Geology and Geoarcheology of Northeastern Kansas Field Trip

A Field Trip for the Kansas Earth Science Teachers Association (KESTA)
Conference in Lawrence, Kansas
September 29, 2007

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Kansas Geological Survey
Open-file Report 2007–23

Kansas Geological Survey
1930 Constant Avenue
University of Kansas
Lawrence, KS 66047–3726

KESTA Field Trip Itinerary - September 29, 2007

7:45 Leave KGS.

- South (left) on Constant Ave.
- South (right) on Iowa St.
- West (right) on 23rd St/W Clinton Pkwy.
- South (left) on E 900th Rd.
- U-Turn at E 902nd Rd.
- North on E 900th Rd to roadside parking at Clinton Lake Spillway bike path.
- Stop 1 in road shoulder at bike path.

8:15 Stop 1 Cyclothems - Clinton Lake Spillway.

8:45 Leave Stop 1.

- North on E 900th Rd.
- East (right) on 23rd St/W Clinton Pkwy and north (quick left) to K–10 on-ramp.
- North on K–10.
- West on I–70 Turnpike to Topeka Service Area at milepost 188.
- Rest stop at Topeka Service Area.

9:00 Rest Stop at Topeka Service Area.

9:15 Leave Topeka Service Area.

- West on I–70 Turnpike.
- Exit at Topeka toll exit 183.
- West on I–70.
- Exit north on K–4 at exit 366.
- Stop 2 at K–4 and US–24 Interchange.

9:30 Stop 2 Fossil Collecting - Calhoun Bluffs at the K–4 and US–24 Interchange.

10:30 Leave Stop 2.

- South on K–4.
- Right to I–70 west.
- I–70 west.
- Exit south on Carlson Rd at exit 346.
- West (right) on K–4/57th St.
- South (left) on Echo Cliff Rd.
- Stop 3 at Echo Cliff Park.

11:00 Stop 3 Lunch / Channel Fill - Echo Cliff.

12:30 Leave Stop 3.

- North (right) on Echo Cliff Rd.
- West (left) on K–4 ½ mile.
- North (right) on Gladden Rd.
- West (left) on S Boundary Rd.
- South (left) on Sunnyside Rd.
- West (right) on K–4 through Keene.
- West (straight) on Skyline Rd.
- North (right) on Snokomo Rd.
- Stop 4 at Snokomo Rd.

1:00 Stop 4 Fossil Collecting and Carboniferous–Permian Boundary - Flint Hills.

1:45 Leave Stop 4.

- North on Snokomo Rd ½ mi.
- East (right) on Vera Rd.
- North (left) on Vera Rd.
- West on I–70 to Paxico service area at milepost 33.
- Rest stop at Paxico Service Area.

1:55 Rest Stop at Paxico Service Area.

2:15 Leave Paxico Service Area.

- West to Claussen Site.

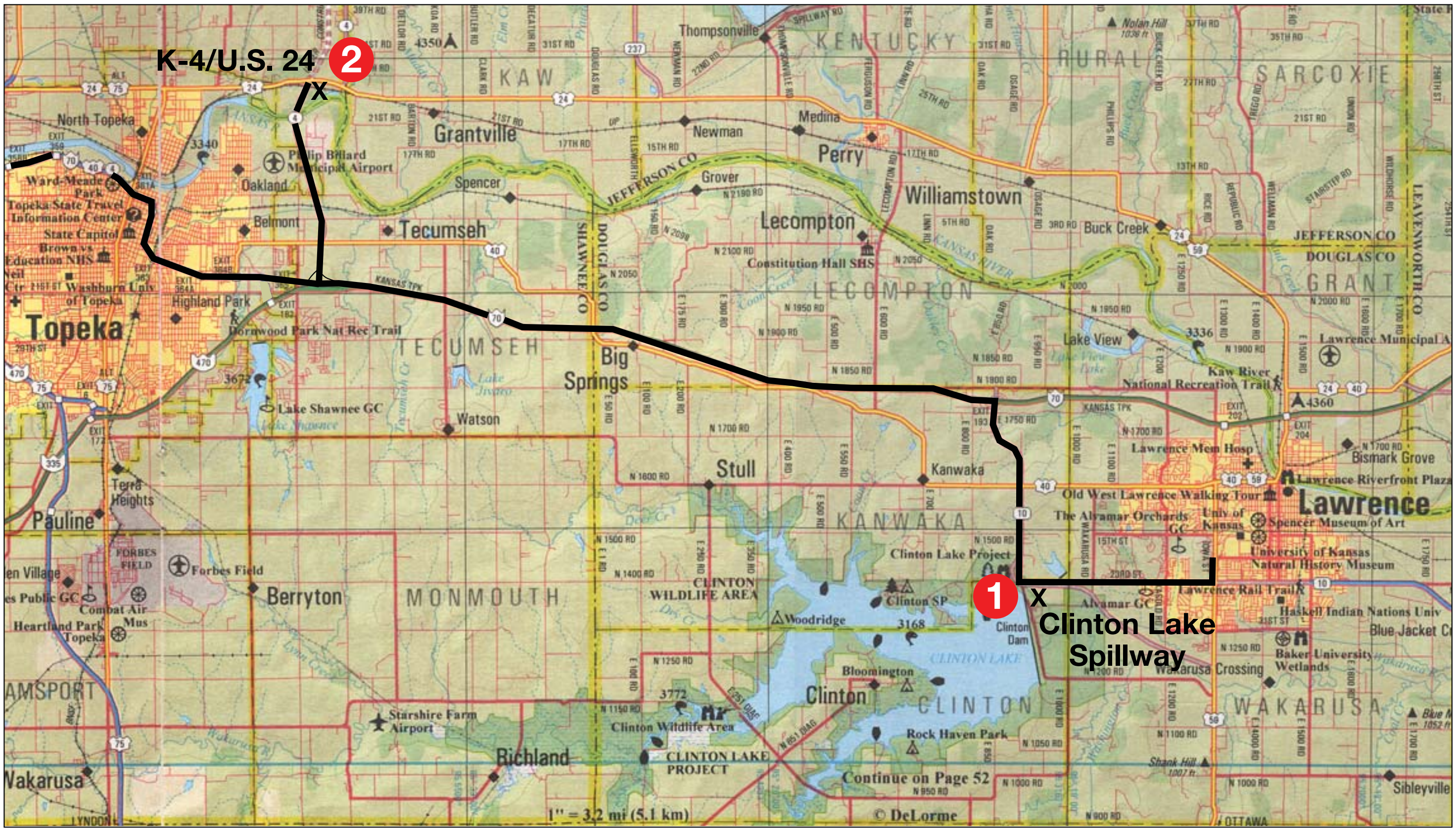
2:30 Stop 5 Geoarcheology - Claussen Site.

3:15 Leave Stop 5.

- I–70 west.
- Exit north N McFarland Rd at exit 330.
- North on N McFarland Rd.
- Stop 6 at Tower Hill at intersection of N McFarland Rd and Homestead Rd.

3:30 Stop 6 Kansas Glaciers - Tower Hill.

4:00 End Field Trip.


K-4/U.S. 24
2
X
1
X
Clinton Lake
Spillway
Topeka
Lawrence
Tecumseh
Big Springs
Lecompton
Perry
Grantville
Williamstown
Clinton Lake Project
Continue on Page 52
1" = 3.2 mi (5.1 km)
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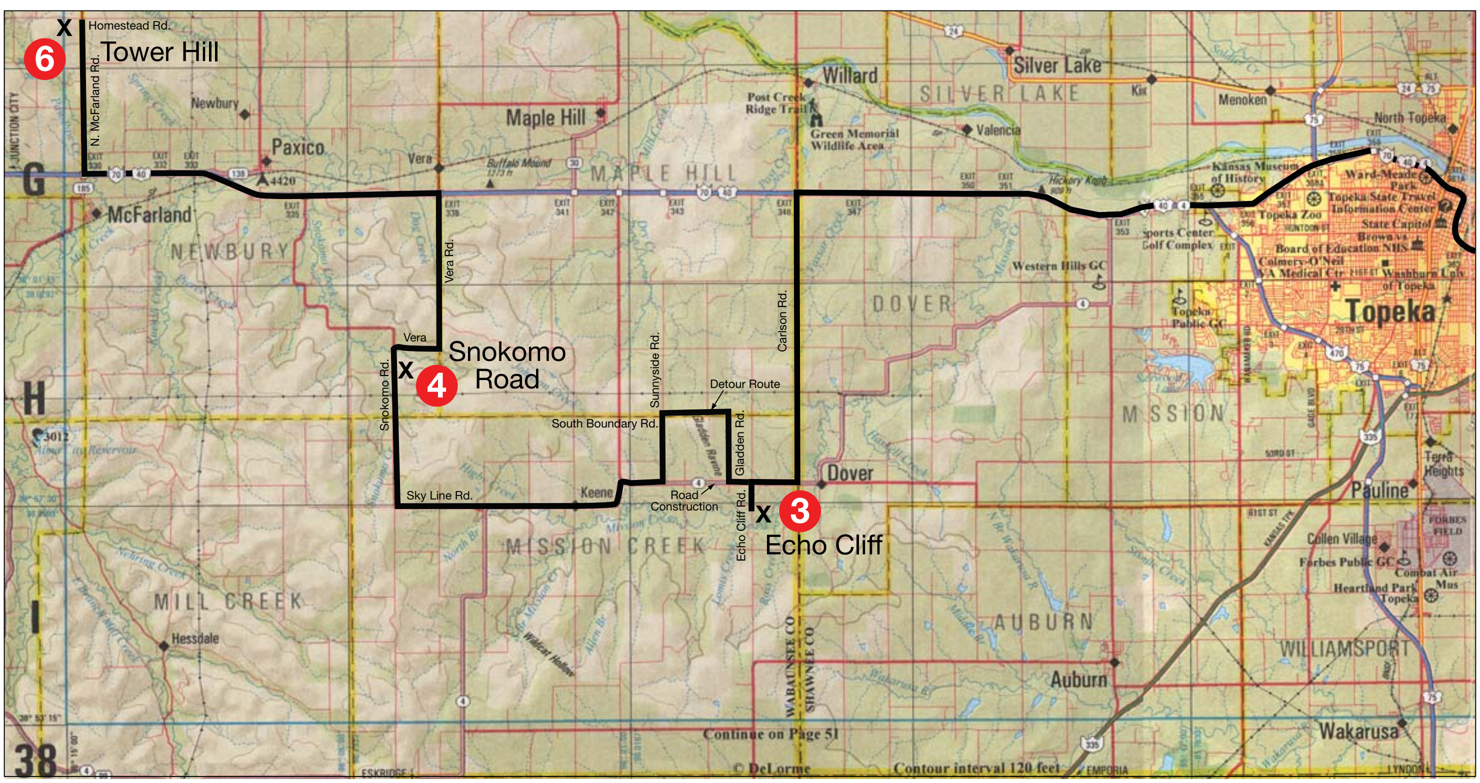
X
Homestead Rd.
6
Tower Hill
N. McFarland Rd.
Vera Rd.
Vera
X
Snokomo
Road
4
Snokomo Rd.
Sunnyside Rd.
Detour Route
South Boundary Rd.
Gladden Rd.
Carlson Rd.
Sky Line Rd.
Keene
Road
Construction
Echo Cliff Rd.
X
3
Echo Cliff
Dover
Topeka
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© DeLorme
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Introduction

Today's field trip focuses on the geology and geoarcheology of eastern Kansas. Our stops will be in rocks of late Carboniferous (Pennsylvanian) and early Permian age, as well as unconsolidated Neogene-age (Quaternary) glacial deposits and very recent alluvial sediments which contain cultural deposits. The Carboniferous is also known as the Coal Age, when rocks were deposited in shallow seas over 300 million years ago. The Permian rocks that we will view represent a transitional period of climate change from a tropical environment in the Carboniferous to a dry, arid climate in the Permian. The northeastern corner of Kansas was covered by ice sheets during glaciation that occurred about 700,000 years ago; we will see this much younger glacial material that lies atop the considerably older Permian bedrock. Very old archeological records are rare in eastern Kansas, and we will get a unique opportunity to view cultural deposits left behind by early Kansas inhabitants during the Paleoarchaic cultural period about 9,000 years ago.

