KANSAS GEOLOGICAL SURVEY
OPEN-FILE REPORT 93-11

Guidebook for the Lawrence/Kansas City Field Trip

National Science Teachers Association
April 2, 1993

by

Leaders:
Rex Buchanan
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ROAD LOG
NSTA FIELD TRIP, 2 April 1993
by Rex Buchanan and Jim McCauley
Kansas Geological Survey

The following field trip begins in the Kansas City area, runs west to Lawrence, then returns to Kansas City, with a stop at the University of Kansas Museum of Natural History. The trip focuses primarily on Pennsylvanian formations, mostly limestones and shales that were deposited about 300 million years ago. We should have several opportunities to collect invertebrate fossils from organisms that were common in the shallow Pennsylvanian seas. We also will see evidence of glacial, wind, and river deposition from the Pleistocene, about a million years ago.

The numbers in the left-hand column of this guidebook should help you identify features during the trip. The upper number represents total elapsed mileage during the trip (we realize that you don't have ready access to an odometer, but you can use these numbers to estimate the distance from one feature to the next). The lower number, in parenthesis, is the milepost number. Mileposts are the green, rectangular signs on the right-hand side of the road. Because we will be on several highways, each with its own numbering system (and some county roads that don't have mileposts), these numbers will vary considerably during the course of the trip. Also, the highways are numbered from south to north and from west to east, so the milepost numbers grow progressively smaller as we travel from east to west or from north to south on these highways. If you still want to follow the mileposts, you'll need to sit on the right side of the bus.

Much of the information for the following guide was taken from **Roadside Kansas: A Traveler's Guide to its Geology and Landmarks**, by Rex C. Buchanan and James R. McCauley (University Press of Kansas, 1987).

0.0 Allis Plaza Hotel. The Allis Plaza Hotel is located in Kansas City, Missouri, the largest city in Missouri. Naming the city for an adjacent state causes no end of confusion for outsiders, especially since the like-named but smaller Kansas City, Kansas, is immediately across the state line. Kansas City was named for the early Kansas Territory, which extended from the cities' doorstep westward to the crest of the Rocky Mountains. Early names for Kansas City included the town of Kansas and Kansas Landing. The city was incorporated in 1850 and chose the name Kansas City. Eleven years later part of Kansas Territory became the state of Kansas and the confusion began. The choice of the name by the cities' elders may not have been too prescient, but it could have been worse. Legend has it that an early meeting to select a name for the rapidly growing city rejected the name "Possum Trot" by one vote.

Kansas City has a population of just under a half a million and comprises about a third of the population of the metropolitan area, which extends into Kansas. Kansas City calls itself the city of fountains and claims more boulevard miles than Paris. However, the cities' rough and tumble frontier origins and wide-open, anything-goes machine politics, which lasted until World War II, belie the serene image the cities now try to put forward.

Located near the terminus of both the Oregon and Santa Fe trails as well as its strategic location on the Missouri River made Kansas City an early outpost of commerce on the rapidly changing frontier. Rivermen, trappers, traders, mountain men, gamblers, lumbermen, gun fighters, and Indians were all major players in the cities' early history. With the coming of the railroads in the 1860s and the beginning of the Texas cattle drives to the rail heads in Kansas, beef cattle became a major industry for the city and led to the construction of the stockyards that straddled the state line in the Kansas River bottoms. Many large packing plants soon followed.

Kansas City was the last bastion of big city refinement and amenities for those venturing west, facing the bleakness and hardship of the Great Plains. In addition to being a commercial hub for the Great Plains, Kansas City was an entertainment center for cowboys, cattlemen, lawmen, and others who were making their mark on the west. Nearly every notorious character of the old west either lived or passed through here at one time or another. The entertainment provided was distinctly of a non-family nature. The Allis Plaza Hotel sits atop the site of one of those early entertainment centers, 12th Street, the inspiration for the 12th Street Rag. In the midst of the saloons, burlesque houses, gambling dens, and even less reputable enterprises, about a block east of the Allis Plaza was a small haberdashery that tried to make a go of it in the years before World War I. The Truman-Jacobson store operated for three years but failed in 1922, leaving a debt that took Harry Truman 15 years to pay off. Though a failure in business, Truman later found success in other endeavors.

Proceed north from the Hotel to 11th Street, then turn west (or left). Go to Broadway and turn south (or left). Ahead is the gold cupola of the Cathedral of the Immaculate

Conception. Go south one block on Broadway to 12th Street and turn west (or right).

0.3 Here 12th Street crests Quality Hill, capped by the Wyandotte Limestone. This is where the social elite of early Kansas City lived, overlooking the West Bottoms with its rail yards, stockyards, packing plants, factories, and warehouses, where much of the cities' work got done.

0.9 After a drop of nearly 200 feet, 12th Street levels out on the floodplain of the Kansas River. In this area in 1881, the son of Irish immigrants, Jim Pendergast, won big on a horse named Climax, quit his job at the packing plant, and bought a combination hotel and saloon. His success as a saloon keeper eventually led to a career in politics and the creation of the Pendergast Machine. His younger brother Tom took control in 1910 and dominated Kansas City politics and shaped the cities' character until the late 1930s. One of the products of this political dynasty was Harry Truman, a county judge who went on to become a Missouri senator, vice-president, and eventually President of the United States.

1.1 Genessee Street. Turn south (or left) and proceed a short distance, and then turn west (or right) onto the westbound entrance ramp to Interstate 670. Kemper Arena, a large white structure to the south, was the site of the 1976 Republic National Convention and the 1988 NCAA basketball championships, won by the University of Kansas.

1.3 Kansas/Missouri state line. The state boundary here is a north-south line leading south from the intersection of the thalwegs of the Kansas and Missouri rivers. A thalweg is a line connecting the deepest part of the river channel. Kansas, which became a state in 1861, is named after the Kansa Indians, who lived in northeastern Kansas prior to European settlement. The name Kansa has been spelled and translated a variety of ways, but generally is interpreted to mean "people of the south wind." Today Kansas has a population of about 2.5 million people, many of whom live in cities, such as Wichita, Topeka, Lawrence, and Kansas City, along I-70 and the Kansas Turnpike. Kansas City, Kansas, with a population of 150,000, is the second largest city in the state, behind Wichita, and is the birthplace of Charlie "Yardbird" Parker.

1.5 I-670 crosses the Kansas River. A mile to the north is the confluence of the Kansas and Missouri rivers. The Lewis and

Clark expedition camped at the mouth of the Kansas River during its exploration of the Louisiana Purchase in 1804. While in northeastern Kansas, Lewis and Clark described the area as "some of the most charming bottom lands and uplands by no means bad."

1.8 To the north is a portion of Kansas City, Kansas, called Strawberry Hill. This area was home to many immigrants from eastern and southeastern Europe, who came west in the 1800s to work in the huge packing plants that operated in the Kansas River bottoms to the east. Many descendants of these immigrants still live in this neighborhood, although the packing plants and stockyards have largely disappeared from the bottoms. With the development of irrigation systems on the High Plains to the west, and the concomitant development of feedlots, many of the packing plants moved west. In fact, one of the world's largest packing plants--located in Holcomb, Kansas, just outside of Garden City--slaughters an average of about 4,500 head of cattle per day.

2.0 Straight ahead, atop a hill, is the onion-shaped spire of the Holy Trinity Eastern Orthodox Church.

2.8
(421.5) At this point, I-670 merges with I-70 and drops into the flood plain of the Kansas River. On Friday, July 13, 1951, low-lying neighborhoods and industrial districts on both sides of the state line were inundated with the waters of the Kansas River. At the height of the flood, brown, silt-laden water stretched from bluff to bluff, reaching depths of 30 feet. The spring and summer of 1951 were unusually wet. Then a stalled frontal system dropped up to 16 inches of rain on the already-saturated ground of the Kansas River basin. Flooding occurred up and down the Kansas River and along many of its tributaries. Forty-one people died in the flood, one of the most destructive in the nation's history, causing $900 million worth of damage. The flood is still legendary, and provided much of the impetus for a series of dams and reservoirs that were constructed on tributaries of the river.

Also, I-70 reaches its lowest point in Kansas about here, approximately 760 feet above sea level. The highest point in Kansas is south of I-70, at Mount Sunflower in Wallace County (near the Colorado border), where the elevation is 4,039 feet.

4.0
(420.5) To the south, in the Kansas River valley, is an area of Kansas City, Kansas, called the Argentine. The name comes from the Latin word *argentum*, which means silver. A smelter that once operated in this area actually refined small amounts of silver from ore that was shipped in from outside of the area.

4.1-4.9
(419.6-420.4) Westerville Limestone Member of the Cherryvale Shale, overlain by the Drum Limestone. These are shallow-water Pennsylvanian units that crop out in broad bands from northeastern Kansas, south into southeastern Kansas and northeastern Oklahoma. Oolites (small spheres of calcium carbonate) are common near the top of the Westerville, which reaches a thickness of 20 feet around Kansas City, where it is sometimes called the Kansas City Oolite. The Cherryvale Shale is named for a town in Montgomery County in southeastern Kansas. A cross section of the units on this trip is attached.

5.1
(419.4) Mattoon Creek.

5.5
(419.0) Interchange with Interstate 635, which runs through western Kansas City. To the north it connects with Interstate 29, providing a quick route to Kansas City International Airport. North of the highway is an exposure of Iola Limestone.

5.8
(418.7) Argentine limestone north of the highway.

6.1
(418.4) North of the highway is a quarry in the Argentine limestone.

6.3
(418.2) Lane Shale, overlain by Argentine limestone.

6.4
(418.1) Kansas River, also known as the Kaw, to the south. Between 1854 and 1866, 34 steamboats paddled up the Kansas; one made it as far west as Fort Riley. But shallow water, sand bars, and construction of railroads eventually halted steamboat traffic. As one Lawrence newspaper editor wrote, the Kansas River was "a hard road to travel."

6.5 (418.0)	Lane Shale overlain by the Argentine Limestone Member of the Wyandotte Limestone. The Argentine is mined extensively in the Kansas City area. One by-product of this mining is underground space; more than 120 million square feet of underground space exist within 25 miles of Kansas City. The constant temperature and humidity of these man-made caves make them ideal for storing all sorts of items, including government records. The cool temperature allows economical refrigeration and the cold storage of food. The caves are also used for office space and factories.
7.0 (417.5)	Loess on the north side of the highway.
7.2 (417.3)	Brenner heights Creek.
7.6 (416.9)	Thick loess deposits on the west side of the highway. Loess is a fine silt that was blown out of the river channels as glaciers retreated during the Pleistocene. Loess has the ability to maintain a steep slope face and forms high bluffs and hills through much of the glaciated tip of northeastern Kansas. Glaciers moved into northeastern Kansas about 750,000 years ago, and inched as far south as roughly the Kansas River and as far west as the Big Blue River near Manhattan, about 150 miles to the west.
7.9 (416.6)	Muncie Creek.
8.5 (416.0)	Loess exposure.
8.7 (415.8)	Interchange with Kansas Highway 132.
8.8 (415.7)	Mill Creek.
9.2 (415.3)	Argentine Limestone Member of the Wyandotte Limestone.

9.4
(415.1) North of the westbound lane is a tourist information center. In the parking lot north of the center are outcrops of two layers in the Farley limestone, the uppermost member of the Wyandotte Limestone. The lower unit here is oolitic and cross-bedded.

10.4
(414.5) Cross-bedded limestone in the Farley Member of the Wyandotte Limestone. The oolites are arranged in angled lines in the limestone, probably the result of deposition by running water.

10.5
(414.0) Two miles south is the site where the first ferry operated across the Kansas River. Moses Grinter built the ferry in 1831, providing a vital link in the military road from Fort Leavenworth to Fort Gibson, Oklahoma. A two-story farmhouse, built in 1867 near the site of the ferry, is open to the public.

11.4
(413.5) The Bonner Springs Shale is north of the road. To the south one mile is the Edwardsville Northeast oil field, one of only four oil fields that have been discovered in Wyandotte County. During 1991, Kansas produced 56.7 million barrels of oil, enough to place it eighth among the oil-producing states in the country. Kansas production began in the 1860s in Miami County, about 40 miles south of here. In the early 20th century, most production came from shallow wells in Pennsylvanian units in southeastern Kansas. Around World War I, several large fields were discovered in south-central Kansas, near Wichita. Later, production centered on a subsurface structure called the Central Kansas Uplift in west-central Kansas. This feature is one of the most densely drilled targets in the country and Ellis and Russell counties, along the uplift, are the state's leading oil-producing counties.

12.2
(412.7) Stanton Limestone.

12.4
(412.5) Vilas Shale, overlain by the Captain Creek limestone, Eudora shale, and the Stoner limestone, all members of the Stanton Limestone.

12.6 (412.3)	Plattsburg Limestone.
12.8 (412.1)	Farley limestone.
13.1 (411.8)	Farley Limestone Member of the Wyandotte Limestone overlain by Vilas shale and a thickened section of Merriam limestone.
13.2 (411.7)	Interchange with Interstate 435. This highway loops around the Kansas City area. To the north it connects with the Woodlands (a race track for horses and greyhounds), Interstate 29, and Kansas City International Airport. The final stop on today's field trip will be at the intersection of I-70 and I-435 on our return to Kansas City.
14.9 (226.0)	East Mission Creek. From here to the West Lawrence Exit, the milepost numbering system is that of the Kansas Turnpike, which runs from the Kansas City area, through Lawrence, Topeka, and Wichita, to the Oklahoma border.
15.1-15.9 (225.0-225.8)	Scattered roadcuts in the Tonganoxie Sandstone Member of the Stranger Formation. This sandstone was deposited in a broad river valley, up to 20 miles wide, that stretched from near Leavenworth, southwestward across much of eastern Kansas. These outcrops display the angled lines of crossbedding that are indicative of sediment deposited by flowing water. The Tonganoxie reaches a thickness of 160 feet and appears to be a valley deposit of a large southward-flowing river that cut down into older rocks during the Pennsylvanian. The formation is named after a small town eight miles to the west, in southern Leavenworth County, and is an important aquifer, supplying groundwater to farms and small towns in the area.
16.3 (224.6)	West Mission Creek.
16.5 (224.4)	Toll booth for Kansas Turnpike.

16.7
(224.2) Exit for Kansas Highway 7. To the north are the Agricultural Hall of Fame and the city of Leavenworth, site of Leavenworth Federal Penitentiary and historic Fort Leavenworth. To the south is Bonner Springs.

17.7
(223.2) Tonganoxie sandstone.

18.0-18.5
(222.4-222.9) The top of the Stanton Limestone down through the Vilas Shale, Plattsburg Limestone, and the Bonner Springs Shale. The Wyandotte/Leavenworth county line is at milepost 222.9.

19.1
(221.8) Wolf Creek. The name of the stream serves as a reminder that gray wolves were once common through most of Kansas. Last reported in Kansas in 1905, wolves preyed almost entirely on buffalo.

19.5
(221.4) Bonner Springs Shale overlain by Plattsburg Limestone.

19.9
(221.0) Stanton Limestone.

20.2-20.4
(220.5-220.7) Tonganoxie sandstone.

22.5
(218.2) To the west on the skyline is the Oread escarpment, which is capped by the resistant limestones of the Oread Formation. This prominent break in the landscape extends from extreme northeastern Kansas to the Oklahoma border. Also note the overpass marked 218.202. The Kansas Turnpike conveniently designates overpasses according to their distance along the road from the Oklahoma border. The precision is remarkable.

24.8
(215.9) Stranger Creek. The name is a translation of an Indian word that means "wandering aimlessly about," an apt description of the meandering habit of this stream.

28.5
(214.9) Stoner limestone.

28.5 (212.2)	Cow Creek, one of seven Cow creeks in Kansas.
29.1 (211.6)	Sandstone in the Stranger Formation.
30.0 (210.7)	Nine-mile Creek.
31.7 (209.0)	Lawrence Service Area.
32.5 (208.2)	Kent Creek.
34.7 (206.0)	Mud Creek.
34.9 (205.8)	Douglas County/Leavenworth County line.
35.3 (205.4)	A river channel abandoned by the Kansas River. The slightly higher ground east of this channel is underlain by the Newman Terrace. Several center-pivot irrigation systems are also visible in the fields on either side of the highway. These units draw water from the alluvium bordering the river, then spray it on crops grown in the rich bottom land of the river. Similar systems are used in western Kansas, where they draw water from the Ogallala aquifer and irrigate crops such as corn. The center-pivot systems create large green circles of crops that are strikingly visible when flying over the High Plains.
36.1 (204.6)	Sand pits appear on the south side of the road. Mount Oread and the University of Kansas are visible to the southwest.
36.4 (204.3)	To the north is another old river channel. The Kansas River has wandered across this area for centuries, regularly changing course.
37.2 (203.5)	East Lawrence Interchange.

38.0
(203.0) Kansas River. The Kansas River begins near Junction City, Kansas, at the confluence of the Smoky Hill and Republican rivers. The Kansas and its tributaries drain much of the northern half of Kansas, while precipitation to the south generally flows into the Arkansas River drainage basin. Here the Kaw looks wider and deeper than at other places along its course, primarily because it is impounded a little more than a mile downstream by Bowersock Dam, the only dam on the Kansas River and the only hydroelectric dam in the state. It has the capacity to produce just under two megawatts of electricity. With its sandy bottom and connection to the Mississippi River via the Missouri, the Kaw is home to several species of fish that are rarely found elsewhere in Kansas, including sturgeon, lamprey, and eels.

At Lawrence, the first bridge across the Kansas River was completed in 1863. Construction was held up when eight members of the building crew were killed in a raid on the town of notorious outlaw William Quantrill and his raiders. When the wooden bridge was finally finished, the construction company charged a toll of 25 cents per trip.

39.3
(201.9) West Lawrence Interchange. With a population of 66,000, Lawrence is the fifth largest city in Kansas. It is home to the University of Kansas, established in 1866. The town itself was founded in 1854, at the time Kansas was organized as a territory. Territorial Kansas was involved in the dispute over whether the state should enter the Union as a pro-slavery state or an abolitionist state. Lawrence, founded by settlers from Massachusetts and named after a Massachusetts businessman, was known as an abolitionist stronghold. Through the 1850s, Lawrence citizens fought with pro-slavery forces in nearby Lecompton, Leavenworth, and Missouri. Those disputes gave the state its title of "Bloody Kansas," and eventually culminated in Quantrill's 1863 raid on the city, during which more than 100 people were killed and many of the town's buildings were burned. Today, many of Lawrence's streets are named after states; the road exits here to Iowa Street, for example, and the town's primary business thoroughfare is called, appropriately, Massachusetts Street.

39.7 West Lawrence Exit toll booth.

40.9 Ninth Street. This marks the edge of the Oread escarpment.

41.7 15th Street. The Toronto limestone is exposed in the northeast corner of this intersection.

41.9 Daisy Hill. Exposure of Leavenworth and Plattsmouth limestone members of the Oread Limestone are visible in the roadcut. Dormitories from the University of Kansas are also visible to the east. Most of the University buildings are located atop a limestone hill to the east that was originally called Hogback Ridge, but the name was later changed to the more elegant Mount Oread. The building under construction to the west is a new performing arts center for KU.

42.0 To the west is Pioneer Cemetery, burial place for victims of Quantrill's raid on Lawrence in 1863. This is also the cemetery for a number of KU professor and staff members, including R.C. Moore, who was director of the Kansas Geological Survey from 1916 to 1954. Moore was known for theories about cyclic deposition and as the founder of the *Treatise on Invertebrate Paleontology.*

42.2 19th Street. The Kansas Geological Survey is headquartered in the buildings on the southwest corner of this intersection. The tallest red brick building is named for R.C. Moore.

42.7 23rd Street. Turn west (right) onto Clinton Parkway and proceed past the Shenk Recreational Sports Complex.

43.2 The buffalo sculpture on the north side of the road was created by local artists from native Kansas limestone supplied by the Bayer Stone Company in St. Marys.

43.7 Kasold Drive.

44.9 The Toronto Limestone Member of the Oread Limestone is exposed north of the road. In this area, the Toronto is characteristically brown and massive, one of the more recognizable units in the Oread. Here the road gradually climbs the Oread Escarpment. The Oread Limestone is named for nearby Mount Oread, which was itself named after the Massachusetts home of Eli Thayer, a promoter of the New England Emigrant Aid Society, which helped settle Kansas in the 1850s. An oread was a mountain nymph in Greek mythology. The name is derived from oros, the Greek word for mountain, which is the root for geologic terms such as orogeny--the process of mountain building--and orographic--

an adjective describing things related to mountains. The Oread Limestone can be traced from far northeastern Kansas, south to Oklahoma.

The alternating limestone and shale sequences of Upper Pennsylvanian rocks (such as the Oread) are visible throughout this part of Kansas. These rocks dip at a slight angle to the west and northwest, away from the Ozark Dome. Limestones are more resistant than shales to erosion and tend to cap hills and ridges, while gentle slopes are developed on the shales. The result is a series of escarpments or cuestas (Spanish for slope) that trend in a parallel north-south pattern across this end of the state. Each escarpment is capped by a limestone.

45.2 Wakarusa Drive. Before development in Lawrence reached this far west, this street had the less euphonious name of Dragstrip Road.

45.4 The Plattsmouth and underlying Toronto limestone members of the Oread Limestone are exposed in roadcuts as the road descends from the Oread Escarpment.

45.8 Yankee Tank Creek, which begins north of Clinton Lake and dumps into the Wakarusa River south of Lawrence. After passing over this creek, the road again ascends the Oread Escarpment.

46.0 The road climbs through the Lawrence Formation and much of the Oread Formation.

46.5 STOP 1. Just south of the road, the emergency floodway for Clinton Dam has been carved through the Plattsmouth limestone, Heebner shale, Leavenworth limestone, Snyderville shale, and Toronto limestone members of the Oread Limestone and on down into the upper portions of the Lawrence Formation, which is mostly shale.

These interbedded limestones and shales are probably the result of changing levels in the Pennsylvanian sea. Where the water in that sea was deep (tens of feet, say), it deposited limestone. Where it was shallower, it left behind gray shales. Beginning in the early 20th century, geologists began to discern the pattern to this limestone/shale deposition; a typical limestone/shale sequence was called a "cyclothem." R.C. Moore was an early proponents of the notion of cyclothems, and the concept is still strongly identified with him.

While the cyclicity of these deposits is obvious, the theory of cyclothems has sparked undying geologic debate, which includes disagreement over the environment in which the rocks were deposited (black shales, such as the Heebner, are a common component of a cyclothem; Moore said they were shallow-water deposits, but many geologists today believe that they represent deposition in the deepest part of the ocean) and the source of sea-level change (did the land move up and down, changing sea level, or did melting and refreezing of ice caps change sea level? This question has obvious relevance to today's debates over climate change). See the attached measured section by Stephens and Watney.

46.8 Stop sign. Turn south on County Road 13, the "Corps Road."

47.0 The man-made emergency floodway is east of the road. The floodway is designed to handle excess water in Clinton Lake, in the event that the spillway isn't sufficient. The floodway, however, has never been used.

47.3 North end of Clinton Dam. This dam was built in the 1970s and named after a small town about three miles west of here. The dam impounds water of the Wakarusa River and provides water supply for Lawrence and much of the surrounding rural area. Much of eastern Kansas relies on surface water (lakes and rivers) for its water supply, while western Kansas (where precipitation is much less and surface water less plentiful) relies on groundwater. The U.S. Army Corps of Engineers dams in eastern Kansas are built on sites in which a major stream cuts through prominent escarpments, such as this location where the Wakarusa River cuts through the escarpment supported by the Oread Limestone. The range of hills to the south are capped by the Oread Limestone, as is Blue Mound, a lonely outlier rising above the Wakarusa floodplain eight miles to the east.

47.7 Clinton Dam spillway and control structure. To the east, the Wakarusa flows through a mile-long man-made channel before it rejoins its natural course. The normal pool elevation of Clinton Lake is 876 feet. At its deepest point just off the dam, it is about 55 feet deep.

