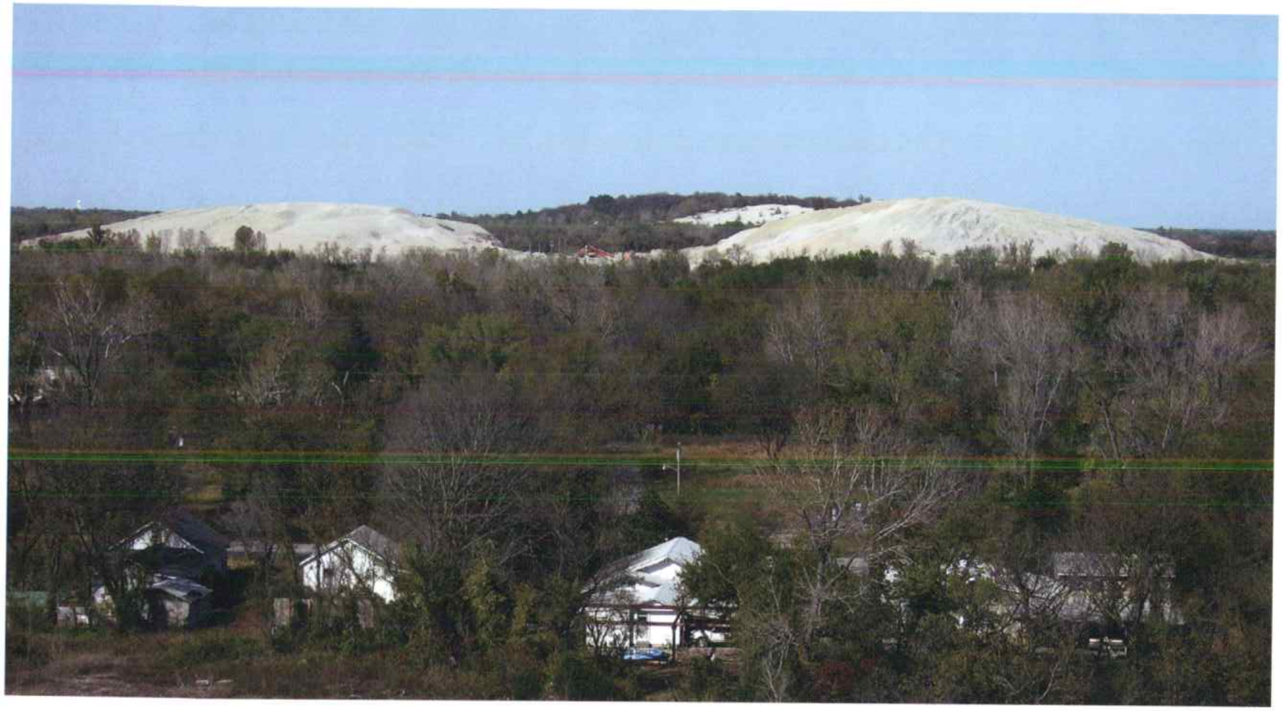
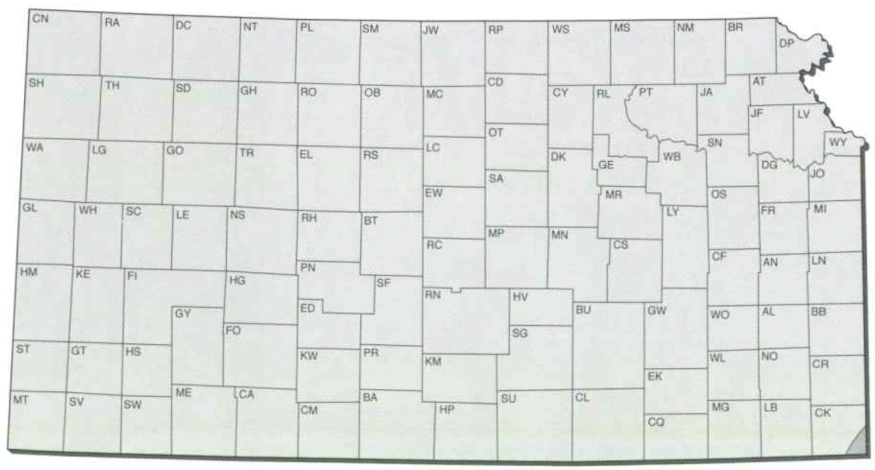


FIGURE 76—Northerly view from the top of a chat pile in Picher, Oklahoma. Chat piles on the horizon are along the Oklahoma–Kansas border near Treece. October 2007.



Counties in the Ozark Plateau

The Ozark Plateau region, more extensive in adjacent Missouri and Oklahoma, covers only the far southeastern corner of Cherokee County in Kansas.

Conclusion

Each physiographic region in Kansas has distinctive, indeed unique, expression in the landscape. Viewing these landscapes from a bird's-eye vantage enables greater appreciation of the geology, landforms, soils, drainage, environment, and resources within the state. The mosaic of colors, patterns, and textures exhibited by each physiographic region reminds us that human management for sustainable use of these resources is important for both our own long-term well being as well as the natural environment upon which native plants and animals depend.

About the Authors

James S. Aber (Ph.D. University of Kansas) is a distinguished professor and Susan W. Aber (Ph.D. Emporia State University) is a lecturer and the Federal depository map librarian in the earth science department at Emporia State University, Kansas. They have extensive experience conducting geological field work and taking aerial photographs (fig. 77) throughout the coterminous United States, Canadian prairie provinces, and several countries in northern and central Europe.