Our trip starts in Lawrence, then makes a stop just west of town that will serve as an introduction to the rock types and environments of deposition that are common in eastern Kansas and much of the midcontinent, primarily interbedded limestones and mudrocks deposited in or near shallow seas. This stop is not a particularly good place to collect fossils, but it will provide an orientation for the rest of the day. We will then move to a roadcut northeast of Topeka where we will see the well-preserved remains of numerous invertebrates that lived in these Carboniferous seas (crinoids, bryozoans, fusulinids, foraminifers, bivalves, brachiopods, corals, sponges, echinoderms, gastropods, and maybe even a stray trilobite). From Topeka we will head west to Echo Cliff, a 75-ft cliff that is an example of ancient river-channel deposits. After Echo Cliff, we will continue on into the Flint Hills to collect fossils and examine the paleoecology of rocks deposited in an environment more akin to the Persian Gulf rather than eastern Kansas. Leaving this example of an arid climate behind, we will again look at river-channel deposits, albeit very much younger, which have cultural deposits from some of Kansas' first human inhabitants. The final stop is Tower Hill, a scenic vista of the Flint Hills north of McFarland. Tower Hill provides a good viewpoint at which to see the maximum glacial advance in Kansas and understand how the glacier-dammed Kansas River created the ancestral Kaw Lake. Dwarfing nearby Milford and Tuttle Creek reservoirs, Kaw Lake stretched east of Wamego to perhaps as far west as Salina.

Today, two stops will include fossil-collecting opportunities: stops at north Topeka and in the Flint Hills. See fig. 1–1 for examples of fossils we will encounter today. In addition, there will be an opportunity to collect glacial erratics near Tower Hill. The Flint Hills and Tower Hill stops are on private property. While we have permission to visit these sites, please remember that we are here through the courtesy of the landowner. You can collect fossils at any of these stops, but collecting is forbidden at the Claussen stop to help preserve the site. Be careful about turning over rocks. Snakes are rare and mostly harmless, but they are around. Because fossils have weathered out of the surrounding material, you won't need a rock hammer to help you collect. Climbing isn't really required to collect fossils at any of these stops. But if you do get on top of an outcrop or roadcut, stay away from the edge and be aware of people below you. Please, be careful out there.

The authors express their appreciation to Dr. Dave Newell with the Kansas Geological Survey for speaking about cyclothem deposits at Stop 1; to Dr. Ron West with Kansas State University for speaking about the paleoecology at Stop 2 and Stop 4; to Dr. Jim McCauley of the Kansas Geological Survey for speaking about valley-fill deposits and Kansas glaciation at Stop 4 and Stop 6, respectively; to Dr. Rolfe Mandel of the Kansas Geological Survey for speaking about the geoarcheology of Kansas at Stop 5; and to Marla Adkins–Heljeson and Jennifer Sims of the Kansas Geological Survey for their assistance in preparing this guidebook. Also, some of the material in this guidebook is from McCauley and others, 2000, and Buchanan and others, 2003.

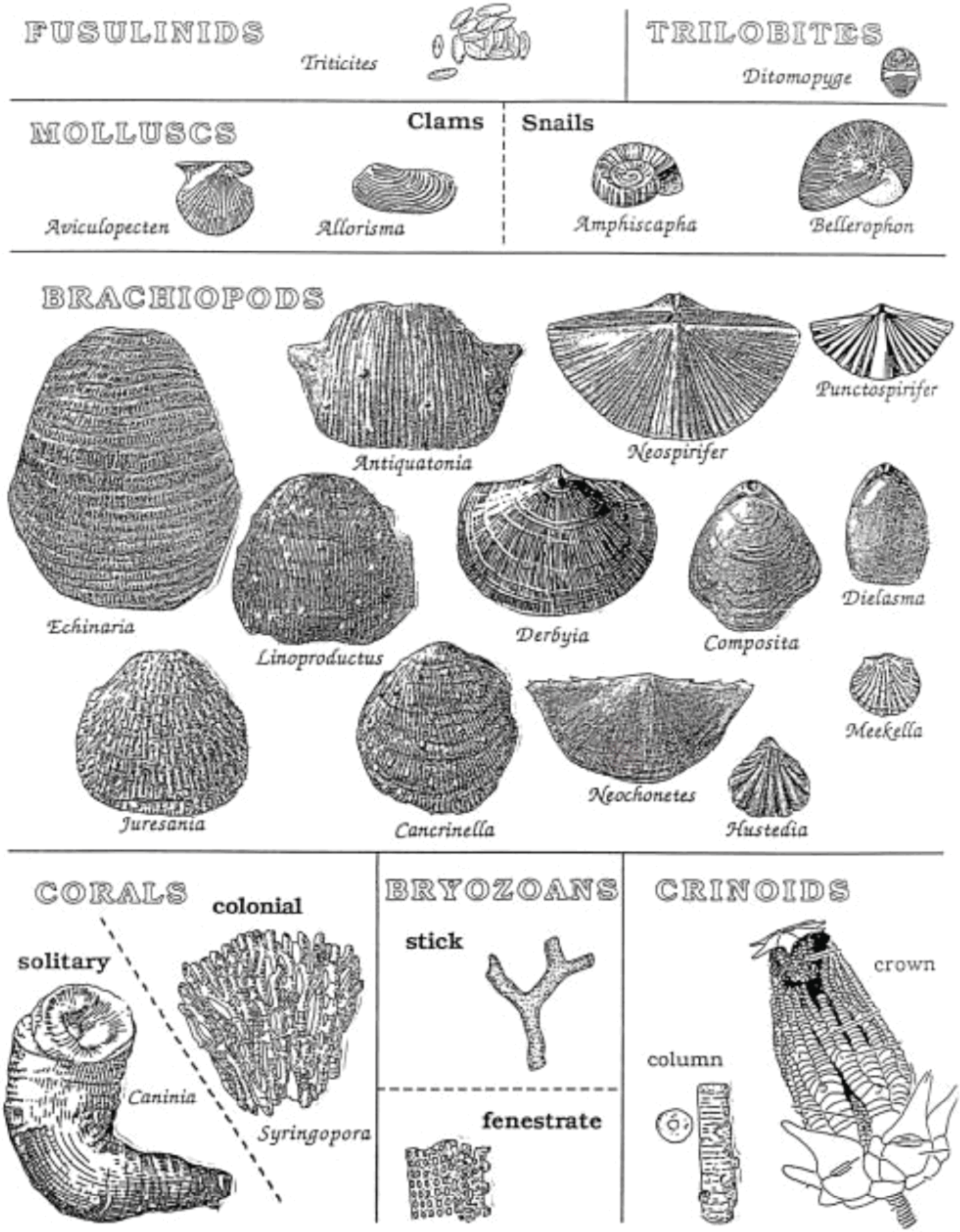

FIGURE 1–1—Examples of the types of fossils we can expect to see in the rocks encountered on this field trip (Buchanan and others, 2003).

STOP 1—Cyclothems at Clinton Lake Spillway

The spillway at Clinton Lake provides an excellent introduction to the geology of eastern Kansas. The dam here was constructed on the Wakarusa River, a tributary of the Kansas River, in the late 1970's. The spillway is a means by which water can move out of the lake during times of extremely high water levels (though the water has never been that high). The bike path along the floor of the spillway was added in the 1990's.

The spillway is a good place to view a vertical sequence of the rock layers that are typical of this area. These interbedded limestones and mudrocks were deposited late in the Carboniferous Period of geologic history (also known as the Coal Age or Pennsylvanian subperiod), over 300 million years ago. At that time, Kansas was near the equator, the climate was warmer, and a shallow sea advanced and retreated repeatedly across eastern Kansas as glaciers waxed and waned in the southern continents (figs. 1–2 and 1–3). Life flourished in the clear, warm water, producing abundant carbonate sediments that later consolidated into limestone.

Occasionally this area was at or slightly above sea level and sands (now sandstone) were deposited in the channels, estuaries,

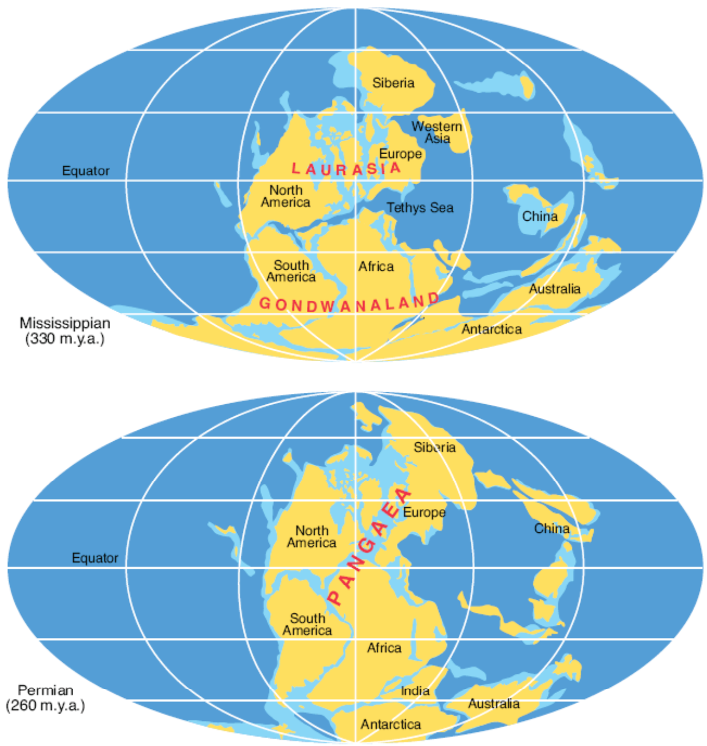

FIGURE 1–2—Portions of the lithosphere plates during the Mississippian subperiod and Permian Period, the two periods bracketing the Pennsylvanian subperiod. During the Pennsylvanian, Kansas lay near the equator (adapted from Tarbuck and Lutgens, 2000).