49.0 South end of Clinton Dam. Here the road again climbs briefly onto the Oread Escarpment.

49.2	The road climbs through the Toronto limestone, up to the Plattsmouth limestone, then descends through the same units.
49.4	Here the Toronto limestone, the basal member of the Oread Limestone, overlies a thick exposure of the Lawrence Formation. At the base of the roadcut, on the opposite side of the road, is a layer of coal in the Williamsburg coal bed, one of the units that was commonly mined in Osage County.
50.0	Stop sign. Turn south on Douglas County road 458, traveling across the Buck Creek Terrace of the Wakarusa River.
50.4	Wakarusa Valley School. For the next few miles the road passes through the valley of the Wakarusa River and Washington Creek. These river valleys make good farm land; the predominant crops in the area are corn, soybeans, milo (a form of sorghum grown as cattle feed), alfalfa hay, and wheat.
53.9	Intersection with Douglas County roads 1 and 4039. Turn south.
54.6	The town of Lone Star. Take Douglas County Road 1 to the west. This small community is centered around the Church of the Brethren. In June, 1988, the town was devastated by a flood, when a thunderstorm dropped up to twelve inches of rain in the drainage basin of Washington Creek.
56.9	Washington Creek.
57.2	Lone Star Lake dam. This dams impounds the waters of Washington Creek to form a small public lake. The dam was a WPA project in the 1930s.
58.8	Lone Star Lake spillway, STOP 2. This location is described in more detail in an attached measured section. From here return to Douglas County 458.
60.5	Intersection with Douglas County 458. Turn east.
65.4	Here the road drops onto the floodplain of the Wakarusa.
65.3	T-road intersection. Turn east.
66.1	The road climbs back onto the Buck Creek Terrace for the next 0.7 miles. This terrace was formed during the Illinoisan stage of glaciation, the next to last of the four glacial advances

during the Pleistocene. At this time, as the glaciers were retreating and melting, the Wakarusa River flowed at a higher level and terraces such as these are relics of the former elevated floodplain.

66.7	Washington Creek. This creek begins in southwestern Douglas County and dumps into the Wakarusa just north of here.
67.2	The hill to the south, capped by the Oread Limestone, has an elevation of 1065 feet and rises more than 250 feet above the Wakarusa River, which is just beyond the line of trees north of the road.
68.7	Stop sign. Turn north on U.S. 59.
68.8	Wakarusa River has its source in eastern Wabaunsee County, where it drains part of the east face of the Flint Hills.
69.5	Here the highway leaves the floodplain and climbs back onto the Buck Creek Terrace.
70.0	31st Street.
71.0	23rd Street. Turn east (or right).
71.5	Naismith Drive. Turn north (or left). Naismith Drive is named after Dr. James Naismith, the inventor of basketball and the first basketball coach at the University of Kansas. Naismith was, however, the only KU coach to compile a losing record for his coaching career. He is buried in a Lawrence cemetery.
72.4	Allen Field House, to the west, was constructed during the 1950s and was named after long-time KU coach Phog Allen.
72.5	Sunnyside Drive. Turn east (or right).
72.8	Sunflower Road. Turn north (or left).
73.0	Jayhawk Boulevard. Turn east (or left).
73.1	University of Kansas Museum of Natural History. STOP 3. The Museum is housed in Dyche Hall, named for Lewis Lindsay Dyche, an explorer and director of the museum and the creator of the panorama that you will see upon entering. Dyche was later also the head of the Kansas Fish and Game

Commission, headquartered in Pratt, Kansas. From Dyche Hall, return to Jayhawk Boulevard and proceed back toward Sunflower Road.

73.3 Sunflower Road. Turn south (or left).

73.8 19th Street. Turn east (or left).

73.9 Louisiana Street. Turn south (or right).

74.4 Kansas Highway 10/23rd Street. Turn east (or left).

74.7 Massachusetts Street.

74.9 To the south is Haskell Indian Junior College, a two-year college for Native American students.

75.2 Haskell Avenue.

77.9 Here the highway drops onto the Newman Terrace (elevation 815 feet), formed on the floodplains of the Kansas and Wakarusa rivers. This floodplain, measuring five miles from north to south, was created by the erosion of shales and soft sandstones in the Lawrence and Stranger formations. During the 1951 flood, the entire floodplain was under water. The Kaw River bottoms are generally sandy while the Wakarusa River bottoms are more gumbo, higher in clay. Until the past decade or so, these bottoms were known for the vegetable and melon crops they produced. On the hill to the south is the site of the former town of Franklin, a proslavery stronghold that was the site of an 1856 battle between opposing sides of the slavery issue in during the days of Bleeding Kansas.

78.2
(7.0) Blue Mound (elevation 1,052 feet) is visible 2.3 miles to the south. This outlier is capped by the Oread Limestone and was once the site of the only ski slope in Kansas.

78.6
(7.4) The borrow pit south of the highway was created when sand and gravel were dug out to build up the road bed. Today it is the home of the KU water-skiing club.

79.7
(8.5) Oxbow lake, formed by the Wakarusa River, south of the highway. The few naturally occurring lakes in Kansas are of

two types. One is formed in sinkholes caused by solution and collapse of evaporite beds in central and western Kansas. The second is oxbow lakes, such as this one, that occur in the floodplains of larger rivers, primarily in the central and eastern parts of the state. The small scarp between the lake and the highway marks the edge of the Newman Terrace.

80.3
(9.1) Wakarusa River, the largest right-hand tributary of the Kansas-Smoky Hill River drainage basin, joins the Kaw River immediately east of Eudora. About a half-mile south is Blue Jacket Crossing, a natural ford on the Wakarusa, over which the Oregon Trail passed on its way to Lawrence and points west.

80.4
(9.2) Orange glacial deposits are exposed north of the highway.

82.4
(11.2) The town of Eudora, named after the daughter of a Shawnee Indian chief, is north of the highway.

84.1
(13.0) Stoner Limestone Member of the Stanton Limestone is exposed north of the highway. The Stoner is generally 10-20 feet thick in eastern Kansas, thickening to 50 feet in southern Kansas.

84.3
(13.2) Vilas Shale overlain by the Captain Creek Limestone Member of the Stanton Limestone. The Stanton is part of the Lansing Group, which is an oil reservoir in the deep subsurface in central and western Kansas and locally here in eastern Kansas. Oil geologists often lump the Lansing Group together with the slightly older Kansas City Group and speak of oil production from the "Lansing-Kansas City." The most common pay zones are porous limestones.

84.4
(13.3) Captain Creek (elevation 785 feet). The Captain Creek Limestone Member, visible throughout the field trip, is named after this stream.

84.7
(13.6) Captain Creek limestone. This is also the Douglas County/Johnson County line. Douglas County is named after Illinois Senator Stephen Douglas and Johnson County is

named after the Rev. Thomas Johnson, who founded the Shawnee Methodist Mission in 1830 in present-day Kansas City. Johnson County and Wyandotte County, northeast of here, have a combined population of more than 500,000. Most of the people in Johnson County live in 14 towns and villages, ranging in size from Overland Park (population 81,784) to Mission Woods (population 213). The 500,000 people in these two counties account for more than a third of the population in metropolitan Kansas City and about one-fifth of the population of Kansas.

85.9
(14.8) Sunflower Army Ammunition Plant to the south was first used in World War II to make weapons' propellant. It closed at the war's end, then reopened during the Korean War, the Vietnam War, and again in 1984, before closing again shortly thereafter.

87.0
(15.9) Stoner Limestone Member of the Stanton Limestone.

87.2
(16.1) STOP 4. Edgerton Road. The base unit here is the Vilas Shale, which is visible along the south entrance ramp back onto K-10. Here the Vilas includes some sandstone. Above that is the Captain Creek Limestone, the Eudora Shale, and the Stoner Limestone. These rocks represent a typical Kansas cyclothem, beginning with the shallow-water shale (in this case, the Vilas), a transgressive limestone (the Captain Creek) as the Pennsylvanian sea became deeper, the offshore shale (the Eudora) where the water was deepest, and the regressive limestone (the Stoner) as the water became shallower. Today's interpretation is that these sea-level changes were the result of fluctuation in the amount of water held in glaciers and polar ice caps. A measured section and a description of this roadcut (by Lynn Watney, John French, and Evan Franseen) are attached.

This is also the road to Sunflower Nature Park, a 60-acre park that was originally part of the Sunflower Ammunition Plant. The park includes a fishing pond and areas of tallgrass prairie; it is operated by the Johnson County Park and Recreation District.

87.6
16.5) Eudora Shale Member overlain by the Stoner Limestone Member. Part of the Eudora is a gray-black shale that

contains phosphate nodules and is somewhat radioactive, making it an important marker bed on geophysical logs taken in the Kansas subsurface. The radioactivity creates a strong kick on gamma-ray logs. These black shales and the phosphate nodules are also considered as a possible source of radon gas in northeastern Kansas.

88.7 (17.6)	Captain Creek limestone.
89.2 (18.1)	Kansas Highway 285 to the town of DeSoto, named after the discoverer of the Mississippi River.
89.9 (18.7)	Kill Creek (elevation 770 feet). Kill is an old Dutch word for creek.
90.1-90.4 (18.9-19.2)	Captain Creek limestone, overlain by Eudora shale overlain by the Stoner limestone, all members of the Stanton Limestone.
91.1 (19.9)	Captain Creek limestone.
91.7 (20.5)	Stanton Limestone.
92.2-92.4 (21.0-21.2)	The highway descends through members of the Wyandotte Limestone, which averages 60 feet in thickness in the area.
93.4 (21.3)	Camp Creek (elevation 780 feet).
93.7 (21.6)	Cedar Creek.
94.5 (22.4)	Iola Limestone overlain by Lane Shale in a roadcut along a county road to the north.
94.7-95.2 (22.6-23.1)	Wyandotte Limestone. The lowermost unit here is the Argentine limestone, named after an area in Kansas City where a smelter was operated in the early 1900s. The

Argentine is about 17 ft thick and contains abundant algae. Above the Argentine is a thin layer of the Island Creek shale, overlain by a thicker layer of the Farley limestone, a layer that is visible several places along the field trip. Above the Farley is the Bonner Springs Shale, which is greatly variable in thickness. The roadcut is capped by the Plattsburg Limestone. Immediately south of the road here is a quarry where the walls show the Bonner Springs pinching out and disappearing within a few hundred feet. This is also the city limits of Olathe, the seat of Johnson County

95.6
(23.5) Captain Creek limestone (elevation 1,000 ft) and Cedar Creek Parkway.

96.0
(23.8) Stoner limestone.

96.1
(23.9) Captain Creek limestone.

96.5
(24.3) Plattsburg Limestone.

97.5
(25.3) Kansas Highway 7 Interchange. K-7 runs 10 miles north to Bonner Springs and 7 miles south to Olathe. We exit right and proceed north on K-7.

98.3
(157.0) Sandstone in the Rock Lake Shale Member of the Stanton Limestone.

98.6
(157.3) Stoner Limestone Member of the Stanton Limestone.

99.2
(157.9) Captain Creek limestone overlain by the Eudora shale and Stoner limestone, all members of the Stanton Limestone.

100.3
(159.0) Shawnee city limit. The highway passes through the western part of the Craig-Monticello Natural Gas Storage Area. Gas is stored here at an average depth of 582 feet in the "Squirrel sand" of the upper part of the Cherokee Group (Pennsylvanian). Sandstone bodies, such as the Squirrel, are called "shoestring sands" because of their configuration when

plotted on a map; they are thought to be ancient sand-filled river channels. Shoestring sandstones are common sources of oil in eastern Kansas, but they are narrow and provide only small drilling targets, a characteristic that produced the name Squirrel sandstones, because drillers thought the sand body behaved "squirrelly." Monticello is a nearby town and the name of a township just north of here. Wild Bill Hickock's first law enforcement job in Kansas was policing the streets of Monticello.

101.2 (159.8) Captain Creek limestone and Vilas Shale.

101.4 (160.0) Plattsburg Limestone.

102.2 (160.8) Shawnee Mission Parkway interchange. Exit east. The Argentine limestone is exposed here in several roadcuts.

103.0 Monticello Road. Turn north (or left). Monticello is Italian for "little mountain" and is the name of Thomas Jefferson's home near Charlottesville, Virginia, and the name of the small community on the hilltop a half mile south of here.

103.6 STOP 5. Here, along the road and near Clear Creek, are exposures of Kansan age sand, gravel, cobbles, and boulders that are glacial in origin. Some glacial debris in this area may have been reworked by ice-margin streams and deposition in a glacially dammed lake. This area, west of Holliday, lacks the high bedrock bluffs that border the Kansas River floodplain to the east and west. At times during the Kansan glaciation, the ice apparently dammed the ancestral Kansas River temporarily, resulting in thick upland deposits of reworked till (such as we have here) in ephemeral lakes that extended well above the level of the current Kansas River floodplain. The till in this area is composed of primarily locally derived rocks; however a few erratics, primarily pink Sioux Quartzite, can be found. Some studies indicate that the Kansan glaciation may have had two glacial advances. An early stage left behind till that is sandy, unoxidized, and containing few erratics, as at this site; a later glacial episode left behind a red, oxidized till with a clay matrix and containing many erratics. See the attached discussion by Wakefield Dort.

104.5 Johnson Drive, turn right.

105.7 Mill Creek and Mill Creek Park.

106.3 Barker Avenue. Turn north (or left).

1071. Iola Limestone overlain by Lane Shale and farther up the hill, lower units in the Wyandotte Limestone, which we will see at the next stop.

107.7 Holliday. This small town sits along the Atchison, Topeka, and Santa Fe Railroad, which was founded by the town's namesake, Cyrus K. Holliday. He was also an early promoter of the town of Topeka, 50 miles to the west, and became its first mayor.

108.0 Westerville Limestone Member of the Cherryvale Shale in the creek south of the road.

108.3 Iola Limestone.

108.5 Iola Limestone.

108.7 STOP 6 shows two complete cyclothems (the attached cross section and discussion are by Lynn Watney, John French, Philip Heckel, and Evan Franseen). The road at the base of the hill runs atop the Drum Limestone, which crops out in the Kansas City area. The lowest visible unit is the Chanute Shale, overlain by the Paola limestone--a thin, barely visible limestone. Above that is the Muncie Creek shale, a black, fissile shale that contains abundant marble-sized, rounded nodules that are rich in phosphate and found in several black marine shales in Kansas cyclothems. Above the Muncie Creek is a thicker limestone, the Raytown, overlain by a very thick shale, the Lane. The Chanute Shale, Paola limestone, Muncie Creek shale, the Raytown limestone, and the Lane Shale represent a complete cyclothem.

Above these layers is a second cyclothem, beginning with the thin Frisbie limestone. Above that is the Quindaro shale, a black, thin shale. On the east side of the roadcut, about halfway up the exit ramp, is a reef or mound structure where the Quindaro is draped over the Frisbie. This mound was probably created by algal colonies that built up on the sea bottom and were surrounded by thickets of crinoids. Above the Quindaro is the Argentine limestone, overlain by the Island Creek shale, overlain by the Farley limestone.

The Kansas River (740 feet) is visible northwest of this stop. A sand-dredging operation is generally visible on the river to the northwest. The Kansas River occasionally washes Pleistocene fossils out of the sandbars along its path in this area, including the remains of mastodons and mammoths.

Proceed east on Holliday Drive and take the I-435 north exit and proceed north.

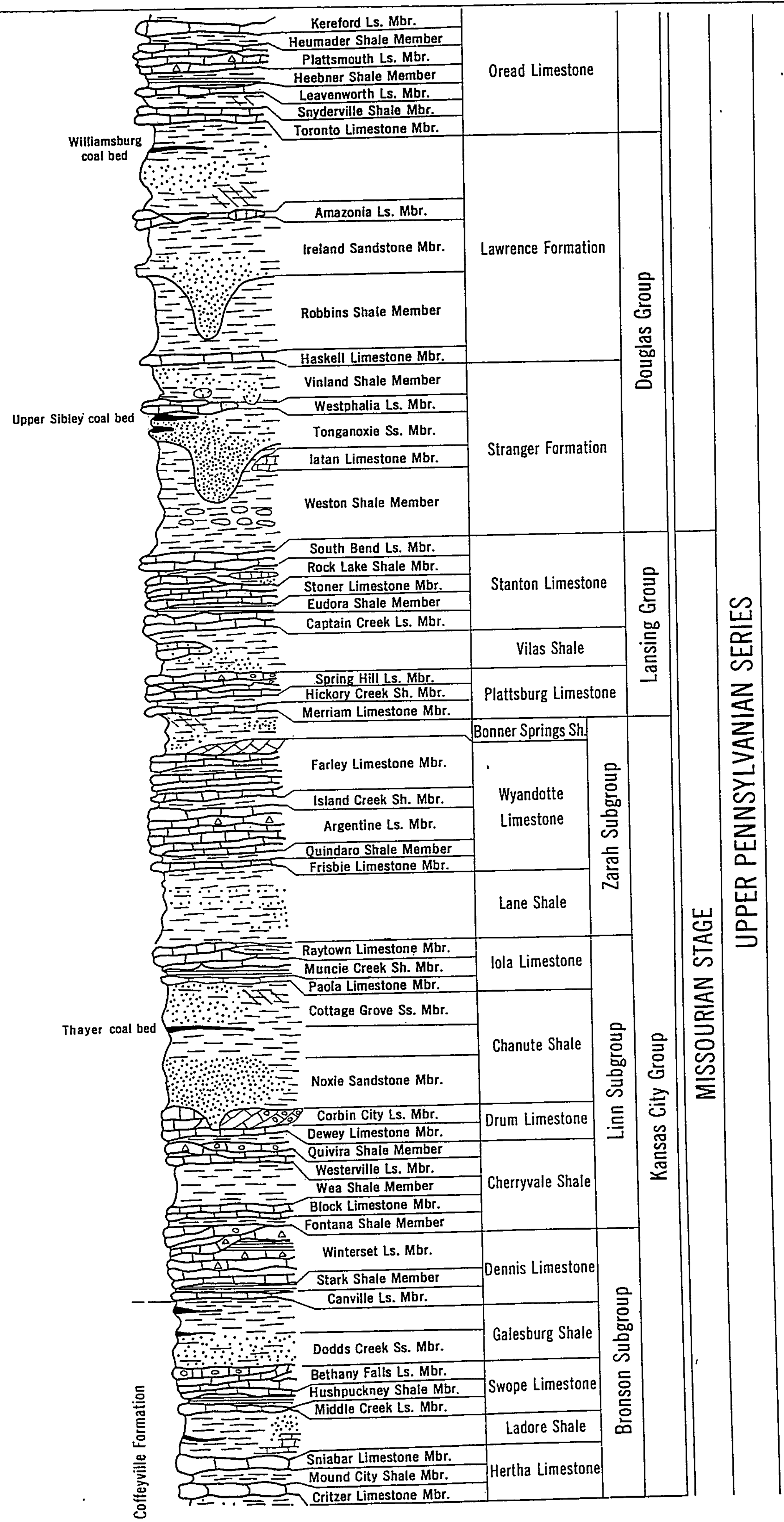
109.6
(8.4) Kansas River and Wyandotte County/Johnson County line. Downstream is a man-made weir designed to retain water, especially during low flow, and divert it to the right-hand bank where a water intake station for the Johnson County water district is located. This is also the Wyandotte/Johnson county line.

110.2
(9.0) The Kansas River floodplain once contained many truck farms. A few vegetable farms still exist, as do numerous sandpits. Downstream the floodplain is heavily industrialized and contains several large railroad yards as well as the once world-famous Kansas City stockyards.

110.8
(9.6) Kansas Highway 32 underpass. Kansas City, Kansas, city limits.

111.4 Interstate 70. Take the west exit. STOP 7 is located along the loop of this exit ramp. The roadcut here consists of the Farley Limestone, overlain by the Bonner Springs Shale, topped by the Merriam Limestone. Several of these units are extremely fossiliferous, including a layer of bivalves in the Farley and productids in the Merriam. The most noticeable feature at this roadcut, however, is probably the large channel formed by the Bonner Springs Shale that is described in the attachment by Paul Enos, Derek Herman, Lynn Watney, and Evan Franseen.

From this point, we return to Kansas City, Missouri, and the Allis Plaza Hotel via Interstate 70. That portion of the route is described in the first 14 miles of this guide.



SECTION SEEN DURING FIELD TRIP
FIGURE AFTER THAT IN ZELLER'S
THE STRATIGRAPHIC SUCCESSION
IN KANSAS.

STOP (1)

OREAD LIMESTONE

at

CLINTON SPILLWAY

by Bryan Stephens and Lynn Watney

The gentle eastward-sloping upland surface in the vicinity of Lawrence is interrupted by several parallel northeasterly trending hills or cuestas resulting from differential erosion of slightly westward-dipping Pennsylvanian limestones and shales. Although local anticlines, synclines, and small faults may disrupt this shallow westerly dip, it provides for broad exposures of strata along valleys carved by rivers flowing east down the regional slope.

Mount Oread, the hill on which the University of Kansas rests, is capped by the Upper Pennsylvanian (Virgilian) Oread Formation. The same strata are exposed here on the north face of the spillway near Clinton Lake dam on the Wakarusa River, 5.5 kilometers (3.5 mi) west of Lawrence (Fig. 1). The interval from the Plattsmouth Limestone down to the Amazonia Limestone Member of the Lawrence Shale is well exposed on the spillway wall (Fig. 2). The measured section at this locality is attached.

The Oread Limestone, originally described by Haworth (1894), consists, from base to top, of the Toronto Limestone, Snyderville Shale, the thin Leavenworth Limestone, the black fissile Heebner Shale, the thick Plattsmouth Limestone, Heumader Shale, and Kereford Limestone (Fig. 3). The Oread Limestone, according to Moore (1936), is part of a **megacyclothem**, a sequence of distinctive shale-limestone couplets repeated in several successive formations. Moore identified five limestone members in the idealized megacyclothem. The **lower limestone** is the Toronto, followed upward by the **middle limestone** (Leavenworth), the **upper limestone** (Plattsmouth), **super limestone** (Kereford), and finally the **fifth limestone** (Clay Creek) at the top of the cycle (Fig. 3). The **inside or core shale** is the Heebner Shale. Moore suggested that a marine transgression peaked during accumulation of the Plattsmouth Limestone based its abundance of fusulinids. The **lower**, **super**, and **fifth** limestones are not always present in a single megacyclothem, but are compositely expressed in the four late Missourian and early Virgilian megacyclothem sequences seen in Figure 3.

Heckel (1977) describes a simpler cyclothem consisting of four components: the **middle limestone**, core shale, upper limestone, and **outside shale** (Fig. 4). Maximum regression is associated with the outside shale (i.e., Kanwaka) and **maximum** transgression is recorded by the **core shale** (i.e., Heebner).

The Toronto Limestone of the Oread Formation (the lower limestone in Moore's megacyclothem classification) may represent an intermediate marine inundation separate from the transgression accounting for the Oread cyclothem (Troell, 1969). The black **Heebner Shale** Member of the Oread cyclothem is attributed to maximum inundation when anoxic bottom-water conditions prevailed during deposition. The Oread Limestone is a wide-spread unit in the Midcontinent. It is exposed on outcrops in Kansas, Missouri, Nebraska, and Iowa, and in the subsurface to at least western Kansas where the Heebner Shale serves as an important stratigraphic marker.

We would like you to begin the examination of the exposure with the **Amazonia Limestone** near the base of the slope and work your way up to the upper portion of the **Plattsmouth Limestone** at the crest of the exposure. The stratigraphic relationships are identified for you in the attached measured section. Take time to look at the rocks and section and ask Bryan and Lynn questions about what you observe.

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Moore, R.C., 1936, Stratigraphic classification of the Pennsylvanian rocks of Kansas: Kansas Geol. Survey Bull. 22, 256 p.

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Troell, A.R., 1969, Depositional facies of Toronto Limestone Member (Oread Limestone, Pennsylanian), subsurface marker unit in Kansas: Kansas Geol. Survey Bull. 197, 29 p.