Figure 77—The authors conducting blimp aerial photography. Vertical view with blimp shadow. Kaw Point, Kansas City, Wyandotte County, northeastern Kansas, June 2004.

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Glossary

Alluvium: Sediment deposited by rivers, streams, or creeks. The word alluvial refers to any process, landform, soil, or sediment associated with streams.

Aquifer: Geologic formation that yields ground water into wells in economic quantities for any type of human use, consumption, or application.

Butte: Relatively small, flat-topped hill, usually capped with a resistant rock layer such as sandstone, limestone, or gravel (see fig. 21, p. 17).

Cenozoic Era: Youngest era on the geologic timescale, it began approximately 65 million years ago. The primary Cenozoic vertebrate fossils are mammals (see fig. 7, p. 5).

Cuesta: Broad, flat surface that slopes gently in one direction and is terminated by a steep slope (escarpment) in the other direction (see fig. 61, p. 54).

Cyclothem: Systematic repetition of rock layers in a cyclic pattern. One cycle of strata comprises a cyclothem (see fig. 47, p. 43).

Erratic: Rock fragments—pebbles, cobbles, and boulders—that are foreign or exotic to the region in which they are found. Erratics were transported long distances from their sources to their current locations (see fig. 57, p. 50).

Escarpment: A series of cliffs, bluffs, or steep hills that extends across the upland terrain for considerable distance (e.g., several counties). An escarpment is usually supported by resistant bedrock, such as cherty limestone or well-cemented sandstone (see fig. 61, p. 54).

Holocene: Youngest epoch on the geologic timescale, it began about 10,000 years ago and still continues. Climatic and environmental conditions throughout the Holocene are comparable to modern conditions (see fig. 7, p. 5).

Ice age: Period in earth's history dominated by large ice sheets, low sea level, and cold climate globally. Major ice ages affected Kansas during the late Cenozoic and late Paleozoic eras.

Karst: Landforms created primarily by dissolution of soluble rock, such as limestone and gypsum. Typical features in a karst terrain include caves, sinkholes, springs, and disappearing streams (see fig. 50, p. 44).

Loess: Silt and clayey silt deposited by wind on upland surfaces; essentially windborne dust sediment. Typically derived from floodplain sources of major valleys, loess is transported in a prevailing downwind direction and scattered over broad areas. It is especially common in the High Plains and Glaciated Region but also is found in nearly every physiographic region of the state.

Mesa: A flat-topped hill similar to a butte but generally larger in extent.

Mesozoic Era: Second youngest era on the geologic timescale, it ranges from about 245 to 65 million years ago. The primary Mesozoic vertebrate fossils are reptiles (see fig. 7, p. 5).

Miocene: Epoch on the geologic timescale that ranged from about 24 to 5 million years ago. This was the time of major uplift in the Rocky Mountains when alluvial fans spread eastward to form the High Plains (see fig. 7, p. 5).

Neogene: Youngest portion of the Cenozoic Era on the geologic timescale, it began about 24 million years ago and comprises the Miocene, Pliocene, Pleistocene, and Holocene epochs. Most modern landscapes of Kansas came into being during the Neogene (see fig. 7, p. 5).

Paleozoic Era: Older than the Cenozoic and Mesozoic eras on the geologic timescale, it ranges from about 570 to 250 million years ago. Most Paleozoic fossils are marine invertebrates (see fig. 7, p. 5).

Petroglyph: Prehistoric carvings made by Native Americans on natural rock surfaces, such as boulders, cliffs, and cave walls.

Playa: Shallow topographic basin or depression in semiarid environments. Playas may contain water seasonally during wet years but remain dry most of the time. In Kansas, they are located mainly in the southwest and south-central areas of the state in the High Plains and Arkansas River Lowland regions (see fig. 17, p. 13).

Pleistocene: Next to youngest epoch on the geologic timescale, it lasted from approximately 2.6 million to 10,000 years ago when the current Holocene Epoch began. The Pleistocene was a time of repeated continental glaciations and global sea-level fluctuations (see fig. 7, p. 5).

Pliocene: Epoch on the geologic timescale lasting from about 5 million to 2.6 million years ago. This was a time of regional uplift and gradually cooler and drier climatic conditions in Kansas (see fig. 7, p. 5).

Glossary (continued)

Proterozoic: Ancient rocks of the basement. In Kansas these are crystalline rocks ranging from about 1.8 to 1.0 billion years old. Fossils are generally lacking in the Proterozoic (see fig. 7, p. 5).

Ramsar: International treaty for recognition and conservation of wetlands of major importance. More than 1,700 wetland sites are designated worldwide (see http://www.ramsar.org/).

Till: Unsorted, unstratified mixture of clay, silt, sand, and gravel deposited beneath or at the margin of a glacier or ice sheet. It is also known as boulder-clay, which reflects the wide range of sediment sizes carried in and deposited by the advancing glacier.

Unconformity: A missing interval in the sequence of rock, which represents a period of non-deposition or erosion of strata.

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Great Plains Kite Aerial Photography
by James S. Aber and Susan W. Aber
http://www.geospectra.net/kite/kaphome.htm

This website provides insight into the fundamentals and applications of kite aerial photography, information on kites and cameras, and a gallery of the author's aerial photographs.

Kansas Geological Survey
http://www.kgs.ku.edu

The Kansas Geological Survey website is full of information on the Survey and the geology and natural resources of Kansas categorized into water, energy, geology, geophysics, publications, and education. Two educational features are GeoKansas and a photo library.

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