FIGURE 1–3—Paleogeographic reconstruction of North America during the Pennsylvanian subperiod (from Crouch, 1996, modified from Scotese and Golonka, 1992).

and deltas of rivers. At other times, mud was deposited by sluggish rivers; these muds eventually formed mudrocks, the softer, thinly layered rocks between limestones. Geologists often further subdivide mudrocks into five categories (siltstone, claystone, mudstone, shale, and argillite) based on their clay content and bedding characteristics. Most mudrocks in Kansas are collectively known as shales (e.g., Snyderville Shale Member or Calhoun Shale) even though these rocks are not fissile or layered enough to by truly classified a shale. The Heebner Shale Member here at the spillway is an example of a rock that might truly be classified shale because of its platy bedding planes.

Although each rock layer here is only a few feet thick, these formations extend vast distances across Kansas and adjacent states. Geologists have given each of these rock layers a name, based on the location where it was first described (fig. 1–4). The limestones and mudrocks here are part of two formations, the Oread Limestone (the upper unit) and the Lawrence Formation. The Oread Limestone is named after nearby Mount Oread, home of the University of Kansas (KU), where the formation was first described by geologist Erasmus Haworth in 1894. In spite of its name, the Oread Limestone, like many other formations, contains about as much mudrock as limestone. The Lawrence Formation,

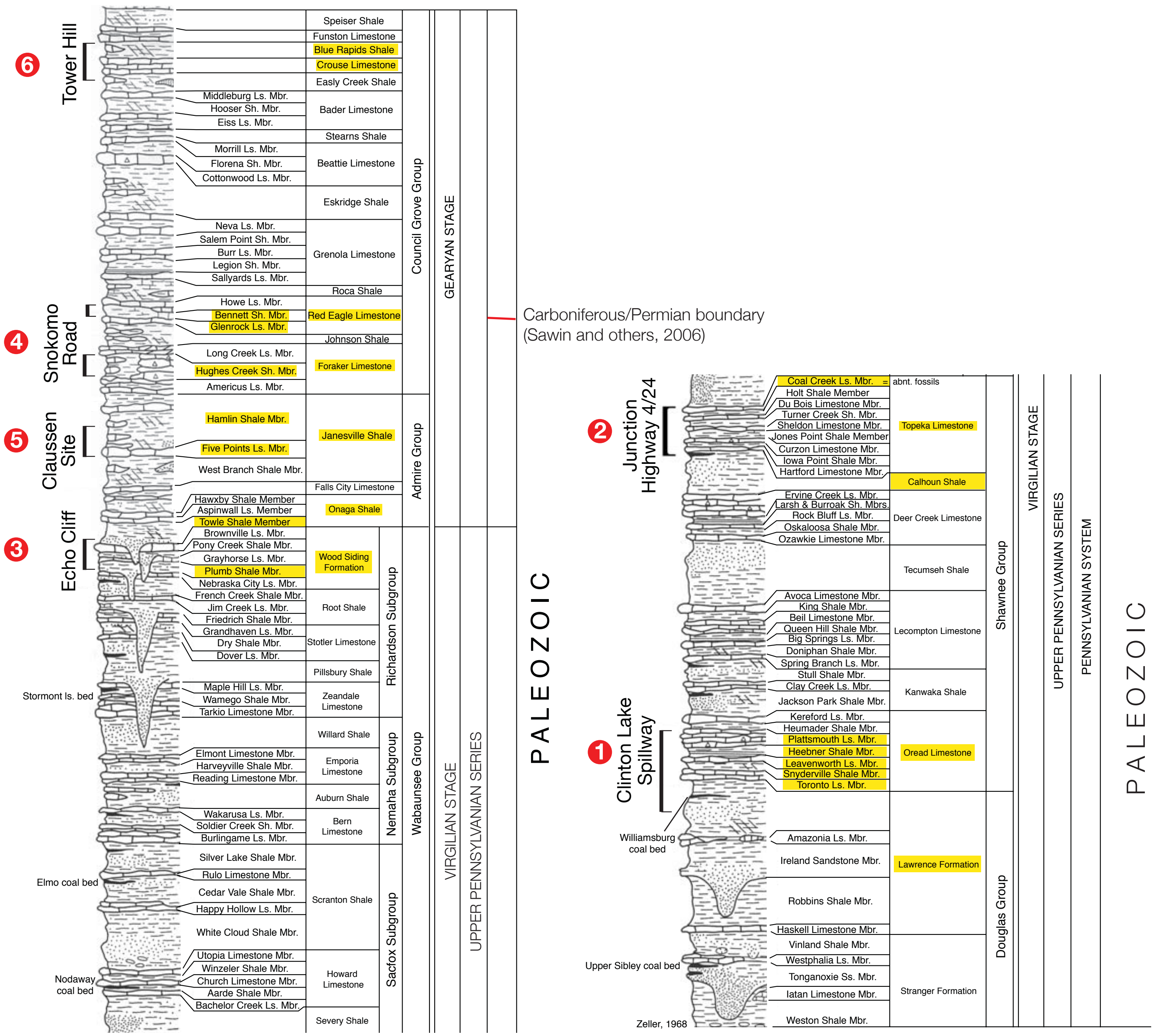

FIGURE 1–4—Stratigraphic classification of Carboniferous and Permian rocks in Kansas (adapted from Zeller, 1968). The brackets indicate the rocks that will be encountered during that stop.

which lies below the Oread (and is thus older), consists of a variety of mudrocks as well as some sandstone, thin limestones, and very thin coals. This unit is named for the city of Lawrence.

Geologists have divided the rock layers in the Oread and the Lawrence into smaller units called members, much the way that biologists divide a genus into smaller groups of species. The rock layer at the bottom of the spillway is called the Amazonia Limestone Member, named for the small town of Amazonia, north of St. Joseph in Andrew County, Missouri. Above the Amazonia are mudrocks of the 'Wathena' member of the Lawrence Formation. This part of the Lawrence Formation includes one or two thin coal layers called the Williamsburg coal, named for the small town of Williamsburg, Kansas, southwest of here. Locally, carbonized tree stumps have been found in the Williamsburg. Small brittle-star fossils are also sometimes found here in the sandy mudrocks of the Lawrence. This part of the Lawrence Formation may have been deposited on the plain of an ancient delta, where local swamps had formed (see fig. 1–5).

Above the Lawrence Formation is the Toronto Limestone Member of the Oread Limestone (see fig. 1–6 for a depiction of the depositional environment). It is named for the town of Toronto, Kansas, and not the more famous (and slightly larger) city in Ontario, Canada. The Toronto is a thick, light-gray limestone that weathers rusty brown; it contains a few fossils. Above the Toronto is the Snyderville Shale Member, which is unfossilferous gray clay, and above that is the Leavenworth Limestone Member. The Leavenworth is a thin layer of gray to brown limestone that was first described from exposures

FIGURE 1–5—Restoration of the ecosystem associated with the time of the deposition of the Lawrence Formation. Drawn by R. C. Moore (1964), the original caption says that this is a "view looking west from site of Douglas County courthouse in Lawrence."

FIGURE 1–6—From a paper by R. C. Moore (1964), this illustration includes a caption that reads, "Seascape at Lawrence, Kansas, of early Oread time, defective as a paleoecologic illustration in that depth of water, nature of salinity, and type of bottom sediment cannot be shown."

northeast of here, near the town of Leavenworth, Kansas (home of the Federal penitentiary and Fort Leavenworth, site of the Army Command and General Staff College).

The next unit up is the Heebner Shale Member, one of the most distinctive rock layers in the spillway. The Heebner is very different from the Snyderville Shale Member and other mudrocks in the Lawrence Formation. The Heebner is black, brittle, and bedded in layers so thin that they resemble pages in a book. Fossils include abundant conodonts (microscopic tooth or jawlike fossils of an elongate and wormlike creature) and rare inarticulate brachiopods and fish fragments. The Heebner also contains phosphate nodules, pebble-sized spheroids that are high in phosphate and contain about 170 parts per million of uranium, making them slightly radioactive.

When studying rocks in the subsurface, geologists use logs that measure various rock properties. These higher levels of radioactivity make the Heebner easier to recognize on logs that measure gamma radiation, so that the Heebner serves as a “marker” bed, helping geologists orient themselves stratigraphically when working with subsurface data. Geologists agree that the Heebner was deposited on a stinking, anoxic sea bottom, but disagree about the origin of these conditions. Some regard it as representing deposition when the Carboniferous sea was at its deepest, perhaps 200 m. Others argue for a shallow lagoon.

Above the Heebner Shale Member is the Plattsmouth Limestone Member of the Oread Limestone. The Plattsmouth is a wavy-bedded, light-gray limestone. It contains several layers rich in chert (flint) and fossils such as crinoids, corals, and fusulinids.

One obvious characteristic of the rock layers exposed here at the spillway is their cyclicity. That is, these rocks were deposited in a regular vertical sequence of limestone, mudrock, limestone, mudrock, etc. This sequence of rocks, which geologists call a “cyclothem,” is found not only in the Oread Limestone and Lawrence Formation, but it is repeated in Pennsylvanian rocks above and below these formations, in Kansas and throughout the midcontinent. Geologists believe that this regular sequence of deposition is probably the result of fluctuations in sea level. As the sea levels deepened (in the range of tens of meters), mud was trapped in the shore zone and limestone was widely deposited offshore. As the seas shallowed, shoreline muds spread much further, resulting in mudrock intervals (except, perhaps, in the case of the Heebner, which represents the time when the ocean was deepest).

Geologists generally agree that the changes in Carboniferous sea levels were the result of the alternate shrinking and growing of continental glaciers documented in the southern hemisphere. When the glaciers melted, sea levels rose, resulting in limestone deposition. During colder times, ice caps grew, sea levels went down, and mudrock was deposited. There are other theories about the reasons behind the sea level-change. Still, it is possible to look at the rock layers in the spillway as hard evidence of sea-level fluctuations in this long-ago ocean.

These rocks also exhibit larger-scale cycles. The rock types that make up the Oread Formation are repeated with only slight variations in the same sequence in the three overlying limestone formations. The intervening shales are also similar. The upper three members of the Oread at this outcrop (the thin, dark Leavenworth Limestone Member, the black Heebner Shale Member, and the thick, wavy-bedded Plattsmouth Limestone Member) have counterparts in most of the underlying middle Carboniferous limestone formations.

A name that remains widely associated with the idea of cyclic deposition—the cycles of deposition that resulted in cyclothems, or the packages of limestones and mudrocks that we have seen today—is R. C. Moore. Moore, a renowned paleontologist, was the director of the Kansas Geological Survey and professor of geology at KU from 1916 until 1954, and continued to be active in paleontology and geology until his death in 1973. The Kansas Geological Survey is a division of KU, and its headquarters building on west campus is named after Moore. Moore was the creator and editor of the *Treatise on Invertebrate Paleontology*, the standard reference on genera- and higher-level fossil taxa that continues to be updated and revised. He wrote textbooks on invertebrate paleontology and historical geology and helped produce the first detailed geologic map of Kansas. Moore so vigorously defended ideas about cyclothems that they became perceived as his own and grew to be strongly identified with him (Buchanan and Maples, 1992).