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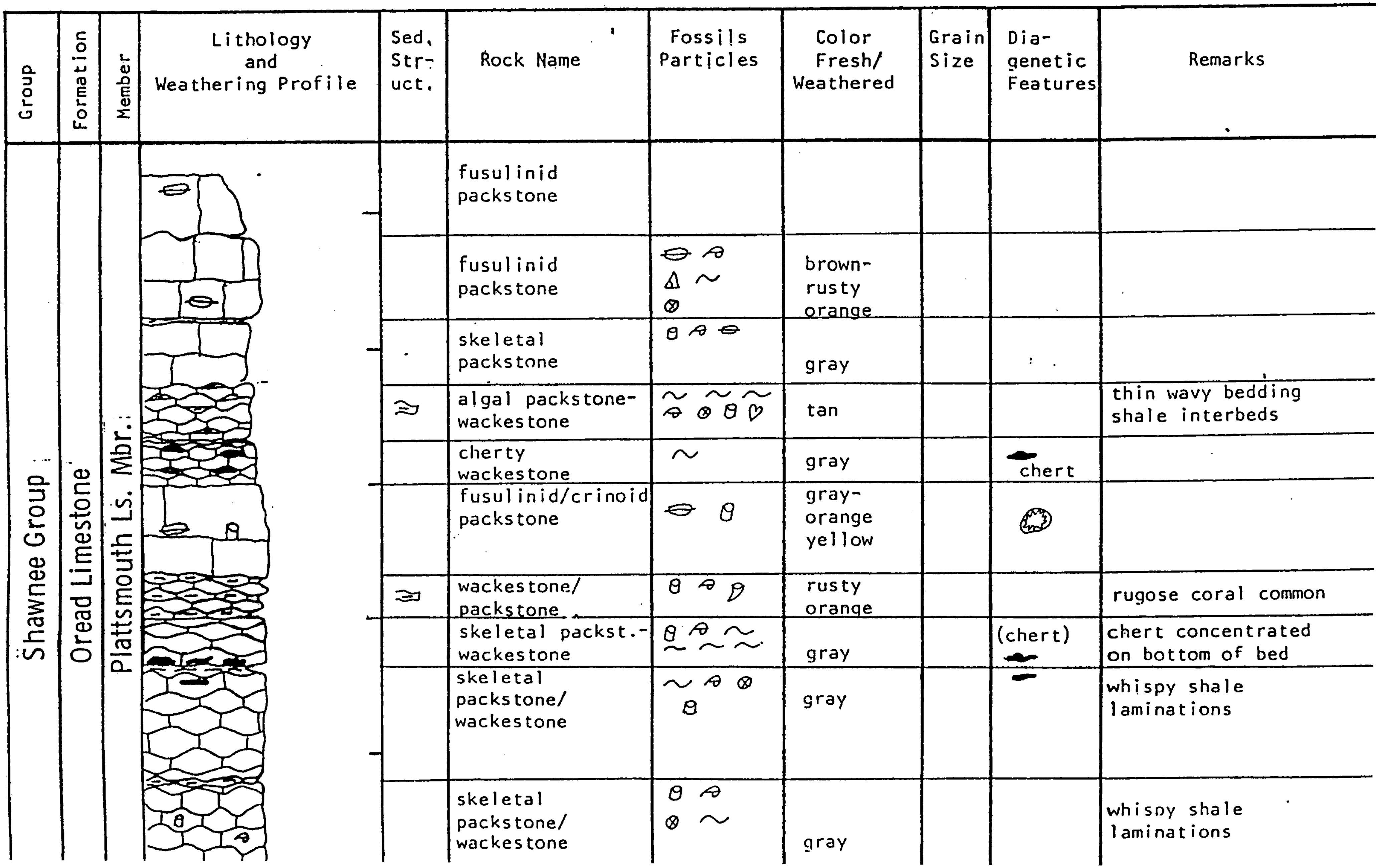
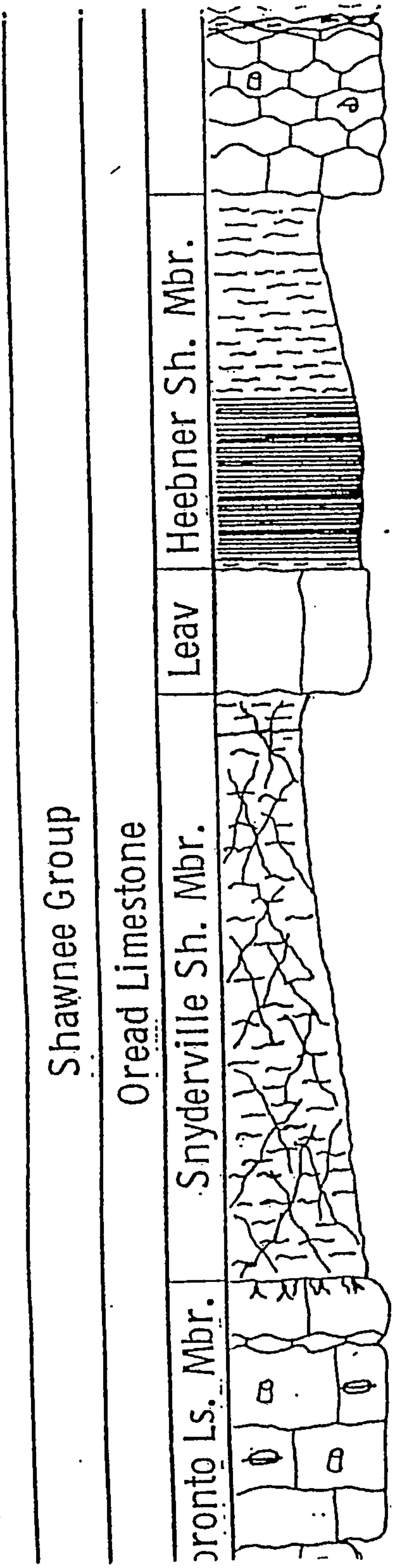
Measured Section of Clinton Spillway
Douglas Co., Kansas

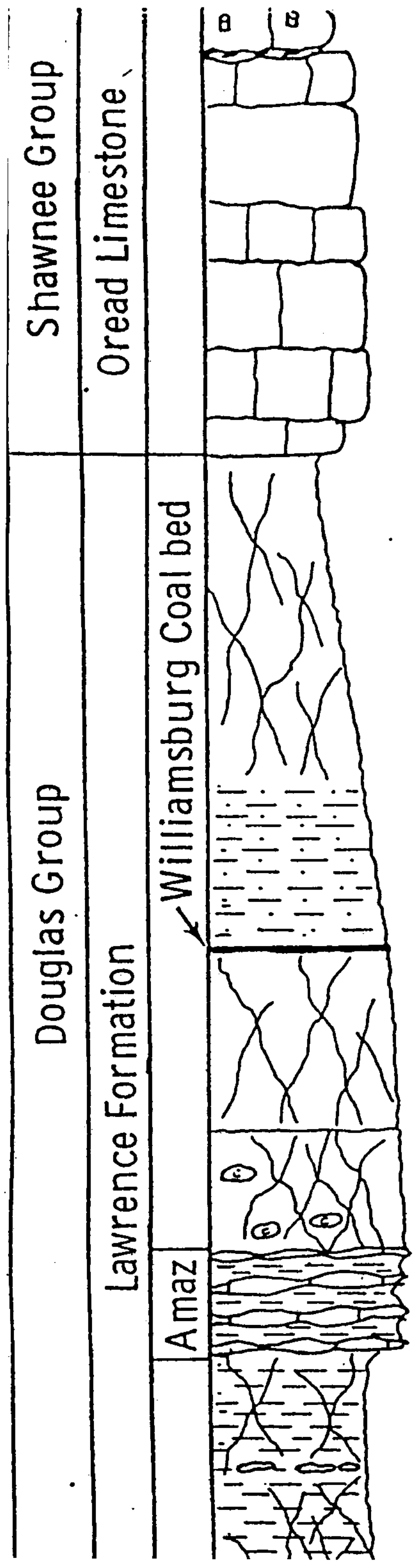
Vertical Scale: 1 m



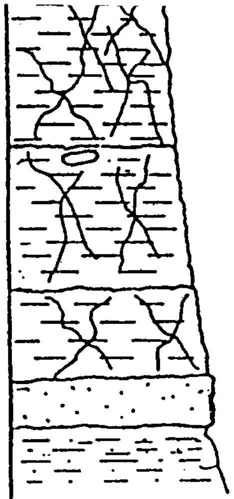
Group	Formation	Member	Lithology and Weathering Profile	Sed. Struct.	Rock Name	Fossils Particles	Color Fresh/ Weathered	Grain Size	Diagenetic Features	Remarks
Shawnee Group	Oread Limestone	Plattsmouth Ls. Mbr.			fusulinid packstone					
					fusulinid packstone	Δ ∼ ⊗	brown-rusty orange			
					skeletal packstone		gray			
				≈	algal packstone-wackestone	∼ ∼ ∼ ⊗	tan			thin wavy bedding shale interbeds
					cherty wackestone	∼	gray		chert	
					fusulinid/crinoid packstone		gray-orange yellow			
				≈	wackestone/packstone		rusty orange			rugose coral common
					skeletal packst.-wackestone	∼ ∼ ∼ ∼	gray		(chert)	chert concentrated on bottom of bed
					skeletal packstone/wackestone	∼ ⊗	gray			whispy shale laminations
					skeletal packstone/wackestone	⊗ ∼	gray			whispy shale laminations



clay shale		greenish yellow dark gray brown	clay		softer and less platy than shale below
black shale		black		Ⓟ	hard platy phosphate nodules conodonts, sulfides 3 cm. soft shale at base
Leavenworth Ls. wackestone		dark gray-brown			
clay shale		dark gry-brn			
clay shale		dark gray	clay		
micrite		tan		■	tube-like structures at top of bed filled wit shale, Weather to tubes pyrite
crinoid/ fusulinid packstone/ wackestone		light gray			algal oncolites coated grains glauconite
		greenish			



	crinoidal packstone/ wackestone	θ ~ θ ~ ∂	light greenish gray			whispy shale laminations
	skeletal packstone	~ θ ∂ ⊖	light gray -orange yellow			iron stains
	skeletal wackestone	θ ⊖ ∂ ♡	light gray			iron stains
	wackestone	∂ ~	light gray			
	mudstone/ clay shale		gray			thin (1 cm.) silty laminations weathering to yellow color
	coal smut		black			
	mudstone		greenish gray greenish gray with maroon mottling			clayey light brown calcareous nodules cylindrical and branching
	Amazonia Ls. Mbr. micrite, silty Ls. & clay shale		greenish gray/orange yellow			solution breccia sheet cracks fitted clasts
	slightly silty clay shale		greenish gray lt. gray			maroon lenses around iron rich nodules soft thinly laminated

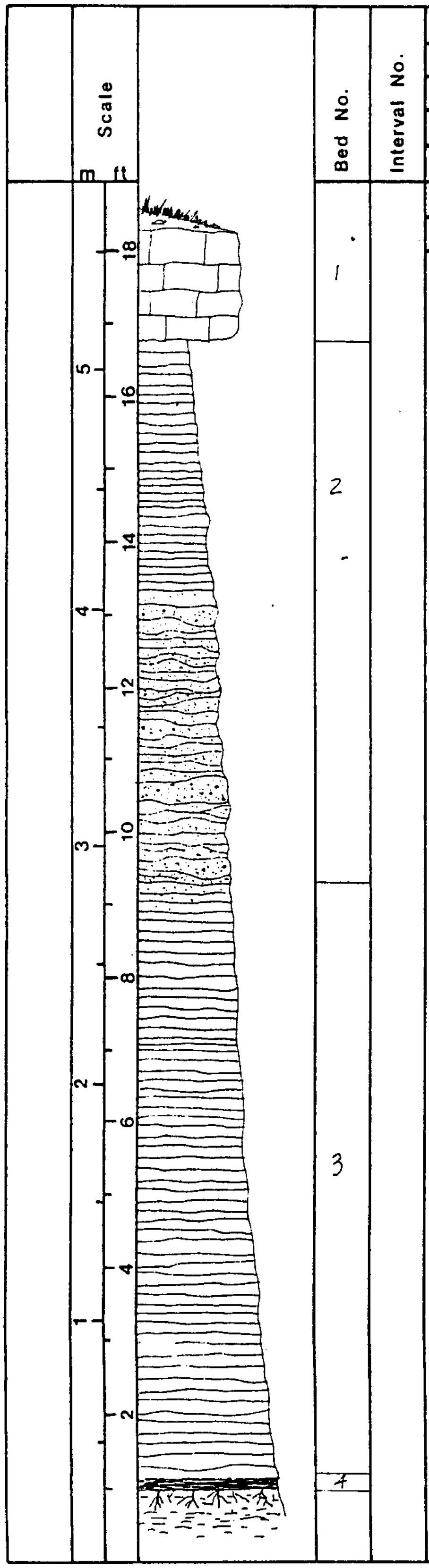


	clay shale		red			some v. fine silt platy laminated
	clay shale		greenish gray			weathers blocky
ʋ ♭	siltstone		pale green-gray			micaceous thinly laminated in places red, iron hardened burrows

KEY TO SYMBOLS

- brachiopods
- gastropods
- crinoids
- phylloid algae
- fusulinid forams
- bivalves
- rugose coral
- conodonts
- bryozoans
- oncolites
- coated grains
- vug
- pyrite
- shale interbeds
- burrows
- tubes
- shale interbeds
- phosphate nodules
- chert
- calcareous nodules
- iron rich nodules

STOP ②



Locality Description: Center of South line of Sec. 11, T.14S., R.18E., Douglas Co., Kansas; Globe 7.5' Topographic Quadrangle, revised 1983.

Location: Lonestar Lake Spillway

Measured By: B. Smith, B. Tilley, K. Ross, & K. Krogstad: Fall'90.

Remarks: 1 of 3

Description

Bed No.	
1	Slabby calcarenite (packstone to wackestone), moderate yellowish brown, fossiliferous; crinoid, bivalve, and brachiopod fragments, fusulinids, lower contact sharp. Basal Toronto limestone.
2	Thinly laminated siltstone, 228cm thick, gray-green, lower 122cm contains interbedded flaser micaceous sandstone lenses.
3	Finely laminated silty mudstone, 249cm thick, gray.
4	Thin blocky coal, 3cm thick.
5	Blocky mudstone, 218cm thick, purple brown gray.

STOP ④

Edgerton Road: Vilas Shale and Stanton Limestone, (Captain Creek Limestone, Eudora Shale, Stoner Limestone)

Location: SE SE SE sec. 2, T. 13 S., R. 21 E., Johnson County, Kansas

Arrive: 8:20 AM
Leave: 9:00 AM

(15 minutes to Stop 2)

Contributors: *Lynn Watney, John French,* and *Evan Franseen*

Introduction

Stop 1 is located 12 mi (19 km) east of Lawrence at the Edgerton Road exit off Highway 10 (fig. 1-1). The Lansing Group, here represented by the Stanton Limestone, is composed of cyclical mixed-carbonate and siliciclastic deposits in eastern Kansas. The stratal succession seen here is a typical example of a Kansas cyclothem presented by Heckel (1977). A Kansas cyclothem contains four lithologic components; in ascending order these are the middle (or transgressive) limestone, the core (offshore) shale, the upper (or regressive) limestone, and the outside shale. This classification was previously discussed in the Introduction in the section on cyclothem concepts and illustrated in fig. 21.

A complete Kansas cyclothem represents a major marine inundation in a shelf setting. Carbonate-dominated cyclothems of equivalent age in other areas of the world are similarly developed, e.g. on the Russian platform and in the Paradox basin. Glacial eustasy is strongly supported as the cause of these relatively short-term (250 to 400 ka) but high-amplitude (perhaps 300+/- ft, 90+/- m) fluctuations in sea level. Evidence for eustatic change includes the ability to correlate individual marine inundations among basins and continents (Ross and Ross, 1987; Boardman and Heckel, 1989). Subsequent sea- level falls have been documented to extend in most cases to the shelf margin in the midcontinent (Heckel, 1980, 1986; Watney, 1984).

The Pleistocene analogue to late Paleozoic glacial eustasy suggests considerable variability in the shape of the eustatic curve from one inundation to another (also discussed in the Introduction). Pleistocene sea-level changes varied from symmetric to asymmetric and, in terms of other mechanisms of sea-level change, were potentially very rapid (2 to 10 m/ka [7–33 ft/ka]). Sea-level falls varied from uniform to very erratic.

Although the typical cyclothemic lithologic succession discussed above occurs repeatedly in Missourian strata in the midcontinent, in some cycles or in some shelf positions additional limestones and shales may occur, or some units may be missing. This variability makes modifications to this four-component format necessary.

An alternative methodology that we are using to describe these shelfwide marine inundations and withdrawals is sequence stratigraphy. Sequence-stratigraphic principles center on the recognition of temporally distinct stratal units and stratal geometries that are related to cycles of relative base-level change. It is almost universally agreed that such cycles were the major cause of midcontinent cyclic successions.

The procedures and nomenclature related to sequence stratigraphy are described in section V and appendix A of the Introduction. The measured sections of the stops are annotated with stratigraphic units (e.g., paleosols and condensed sections) and surfaces (such as flooding surfaces, erosion surfaces, and sequence boundaries) that are essential to sequence-stratigraphic analysis (fig. 1-2).

Stratigraphy at Stop 1

At all stops the exposed interval will be described from base to top.

The *Vilas Shale* is an outside shale that caps the underlying Plattsburg cyclothem. The Vilas Shale is well exposed to our east at the southeast corner of this intersection and is included in the measured section (fig. 1-3). It is a silty gray shale that contains lenses and beds of fine-grained, rippled and in places cross-stratified quartz sandstone. Brachiopods, crinoids, and trace fossils are present in the sandstones, especially at the top of the Vilas Shale immediately below the overlying Captain Creek Limestone. No evidence of subaerial exposure is present in this exposure of the Vilas, making the placement of the sequence boundary problematic. The top of the underlying regressive carbonate unit underwent subaerial exposure north of this location but apparently did not this far south. The turnaround from falling to rising relative sea level probably occurred at some point during deposition of the Vilas.

Outside shales of the upper Kansas City and Lansing groups are of variable thickness but generally consist of several meters of shallow-marine shelf and deltaic siliciclastics.

The *Captain Creek Limestone* overlies the Vilas Shale and is the lower member of the Stanton Limestone. The Captain Creek Limestone is the middle (transgressive) limestone of the Stanton cyclothem and the flooding unit of the Stanton sequence. The unit is much thicker than other middle limestones in this shelf setting. It represents the initiation of carbonate sedimentation during inferred eustatic rise. Initial marine flooding begins in the upper Vilas Shale and is marked by a fossiliferous horizon at the top of the unit. The recognition and correlation of the initial flooding surface becomes relatively subtle when this surface diverges from the marine-flooding unit.

The Captain Creek Limestone is predominately a normal-marine phylloid-algal wackestone. Its homogeneity is also indicated by the gamma-ray profile. The unit thins markedly and contains mud-pebble conglomerates a few miles east of this locality. Farther east of this anomalous setting the Captain Creek Limestone is again the more resistant limestone ledge that is so prominently exposed along K–10.

This unit contains numerous shale partings and microstylolites, which are more typical of regressive limestones than transgressive limestones such as the Captain Creek. There are no apparent facies changes across most of these partings, and evidence of dissolution along them indicates that they most likely represent nonsutured seam solution analogous to that described by Wanless (1979). Some seams in certain regressive units have been traced for 10's of kilometers; a depositional signal probably exists for such continuous seams.

The Eudora Shale at this location is a typical core shale (of the Stanton cyclothem) that contains a platy, black, phosphatic facies. This unit is continuous over a wide area and is classified in sequence-stratigraphic nomenclature as a condensed section that originated during maximum rate of eustatic rise and/or in the deepest water associated with the Stanton sequence. The black facies grades between Stops 1 and 2 to soft-gray shale containing abundant benthic fauna. East of Stop 2 the shale is very similar to that at Stop 1 (fig. 1-4). The black shale is associated with elevated gamma radiation. Although the gamma radiation is higher than in the gray shale, the magnitude is considerably less than the Hushpuckney and Stark shales seen later at Stop 7. The radiation is primarily attributed to uranium content (see fig. 34 from the introduction) that is in turn related to the amount of organic matter and phosphate content (Coveney et al., *in* Franseen and Watney, 1989).

A minimum of 4% total organic carbon is needed to make a shale black (J. Hatch, personal communication, 1984). Other features of the black- shale facies include an abundance of conodonts usually at the exclusion of benthic fauna, suggesting anoxic bottom waters. Conodonts are sufficiently abundant on bedding surfaces of the black shale to be seen with a hand lens. Phosphate is present as light brown laminae or nodules. Remains of fish and scattered woody-plant material is also present.

Dark-gray shale overlies and underlies the black-shale facies at this location. This succession is typical for the Eudora Shale and common for other black shales. These shales commonly exhibit a diverse and taxonomically distinctive fauna that has been interpreted to represent dysoxic environments (Boardman et al., 1984).

The *Stoner Limestone* at this location is a typical upper limestone of a Missourian cyclothem. It consists of wavy-bedded skeletal/phylloid-algal wackestone, and with a host of other normal- marine organisms. It is a shallowing-upward unit and includes cryptic fenestral voids near the top; about 10 mi (16 km) to the northeast, near Stop 3, the Stoner Limestone is capped by an abraded skeletal grainstone. The Stoner Limestone most likely represents carbonate aggradation during relative sea-level stillstand and fall. There is no apparent evidence for subaerial exposure here, although it has been noted in other locations on the northern shelf (Heckel, 1989). The Stoner is usually capped by the Rock Lake Shale, which in places contains a mollusk-dominated fauna and a thin coal.

Common macrofossils that occur in these strata are included in figs. 1-5 and 1-6

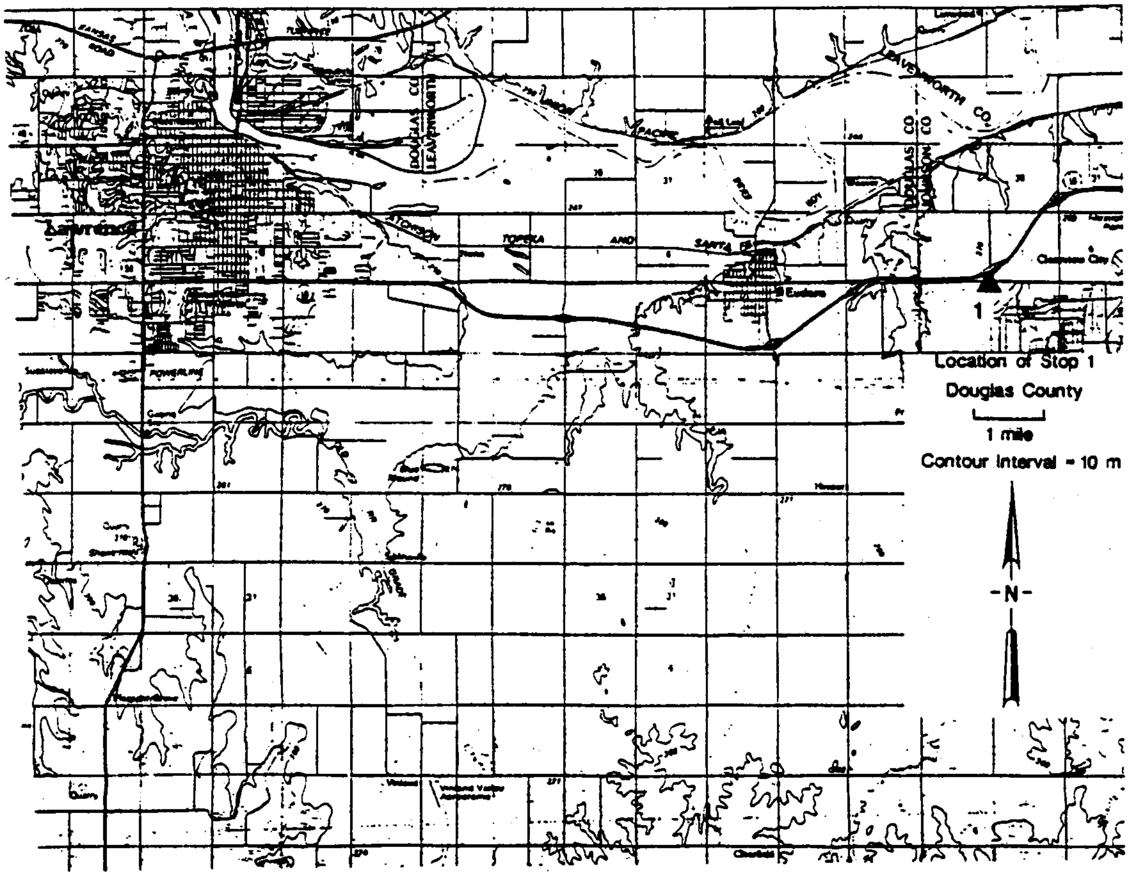


FIGURE 1-1—Location map for Stop 1, Edgerton exit on Highway 10 east of Lawrence.