References

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STOP 2—Fossil Collecting at Calhoun Bluffs

We are now in Shawnee County, at Calhoun Bluffs northeast of the city of Topeka, the capital of Kansas. The interchange at the junction of K–4 and US–24 is a good place to see and collect invertebrate fossils.

Two rock units here, the Holt Shale and Coal Creek Limestone Members of the Topeka Limestone, are particularly fossiliferous. The Holt Shale Member is a dark-gray, layered siltstone, about 2 ft thick. Fossils of brachiopods and bryozoans are common in this member. The Coal Creek Limestone Member, which is directly above the Holt Shale Member, is a light-gray or olive, silty limestone, about 4 ft thick. Both of these units are about a million years younger than the rocks in the Oread Limestone and the Lawrence Formation that we saw in the Clinton Lake spillway; they are separated by two limestone and three mudrock formations. Although most of the rocks in eastern Kansas look layer-cake flat, many of them dip at slight angles. In this area, the general dip is to the west, so that rocks that are at the surface in, say, Lawrence, dip down into the subsurface as you move to the west; the rocks that we saw at Stop 1 are overlain here by more than 100 ft of younger rocks.

In addition to the fossils at this site, a thin coal is also visible here, exposed in the Calhoun Shale, the formation just below the Topeka Limestone. Pyritized wood is also found just above the coal layer in the Calhoun Shale. Although there are many coal layers in eastern Kansas, and a thriving coal industry once existed in southeastern Kansas, most are too thin or contain too much sulfur to be burned as fuel, and nearly all of the electricity generated in the state comes from burning coal from Wyoming. In the past few years, however, a number of natural-gas wells have been drilled into these coal beds in eastern Kansas to produce coalbed methane.

From here we return south and west, crossing the Kansas River. The Kansas River is generally regarded as the southern boundary of glaciation in Kansas. In fact, the original Kansas (or Kaw) River was probably created as a meltwater stream from those glaciers, which got this far south and as far west as the Big Blue River near Manhattan. Hence, the Kansas River valley is much larger than befits the present modest-sized river and has a very thick fill of sand and gravel. These glaciers were massive sheets of ice; one geologist estimated that ice would have been as much as 500 ft thick at Mount Oread (Wakefield Dort, personal communication, 2001). Some of the most visible pieces of evidence for glaciation are large red boulders of quartzite, a billion-year-old metamorphic rock that was originally in place around Sioux Falls, South Dakota. These glacial erratics were carried here, then left behind, by the glaciers about 700,000 years ago. Because glaciation occurred so long ago, erosion has since erased most other glacial features in Kansas (such as moraines). This is particularly true relative to glaciated areas north of here, such as Wisconsin, where evidence of recent glaciation (in the past 15,000 years) is still apparent.

Throughout the day we will head west and skirt along the terminal edge of the glacial advance until we reexamine this topic again near the western edge of Kansan glaciation at our last location, Tower Hill.

STOP 3 —River Channel Deposits at Echo Cliff

Echo Cliff, which stands about 75 ft above the stream, is an excellent example of ancient river channel deposits. Cycles of submergence and emergence, caused by changes in sea level, occurred many times during the Carboniferous here in the midcontinent. When sea level fell, streams cut deep channels into previously deposited layers of limestone and shale. As channels meandered across the landscape, sand, silt, and clay-sized sediments were deposited, removed, and redeposited again and again, much as they are in a modern river like the Kansas River. Evidence indicates that channel cutting occurred in a freshwater environment when the ground was above sea level, and in most cases, the channels filled with nonmarine sandstones and shales. Some channel filling, however, may have taken place in a transitional setting, where marine and nonmarine environments met and tides affected sediment deposition. Much of the material filling the channel probably came from the uplands to the north and northwest.

The Towle Shale Member and Plumb Shale Member (Wood Siding Formation) channel deposits at Echo Cliff probably represent two separate channels (fig. 3–1). The first river channel, which developed about the same time the Plumb Shale Member was being deposited, cut into and down below the Plumb Shale Member nearly to the Maple Hill Limestone Member. Subsequent sea-level rise led to the deposition of the Grayhorse Limestone, Brownville Limestone, and Towle Shale Members, which buried the sandstone deposits in the river channel. Later, a second river channel started in the Towle Shale Member and cut down into the older Plumb Shale Member channel. A prominent layer of conglomerate (a rock composed of pebbles and rock fragments that have been naturally cemented together) can be seen about two-thirds of the way up from the base of the cliff; this marks the base of the Towle Shale Member channel.

Plumb Shale Member Channel—About 48 ft of the Plumb Shale Member channel is exposed at Echo Cliff. The Plumb channel fill is alternating layers of very fine grained micaceous (containing flakes of the mineral mica) sandstone and micaceous siltstone and claystone. The entire deposit exhibits large-scale crossbedding. Crossbedding is a series of thin, inclined layers in a large bed of rock (usually sandstone) that is inclined at a distinct angle to the typically horizontal bedding surface. Formed by currents of water or wind, crossbedding is found in dune, stream-channel, or delta deposits. The direction in which the beds are inclined usually indicates the direction the current of water or air was flowing at the time of deposition. In this case, the crossbedding was formed by water. Some sandstone crossbeds fill small channels cut into more massive beds. Carbonized leaf and wood fragments are common on bedding planes, giving the outcrop a streaked or banded appearance. Limonite (iron oxide) nodules are abundant, and the entire outcrop is stained with iron oxide. Calcium carbonate, iron oxide, and locally, barite cement the sand grains together.

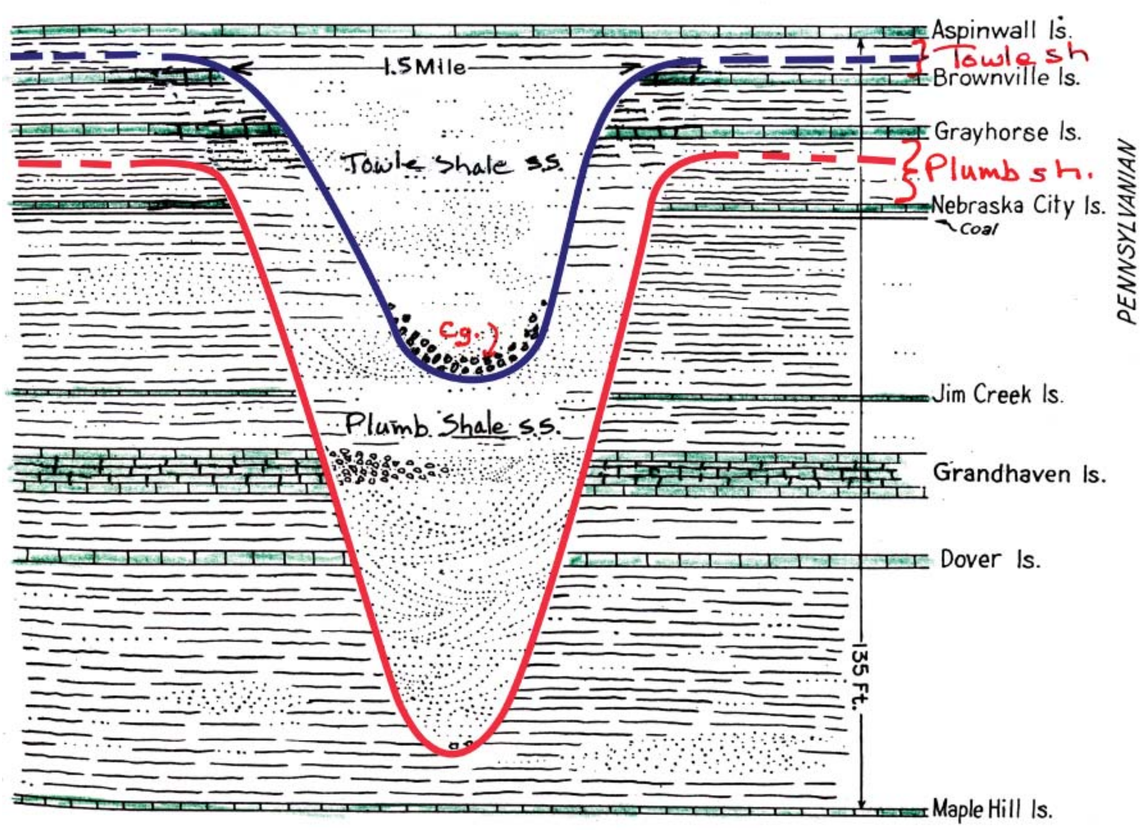

FIGURE 3–1—Channel deposits exposed at Echo Cliff (cg = conglomerate, ss = sandstone, ls = limestone, sh = shale; McCauley and others, 2000).

Normally, the Plumb Shale Member is about 10 ft thick, but where deep channels develop, it can be up to 105 ft thick. The Plumb Shale Member channel at Echo Cliff trends east to southeast and is probably not more than 1.5 mi wide.

Towle Shale Member Channel—The Plumb Shale Member channel is separated from the overlying Towle Shale Member channel by a limestone conglomerate. The conglomerate commonly forms a prominent ledge and breaks into large slabs. This conglomerate is 2–3 ft thick and consists of angular to subrounded fragments of local limestone and shale. Many of the limestone fragments are from the Brownville Limestone and Grayhorse Limestone Members of the Wood Siding Formation; this is evidence the channel is younger than these units. In other words, some time when the Towle was being deposited, a downcutting channel eroded through the limestone layers in the Brownville and Grayhorse, and fragments of these limestones were broken off and carried downstream to be deposited within the conglomerate at a level lower than where they initially occurred. This dates the Towle channel as younger than the Brownville. It also shows the channel cannot be the same age as the Plumb because the Brownville and Grayhorse, which occur above the Plumb, had not been deposited when the Plumb channel was active.

At Echo Cliff, the conglomerate is overlain by about 23 ft of very fine grained micaceous sandstone that is interbedded with sandy siltstone. The Towle channel trends west to southwest. The channel is less than a mile wide and is about 85 ft deep. Normally, the Towle is only 10–20 ft thick in Wabaunsee County.

The channel sandstone in the Towle Shale Member is informally called the Indian Cave sandstone, referring to sandstone bluffs, locally called the “Indian Caves,” on the Missouri River in southeast Nebraska where this unit was first described.

At one time, the boundary between the Carboniferous and the Permian rocks, which begin to crop out in the Flint Hills just east of here, was placed at the base of the conglomerate in the Towle Shale Member, so that everything above would have been considered Permian and everything below Carboniferous. In 1994, however, the Carboniferous–Permian boundary was moved, based on fossil evidence, much higher up in the geologic rock section. In 2006, new research linked a new boundary to its globally recognized reference point in the Ural Mountains, and it was again moved to its present location in the Red Eagle Limestone. This is not the first time this boundary has been moved; dating back to 1940, at least 84 literature references have expressed an opinion as to where this boundary should be placed in Kansas. We will take a closer look at the latest stop of this wandering boundary at the next location, Stop 4, in the Flint Hills.