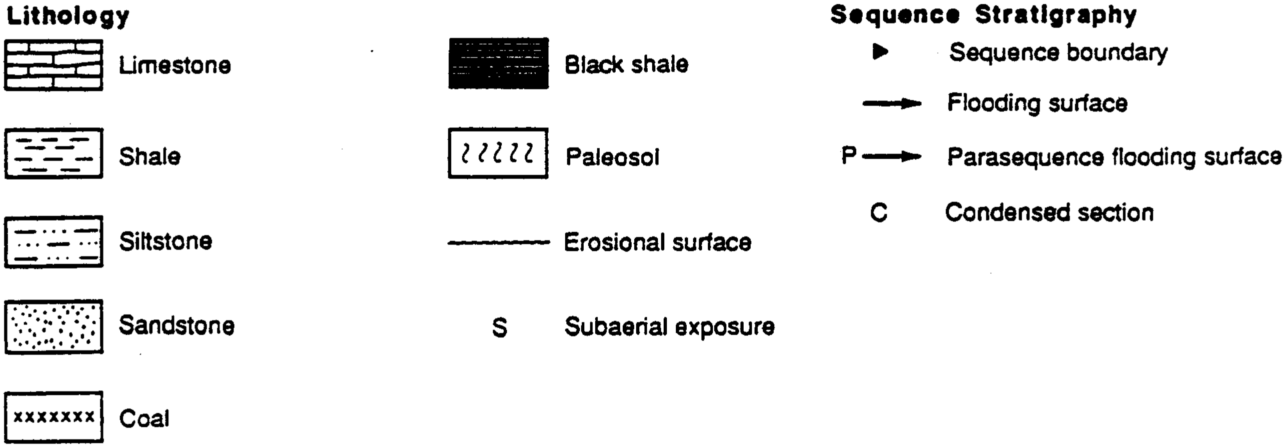
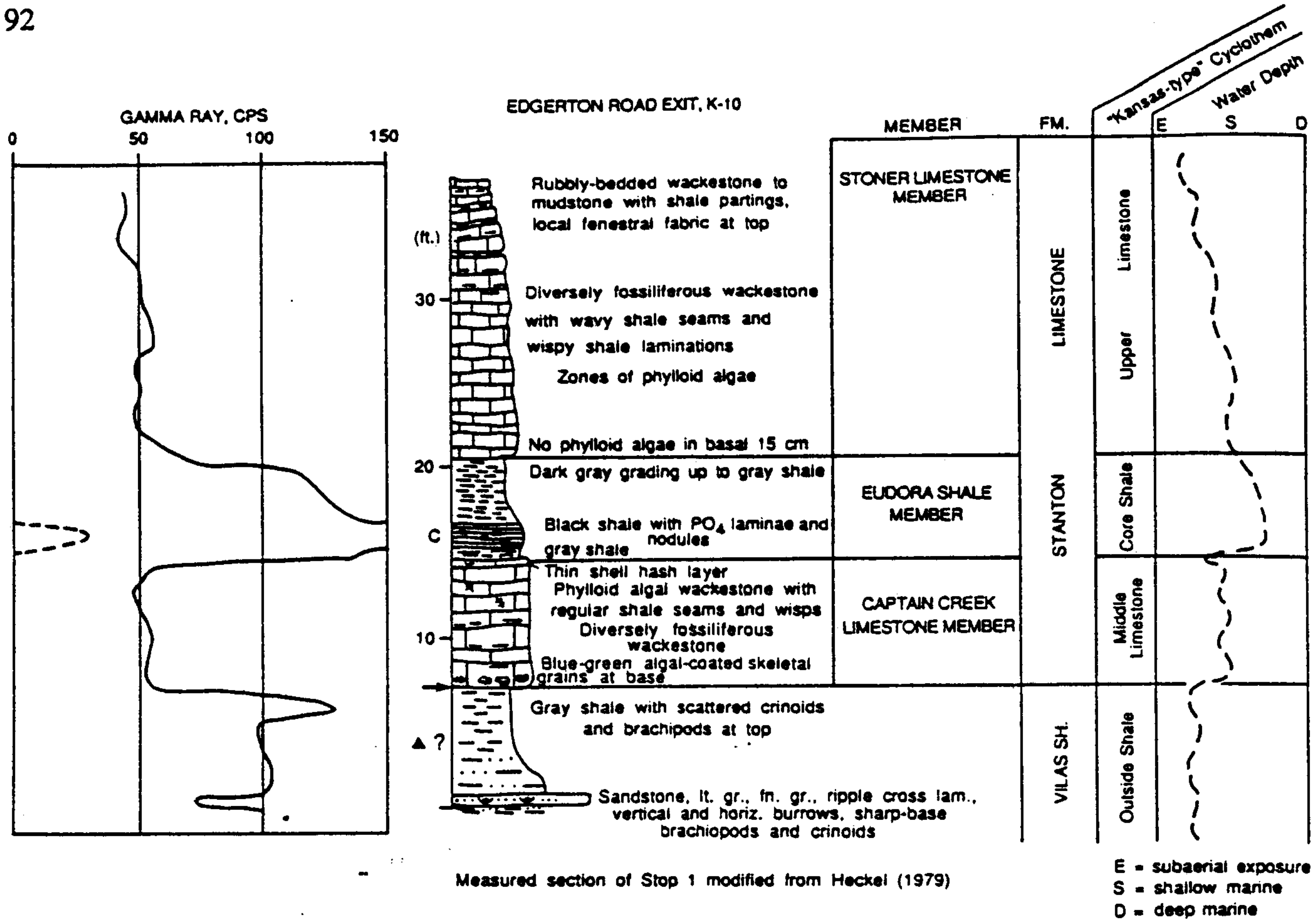


FIGURE 1-2—Legend with major lithologies, surfaces, and sequence-stratigraphic terms.



Measured section of Stop 1 modified from Heckel (1979)

FIGURE 1-3—MEASURED SECTION OF STANTON LIMESTONE AT STOP 1. Natural gamma-ray profile obtained with hand-held gamma scintillation counter. Symbols used in graphic columns are shown in fig. 1-2.

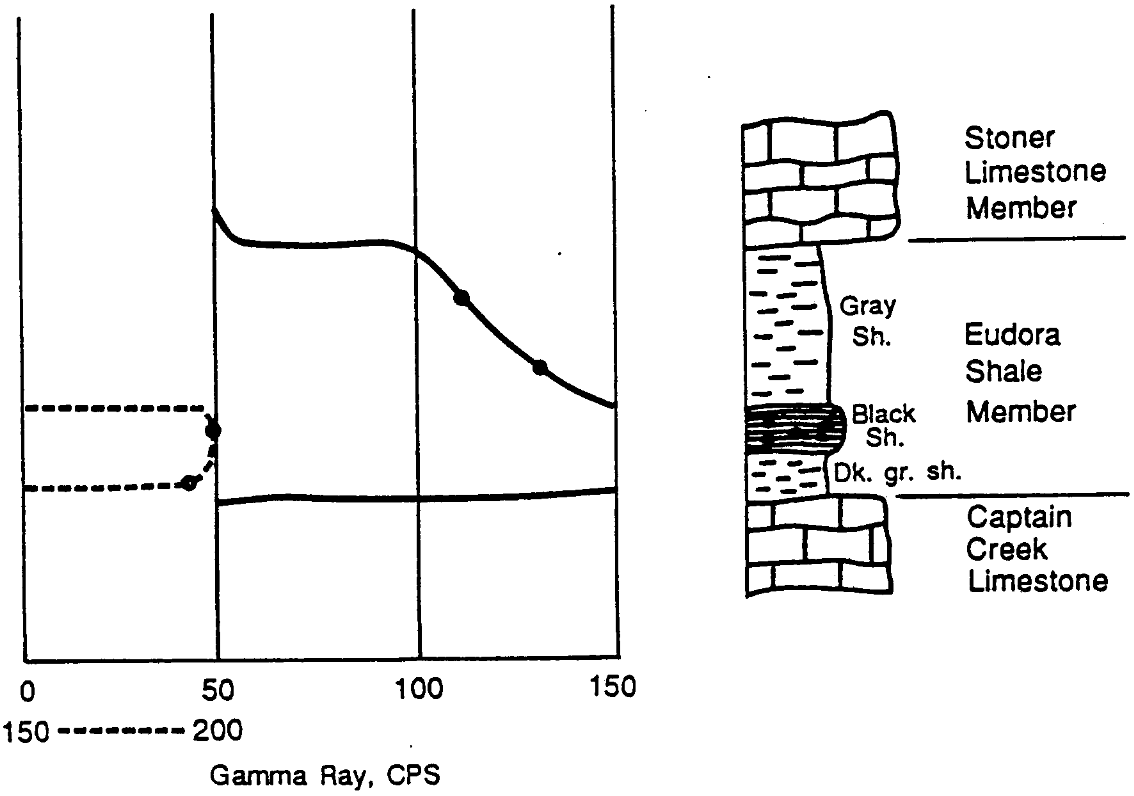


FIGURE 1-4—FOUR-FOOT (1.2-M)-THICK SECTION OF EUDORA SHALE EXPOSED ALONG I-435, 14 mi (23 km) east of Stop 1. Section is very similar to that seen at Stop 1.

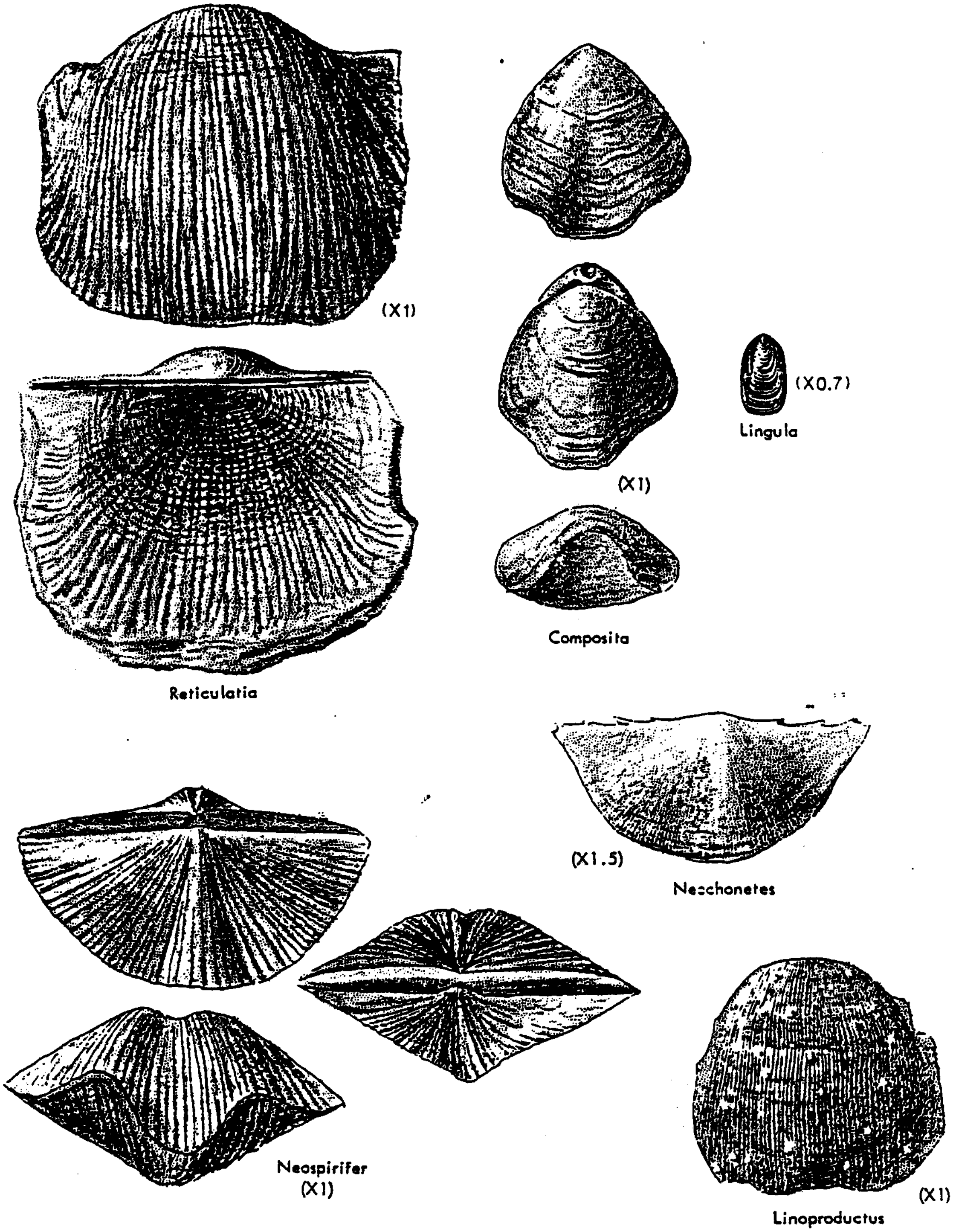


FIGURE 1-5—COMMON MACROFOSSILS OCCURRING IN UPPER PENNSYLVANIAN STRATA (from Moore, 1964).

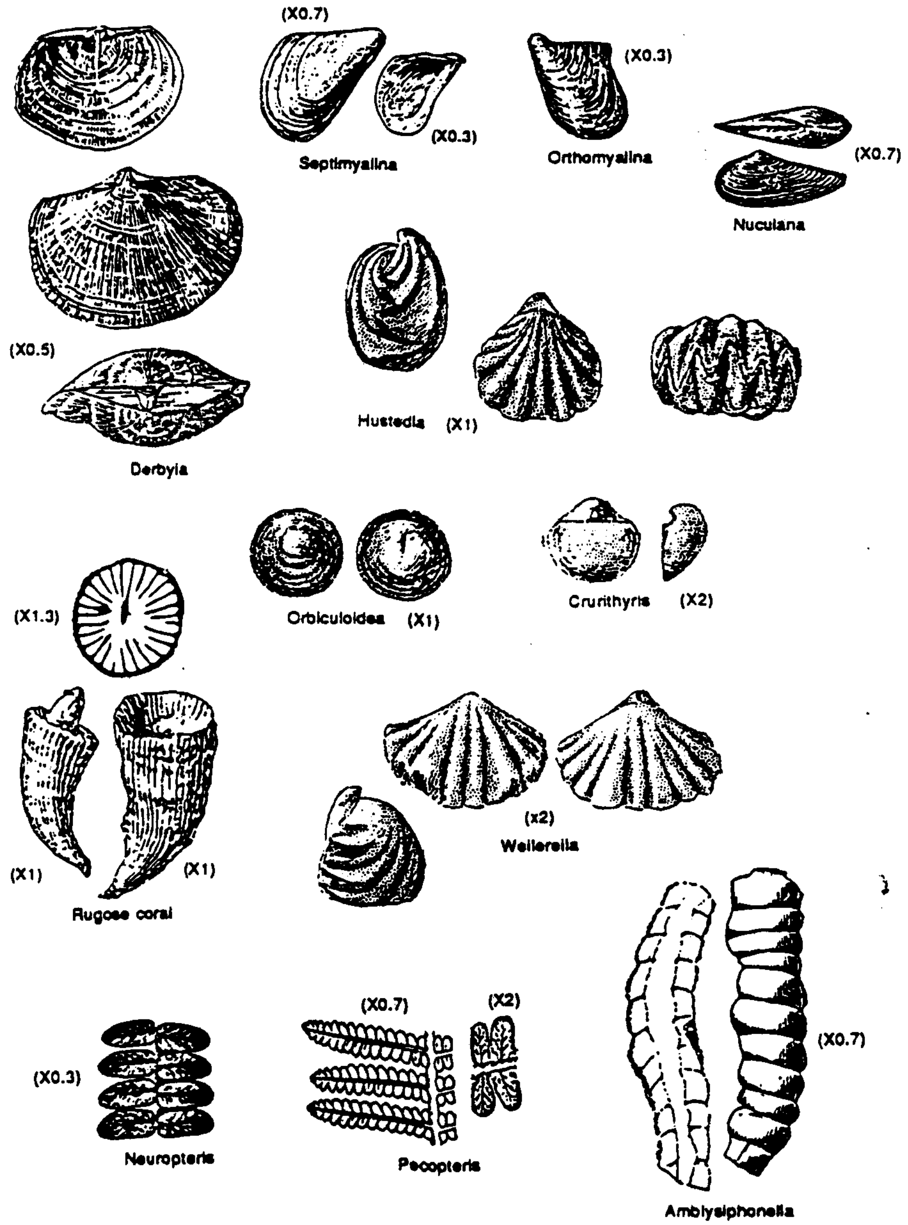


FIGURE 1-6—Common macrofossils occurring in Upper Pennsylvanian strata (from Moore, 1964).

STOP (5)

Salient aspects of the terminal zone of continental glaciation in Kansas

by *Wakefield Dort, Jr.*, Department of Geology, University of Kansas, Lawrence, Kansas

Abstract

Extent of glaciation in Kansas and location of the ice-sheet terminus is best determined by mapping the distribution of Sioux quartzite erratics. Even the presence of less than 1% quartzite in a basal chert-limestone gravel is evidence of a temporal and spatial relationship with a glacier. From Wamego to Topeka, the terminus can be located within very narrow limits. Not as clearly defined is the amount of post-glacial erosion that has or has not been accomplished. Ridge-top concentrations of quartzite boulders may be paleovalley lag concentrates preserved by topographic reversal or, conversely, primary concentrations marking the bottoms of major crevasses. Till units of contrasting lithologies, as well as till units separated by a paleosol, provide evidence of at least two advances to the terminal zone. At maximum advance, glacier ice blocked the Kansas River, impounding a lake that extended more than 100 km (60 mi) upstream. Flow over a spillway at 1,165 ft (350 m) above sea level proceeded to Topeka through several small ice-front lakes.

In North America, glacial theory and history understandably developed mainly where the records of past glaciations are most clear. This was in those states bordering the Great Lakes. There the deposits and land forms are youngest, hence best exposed, least modified, and so easiest to understand. This region, extended to included Iowa, has been the cradle of American Pleistocene history and reconstruction. Only the older ice sheets advanced into northern Missouri, northeastern Kansas, and southern Nebraska. Their deposits are thin and scattered and few, if any, actual glacial land forms remain.

The history of glacial geology in Kansas was well summarized by Aber in 1984. It will suffice to say here that early field observations by Hay, Smyth, and Todd demonstrated that continental ice had indeed reached northeasternmost Kansas. They recognized effects the presence of the ice sheets had on local drainageways and they delineated the general limits of ice advance, information that was somewhat modified by Schoewe in the 1920's and 1930's.

The presence of John C. Frye as Director of the Kansas Geological Survey from 1943 to 1954 led to studies of many aspects of Pleistocene geology and publication of results by students, professors, and Survey staff. The 230 pages of Bulletin 99, *Pleistocene geology of Kansas* by Frye and Leonard, provided an outstanding compilation of knowledge available in 1952. However, a paucity of detailed maps, sections, and other explanatory diagrams has been a source of constant frustration to later researchers and markedly reduced the usefulness of many of these publications.

Although most of their research efforts have been directed toward other geographical areas, Dort, Sorenson, Johnson, and Martin, and their students, have recently modified and expanded details of knowledge about the Pleistocene history of Kansas. Notable impetus has been provided by establishment of a palynological research laboratory at the University of Kansas with support from the General Research Fund and by preparations for the 1986 Friends of the Pleistocene field trip. Presented here is a brief summary of salient aspects of their observations and working hypotheses.

Initial concepts

A general framework of Pleistocene history was compiled almost a century ago when it was proposed that four major advances and retreats of the continental ice sheets had occurred in both Europe and North America. Only the first two of these advances were believed to have reached Kansas, one (named the Nebraskan) barely entering the northeasternmost corner, the other (named the Kansan) extending as much as 80 km (48 mi) farther south and southwest (fig. 1).

This purported sequence made it very easy to identify till bodies or determine ages of associated sediments. In the far northeastern part of the state, the upper of two tills had to be, by definition, of Kansan age, the lower one, Nebraskan. Deposits of nonglacial origin could, by their position relative to one or both of those tills, be identified as of pre-Nebraskan, Aftonian, or Yarmouthian age. Furthermore, an apparently positive time line could be recognized in many localities where there were exposures of what was thought to be a single regional airfall, the Pearlette volcanic ash. This was assigned a late Kansan age on the basis of indirect stratigraphic correlations. Another time line seemed to be provided by the post-Illinoian Sangamon soil, supposedly the only red pedogenic unit in the Pleistocene section. Unfortunately, all aspects of this simple stratigraphy have been shown to be erroneous.

Evidence of glaciation

In Kansas, as elsewhere in the world, the former presence of glacier ice is indicated by deposits of unstratified sediment composed of a heterogeneous mixture of grain sizes and shapes—a till. Some of the included fragments bear scratches or striations and the whole deposit may rest on a smoothed and striated bedrock surface.

Although most of the fragments in a till body usually are of rock types that crop out nearby, some will have been derived from distant sources. The presence of these far-traveled erratics helps distinguish a glacial till from colluvium formed by downslope movement of rock debris from nearby outcrops.

In Kansas, pebbles and even small cobbles of granitic rock could conceivably have been carried by streams flowing eastward from the Rocky Mountains in late Tertiary time and deposited to form the Pliocene Ogallala Formation. Their presence in a sediment does not, therefore, constitute unequivocal proof of a glacial origin. On the other hand, certain lithologies are known to crop out only to the north, and glacial transport to Kansas is believed certain. Chief among these is the Sioux quartzite. Its outcrops are restricted to a small area in southwestern Minnesota and nearby parts of Iowa and South Dakota (fig. 2). Its distinctive pink to lavender color makes even tiny pieces of this rock readily identifiable, so it is an excellent indicator rock. Any sediment containing Sioux quartzite either is of direct glacial origin or was derived by reworking of a primary glacial deposit.

In addition, it is believed that fragments of metamorphosed volcanics, or greenstone, which are moderately common in northeastern Kansas, were derived from the Canadian Shield. Also present, though much less common, are pieces of hematitic iron ore, probably from the Iron Ranges of Minnesota, and Lake Superior agates from the Keewenawan volcanics of Minnesota, Wisconsin, and Michigan.

The presence of these "foreign" rock types in sediments not only constitutes almost incontestable evidence of a glacial origin for the original host deposit, but also provides indication of the direction of ice flow. Although movement may not have had straight-line directness from outcrop source to the locus of final deposition, there could not have been much deviation. Even if one admits the possibility that some clasts were picked up by an early ice-sheet advance, carried only part way to Kansas, deposited, then incorporated into a later glacier, movement from outcrops of Sioux quartzite must have been at least almost direct. The presence of the glacier terminus nearby to the west would seem to preclude any sizable detours (fig. 2).

Published here for the first time is a map by J. S. Aber showing locations of striated surfaces and ice-push structures which provide indication of the direction of glacier

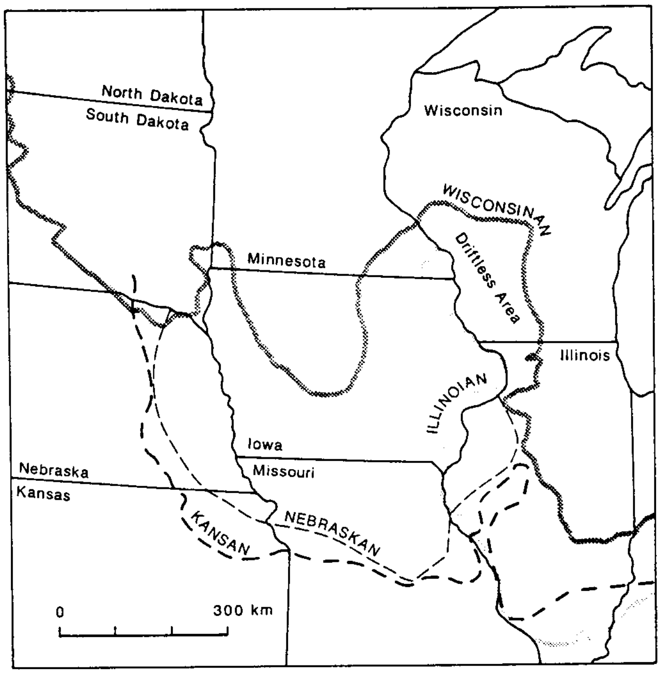


FIGURE 1—Known or inferred termini of the four classical glaciations in central United States (modified from Flint, 1971). Note the position of Kansas at the southwestern limit of pre-Illinoian ice sheets.

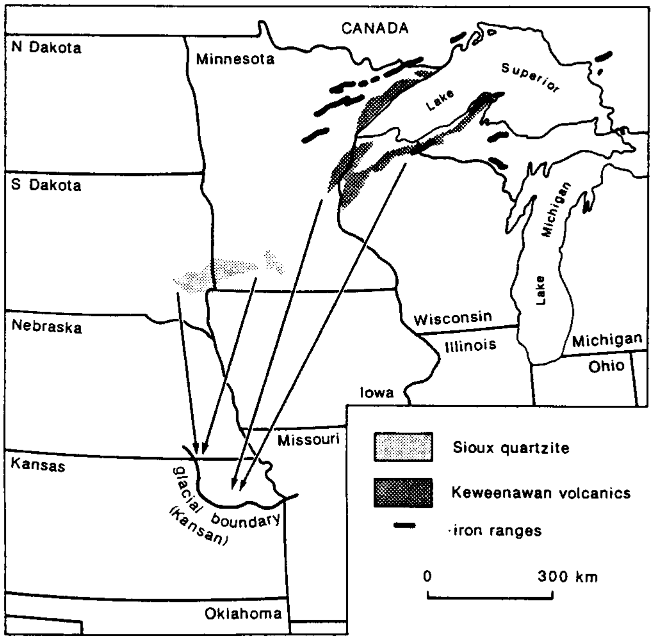


FIGURE 2—Sources of identifiable glacial erratics found in northeastern Kansas. Fragments of Sioux quartzite are common throughout the terminal zone; specimens of ore from the Iron Ranges are scarce. Distribution of Lake Superior agates from the Keweenawan volcanics is highly localized.

flow (fig. 3). Correlation of a specific indicator with a specific advance of the ice sheets, or with an advancing or retreating hemicycle, may be difficult or impossible. Orientation of indicator travel paths produced during marked lobation of the ice front may deviate considerably from the regional direction of flow.

The presence of pebbles of Sioux quartzite and other erratic fragments is especially important for interpretation of scattered occurrences of a basal gravel. Most of the clasts are composed of chert or limestone. Indeed, the quartzite comprises much less than 1%. Nevertheless, it is believed that these pebbles could have been carried from outcrops in Minnesota only by glacier ice and their presence is taken as positive proof that this gravel was deposited in association with or after an episode of continental glaciation.

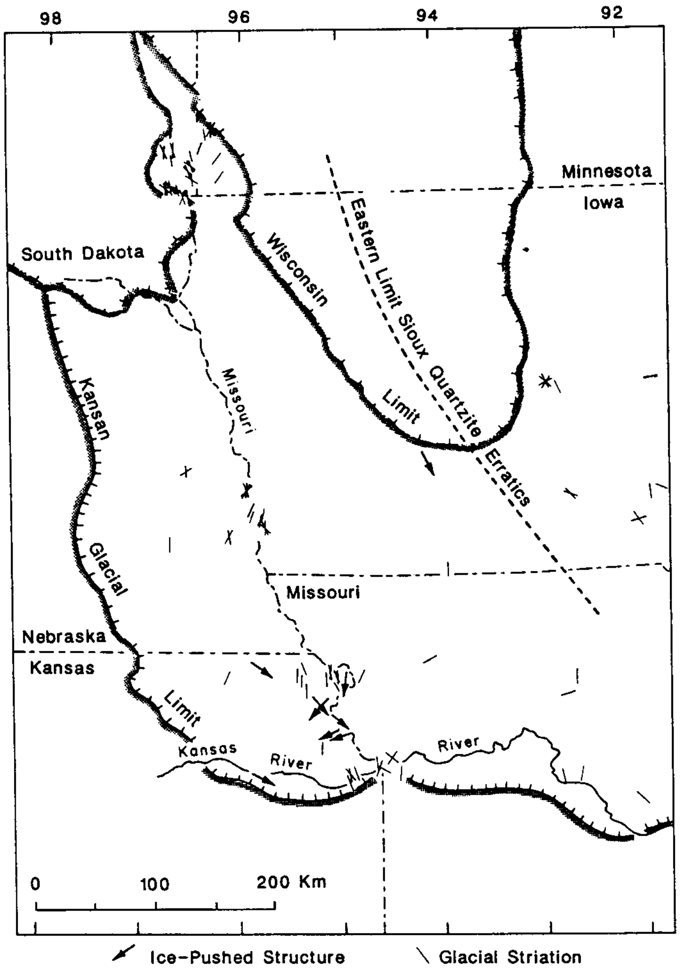


FIGURE 3—MAP SHOWING DIRECTIONAL FEATURES FOR KANSAN AND OTHER PRE-ILLINOIAN GLACIATIONS OF THE LOWER MISSOURI BASIN REGION. Directional features are, for the most part, not stratigraphically controlled and could relate to any of several pre-Illinoian ice advances. In Kansas, northeasterly ice movement is associated with the lower Kansas till, and northwesterly ice advance is related to the upper Kansas till. Primary data sources include Chamberlin (1886), Todd (1899), Barbour (1900), Norton (1911), Schoewe (1941), Flint (1955), Lammerson and Dellwig (1957), Dellwig and Baldwin (1965), and Aber (1985), plus other published and unpublished sources. Eastern limit of Sioux quartzite erratics from Willard (1980); glacial limits adapted from Flint et al. (1959). Compiled and drafted by J. S. Aber in 1986.

Location of terminus

As a consequence of the relatively great antiquity of the glaciation of Kansas, no land forms of direct glacial origin have been recognized. Delineation of the limits of glacier advance must, therefore, be based on the extent of sediments of unequivocal glacial origin—those deposited directly by the ice rather than by streams or in lakes adjacent to the ice. In effect, this is accomplished by finding, in the field, the farthest south distribution of till or of fragments of Sioux quartzite which, on the basis of size or topographic location, are believed to have been left by the ice sheet itself without subsequent redistribution by meltwater or floating icebergs, or post-glacial movement by gravity or streams (figs. 4 and 5).

Meltwater streams are capable of transporting only pebble- or perhaps cobble-size masses of frozen till. Somewhat larger bulks can be floated on icebergs, but not enough to form later an extensive deposit. Exposure of unsorted, unstratified till can therefore be accepted as proof of the former presence of glacier ice at a specific locality. In addition, erratic boulders situated on hill tops or ridge crests or anywhere else clearly above limits of proglacial water flowage or impoundments and unaffected by post-glacial downslope movement also demonstrate where ice was present. These relationships have been very successfully used in the field to locate the glacier terminus.

Along most of the 100-km (60-mi)-long terminal line between Wamego and Topeka, it is believed that the ice-front position can be fixed within a zone at most a few hundred meters wide. In some places the apparent boundary can be placed within less than 100 m (330 ft; fig. 6). This line can be followed across the existing landscape, generally with no apparent topographic control.

Postglacial erosion

Behind the terminus there is not a continuous sheet of till. Only scattered patches are present, leading Schoewe to coin the descriptive term "attenuated drift border." Thicknesses vary markedly over short distances. In most places bedrock underlies loessal soil with no till whatever. Locally there are only erratic boulders on a nearly bare bedrock surface.

Details of the distribution of till and erratic boulders, especially where found on hill tops and ridge crests, have

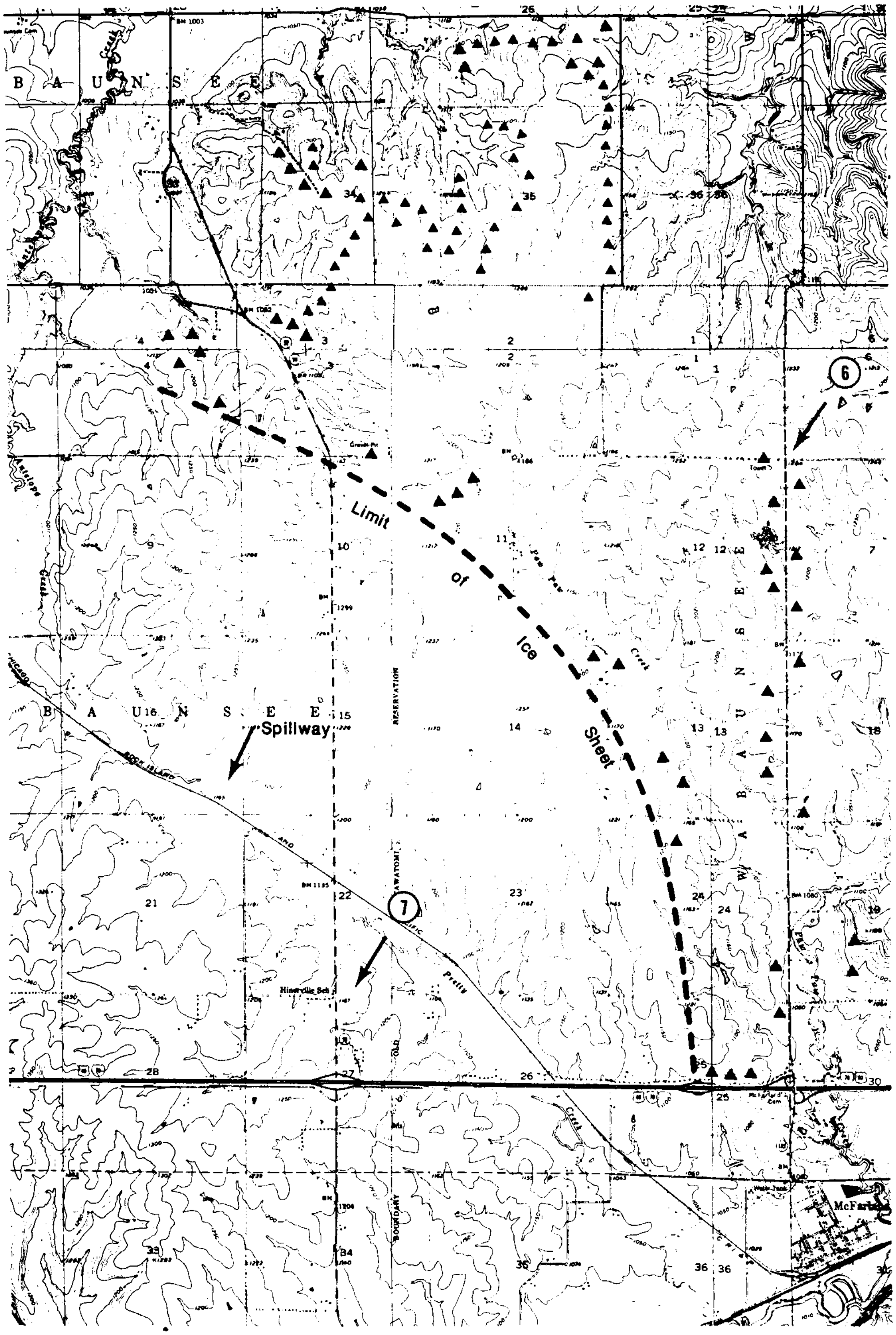


FIGURE 4—Generalized distribution of Sioux quartzite erratics (triangles) and location of the ice margin. Wamego is 3 mi (4.8 km) north of the top of this map. The spillway controlled outflow from Kaw lake and stabilized water level at an elevation of 1,165 ft (355 m).

elicited considerable speculation regarding relationships between present topography and that across which the ice sheets advanced. How much general erosion, or even local dissection, has occurred in postglacial time?

A reasonable first assumption is that because the glaciation of Kansas took place at least several hundred thousand years ago, postglacial processes must have been able to modify the glaciated landscape to a considerable degree—whatever that phrase might mean. Indeed, the very patchiness of till has been attributed to just this purportedly extensive removal, and the patches have been spoken of as "remnants." The localized accumulations of Sioux quartzite boulders resting on bedrock have been interpreted as lag deposits, the last, resistant remains of once-thick till.

This debate is especially germane to a locality south of Wamego where a short, narrow ridge rises precipitously about 35 m (116 ft) above flanking creek valleys. The flat crest of this ridge is covered by a sea of thousands of small boulders of Sioux quartzite (fig. 7). Exposures on the sideslopes show, however, that this accumulation is a veneer, at most only a few boulders thick, resting on limestone bedrock. Similar ridge-top accumulations of numerous quartzite boulders occur in perhaps half a dozen localities in the marginal zone of the glaciated area of Kansas.

One possible explanation of localized ridge-top felsenmeer would be based on topographic reversal. The hypothetical sequence would begin with deposition of thick, boulder-bearing till on the preglacial landscape. Postglacial drainage would create narrow, steep-sided gullies in this cover. As erosion proceeded, finer constituents of the till would be differentially removed, resulting in a lag concentration of the larger clasts in the gullies. Wherever the original till was especially rich in boulders, the valleys would become choked with them. Subsequently, the quartzite boulder fill would be more resistant to continuing erosion than the flanking limestone bedrock and whatever till cover remained. The boulder-filled gullies would remain essentially unaffected while the limestone hills would be worn away and, eventually, a reversal of topography would result. The former valley floor would then stand high as a boulder-capped ridge.

This is a very enticing hypothesis, but some problems remain. Chief among these is an explanation of why modern valley floors, no matter of what size or location relative to the ridge-top felsenmeer, show few, if any, quartzite boulders. It might be expected that in most areas, where quartzite boulders were not sufficiently numerous to form a protective cap on the bedrock, the few boulders present would be moved downslope by gravity and streamflow and collect in the modern valleys. Such concentrations are rarely found. At sites where the valley floor consists of bare bedrock, it clearly is not possible to suggest that these boulders are indeed present but covered by younger alluvium. Even the boulder beds encountered by wells bored beneath the floodplain of the Kansas River cannot reasonably account for all of the proposed lag concentration.

An alternative explanation would begin with a subglacial topography essentially the same as that now present. As the frontal zone of the ice sheet began to thin during the recessive phase, major crevasses could be expected to open above submerged ridges. A few of these might be favorably located so as to receive large numbers of quartzite boulders being carried on or within the ice. Concentrations of boulders would thus accumulate on the crests of a few pre-

FIGURE 5—Sioux quartzite boulder 2 mi (3 km) northwest of Dover. Although it is located within the limits of a proglacial lake, its association with till suggests that is was emplaced directly by the glacier rather than rafted on an iceberg.

existing bedrock ridges, remaining there as the flanking ice melted away. One of the problems associated with this hypothesis is the need to explain why the felsenmeer are composed almost entirely of quartzite boulders whereas the glacier was undoubtedly carrying other lithologies as well, as is shown by occurrences of boulders of granite, gabbro, greenstone, basalt, and limestone in other topographic situations.

Questions associated with the distribution of Sioux quartzite boulders also arise for an area southeast of Wamego. Boulders of a wide range of sizes are scattered thickly over several rounded hill tops that stand as much as 100 m (330 ft) above the Kansas River (fig. 4). On some of the summits, these boulders are seen to rest directly on limestone bedrock. Are these a residue, the last remnants of till that was originally deposited there? Or are they the only materials that were left by the ice? This is not typical of deposits in areas of younger continental glaciation such as Illinois or Wisconsin. On the other hand, many areas of late Pleistocene or Holocene deglaciation (northern Canada, Norway, Antarctica come to mind) are characterized by widespread exposures of bedrock on which are scattered only small, thin patches of till, or just boulders alone.

Another basis on which the amount of postglacial erosion might be estimated is the relationship between the apparent terminal and existing topography. Does the glacial limit seem to follow a generally straight line for considerable distances, crossing valleys, hillside slopes, and ridge crests without deviation, or is it diverted, blurred, or interrupted by these land forms?

To answer this question with confidence would require mapping in much greater detail than has yet been accomplished. However, the present impression is that the terminal line is, in general, not affected by details of the topography. Admittedly, there are clear suggestions of a broadly lobate front that advanced into some large lowland areas while being restrained at intervening promontories. But at a smaller scale the line, as defined by the southernmost quartzite boulders in each local area, crosses valleys or ridge crests and is oriented diagonally along slopes with no clear deviation. If this pattern is indeed present, then the preglacial topography must be largely preserved in the present landscape. Major postglacial erosion would have displaced or even obliterated much of the linear record.

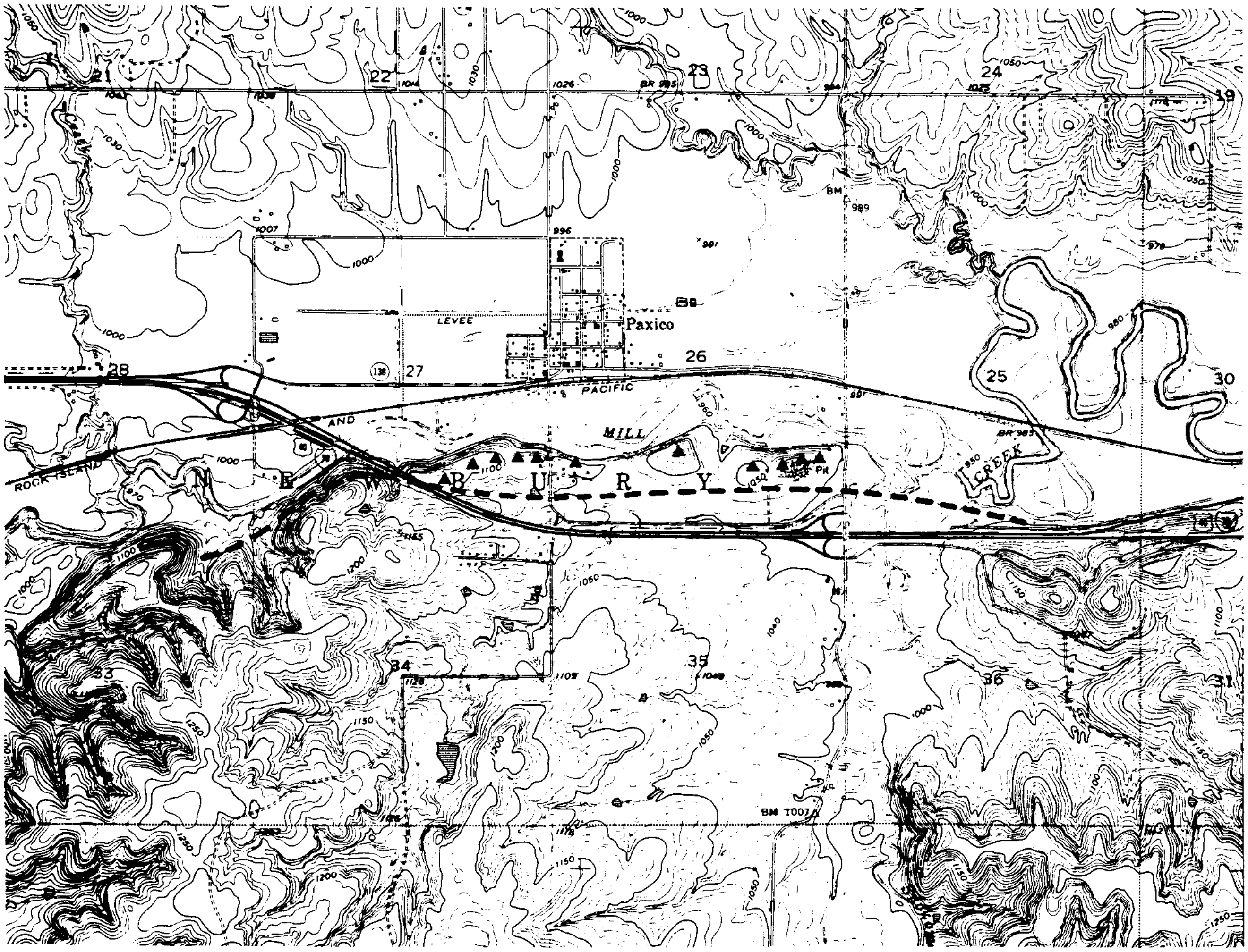


FIGURE 6—Limit of glaciation south of Mill Creek valley. Distribution of till and Sioux quartzite erratics (triangles) closely fixes the glacier terminus. The steep-sided ridge on which the glacial debris rests is composed largely of limestone bedrock and is not a true moraine.

Number of glaciations

From the earliest investigations it became accepted dogma that continental ice sheets reached Kansas only twice and that these advances were the first two of four that occurred during the Pleistocene Epoch. It also was believed that nonglacial sediments of late Kansan age could be positively identified by the presence of a layer of the Pearlette volcanic ash. Those concepts have been effectively destroyed by discoveries made during the past 25–30 yrs.

Concurrent studies in northeastern Kansas and southeastern Nebraska found stratigraphic evidence of more than two glacial advances. By the middle 1960's, the Nebraska Geological Survey had formally recognized two Nebraskan tills and two Kansan tills, designations that were at once accepted by the Kansas Geological Survey, even though there were problems of regional correlation (fig. 8, table 1). At the same time, exploration in northeasternmost Kansas found an exposure that contained units indicating five episodes of glaciation separated by deposition of interglacial sediments and formation of paleosols. Discoveries soon followed of similarly complex records of multiple pre-Illinoian glaciations in Iowa, then in Illinois.

The assumed simplicity of fluctuations in early Pleistocene climate is now known to be wrong. However, it is at present impossible to state how many major glaciations actually occurred or how many lesser advances and retreats marked each of those.

It has been established that glacier ice reached the terminal zone in Kansas more than once. Some of the indications are unclear and subject to interpretation, but other evidence seems to be incontestable. At more than a dozen localities spread from west of Topeka to east of Lawrence, exposures of two till units have been found. In each instance these are set apart by a paleosol developed either in the upper part of the lower till or in nonglacial sediments overlying the lower till. Unfortunately, each of these sites has only a thin sedimentary section above bedrock. Therefore, estimating the duration or importance of the interglacial soil-forming interval is difficult, but it may have been relatively short, perhaps only a few thousand years. Whether all of these exposures are of sediments and paleosols of the same age, marking one interglacial interval, or whether the record is more complex also is not yet known.

Less certain is the meaning of exposures of what appear to be two till units without any intervening nonglacial sediments or paleosols. These units can be separated on the basis of differing texture, color, and lithology. Most outstanding are occurrences of red, oxidized till with a clay-rich matrix and a high content of erratic clasts, both quartzite and granitic varieties, overlying a tan, unoxidized till with a sandy matrix and almost no erratics. It is currently believed that these units are of distinctly different ages and represent separate advances of the ice, but this interpretation cannot yet be strongly supported with quantitative data.

Especially noteworthy is the presence of a few clasts of erratic lithology, notably Sioux quartzite, in chert or chert-

FIGURE 7—Sea of erratics on the edge of a ridge east of highway K-99, 5 mi (8 km) south of Wamego. More than 99% of these clasts, displaying a remarkably small range in size, are of Sioux quartzite; the remainder are of assorted igneous lithologies. The flat-topped deposit is at most only a few feet thick on top of limestone bedrock.

limestone pebble gravel that locally underlies the lowest till and also occurs where no till is present. The gravel might be outwash from the glacier that subsequently left the overlying till, as has been proposed frequently in the literature, but there are suggestions that it is considerably older. More puzzling is the presence of a small hill of erratic-bearing gravel and, apparently, till approximately 7 mi (11 km) beyond the supposed terminus of glaciation as indicated by the Sioux quartzite boulder limit.

Age of glaciation

Once it has been shown that more than two identifiable till units occur in northeastern Kansas, a problem in nomenclature arises. Are the additional units assignable to the Kansan glaciation, to the Nebraskan, or to glaciation "X"? The Nebraska Geological Survey solved this quandry by identifying and naming a medial Kansan Cedar Bluffs Till, an early Kansan Nickerson Till, a late Nebraskan Iowa Point Till, and an early Nebraskan Elk Creek Till (table 1). However, distinguishing criteria and age assignments were not based on clear stratigraphic and sedimentologic data. Reliable correlation into Kansas is impossible and will remain so until additional field mapping, augmented by detailed quantitative studies, has been accomplished. Integration of data from deep-sea cores with the terrestrial observations will have considerable influence on development and acceptance of a new classification. It is, however, certain that there must at the very least be a temporal redefining of the names Nebraskan, Aftonian, and Kansan, and the use of stratigraphic names such as Sappa, Grand Island, and Holdredge seems to be unjustifiable in Kansas.

Effects on drainage

Drainage of the northern quarter of Kansas is accomplished mainly by the eastward-flowing Kansas River. Several major tributaries join this trunk stream from the north; those entering from the south are of smaller size. As an ice sheet advanced into Kansas, it progressively covered more and more of the drainage basins of the southward-flowing streams, ultimately obliterating them. The course of the Kansas River from near Junction City to Kansas City closely approximates the southern limit of glaciation. For this reason, it is believed that the Kansas River may have originated as an ice-marginal stream. However, the actual terminal line of ice advance lies several miles south of the Kansas River valley along most of this reach. This means that not only were all northward-flowing tributaries of the Kansas River blocked by the ice front, but almost all of the mainstem valley also was covered by ice. Inevitably, impoundment occurred and a series of ice-front lakes formed.