Reference

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STOP 4—Fossil Collecting and Carboniferous–Permian Boundary in the Flint Hills

At this location we will collect fossils and geodes from the Carboniferous-age Hughes Creek Shale Member and talk about the paleoecology of the Long Creek Limestone Member of the Foraker Limestone. An important geologic boundary between the upper Carboniferous and the lower Permian rocks is also present where the Red Eagle Limestone crops out near the top of the hill (fig. 4–1).

The geology in this part of Kansas is transitional between the well-defined cyclothem rock units in the Carboniferous and Permian systems east and west, respectively, of here. This location, with rocks near the close of the Carboniferous, marks a prominent shift from wetter to drier climates. This drying climatic trend that began in the later Carboniferous is apparent in these rocks. Absent are Carboniferous coals formed from giant club mosses, horsetails, and ferns that grew in a tropical ever-wet climate. Present now are dry climate features such as quartz or calcite crystal-filled geodes formed in cavities of easily dissolved gypsum nodules and trace fossils formed by mud cracks on arid tidal flats (Miller, 2002). This climate shift was largely caused by latitude changes as Kansas drifted away from the equator during the middle Carboniferous to about 15–20° north of the equator during the Permian (Archer and others, 1995). Movement through these latitudes produced seasonal changes ranging from tropical rains, seasonal monsoons, to an arid environment. The rocks at this stop were probably deposited in an environment similar to the area around Shark Bay in Western Australia. Punctuations of sea-level rise and fall are also recorded in these rocks as continental glaciers on the other side of the globe periodically advanced and retreated across a large landmass at the south pole, called Gondwana, that at the time included the continents of South America, Africa, Australia, India and Antarctica (Miller, 2002). When glaciers advanced, the sea level in Kansas would fall in response as more and more of the Earth's water became incorporated into the growing ice sheets. Conversely when the glaciers retreated, sea level rose as the melting glaciers refilled the Earth's oceans.

The muddy sediments that formed the Hughes Creek Shale Member and the Long Creek Limestone Member indicate that this area of Kansas was a semi-arid to arid, flat, coastal plain. The Hughes Creek was probably a nearshore coastal environment and is very fossiliferous. Stratigraphically, the Hughes Creek contains intervals of mudrock and thinly bedded limestone where most of its fossils are found. *Reticulatia, Neospirifer, Orbiculoidea, Lingula, Hustedia,* and *Composita* brachiopod species are common. Pelecypods (clams) and crinoid fragments are also present in this unit. Burrowing activity from organisms often heavily disturbs sediment-bedding planes in a recognizable way, which geologists call bioturbation, and is sometimes visible in these rocks. Casts of some burrows are present as trace fossils at this stop. The Hughes Creek contains many wheat-shaped fusulinid fossils, while the overlying Long Creek Limestone Member does not. Because the contact is gradational between these two units, the presence or absence of fusulinids is used to biostratigraphicaly separate them.

Geodes are present on the hillside where they weather out just below the top of the Hughes Creek (Jewett, 1941). Geodes, a type of concretion, are crystal-lined cavities in rocks. Geodes are formed by ground water that deposits minerals in solution on the walls of rock cavities. This type of deposition usually forms good crystals, most of which point toward the center of the cavity. Geodes in the Hughes Creek contain crystals of calcite and aggregates of a pink to orange mineral that is probably celestite.

Overlying the Hughes Creek Shale Member is the Long Creek Limestone Member. Generally the Long Creek lithology ranges from alternating beds of yellow shale and yellow limestone to thinly bedded yellow limestone. It represents an ancient intertidal area in a very arid climate known as a sabkha (Archer and others, 1995). A sabkha is a gradational zone just above the intermittently wet tidal flat (called the littoral zone) and the dry land surface. Some of these rocks were probably deposited in a saline marine marsh or tidal flat just above the normal high-tide level. It is not uncommon for a sabkha to extend many kilometers inland even when the tidal range in the littoral zone may be less than a meter. Sabkha is an Arabic term used to describe much of the present-day southern Persian Gulf, which is bounded by extensive carbonate littoral and sabkha flats. The best known and largest of the Persian Gulf sabkhas extends for about 200 km along the coast of Abu Dhabi (Davis, 1992). Much like the Persian Gulf, this Kansas Carboniferous shoreline extends for long distances through the state north and south of here (McCrone, 1963). Another well-known example of a modern sabka is located on the west side of Andros Island in the Bahamas.

Although the modern sabkha analogs in Australia, the Persian Gulf, and the Bahamas are each somewhat different, characteristically, this depositional environment has little relief of any kind. Strong winds typically strip away dry sediments down to the very shallow ground-water level. The arid climate leads to high evaporation rates which result in waters with extreme salinities. In some places algal mats can stabilize the soil and build up mounds of algae and lime mud, called stromatolites, which stick up above the tidal plain. Sediments tend to accumulate in this environment when storm events and wind tides surge and carry suspended sediment over these flats. Surface desiccation, or mud cracking, is quite common as the ground is alternately wetted and dried (Davis, 1992).

Organisms generally live near the high-tide level and escape prolonged periods of exposure in this harsh environment by burrowing in the muddy sediment, leaving some rocks heavily bioturbated. Molds of gastropods (snails) and bivalves (clams) can be found in some places within the upper part of the Long Creek. Further inland on a sabkha, dolomite and gypsum are often deposited with anhydrite and halite occurring at locations farthest from the ocean (Davis, 1992).

Aggregates of the pinkish to orange mineral celestite (strontium sulfate, $SrSO_4$) occur throughout the Long Creek (Mudge and

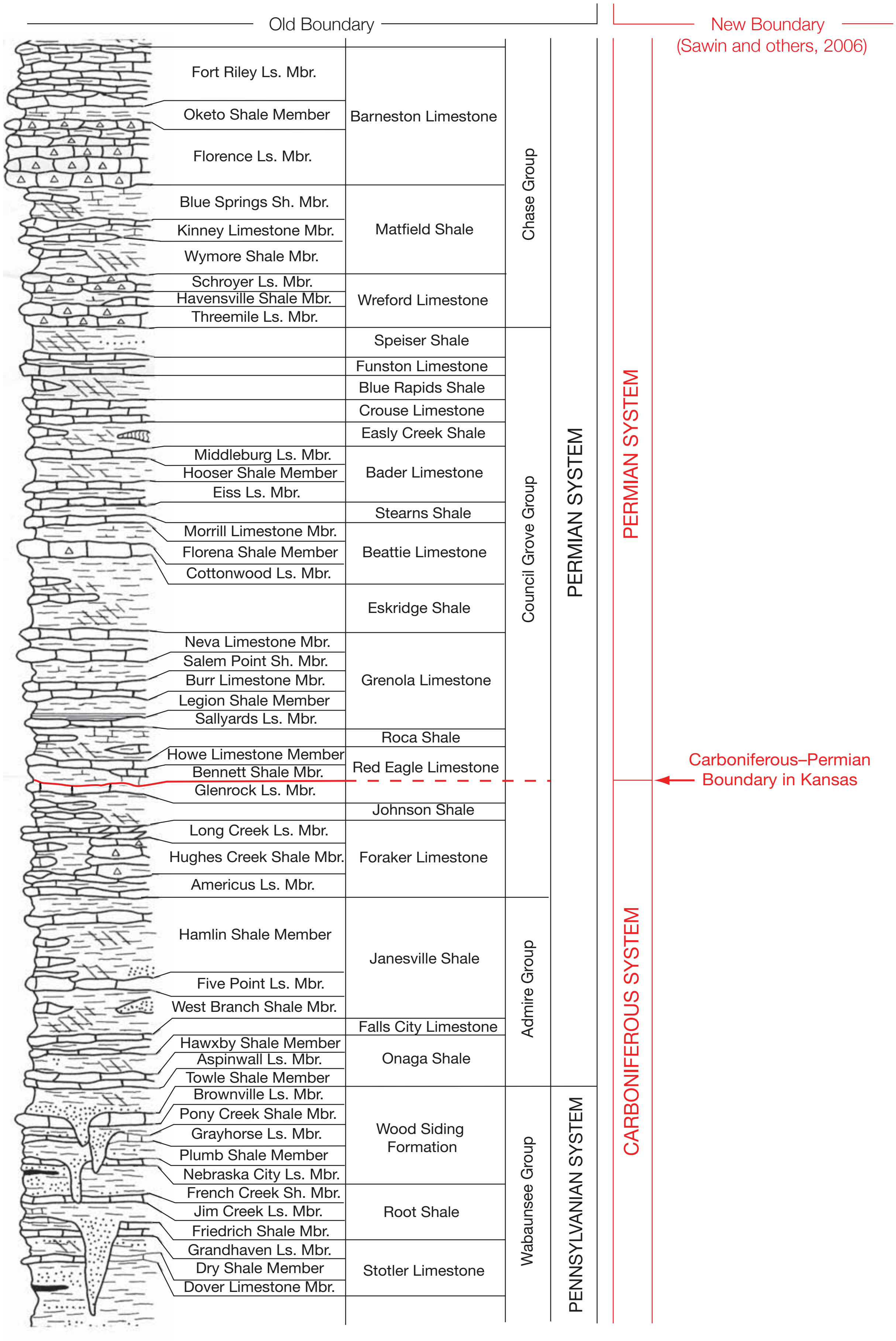

FIGURE 4–1—Stratigraphic section in Kansas showing the new Carboniferous–Permian boundary (adapted from Sawin and others, 2006).

Burton, 1959). Celestite is similar to barite (barium sulfate, $BaSO_4$) in appearance, occurrence, and geologic settings (Tolsted and Swineford, 1986). In some locations, the Long Creek has depositional features referred to as box-work, and blade-shape depressions, which suggest very soluble minerals, such as gypsum and anhydrite, have been dissolved. Geologists often call these minerals evaporites, a term used to describe minerals that are formed by the evaporation of seawater. A feature of the Long Creek at some localities is the abundance of small crystals of quartz on weathered surfaces. The upper surface weathers to a honeycomb-like mass of quartz crystals, many of which are pink, embedded in a small amount of yellow limestone (Jewett, 1941).

Overlying the Long Creek Limestone Member is the Johnson Shale. The Johnson Shale is mostly covered here, but it is dark gray and clay-rich mudrock. Fossils are rarely found in the Johnson Shale (Jewett, 1941). It marks a period when this part of Kansas was exposed to both sabkha and subaerial depositional processes. Subaerial is a collective term that describes conditions or processes, such as erosion or soil formation, that occur on a land surface above sea level. In different parts of the state, this unit often has mud cracks, root traces, and ancient soils called paleosols. Some of these ancient soils are very well developed and have columnar soil structures, called peds, that suggest soil formation under saline conditions with much salt in the soil (Archer and others, 1995).