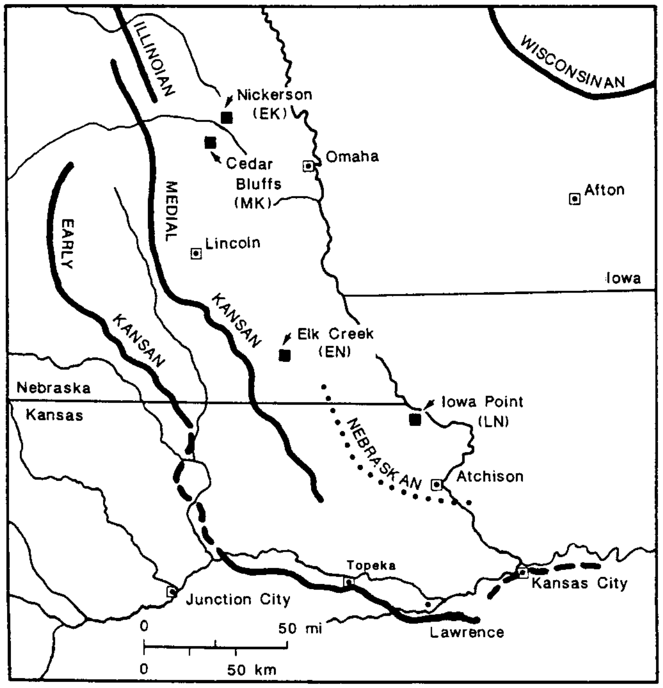


FIGURE 8—Limits of purported stadial advances of continental ice sheets (modified from Reed and Dreeszen, 1965). Termini in Nebraska and northernmost Kansas are from Reed and Dreeszen; those farther south are from the geologic map of Kansas and 1986 field mapping by Dort. Locations of designated type sections are shown for Early Nebraskan (EN), Late Nebraskan (LN), Early Kansan (EK), and Medial Kansan (MK).

Till can be observed in exposures only a few feet above the present floodplain of the Kansas River. It also has been encountered in drill holes. Therefore, it can be stated that the Kansas River valley was present prior to one or more advances of the glacier. The occurrence of tills of contrasting lithologies near the present valley floor suggests that the valley was present before at least two glaciations.

If the Kansas River valley as it exists now is at least a fair approximation of the valley that was over-run by the ice sheets, then the shape of the existing valley should approximate the shape of the lake impounded in that valley upstream from the ice limit. The vertical position of the shoreline would have been controlled by some overflow point.

The position of the ice front, as indicated by the distribution of Sioux quartzite erratics, was a short distance south and west of Wamego. Inspection of existing topography outside this limit quickly led to identification of a col that would have permitted water to spill around the blockade. Elevation of the floor of this broad pass is shown on topographic maps as being 1,165 ft (355 m) above sea level. Tracing the 1,165-ft contour then provides the shoreline of the impounded lake, named Kaw Lake by Todd (figs. 9 and 10).

Greatest uncertainty is present where this elevation crosses the floors of major valleys. Postglacial history has undoubtedly included multiple episodes of incision and aggradation, so the location where the 1,165-ft contour now crosses a floodplain probably deviates somewhat from the actual head of any specific arm of the proglacial lake. However, the proposal that bayheads, and consequent delta formation, were indeed present at these general locations is strengthened by Soil Conservation Service recognition there of unusual clay-rich soils that seem to be of possible lacustrine origin.

The floor of the spillway at 1,165 ft (355 m) south of Wamego was not deeply entrenched because the valley of Mill Creek directly east was occupied by a lake having a surface elevation only slightly lower. Indeed, there may have been a drop of as little as 5 m (17 ft) through the 50-km (30-mi)-long series of small lakes that were present along the ice front eastward to Topeka.

Well established in published literature is the hypothesis that water impounded when the Kansas River valley was blocked by glacier ice rose until it was able to spill westward and southward through the so-called McPherson Valley. As early as 1895, Beede pointed out that such a course on the present topography would require water to flow uphill. A solution suggested in later papers was to call on an isostatically raised glacial forebulge to provide a gradient in the proper direction. This suggestion does not withstand close analysis, however, and westward drainage of Kaw Lake apparently did not take place.

Compilation of subsurface data provided by drill holes does indicate the presence of several buried valleys in northeastern Kansas. However, relating these to the glacial chronology has been handicapped by previous efforts to fit all events into a framework of only two major glaciations of the area. As additional information is acquired, it will probably be found that there was a considerably more complex sequence involving several advances of the ice sheets.

Any situation involving impoundment of large volumes of water by an ice dam contains the ingredients necessary for release of one or more catastrophic floods. If blockage continued at the western end of the Kansas River valley after the area around Topeka had become ice free, ultimate failure of that dam could have released a surge of water and

TABLE 1—CLASSIFICATION OF PLEISTOCENE UNITS ACCORDING TO THE NEBRASKA GEOLOGICAL SURVEY (from Reed and Dreeszen, 1965). This classification also was used by the Kansas Geological Survey. However, studies in many areas have shown that the record is much more complex in Kansas and it is probable that all terms below the Illionian will have to be extensively redefined or, more likely, abandoned.

CLASSIFICATION						TERRACE SURFACES		FAUNAL ZONES
TIME STRATI-GRAPHIC		ROCK STRATIGRAPHIC						
		EOLIAN	FLUVIATILE	GLACIAL	SOILS			
Wisconsinan	Late	Bignell Loess and Dunesand	Bignell Formation { silt / sand-gravel	Absent		2a 2b	2	Late Pleistocene
	Medial	Peoria Loess and Dunesand	Peoria Formation { silt / Todd Valley sand	Hartington Till	Brady	3	3	
	Early	Gilman Canyon Loess	Gilman Canyon Formation	Absent	Unnamed	— ? — 4		— ? — ? — Medial Pleistocene
Illinoian	Sagamonian Late	Loveland Loess	Loveland Formation { silt / Crete sand-gravel	Absent	Sangamon		4	
	Medial	Beaver Creek Loess	Beaver Creek Formation { silt / sand-gravel	Santee Till	Unnamed			
	Early	Grafton Loess	Grafton Formation { silt / sand-gravel	Clarkson Till	Unnamed			
Kansan	Yarmouthian Late	Sappa Loess	Sappa Formation { • • silt • • / Grand Island sand-gravel	Probably Absent	Yarmouth		5	
	Medial	Walnut Creek Loess *	Walnut Creek Formation { silt / sand-gravel	Cedar Bluffs Till	Unnamed	5		
	Early	Red Cloud Loess *	Red Cloud Formation { silt / sand-gravel	Nickerson Till / Atchison Sand	Fontanelle			— ? — ? — Early Pleistocene
Nebraskan	Aftonian Late	Fullerton Loess *	Fullerton Formation { silt / Holdrege sand-gravel	Iowa Point Till	Afton		6	
	Early	Seward Loess *	Seward Formation { silt / basal sand-gravel	Elk Creek Till / David City sand-gravel	Unnamed			

〰 Interglacial Soil ⁄⁄⁄⁄ Interstadial Soil —— Minor Erosion 〰 Major Erosion • • Pearlette Volcanic Ash * Not currently identified

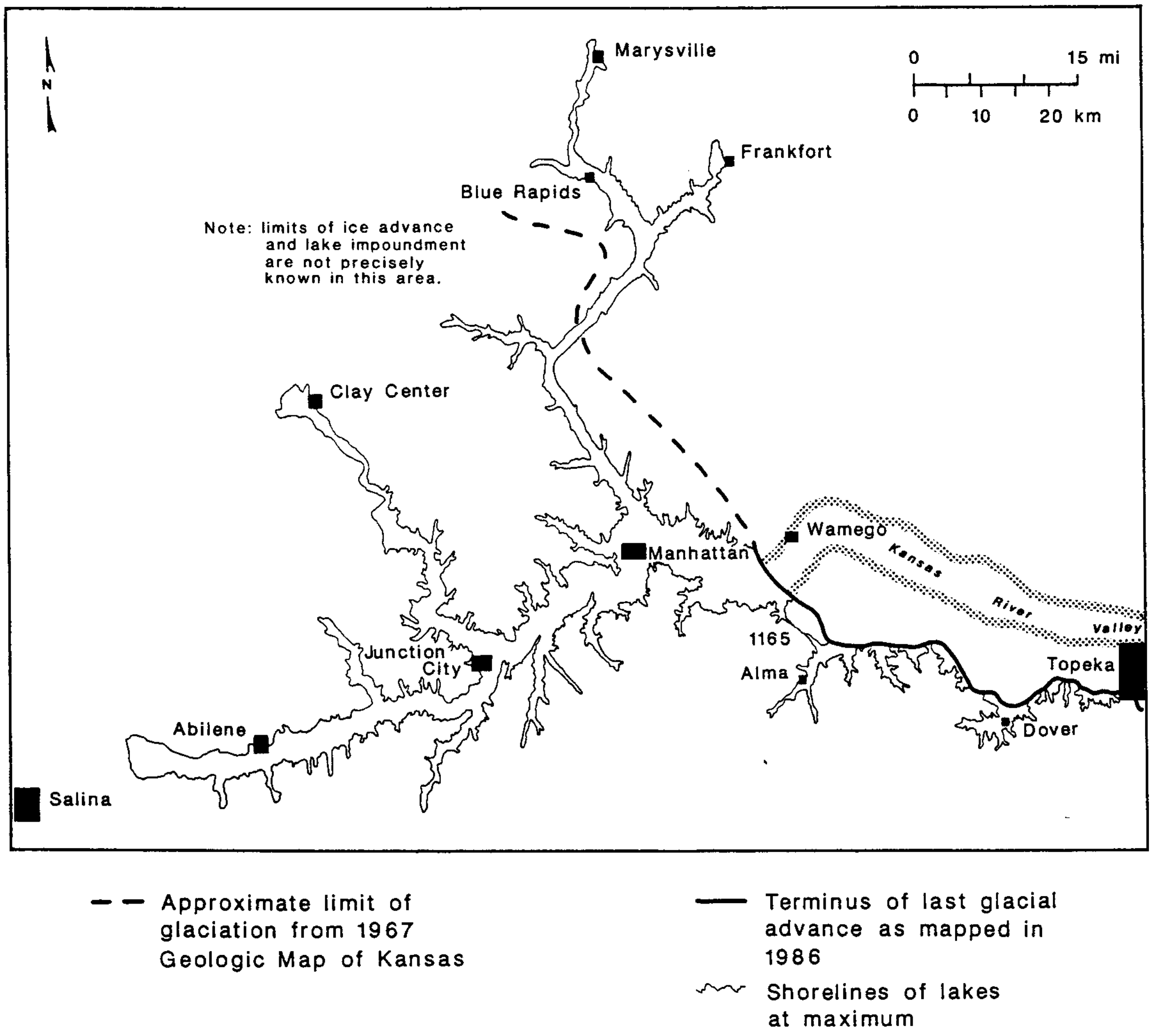


FIGURE 9—PROGLACIAL LAKES WEST OF TOPEKA AT THE TIME OF MAXIMUM ICE ADVANCE. Shorelines depict water levels controlled by spillways against or close to the ice front. It is believed that there has been no significant warping of the land surface since that time and that the glaciated terrain closely approximated that of today, thus permitting plotting on modern topographic maps.

sediment down the deglaciated portion of the valley. Large-scale trough crossbeds in a gravelly sand exposed in a pit just northwest of Topeka might have been formed by such an event. Furthermore, the deep inner bedrock gorge extending more than 60 m (198 ft) below present floodplain level in the Kansas City area could also have been formed, at least in part, by this high-volume discharge.

One other interesting question about Pleistocene drainage relates to the ancestral Missouri River or its precursor. When ice sheets reached northeastern Kansas, all preglacial drainage toward the northeast was effectively blocked. So also was the Missouri River itself, or whatever trunk drainage existed at that time. Yet there still was a vast region in the interior of the continent that received precipitation, as well as at least some flow from the ice itself.

That water had to go somewhere. Flow toward the north and northeast was blocked by ice; toward the west or southwest it was blocked by higher elevations. There seem to be only two possible courses available. Flow might have been diverted through the McPherson Valley, a possibility previously mentioned and discarded, or it could have followed a general ice-marginal route. This latter possibility seems best, but confirmation is frustrated by the absence of a readily identifiable ice-marginal valley large enough to carry drainage from the entire Midcontinental area. It may well be, however, that the broad and deep bedrock valley of the Kansas River, now filled by alluvium to depths of about 30 m (99 ft) away from the narrow inner gorge was carved by this stream and that glacier advance south of the valley, thereby blocking this drainageway, was only short lived.

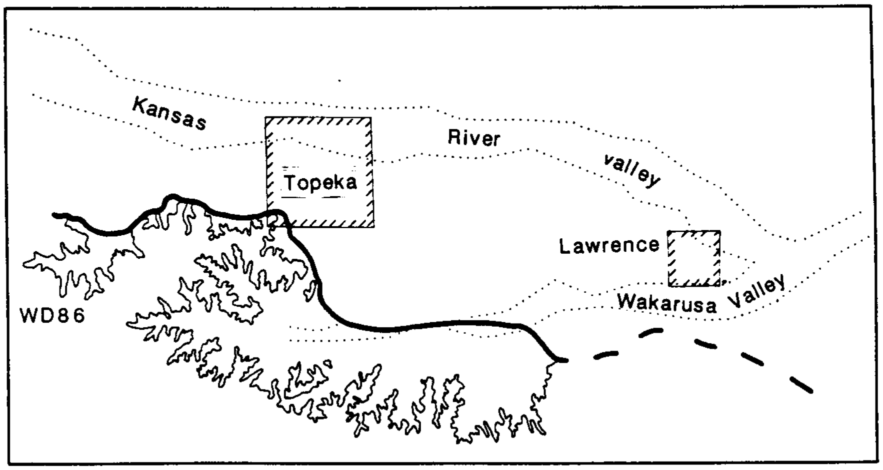


FIGURE 10—Pro-glacial lakes near Topeka and in the Wakarusa Valley.

Conclusion

Study of the Pleistocene history of Kansas is once more in a stage of rapidly expanding knowledge. Recognition of the multiplicity of glacial episodes and of ashfalls from distant volcanoes has made it necessary to revalidate or, more generally, modify previous concepts of stratigraphic relationships. Every sequence or correlation that was published prior to 1960 must be critically re-examined. This is clearly a time of change, but it is to be hoped that the urge to rush into print with new ideas will be tempered by the need for careful testing of hypotheses.

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STOP 6

Roadcuts along I–435 near Holliday Road exit: Section from Chanute Shale to Stanton Limestone

Location: (W/2 NE sec. 6, T. 13 S., R. 22 E.)

Arrive: 10:35 AM
Leave: 11:35 AM

(15-minute drive to next stop)

Contributors: *Lynn Watney, John French, Philip Heckel,* and *Evan Franseen*

Introduction

These outcrops in the vicinity of Stop 3 (identified by the letters A, B, C, and D in fig. 3-1), are some of the best known continuous exposures of Missourian cycles. Limited time precludes our examining the entire sequence, so we will concentrate on the interval from the Chanute Shale through the basal Argentine Limestone (section "A" of fig. 3-1). Fig. 3-2 (a, b, c, and d) is a composite measured section as prepared by Scott Johnsgard, 1984. Fig. 2-9 (C and D) includes a photo of west-facing exposure at Stop 3. The Bonner Springs Shale presented in this measured section (fig. 3-2 c and d) will be the focus of Stop 5. The gamma-ray profile and relative water-depth curve are included in fig. 3-3 (a and b). A gamma ray-neutron log from a nearby well has been correlated to the lithologies of this exposure (fig. 3-4).

Stratigraphy

The *Chanute Shale* is a typical outside shale that records the influx of deltaic clastics. Approximately 40 mi (64 km) to the south, the Chanute is a thicker shale that includes sandstones and coal. This is not a homogeneous shale unit, but contains significant variability exposed at this stop. Irregular carbonate lithoclasts in a maroon blocky mudstone found near the top of the Chanute Shale suggest both subaerial exposure and erosion. The boundary between the Iola sequence (above) and the Dewey sequence is placed at this position.

The *Iola Limestone* is another excellent example of a typical Kansas cyclothem. It represents one of the greatest Missourian marine inundations of the midcontinent. The Iola consists, in ascending order, of

The *Paola Limestone*, which is a more typical thin (1 ft, 0.3 m) transgressive limestone than is the Captain Creek Limestone seen at Stop 1. The Paola Limestone is the marine-flooding unit of the Iola sequence. It is a skeletal calcilutite containing a diverse biota and represents abrupt and shelfwide marine flooding. It can be traced in the outcrop from Oklahoma to Iowa and westward in the subsurface to at least eastern Colorado some 400 mi (644 km) to the west.

The *Muncie Creek Shale* is the core shale of the Iola cyclothem and the condensed section of the Iola sequence. The black, phosphatic facies of this unit, 1.5 ft (0.46 m) thick, is inferred to represent minimal sediment influx during a period of low bottom-water oxygenation that occurred during rapid eustatic rise. It is one of only five black, phosphatic core shales of Missourian age that extend to the Iowa outcrop belt, which is located about 200 mi (322 km) to the north (Heckel, 1986).

The *Raytown Limestone* is the upper (regressive) limestone of the Iola cyclothem. It is a skeletal and phylloid-algal wackestone that was deposited in quiet water, probably below storm-wave base. The thin, lenticular packstone at the top may be a storm deposit, or may record the passage of wave base as relative sea level fell prior to deposition of the succeeding unit. No evidence for subaerial exposure is indicated here or at other sites in the Kansas City area and southward. Besides the lack of subaerial exposure to the south, the Iola and Argentine limestones converge in Miami County 25 mi (40 km) to the south as the intervening "Lane" Shale thins markedly. Sea level fell to an intermediate shelf position between the Iola and Wyandotte sequences, rather than below the shelf margin as occurred with other major episodes of marine inundation. Ensuing rise in sea level took place somewhere in the "Lane" Shale, its precise location yet to be found. This turnaround in sea level is tentatively a sequence boundary, resembling a Type 2 (see appendix A).

The *Lane Shale* overlies the Iola Limestone. The "Lane" Shale is a typical outside shale that resulted from a northeasterly influx of siliciclastics. The terrigenous detritus probably resulted from progradation during eustatic stillstand and fall. Falling sea level or stillstand conditions would have provided time for the advance of these siliciclastics across the shelf. Nevertheless, sediment-accommodation space was sufficient for shallow-marine deltaic deposition.

As was discussed at Stop 2, thickness of the "Lane" Shale varies from 43 ft (13 m) at this stop to over 70 ft (21 m) about 10 mi (16 km) southeast of this outcrop to a pinchout only 7 miles (11 km) to the west of here. These lobate shale accumulations caused depositional topography conducive to formation of the overlying phylloid-algal buildups in the Wyandotte Limestone.

The *Wyandotte Limestone* overlies the "Lane" Shale. We will only examine the basal portion at this stop. In ascending order, the units within the Wyandotte Limestone seen here are

The *Frisbie Limestone* is the transgressive, or middle, limestone of the Wyandotte cyclothem. This unit represents a regional marine incursion (flooding unit of the Wyandotte sequence) that overstepped the "Lane" delta. Marine sedimentation extended beyond the Iowa outcrop belt some 200 mi (320 km) to the north. At this stop, near the center of the east slope, the Frisbie contains one excellent example of a number of discrete phylloid-algal buildups. Isolated phylloid-algal buildups are common in areas of moderately thick accumulations of the underlying "Lane" Shale (Arvidson, personal communication, 1989). These "mini" mounds are flanked by crinoidal grainstones. The phylloids are very obvious because they are unusually large. A systematic study of the Frisbie Limestone and the algal mounds done by George Coyle and Kevin Evans is being prepared for publication. They describe what they believe are algae in growth position. In situ preservation of algae will be seen later on the field trip.

The *Quindaro Shale* is the core shale of the Wyandotte cyclothem and the condensed section of the Wyandotte sequence. It is thin (0.75 ft [0.23 m]) and dark gray (with low gamma radiation) at this stop. However, it becomes black (with high gamma radiation) where the underlying "Lane" Shale is relatively thin. Such lateral variations in these core shales are not uncommon; the Eudora Shale that was exposed at the first stop also varies from gray to black over distances of only a few miles. Such facies variations suggest that oxygen-deficient conditions were restricted in some cases to bottom waters in paleotopographically low areas. In a well located near this exposure, the shale is not distinguishable on the gamma-ray log (fig. 3-4). In addition to being thin and near the detection limit of the wireline gamma ray, the Quindaro Shale also has low- gamma radiation indicated by the surface measurements taken at this exposure (fig. 3-3b). Thus, the Frisbie Limestone cannot be distinguished from the Argentine Limestone on conventional gamma-ray logs.

The *Argentine Limestone* is the upper limestone of the Wyandotte cycle. It is 19 ft (5.8 m) thick at this location. This exposure is located in an area of moderately thick Argentine Limestone associated with a flank position on a lobe of the "Lane" delta (fig. 2-4). This unit consists mostly of phylloid-algal wackestone at this locality and is capped by 3 ft (1 m) of coated skeletal packstone. As at Stop 2, no subaerial exposure is noted on this surface.

The *Farley Limestone* is developed as two distinct units as at Stop 2. Both units are notably thinner than at Stop 2 where they are phylloid-algal buildups, built farther down the flanks of the "Lane" delta than here at Stop 3. Here at Stop 3 the Farley Limestones are of normal thickness, 7 ft (2.1 m) for the lower Farley and 9 ft (2.7 m) for the upper Farley. As seen at Stop 3, it is an intertidal and shoal-water facies, perhaps suggesting that that location was more positive during deposition of the Farley Limestones than to the south at Stop 2. Best access to the Farley Limestone and the upper Argentine Limestone is on the west side of the road.

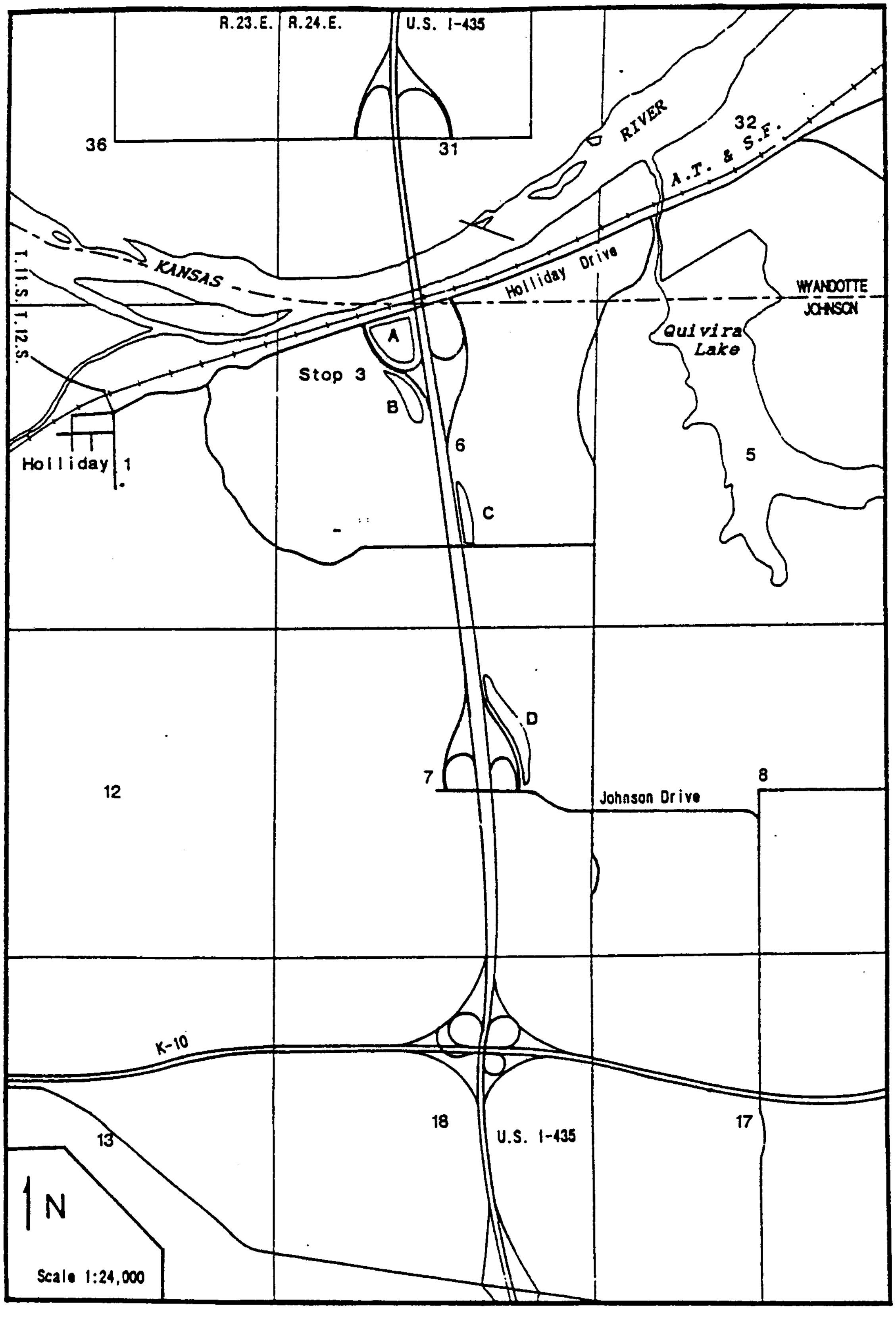


FIGURE 3-1. Location map of Stop 3 and sites A, B, C, and D used in preparing measured section provided with Stop 3 (fig. 3-2, from Johnsgard, 1984).

a

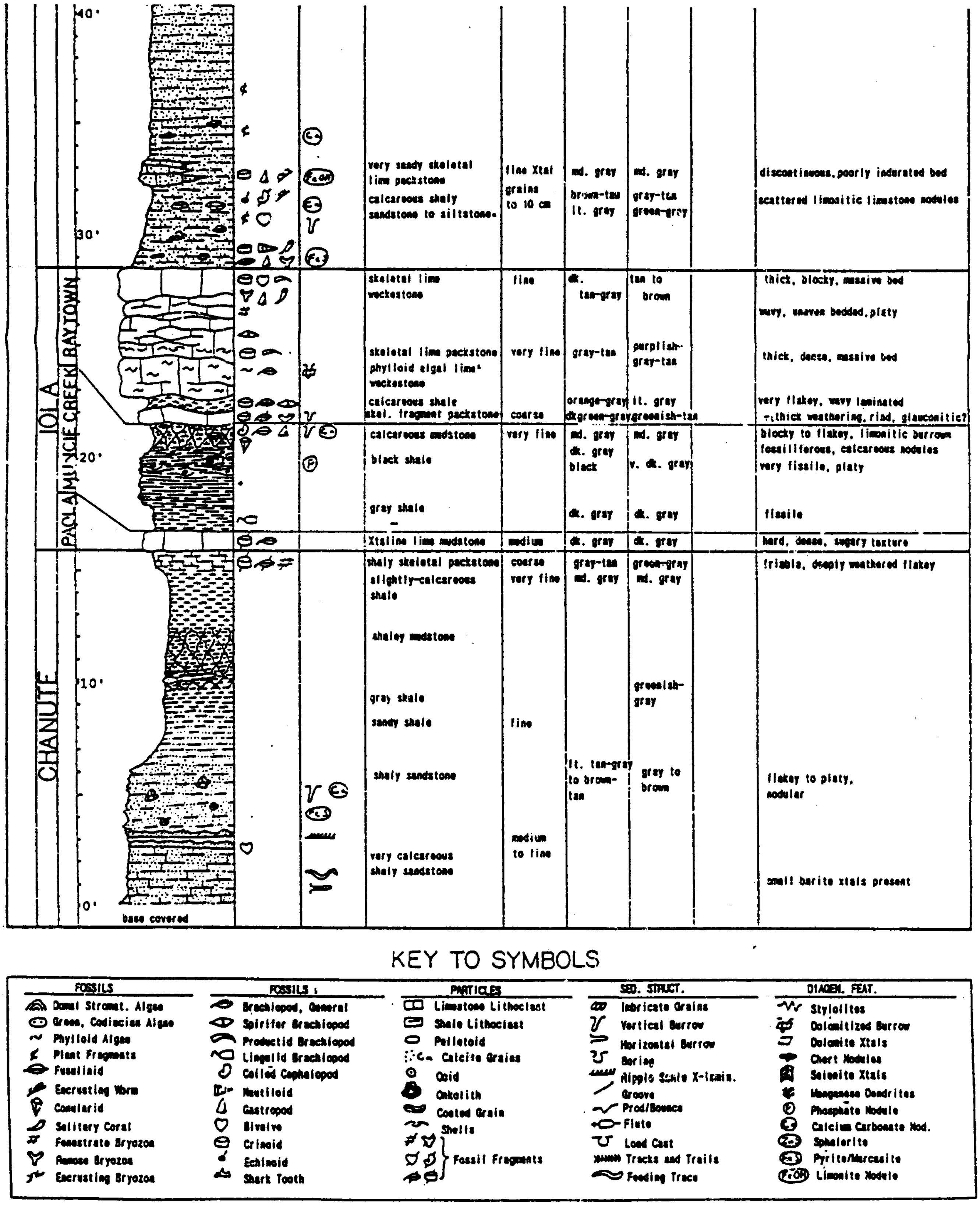
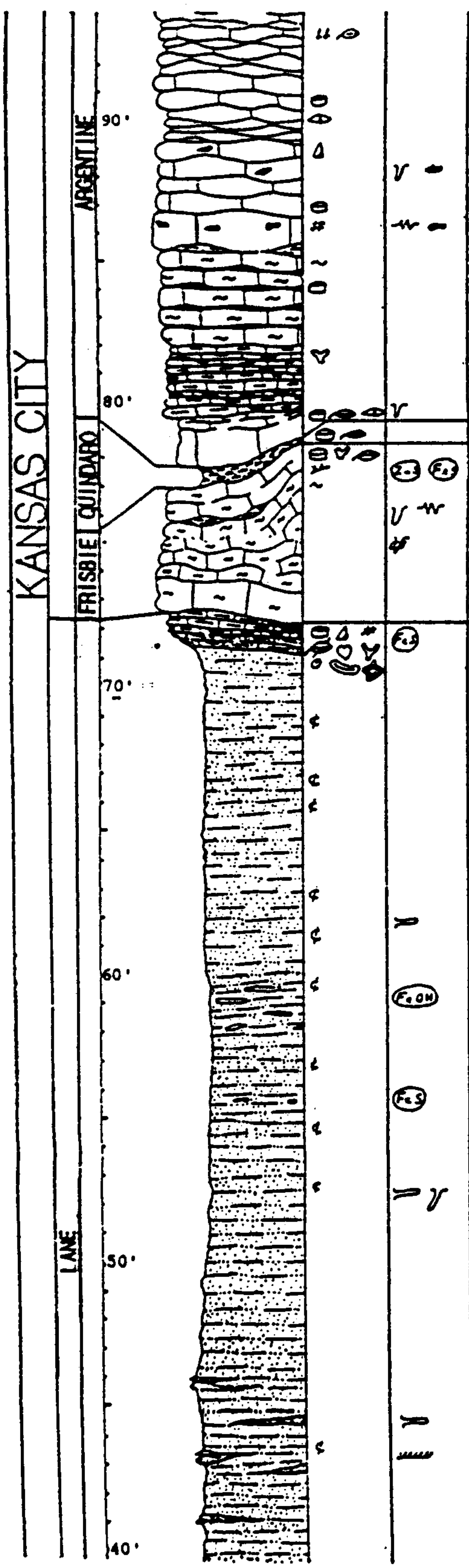


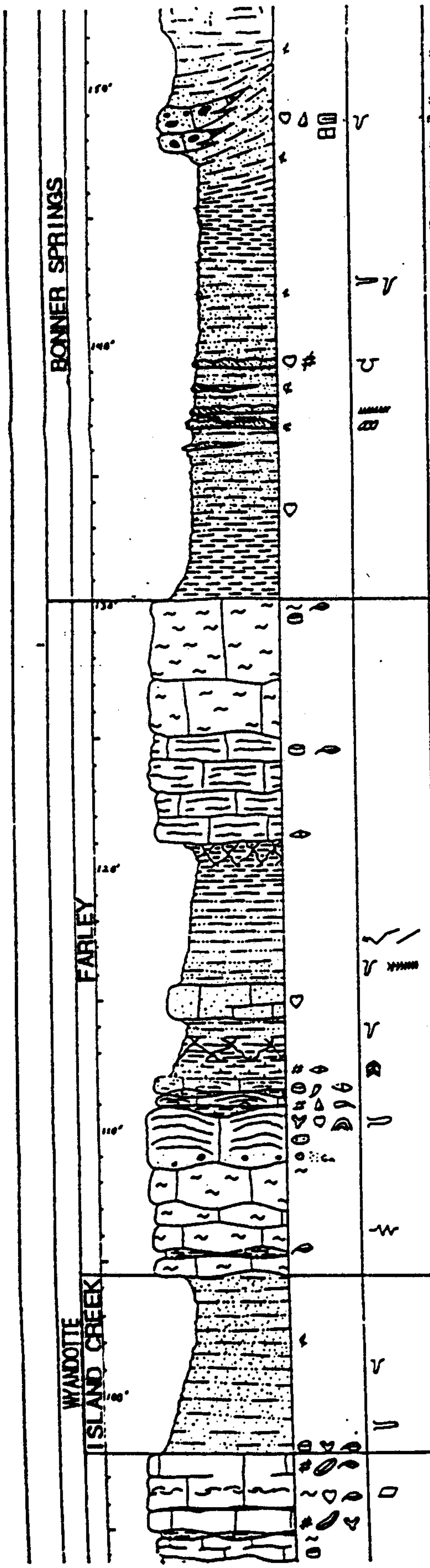
FIGURE 3-2 (A, B, C, D)—MEASURED SECTION OF LANSING AND UPPER KANSAS CITY GROUPS AT JOHNSON DRIVE AND HOLLIDAY DRIVE INTERCHANGES prepared by Johnsgard (1984).

b



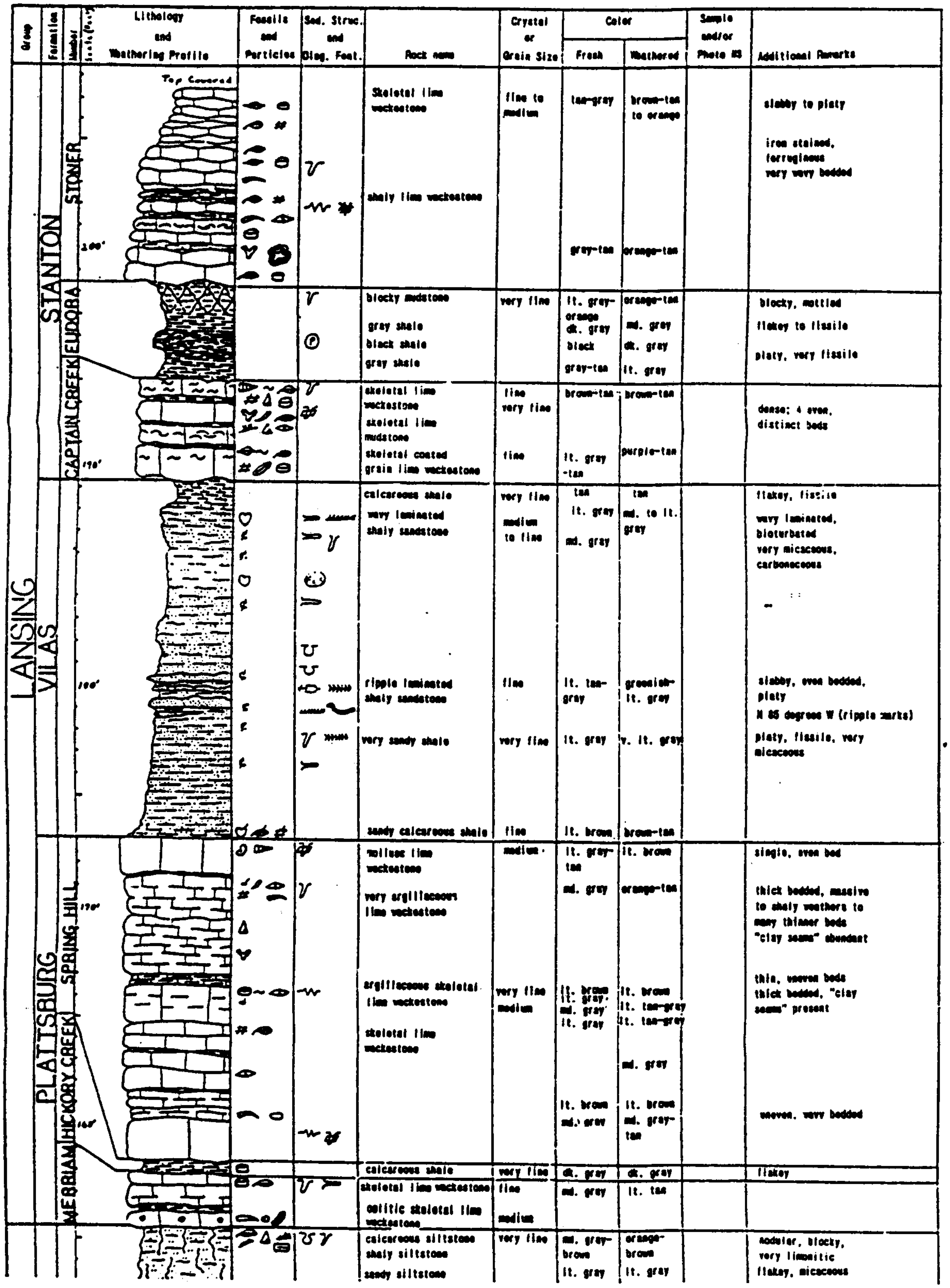
Skeletal phylloid algae lime wackestone		dk gray-tan md. gray	md. gray		thin to very thin bedded shale partings
skeletal lime mudstone	fine to very fine	lt. gray-tan	lt. gray-tan		thin, even bedded, shaly thick bed, weathers to recess
calcareous shale	very fine	dk. gry.blk	dk. gray		flakey to fissile
skeletal lime wackestone (locally) packstone phylloid algal bound(?) stone	very fine Xtal size very coarse grain size	brown-tan to orange-brown	purple-gray to brown-gray		dense, hard, chert-like, mottled locally biohermal, massive bedded calcite, dolomitic, sphalerite and pyrite in burrows and vugs
shaly crinoid packstone	coarse	dk. gray	md. gray		very friable
shaly sandstone to shaly siltstone	medium to fine	lt. to md. gray	greenish-brown-gray		flakey to fissile, micaceous

C



shaly sandstone	fine	md. gray	pink-gray		platy to fissile
sandy lithoclastic mollusc lime packstone	very coarse	md. brown	lt. gray		blocky, limonitic single channel(s) shaped bed
shaly sandstone	fine	md. gray	md. gray to lt. gray		platy, fissile
sandy shale	very fine				
gray shale					
shaly sandstone	fine				
ripple laminated shaly sandstone	medium to coarse		lt. gray		very micaceous
shaly sandstone	fine		md. gray		
sandy shale gray shale	very fine				fissile, shaly
skeletal phylloid algae lime wackestone to packstone	very fine	gray-tan	pale pink-tan		thick bedded, massive
stromatolitic(?) skeletal lime wackestone	fine	tan-gray	md. tan		vague laminations
shaly mudstone gray shale	very fine	md. gray	md. gray		fissile, flakey
shaly siltstone					platy, micaceous
shaly sandstone	fine				
lime mudstone	medium	gray-brown	pinkish-brown		single, persistant bed
shaly sandstone	fine	md. gray	lt. gray		flakey to fissile
shaly mudstone	very fine				
calcareous shale	fine	dk. brown	lt. brown		
stromatolitic skeletal lime wackestone	medium	orange to tan-gray	orange-tan		wavy to nodular bedded, domal stromatolitic(?) laminae
phylloid algal lime mudstone	fine	pink-tan to gray	pale pink-gray		sparse ooids & calcite grains
shaly sandstone	very fine	lt. gray	lt. gray		flakey
coated grain packstone	very fine Xtal size	tan-gray	brown-tan		3 even, distinct beds
skeletal wackestone	very coarse grain size				shells w/calcite, dolomite Xtals
coated grain packstone skeletal lime mudstone	very fine		gray-tan		wavy bedded, "clay seams" present

d



Group	Formation	Member	Scale (feet)	Lithology and Weathering Profile	Fossils and Particles	Sed. Struc. and Diag. Feat.	Rock name	Crystal or Grain Size	Color Fresh	Color Weathered	Sample and/or Photo #S	Additional Remarks
LANSING	STANTON	STONER					Skeletal lime wackestone	fine to medium	tan-gray	brown-tan to orange		slabby to platy
												iron stained, ferruginous very wavy bedded
							shaly lime wackestone					
									gray-tan	orange-tan		
		EUDORA					blocky mudstone	very fine	lt. grey-orange	orange-tan		blocky, mottled
							gray shale		dk. gray	md. grey		flakey to fissile
							black shale		black	dk. gray		platy, very fissile
							gray shale		gray-tan	lt. gray		
		CAPTAIN CREEK					skeletal lime wackestone	fine	brown-tan	brown-tan		
							skeletal lime mudstone	very fine				dense; 4 even, distinct beds
							skeletal coated grain lime wackestone	fine	lt. gray-tan	purple-tan		
	VILAS						calcareous shale	very fine	tan	tan		flakey, fissile
							wavy laminated shaly sandstone	medium to fine	lt. gray md. gray	md. to lt. gray		wavy laminated, bioturbated very micaceous, carbonaceous
							ripple laminated shaly sandstone	fine	lt. tan-gray	greenish-lt. gray		slabby, even bedded, platy N 85 degrees W (ripple marks)
							very sandy shale	very fine	lt. gray	v. lt. gray		platy, fissile, very micaceous
							sandy calcareous shale	fine	lt. brown	brown-tan		
	PLATTSBURG	SPRING HILL					mollusc lime wackestone	medium	lt. gray-tan	lt. brown		single, even bed
							very argillaceous lime wackestone		md. gray	orange-tan		thick bedded, massive to shaly weathers to many thinner beds "clay seams" abundant
							argillaceous skeletal lime wackestone	very fine medium	lt. brown lt. gray-md. gray lt. gray	lt. brown lt. tan-gray lt. tan-grey		thin, uneven beds thick bedded, "clay seams" present
							skeletal lime wackestone					
										md. gray		
									lt. brown md. gray	lt. brown md. gray-tan		uneven, wavy bedded
		HICKORY CREEK					calcareous shale	very fine	dk. gray	dk. gray		flakey
		MERRIAM					skeletal lime wackestone	fine	md. gray	lt. tan		
							oolitic skeletal lime wackestone	medium				
							calcareous siltstone	very fine	md. gray-brown	orange-brown		nodular, blocky,
							shaly siltstone					very limonitic
							sandy siltstone		lt. gray	lt. gray		flakey, micaceous

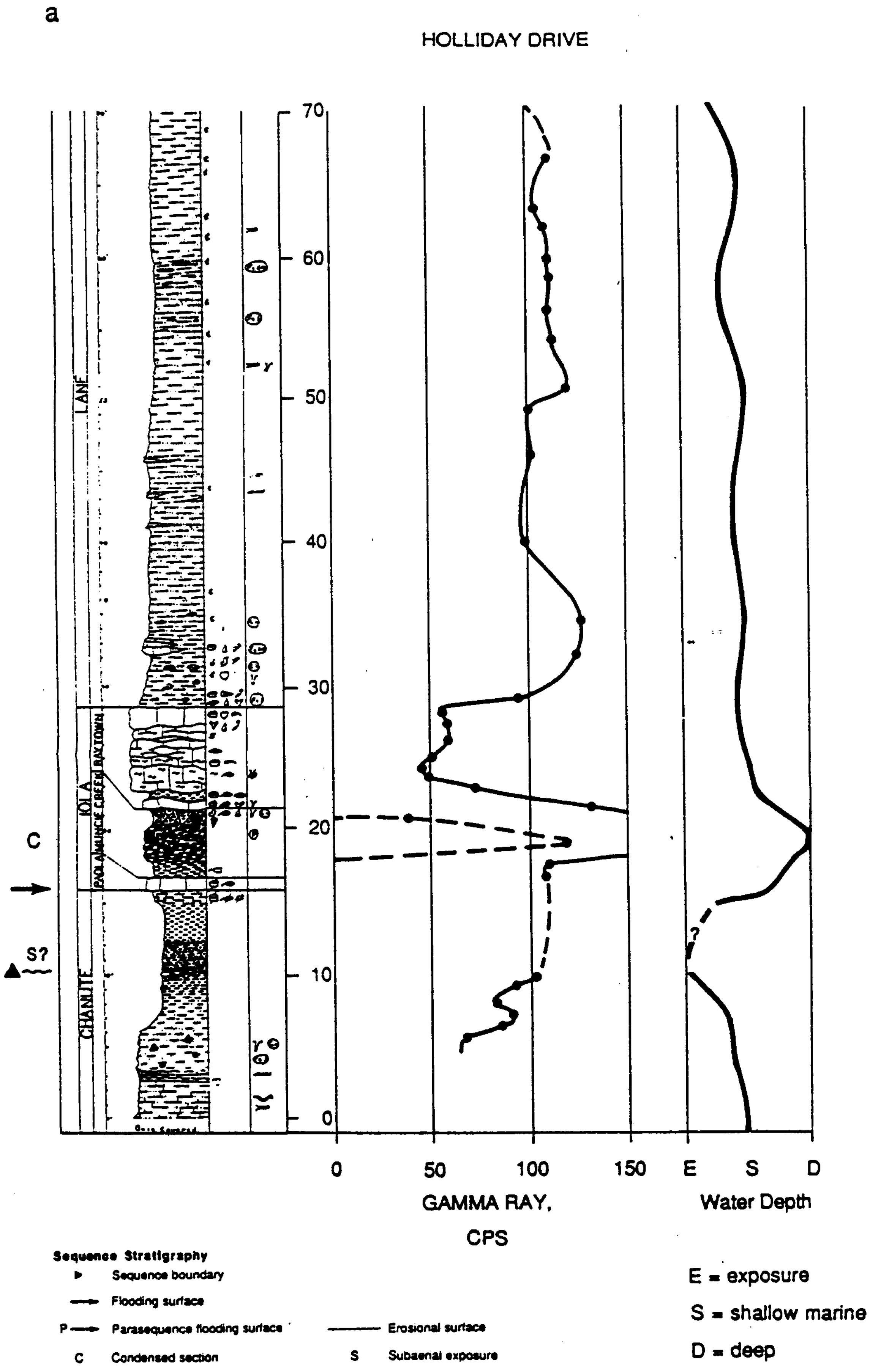
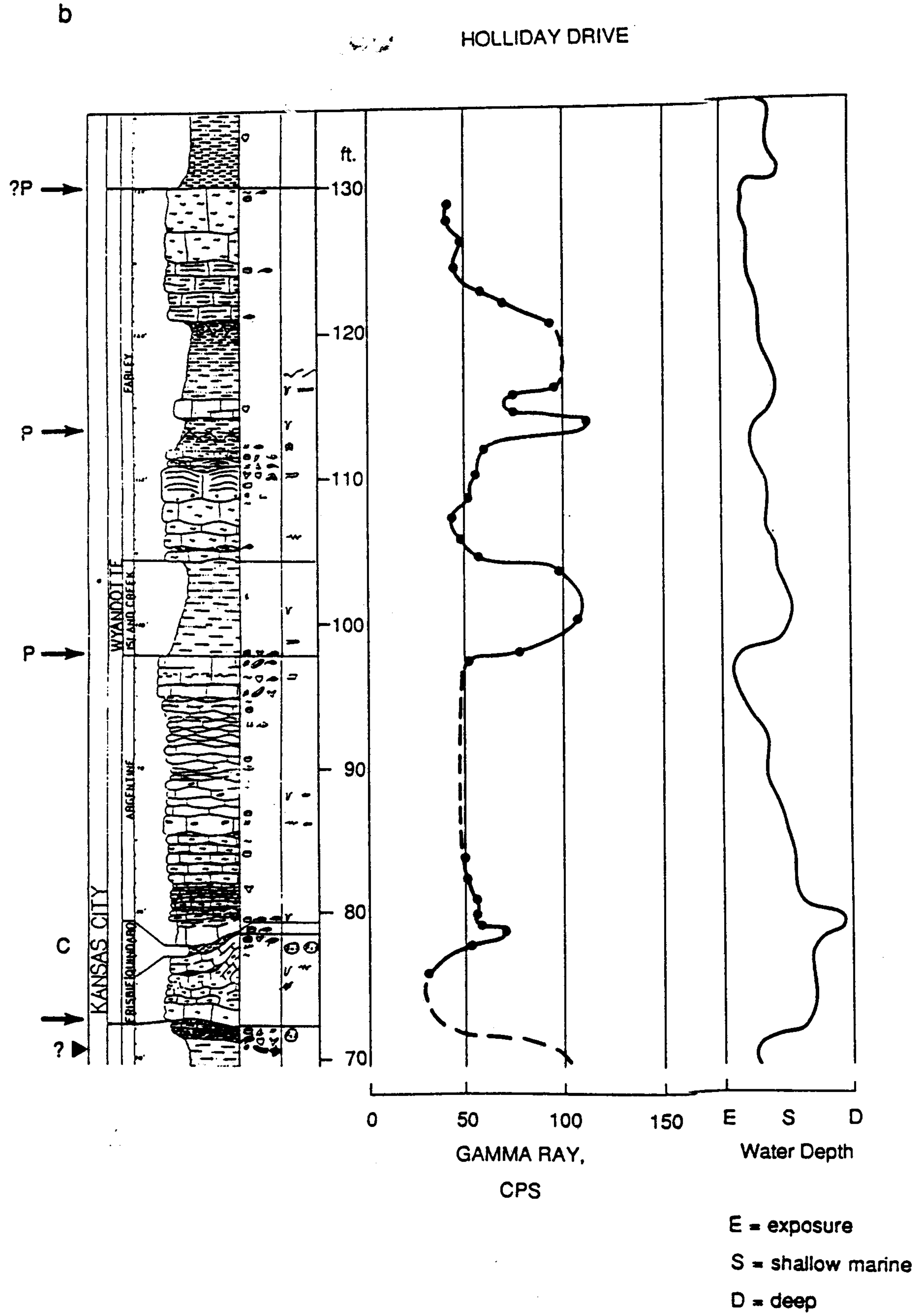