Above the Johnson Shale, the Red Eagle Limestone is present near the top of the hill at this stop. It signifies a return to marine conditions when the sea level rose again during this period. The Glenrock Limestone Member is particularly important because the top of this member marks the division between two important system boundaries, the Carboniferous and Permian. The Glenrock is highly bioturbated and includes broken shell debris, fusulinids, and *Composita* brachiopods. In the past there has been extensive debate among geologists regarding the correct placement of the Carboniferous–Permian boundary in Kansas because of the transitional nature of these rocks. Confusingly, it often appears that mixed Carboniferous and Permian marine fossil assemblages occur together, and a clear lithologic boundary or gap in geologic time was not recognized in these rocks. Recently the Kansas Geological Survey formally reclassified and set this boundary between the Glenrock Limestone Member and overlying Bennett Shale Member of the Red Eagle Limestone (Sawin and others, 2006) (fig. 4–1). This point in geologic time is set from a global benchmark or reference point, called a Global Stratotype Section and Point (GSSP), which in this case is located in the southern Ural Mountains. To tie this Kansas contact to the GSSP in the Ural Mountains, researchers used the first fossil occurrence of a particular species of conodont (*Streptognathodus isolatus)*, much like, as previously mentioned, fusulinids are used to separate the Hughes Creek Shale Member from the Long Creek Limestone Member. Conodonts are small tooth-like fossils that are often used to biostratigraphicaly correlate rock units in time from one location to another. Conodonts are useful because they are particularly resistant to erosion and decay and occur in recognizable assemblages that are specific to different periods of geologic time. The occurrence of this conodont represents a particular instance in geologic time and in essence captures time in bottle at the contact between the Glenrock Limestone Member and Bennett Shale Member, allowing a rare geologic opportunity in parts of Kansas to simultaneously stand with one foot in both the Carboniferous and Permian Systems.

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STOP 5—Geoarcheology at the Claussen Site

The Claussen archeological stop focuses on alluvial stratigraphy and geoarcheology in the central Great Plains. The Claussen site is located along an extensive Mill Creek cutbank in northeastern Kansas. Erosion has exposed a well-stratified section of alluvial sediments and archeological materials from a broad period. Archeological materials collected from these sediments include artifacts from the Paleoarchaic, Early Ceramic, and Middle Ceramic cultural period (fig. 5.1).

A road log is not included with this stop. Unfortunately, cultural sites are threatened by artifact collectors who often turn to the literature for site locations. To help preserve the site, <u>artifact collecting is prohibited.</u> The Claussen site is on private property and should not be revisited.

The Claussen site is in the Flint Hills region of the Central Lowlands Physiographic Province (Fenneman, 1931). The bedrock geology of the Flint Hills is characterized by interbedded limestones and shales deposited in shallow seas during the Carboniferous and Permian Periods about 300 million years ago. The Flint Hills derived their name from the abundance of chert, or flint, scattered across the uplands. Because chert is much less soluble than the limestone that encloses it, weathering of the softer rock forms a clay-rich soil containing many chert fragments. This gravel-rich soil armors the rocky uplands and reduces erosion relative to other areas where the limestone does not contain chert.

Dominant Flint Hills grasses are big bluestem (*Andropogon gerardi*), little bluestem (*Andropogon scoparius*), Indian grass (*Sorghastrum nutans*), and switchgrass (*Panicum virgatum*). Riparian forests include cottonwood (*Populus deltoides*), hackberry (*Celtis occidentalis*), willow (*Salix* sp.), and elm (*Ulmus* sp.). Juniper (*Juniperus* sp.) and bur oak (*Quercus macrocarpa*) tend to occur in ravines and on rocky slopes that are insolated from fire. Black walnut (*Juglans nigra*), green ash (*Fraxinus pennsylvanica*), and sycamore (*Platanus occidentalis*) are common at the base of the hillsides.

From an archeological perspective, the abundance of chert is perhaps the most important characteristic of the Flint Hills environment. Due to its superior flaking qualities, Flint Hills chert provided excellent raw material for chipped stone tools and was heavily used by prehistoric inhabitants of the region.

The cutbank at the Claussen site exposes a cross section of a low (T–1) and high (T–2) alluvial terraces (fig. 5–2). T–1 is about 5–6 m and T–2 is about 10 m above the base level of the stream. A modern floodplain (T–0) about 1–2 m above base level is on the other side of the creek. As the lowest geomorphic surface in the valley, T–0 is frequently flooded.

Alluvium beneath terrace T–1 and T–2 is assigned to three units of the Holocene-age DeForest formation: the Honey Creek, Roberts Creek, and Gunder members. The Holocene is considered recent by geologists and includes a period of time from the present day to about 12,000 yrs B.P. (years before present). Sediments comprising the three DeForest formation members were deposited by Mill Creek as it meandered back and forth through its valley. These alluvial units are categorized or given names by geomorphologists much like geologists classify rock units. At Claussen, the Roberts Creek member fills an old channel at the base of the T–2 scarp and separates the Gunder and Honey Creek members from each other (fig. 5–2).

The terraces and the DeForest formation members represent different periods when Mill Creek was either aggrading (depositing sediment) or incising (eroding sediment) in response to changes in stream grade. The alluvium beneath the terrace represents periods when the stream was aggrading and building up the valley floor with sediment. The terrace surface marks a high water mark where an old floodplain once existed. A terrace, such as T–2, is formed when the stream cuts down into its valley leaving the old floodplain stranded high and dry above a new, lower flooding surface. These cycles repeat and give the terraces their benchlike features.

Archeological investigation of the cutbank revealed stratified artifacts in the Honey Creek, Roberts Creek, and Gunder members. The Honey Creek member of the T–1 terrace has a modern surface soil and contains cultural deposits within the alluvial fill (fig, 5–3). Radiocarbon dating on wood charcoal indicates that this cultural horizon is about 810 yrs B.P., which places it in the Middle Ceramic cultural period. By this time, human subsistence patterns had advanced to include maize cultivation in eastern Kansas while humans in western Kansas used horticulture as a supplement to hunting and gathering. The Historic Plains Indian cultures that relied on equestrian bison hunting and nomadism would not develop for at least another 200 years (fig. 5–1).

The Roberts Creek member of the T–1 terrace has a modern soil and a thick buried soil horizon, or paleosol. Paleosols represent pauses in the sedimentation record where the exposed floodplain surface had enough time to develop a soil profile before being buried by new alluvium. Five separate cultural horizons were recorded in this buried soil (fig. 5–3). Although the age of the deposits is unknown, Early Ceramic pottery sherds (ca. 2,000–1,000 yrs B.P.) were recorded in the top cultural horizon. Domestication of native plants in eastern Kansas had begun by this period (fig. 5–1).

The Gunder member of the T–2 terrace contains one modern and three buried soil horizons that were evaluated for cultural features (fig. 5–3). Soil 1 is a modern soil profile. Radiocarbon dating indicates that the age of Soil 2 is approximately 5,210 yrs B.P., Soil 3 is 7,100 yrs B.P., and Soil 4 is 8,800 to 9,225 yrs B.P.

The most intriguing cultural deposits were found in Soil 4 near the base of the cutbank (fig. 5–3). Archeological excavation and radiocarbon dating in Soil 4 established three cultural horizons at 8,800 yrs B.P., 9,225 yrs B.P., and an undated, lower (therefore older) horizon. While Soil 4 is not geologically old, culturally, it is quite old and dates back to the prehistoric Paleoarchaic cultural

Cultural Period		Date	Dissected Till Plains	Osage Cuestas	Flint Hills	Arkansas River Lowlands	High Plains	Subsistence Pattern
			Physiographic Provinces					
Historic	Modern	A.D. 1950 – A.D. 1900	Americans, including Indian Nations, and immigrants of many cultures					Service economy, light industry, mineral & petroleum exploitation, farming, ranching
			Industrialization, Mechanized Agriculture					
Historic	Historic	A.D. 1870	Iowa, Sac & Fox, Kickapoo, Potawatomi, Delaware, Wyandotte, Shawnee	Shawnee, Sac & Fox of Mississippi, Ottawa, Peoria & Kaskaskia, Wea & Piankeshaw, Chippewa, Potawatomi, Miami	Osage, Kansa	Cherokee	Comanche, Cheyenne, Arapahoe, Kiowa, Kiowa-Apache, Sioux, Pawnee	Reservations, Equestrian Bison Hunting; Maize-based Horticulture East; Equestrian Nomads West
			Immigrant Tribes					
Historic	Late Ceramic	A.D. 1800	Kansa	Osage, Kansa, Wichita	Osage, Kansa, Wichita	Wichita, Comanche, Cheyenne, Kiowa, Kiowa-Apache	Comanche, Cheyenne, Arapahoe, Kiowa, Kiowa-Apache, Sioux, Cuartelejo Apache, Pawnee	Equestrian Bison Hunting, Equestrian Nomadism; Maize-based Horticulture & Trapping East
Proto-historic	Late Ceramic	A.D. 1700	Oneota tradition	Neosho focus		Dismal River aspect	Dismal River aspect	Hunting, Gathering; Maize Horticulture East; Some Supplemental Horticulture West
Prehistoric	Middle Ceramic	A.D. 1500	White Rock, Nebraska, & Steed Kisker phases, Pomona variant	Great Bend Aspect; Pomona variant	Great Bend aspect, White Rock phase, Smoky Hill phase, Pomona variant	Great Bend aspect; Pratt complex, Bluff Creek complex	Great Bend aspect; White Rock, Upper Republican, Smoky Hill, & Odessa phases; Pratt complex	
Prehistoric	Early Ceramic	A.D. 1000	Grasshopper Falls phase, Valley variant, Kansas City Hopewell	Greenwood, Grasshopper Falls, & Cuesta phases	Grasshopper Falls, Greenwood, Schultz& Cuesta phases	No Known Early Ceramic Cultural Manifestation	Keith phase	Hunting, Gathering; Cultivation & Domestication of Native Plants East
Prehistoric	PaleoArchaic	A.D. 1 – 500 B.C.			Walnut & El Dorado phases	Unclassified Archaic Cultural Manifestations		Hunting, Gathering; Incipient Cultivation of Native Plants East
Prehistoric	PaleoArchaic		Nebo Hill phase	Nebo Hill & El Dorado phases	Vermillion, Chelsea, & Munkers Creek phases	McKean complex		
Prehistoric	PaleoArchaic	3000 B.C.	Logan Creek phase	Stigenwalt complex	Logan Creek phase			Hunting, Gathering
Prehistoric	PaleoArchaic	5000 B.C. – 7500 B.C.	Dalton, Cody Complex, Allen, Fredrick					
Prehistoric	PaleoArchaic	10,000 B.C.	Clovis, Folsom, Plainview					

FIGURE 5–1—The chronological sequence of Kansas cultures by physiographic provinces (Hoard and Banks, 2006). Used with permission of the University Press of Kansas and the Kansas Historical Society.

period (fig. 5–1). During this period the climate and landscape was much like present-day Kansas. However, the technological use of cultivation and pottery had not yet emerged on the Great Plains and human subsistence was still hunting and gathering from local resources.

During the Paleoarchaic, slow stream aggradation allowed Soil 4 to build up over a long period and resulted in a stratified record of human existence as people repeatedly occupied the site roughly 8,800 to 9,225 yrs B.P. Old sites such as Claussen are rarely exposed in the eastern Great Plains because they are deeply buried by thick alluvial sediments. The high cutbank underscores the difficulty of finding these sites.

Claussen provides an important "window" to view human cultural adaptations in this part of the Great Plains. Recovered samples include chipped stone, bone, shell, and charcoal. Some tools were identified and include two modified flakes and three flaked and battered cobbles that were probably used as either cores or hammers. All of these were expedient tools that were made, used, and discarded at the site. Many of the flakes are relatively intact with few post-manufacture breaks by trampling, which suggests that the duration of occupation or activity at Claussen was for relatively short periods. A few burned rocks were recovered, which suggests that these rocks were associated with hearths rather than natural surface fires. Also, flake patterns on the tools indicate that they were probably thinned or retouched at the site. This workmanship suggests that other tools, knives, or projectile points were probably manufactured at the site but remain uncovered.

No culturally diagnostic artifacts were excavated; however, a Dalton projectile point was recovered from soil that fell out of the 9,225 yrs B.P. horizon. Dalton and lanceolate projectiles were also found on a gravel bar downstream from the site. Paleoarchaic points help identify different cultural complexes and are recognizable by shape and technological features such as flaking patterns or grinding (Hoard and Banks, 2006). The Dalton point is a type of projectile that was sometimes fluted with a beveled channel down the center of the projectile. The lanceolate point is a long, lance-shaped design used for large game and was also sometimes fluted. Fluting was an adaptation to help attach the points, which were probably hafted on short fore shafts and could be used either as handheld knives or inserted in dart shafts to tip atlatl darts (Hoard and Banks, 2006). The manufacture of these points is characteristic of the Dalton hunter-gatherer cultural group that lived in the forest margin along the Great Plains.

Bones from the 9,250 yrs B.P. horizon indicate that humans at Claussen had a broad diet consisting of 22 different vertebrate and three invertebrate species. Scorch marks on bone fragments suggests that bones were thrown into hearths after they had been eaten as food. Whitetail deer or perhaps pronghorn antelope (*Odocoileus* or *Odocoileus/Antilocapra*) were the most common species. However, avian species, notably wild turkey

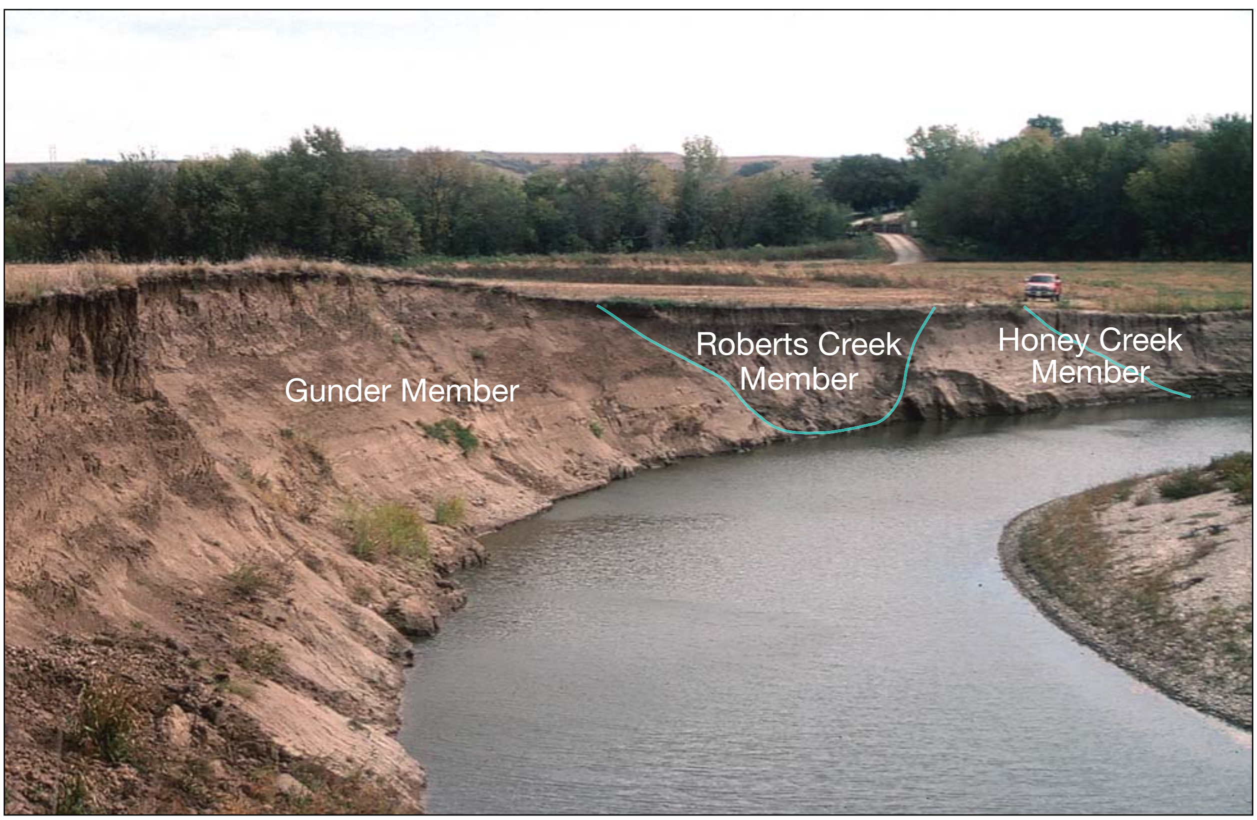

FIGURE 5–2—Photograph of the cutbank at the Claussen site. The vehicle is on the T–1 terrace and the T–2 terrace is in the left foreground. The T–0 terrace is above the opposite bank (modified from Mandel and others, 2006).

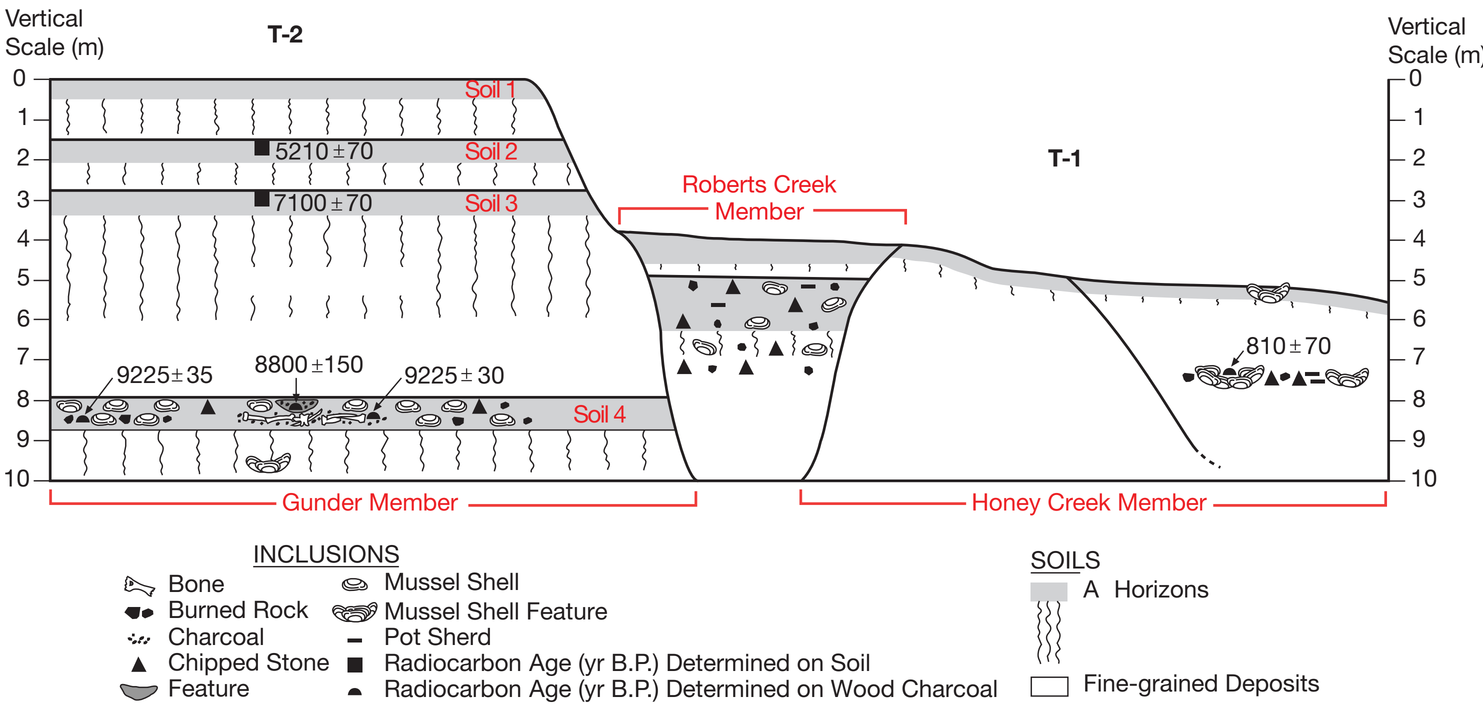

FIGURE 5–3—Cross section of the cutbank at the Claussen site, showing the geomorphology, soil stratigraphy, archeological components, and radiocarbon ages (modified from Mandel and others, 2006).

(*Meleagris gallopavo*), were significantly present. Bison (species indeterminate), swift fox (*Vulpes velox*), rabbit, fish, snake, and rodent species are also present. Preliminary identification also included three different mussel species (*Amblema plicata*, *Quadrula quadrula*, and *Fusconaia flava*). The different bones and mussel shells suggest the people at Claussen probably ate every animal that lived around Mill Creek at the time.

This diverse faunal assemblage and expedient technology makes the archeological record at Claussen most intriguing and exciting. The tools and broad diet indicate a complex range of cultural and non-cultural adaptations which suggests that subsistence patterns at Claussen were very different from the contemporary, bison-focused subsistence strategies found in the Great Plains at the time. It indicates adaptation to a transitional culture more comparable to the Dalton and even younger Eastern Woodland complexes rather than the Paleo-Indian adaptations found to the west. The old age of this site suggests that early humans in the region probably adopted these new subsistence behaviors earlier than previously thought.

The authors wish to express their appreciation to Rolfe Mandel, Associate Scientist in Geoarcheology–Quaternary Geology, at the Kansas Geological Survey for his presentation to the KESTA members at their annual meeting and this stop on the field trip. Most of the material in this section of the guidebook is largely drawn from Mandel and others, 2006.

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STOP 6—Glaciers – Tower Hill

Covered with scattered glacial erratics, the last stop of the field trip is on the summit of Tower Hill; the Kansas River north of here and Buffalo Mound visible to the southeast are important northeast Kansas glacial landmarks. Protruding through the tallgrass prairie around the radio tower are glacial erratics that disconformably overlie the ancient Permian bedrock. Carried by ice, a non-native erratic is characterized by its incongruous position over the native bedrock. Sometimes these rocks occur in such density that geologists describe the feature as a felsenmeer, which is German for “sea of rocks” (fig. 6–1). Some of these especially dense occurrences of erratics are located just west of here on the north side of Tower Hill Road. The presence of erratics at this elevation indicates that glacial ice once overran Tower Hill as far as McFarland, Kansas, to the south and Buffalo Mound to the east.

Most erratics in Kansas are Sioux Quartzite. Sioux Quartzite is over a billion years old and originally derived from ancient sandstone that was metamorphosed into quartzite by pressure and heat so intense that the rock now breaks just as easily through sand grains as around them. These rocks crop out along a fairly specific area in southern Minnesota, southeastern South Dakota, and northwestern Iowa, and were carried into Kansas by glacial ice about 700,000 years ago.

New evidence of an apparently much older glacial period was recently discovered after torrential rain in March 2007 exposed previously undiscovered glacial till deposits in a stream valley just west and north of Tower Hill. Till is a Scottish word for a particular kind of glacial deposit formed directly by and underneath glacial ice without subsequent reworking by meltwater. Here, the till is a weathered, bouldery mixture of clay and igneous rocks, rather than the scattered Sioux Quartzite found elsewhere on the hill. Initial field investigation suggests that the till underlies the younger Sioux Quartzite deposits and could correlate to much older exposures of till found in Missouri that date to 1.8 to 2.4 million years ago (Dort, 2007). If additional research proves true, these deposits could significantly expand the glacial record in Kansas to a much older period than previously thought—exciting times for glacial geology in Kansas to be sure.

Sometimes more exotic igneous and metamorphic rocks from the northern United States or Canada were carried into Kansas by advancing ice sheets. Granitic rocks, Lake Superior agate, Duluth area iron ore, Keweenawan volcanics, and native copper can occasionally be found in different parts of the glaciated region. Isolated occurrences of the Pipestone variety of Sioux Quartzite are sometimes found in the Tower Hill area, too. Also known as catlinite, pipestone is a purplish-red color, ultra-fine

FIGURE 6–1. Sea of Sioux Quartzite erratics on ridge crest 5 mi (8 km) south of Wamego (Dort, 2006).

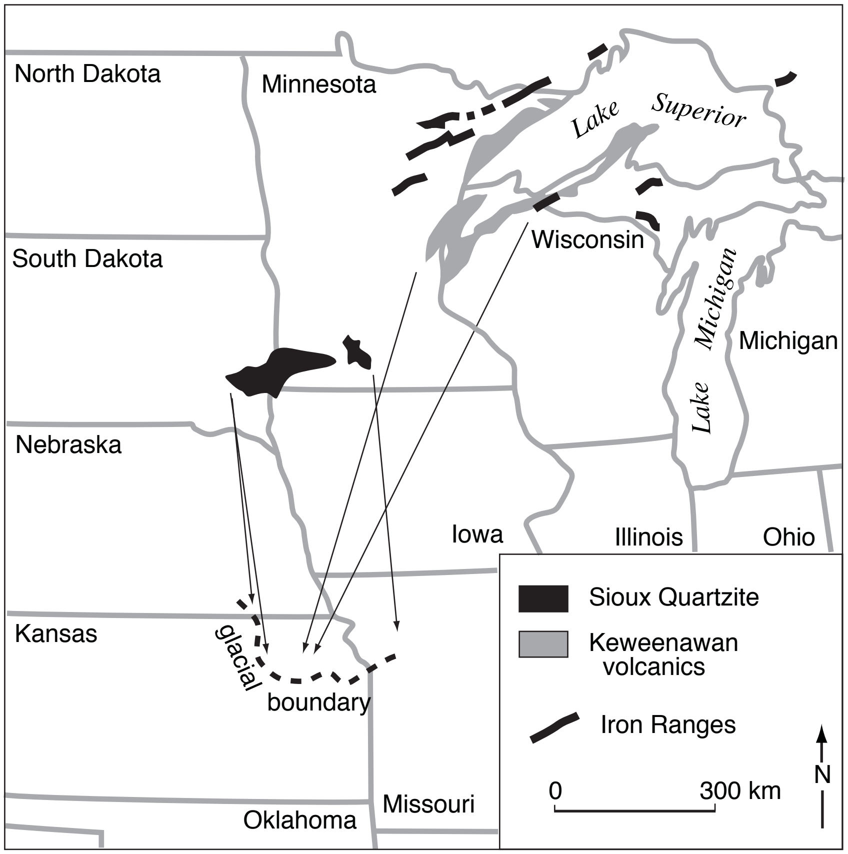

FIGURE 6–2. Sources of identifiable glacial erratics found in northeastern Kansas. Fragments of Sioux Quartzite are common throughout the terminal zone, and eastward into Missouri. Specimens of ore from the Iron Ranges are scarce. Distribution of Lake Superior agates from the Keweenawan volcanics is highly localized, seemingly restricted to an area in and near Topeka (Dort, 2006.)

grained, and soft. Pipestone was valued by Native Americans for carving artifacts and could have been a valuable natural resource in this area if Native Americans were aware of it at the time. The assemblage of these different rocks help geologists better understand the origin and direction of glacial movement (fig. 6–2). In particular, pipestone is limited to a small outcrop area at Pipestone National Monument in southern Minnesota, which means that the ice carrying these rocks would have travelled almost 345 mi straight south before arriving at Tower Hill (Dort, 2007).

The glacial advance that crested Tower Hill would have first filled the Kansas River valley with ice before continuing south towards McFarland and butting against the northern side of Buffalo Mound. The initial ice front that advanced into Kansas was probably tens of feet thick and slid discontinuously and irregularly forward under pressure from thicker ice to the north. As the ice moved, it did so somewhat like a sheet of water running across a flat landscape, first "running" or "spilling" over the north valley wall of the Kansas River and then incrementally filling up the valley. Continued glacier flow from source areas in Canada gradually increased the ice thickness along the northern valley wall, flowed down the ice slope into the valley, and pushed forward along the valley floor until it butted against the south valley wall. Gradually, progressively thicker ice flowed into the river valley until it filled the valley and then passed over Tower Hill and advanced south nearly to where I–70 is today. By the time ice moved over Tower Hill, ice was perhaps 300 ft thick north of the river and 500 ft thick over the Kansas River valley (Dort, 2006).

At the time of the maximum glacial advance, the Kansas River valley was covered by a continental ice sheet all the way east to Kansas City, effectively damming the Kansas River east of Wamego (fig. 6–3). Known as Kaw Lake, the open water of this natural impoundment dwarfed both Tuttle Creek and Milford reservoirs combined and extended west for at least 70 miles, likely reaching Salina. Manhattan, Junction City, Abilene, and Clay Center were all lakefront property some 700,000 years ago.

With climate change and warming, the surface of the ice sheet eventually began to lower and then retreat. Topographically high areas were uncovered first leaving tall hills, such as Tower Hill, islands of land surrounded by ice left in the deeper valleys. The lowest elevations were the last to be ice free. Cut off from rejuvenating ice flow from the north, ice masses in the valleys were separated from the continental ice sheet and melted as the continental ice sheet retreated north. Prevailing winds formed sand dunes from the fine-grained sediment picked up in the upstream delta of Kaw Lake and the drying lake bed when retreating ice drained the lake (Dort, 2007). These sand dunes,

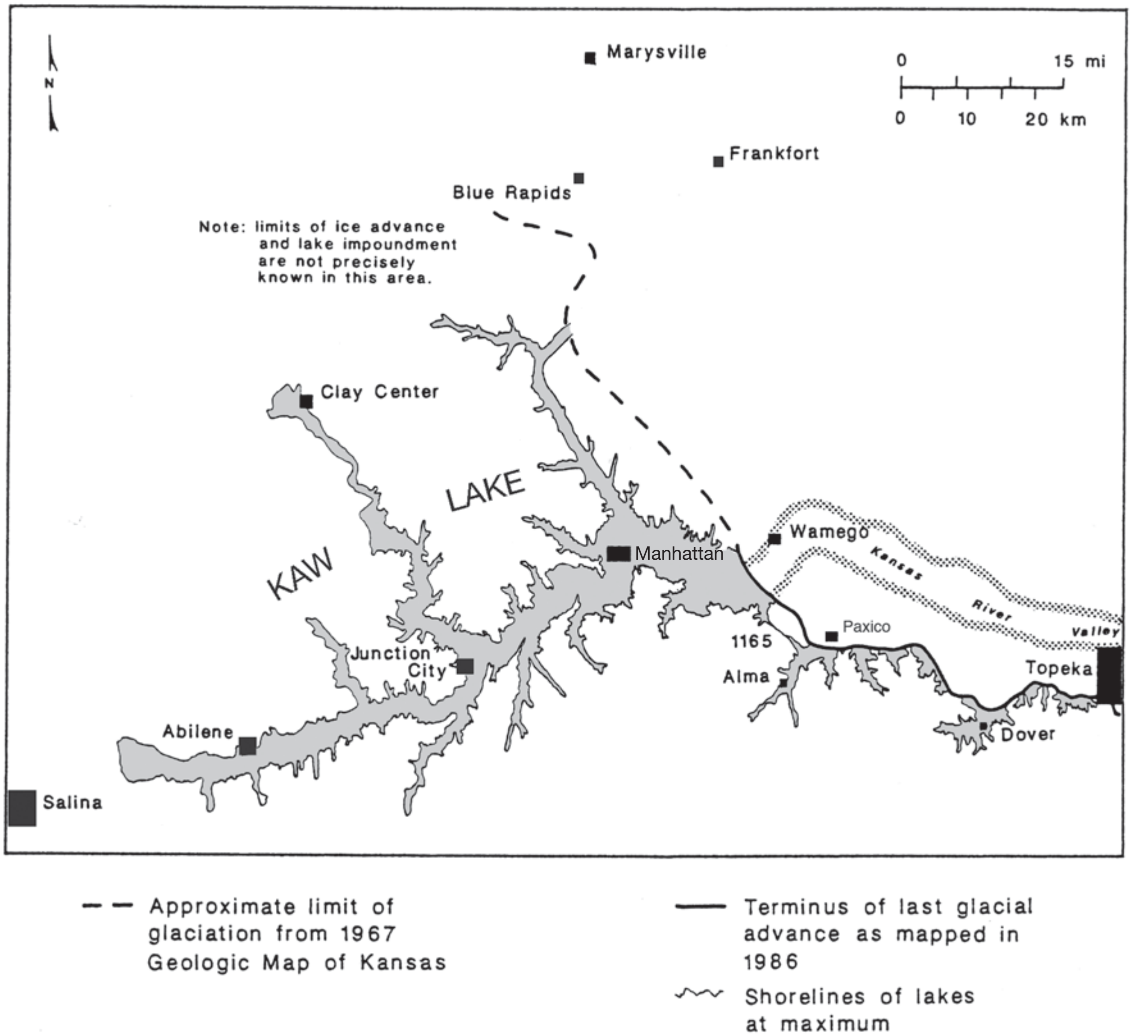

FIGURE 6–3. Proglacial lakes west of Topeka and Kaw Lake at the time of maximum ice advance. Location of Kaw Lake spillway, elevation 1,165 ft, is depicted on the figure north of Alma (Dort, 2006).

now stabilized by modern vegetation, are quite apparent on either side of I–70 near Abilene and the rolling, hummocky topography exists, like the erratics on Tower Hill, as reminders of Kansas' glacial past.

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