FIGURE 3-3 (A AND B)—STRATIGRAPHIC SECTION NATURAL GAMMA-RADIATION PROFILE, WATER-DEPTH CURVE, AND SEQUENCE CLASSIFICATION (extreme left) for lower portion of measured section in fig. 3-2.


b
HOLLIDAY DRIVE
?P
P
P
C
?
KANSAS CITY
WYANDOTTE
FARLEY
ISLAND CREEK
ARGENTINE
FRISBIE
QUINDARO
ft.
130
120
110
100
90
80
70
0
50
100
150
GAMMA RAY,
CPS
E
S
D
Water Depth
E = exposure
S = shallow marine
D = deep

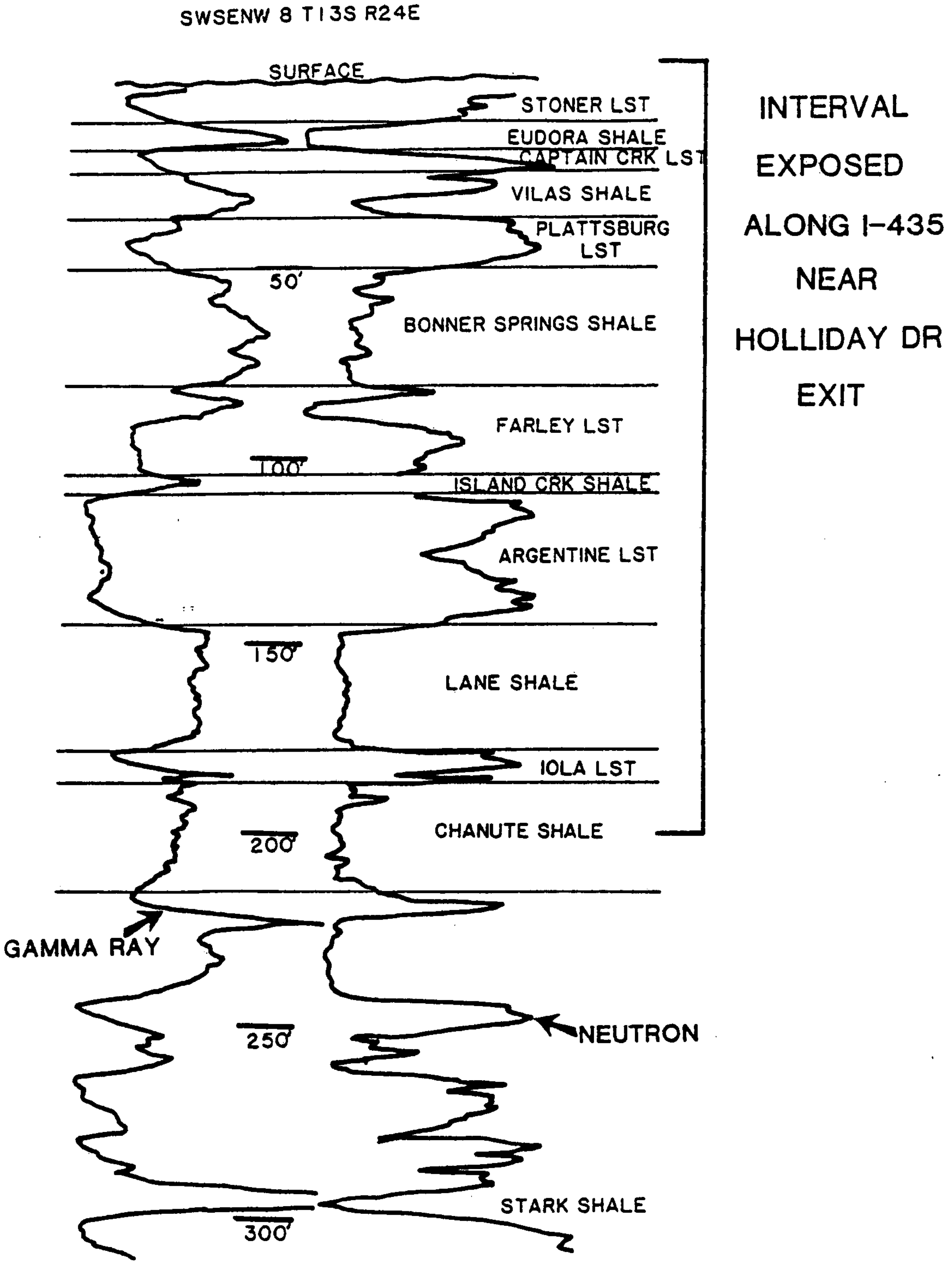


FIGURE 3-4—Correlation of formations in Lansing and Kansas City groups based on gamma ray-neutron log of well located near Stop 3.

STOP (7)

I–70/I–435 Interchange: Bonner Springs Shale and Plattsburg Limestone

Location: NE SW sec. 13, T. 11 S., R. 23 W., Wyandotte County, Kansas

Arrive: 11:50 AM
Leave: 12:50 AM

(10 minutes to lunch; lunch stop 40 minutes)

Contributors: *Paul Enos, Derek Herman, Lynn Watney,* and *Evan Franseen*

Introduction

At Stop 2 the depositional setting of the Bonner Springs Shale was briefly described as the outside shale of the Wyandotte Cyclothem. The Bonner Springs Shale also includes the boundary between the Wyandotte and Plattsburg sequences. The events which occurred at this boundary will be the focus of Stops 4 and 5 (fig. 3). Erosional downcutting, channel sandstones, marine backfilling of erosional topography, and laterally extensive paleosol development near the top of the Bonner Springs Shale at Stop 4 provide an unusual opportunity to examine features not normally preserved at the top of a sequence on the shelf.

Local expressions of erosional topography in the Bonner Springs Shale have been described along some 80 mi (129 km) of outcrop in eastern Kansas running from Wyandotte County to Franklin County (Ball et al., 1963; Harris, 1985; and Enos and Herman, in ms.). This stop, #4, focuses on a spectacular example of multiple episodes of erosional scouring and backfilling in the Bonner Springs Shale. In the succeeding stop (#5), we will briefly examine the Bonner Springs Shale in a more normal development with a capping paleosol.

A cross section prepared by Enos and Herman of measured sections at Stop 4 of the upper Farley Limestone, the Bonner Springs Shale, the Merriam Limestone, and the Spring Hill Limestone in the vicinity of the I–70 and I–435 interchange is shown in fig. 4-2. The index map (fig. 4-1) of the interchange locates the measured sections. Fig. 4-3 provides photos of the Bonner Springs Shale and adjacent units at and near Stop 4. We will make one stop along the northeastern cloverleaf to examine the more prominent and unusual channeling events in the Bonner Springs Shale. Please proceed with caution while on the roadside!

Stratigraphy

Commentary by Paul Enos and Derek Herman (excerpts from manuscript in preparation)

The section observed at Stop 4 includes the *upper Farley Limestone*, which is the unit locally truncated by the channel forms within the Bonner Springs Shale. The upper Farley Limestone averages 2.28 m (6.8 ft) thick and varies only ± 0.32 m (1 ft) in the local area. It is typically skeletal-lime packstone, but varies locally from skeletal mudstone to crossbedded ooid grainstone. Characteristic Farley fossils are brachiopods, (including *Composita*, productids), and bivalve fragments (locally including *Myalina*), phylloid-algal fragments, crinoid columnals, and fenestrate and ramose bryozoan and brachiopod spines. Encrusting organisms, probably worms and foraminifera, are abundant at Sections IX and VII (fig. 4-2). Coated grains are widely scattered in the unit but are concentrated only at Sections VII and IX.

The *Bonner Springs Shale* is a mixed bag of lithologies, as is typical of the thicker deltaic outside shales. In a typical section the Bonner Springs Shale in this area include olive-gray claystone through light-gray to olive-gray silty shale, to a discontinuous band of red to maroon-colored shale a meter or two below the top of the unit (Moore et al., 1951, p. 81; O'Conner, 1971, p. 20; Heckel, 1985, and Harris, 1985, measured sections). Siltstone and sandstone are widely distributed, particularly in the lower half of the unit. A calcareous paleosol is commonly developed above the maroon interval. This will be the focus of our next stop.

The thickness of the Bonner Springs in the vicinity is also extremely variable. Measurements in Wyandotte and northern Johnson County give an average thickness of 7.95 m ± 2.36 m (26.2±7.8 ft) in eight complete sections; the range is from 3.9 to 12.6 m (12.9–41.6 ft). Thinner intervals, down to 22 cm (9 inches), are truncated beneath the overlying Merriam Limestone.

The Bonner Springs Shale is largely unfossiliferous, but plant fragments occur locally within sandstone or nodular mudstone, and shelly fossils, including pectins, *Composita* and spirifid brachiopods, high-spired gastropods, and shell fragments occur near the top of the shale and within some sandstones. Trace fossils include vague burrows in both shale and sandstone intervals; *Zoophycos* and *Protovirgularia* braces in channel siltstones; well-developed U-tubes in a nodular mudrock near the top and starfish impressions in blue-gray claystone in the lower half (location VII; Harris, 1985, p. 35).

The *Merriam Limestone* is the middle limestone of the Plattsburg cyclothem and the flooding unit of the Plattsburg Sequence. It ranges in thickness from 0.31 to 4.88 m (1–16 ft) in 23 measured sections. Normal thickness averages 0.88 ± 0.33 m (0.9 ± 1.1 ft). Lithologically, the basal portion is typically a packstone, but ranges from very argillaceous, nodular- weathering yellow limestone to ooid grainstone. The middle portion of the bed, below the most prominent shale break, is typically a skeletal packstone containing prominent coated grains or oncoids (traditionally "*Osagia*"). Wackestone and oncoid or ooid grainstone are developed locally. An overlying shale bed or parting can be traced over most of the area. The top unit is one or two beds of skeletal packstone. Oncoids are locally prominent in this unit as well. Very argillaceous limestone caps, weathering yellow-brown, are developed at a few localities.

Although certain fossils or particles are particularly characteristic of the base, middle, or top portion of the Merriam, they do not define recognizable units, even locally. A wide variety of biota are developed throughout the interval or erratically in different portions. In order of decreasing abundance, these include: *Composita* brachiopods, crinoid columnals, gastropods, productid brachiopods, fenestrate bryozoans, fusulinids, bivalves, phylloid algae, spiriferid brachiopods, ramose bryozoans, echinoid fragments, brachiopod spines, solitary corals, encrusting bryozoans, pectins, encrusting worms, encrusting foraminifera, large scaphopods (to 5 cm [2 inches] long), and, very rarely, trilobites. A layer of *Composita* is locally prominent near the base of the Merriam and productids up to 5 cm (2 inches) wide are common in the middle portion of the unit in abnormally thick intervals. Prominent particles in the Merriam are oncoids and coated grains, ooids, peloids, unidentifiable skeletal debris, small carbonate and shale clasts, and sand grains locally at the base. Chert is present in some thickened intervals of the Merriam in the middle portion and burrows are prominent at the top, a characteristic noted statewide by McManus (1956).

The *Hickory Creek Shale* is a poorly developed core shale, probably the thinnest and palest in the entire Missourian Series. The unit is also the condensed section of the Plattsburg Sequence (fig. 4-2). The average thickness in 13 measured sections of "normal" development in Wyandotte and Johnson counties is 18.1 ± 5.7 cm (7.2 ± 2.3 inches); the range is from 7 to 27 cm (3–11 inches). Although the Hickory Creek is reported to contain a black, platey, carbonaceous zone in northern Johnson County and Wyandotte County (Newell, 1935, p. 72; Jewett and Newell, 1935, p. 181), we have not seen this development nor is it reported in this area by O'Connor (1971, p. 23), Mann (1957, p. 261) nor Ball et al. (1963, p. 13). The Hickory Creek is apparently nowhere developed as a black, fissile, phosphatic shale characterized by a "hot" gamma-ray response typical of core shales in the subsurface (Bryan Stephens, personal communication, 1987).

The Hickory Creek in Wyandotte and Johnson Counties is typically a dark-gray to olive-gray, flakey shale that weathers yellow to gray brown. It is sparsely fossiliferous, with a few crinoid columnals and brachiopods, although O'Connor (1971, p. 23) notes that it also contains abundant fenestrate bryozoans and fusulinids locally. A numerous but low-diversity molluscan fauna occurs in an anomalously thick Hickory Creek interval (Section V).

The bulk of the Plattsburg Formation consists of the regressive or upper *Spring Hill Limestone*, which ranges in thickness from about 3.1 to 7.1 m (10–23 ft) and averages 4.1 ± 1.2 m (13.5 ± 4 ft) in apparently complete sections in the area. It is predominantly skeletal wackestone, with lenses of grainstone and packstone. Characteristic fossils include abundant crinoid stems, productid, composita, and spiriferid brachiopods; fenestrate and ramose bryozoans; high-spired gastropods; a few corals; phylloid algae; and locally, orthocone nautiloids at the top.

Observations at I–70/I–435 Interchange

Taking it from the base up, the Bonner Springs Shale is fairly typically developed as a uniform, blue-gray shale with a few thin sandstone beds and the maroon marker bed near the top at section VII (fig. 4-2). Nowhere else in the exposures is the Bonner Springs typical. Northeast 300 to 850 m (1,000-2,800 ft, sections VIII-X, ramps E-N and N-E) the Bonner Springs interval is represented by up to 8.7 m (29 ft) of sandstone overlain by 1 m (3.3 ft) of sandy shale beneath a typical Merriam Limestone section (section IX). The upper bed of the underlying Farley Limestone Member is abnormally thin (0.75 cm [0.3 inch]) and shows very abrupt local relief with a bevel of 60 cm (24 inches) in thickness. A layer of lime-mud pebbles and bivalve shells plastered onto the Farley Limestone probably reflects reworking of the uppermost Farley prior to deposition of the sandstone. Small clasts of gray shale, less than 1 cm (0.4 inch) in diameter, are abundant throughout the sandstone, particularly in the base where beds of shale chips compose about half of the bulk. These shale clasts apparently represent the missing typical development of Bonner Springs Shale, ergo the victim of local erosion along with the top of the Farley Limestone.

The sandstone contains a few brachiopods (Harris, 1985), pectins, and high-spired gastropods. The overlying shale contains these fossils as well as fenestrate bryozoans and unidentified shell fragments. The sandstone is extensively ripple cross-laminated with a few festoon sets up to 30 cm (12 inches) thick. An excellent set of climbing ripple-drift cross-lamination is developed near the base. Current directions are persistently toward the east-southeast. Herringbone crossbedding is evident near the base, but no orientations could be measured.

This sandstone, which apparently eroded the entire Bonner Springs and beveled the top of the Farley Limestone, is truncated by a distinct hemi-channel form that removed all but 1.9 m (6.3 ft) of the sandstone in section X (fig. 4-2). The channel form is filled with 2.3 m (7.6 ft) of silty shale; silty, pebbly sandstone; and shale; it extends to the fossiliferous shale beneath the Merriam in Sections IX and VIII. This channel-form sand/shale sequence is in turn beveled by yet another hemi-channel form represented by abrupt westward thickening of the Merriam Limestone from 0.9 m (3 ft; possibly truncated by modern erosion) in section IX through 2.4 m (8 ft) in section VIII and 4.0 m (13 ft) in section X.

The nature of the Merriam expansion is best seen in sections VII, IV, and V where it clearly truncates a normal Bonner Springs Shale interval from 7.2 m to 1 m (23.7–3.3 ft) or less and may bevel the top of the Farley Limestone. An argillaceous interval at the top of the beveled Bonner Springs contains numerous pebbles of argillaceous limestone that are bored by tiny bivalves and heavily encrusted by worms and other organisms. These reworked pebbles, which may derive from the Farley Limestone or calcareous beds within the Bonner Springs, formed a lag in the base of the channel, where they were encrusted and bored.

The thickening of the Merriam involves some expansion of the uppermost limestone bed and an underlying, regionally persistent, intra-member shale; however, the most dramatic thickening is by introduction of numerous beds in the lower portion of the Merriam that are beveled, in a top-lap relationship against overlying beds. These beds contain abundant large (up to 5 cm [2 inches] wide) productids, tentatively identified as *Linoproductus*, *Echinochoncus*, and *Juresania*, and an expansion of the zone of abundant *Chonetes*, common near the base of the Merriam. These fossils are unbroken and many appear to be in life position.

The Hickory Creek Shale also thickens from 20 cm (8 inches) in section VII to 63 cm (25 inches) in section IV to 2.6 m (8.9 ft) in section V, its maximum known development in northeast Kansas. The lithology changes abruptly to a dark-gray, sooty-appearing, platey to flakey, calcareous shale. A low-diversity fauna of low-spired gastropods (*Trepospira* and, rarely, bellerophontids), bivalves (*Palaeoneilo* and pectins), brachiopods, (*Composita*), and, rarely, crinoid columnals occurs in the lower part. Some of the bivalves and gastropods are pyritized.

Finally, the Spring Hill Limestone also thickens in section V to about 6 m (20 ft). In section MB, 700 m (2,310 ft) southeast., the Spring Hill is 3.9 m (12.9 ft) thick and in section II, about 1,200 m (3,960 ft) east, it measures 3.4 m (11.2 ft). Bedding is disrupted and somewhat thickened at the base of the wavy-bedded interval in the lower Spring Hill where the Merriam thickens in section VIII.

To summarize relations at the I–70/I–435 interchange, a typical section of Bonner Springs Shale was reduced to shale clasts in a thick sandstone, which also bevels the top of the underlying Farley Limestone. The narrow sandy body is in turn truncated by a hemi-channel form filled with shale and thin sandstone beds. This channel form is beveled by thickening of the Merriam Limestone into yet another channel form which trends northeast-southwest through sections VIII, X, and IV, where the Merriam rests directly on a truncated surface of normal Bonner Springs Shale. The dramatic thickening of the Merriam is through introduction of beds in the lower portion that toplap against the uppermost Merriam. The Hickory Creek Shale and Spring Hill Limestone also thicken above and westward of the thickest Merriam Limestone. The expansion is approximately five-fold in the Merriam Limestone, 13-fold in the Hickory Creek Shale, and nearly two-fold in the Spring Hill Limestone. Thus, although truncation of underlying units and toplap bedding are seen only in the Merriam Limestone, the entire Plattsburg Limestone thickens. In all, three channel forms are superposed, including that containing the very localized sandstone. Channelization was repeated through a sequence of depositional environments that formed a typical hemi-cycle of sandstone, shale, and limestone, all bearing marine fossils.

Interpretation of Bonner Springs Shale channels

The thick sandstone development, the shale-pebble clasts, and the abrupt lateral terminations within the Bonner Springs Shale at I–70/I–435 appear unique for outside shales (or any other unit) in this area. Elsewhere the Bonner Springs contains only thin, channel-form sand lenses or thin sandstone beds that appear continuous on outcrop scale. These striking lateral changes were discussed by Heckel (1985) and Harris (1985). Heckel (1985, p. 34) proposed that the thinning of the Bonner Springs was . . ."the slope of a subaqueous prodeltaic and delta front sequence that was stranded. . ." and that the sandstone in section IX was delta-front related sand. He noted evidence for subaerial exposure and possible soil formation toward the end of Bonner Springs deposition based on the maroon shale marker and regarded this as evidence of "...further eustatic withdrawal of the sea." Harris cited (1985, p. 35) a) the presence of mud cracks (primarily in the former quarry at Stop 2), "sandy lags" (section VIII), and conglomerates near the top of the Bonner Springs; b) the 5° slope of the Merriam–Bonner Springs contact (sections IV and VII) in contrast to an average slope of half a degree on the Mississippi Delta front; and c) truncation of the maroon zone (section IV) as evidence "that the upper surface of the Bonner Springs

Shale is the result of [subaerial] erosion...along an unconformity."

We agree with Harris that the upper surface of the Bonner Springs is erosional, liberally sculpted by channels, both at and near the top, and with both Heckel and Harris that subaerial exposure near the close of Bonner Springs deposition is indicated by the data cited above. Marine transgression began, however, before the end of Bonner Springs deposition as indicated by marine fossils in the uppermost portion at a few localities. This marine interval is truncated along with the underlying subaerial nodular carbonate and maroon shale. Moreover, the fill of each of the three superposed channels is marine. The sandstone contains a few brachiopods at the base as well as pectins and high-spired gastropods (sect IX, fig. 4-2). The overlying sand-shale sequence (sections X, IX, and VIII) contains Myalina clams, pectins, high-spired gastropods, and bryozoans. The Merriam contains an abundant marine fauna dominated by euryhaline brachiopods. The intra-Bonner Springs channels on I–435/ Holiday Road also contain a marine fauna. Subaerial erosion of each channel would require yo-yo style oscillations of sea level.

Delta lobes are the traditional interpretation of sand bodies within outside shales and unusually thick silty-shale intervals. This interpretation fits the typical Bonner Springs, but the suite and succession of rock types, the ripple-drift and climbing ripple sets, the current reversals, and the small-scale festoons at the I–70/I–435 interchange are typical only of tide-dominated, high-destruct deltas (Miall, 1984), which are unlikely in the low-energy shallow seas of the midcontinent. The postulated slope on the delta front is clearly erosional as demonstrated by truncation of bedding within the Bonner Springs, including the maroon shale, and the superposition of multiple channels. Heckel's argument for a stranded delta seems unlikely. The origin of the Bonner Springs channels must be related to the superimposed thickened intervals of Merriam Limestone.

Interpretations of thickened intervals of Merriam Limestone

Several hypotheses are possible for the local expansion of Merriam Limestone, with or without concomitant thinning of the Bonner Springs. Positive relief on the Merriam could result from mud banks or carbonate deltas such as those in the modern Florida Keys (Enos and Perkins, 1979). A more likely alternative would be some relationship to linear oolite bodies in the Merriam of Franklin County (Ball et al., 1963). The scale, discontinuity, and general alignment of the oolite bodies suggest tidal oolite bars (Ball, 1967). The trend of the expanded intervals in Johnson and Wyandotte Counties, is comparable to that in Franklin County (north-northeast–south-southwest). However, the mud content of Merriam packstones and wackestones in the thick intervals rules out analogy with high-energy oolite shoals apparently represented by the crossbedded oolite bodies in Franklin County. In addition, the truncation of the underlying Bonner Springs Shale and other evidence of channelization presented above militates against any depositional configuration involving positive relief. The hemi-channel forms are interpreted as bonafide channels. It remains to identify the processes that formed them.

Processes responsible for channel formation

Channels could by incised into underlying units by fluvial, storm, or tidal erosion. Fill of the channels variously with sandstone, shale, and muddy limestone, each with exclusively marine or brackish fossils, limits the possibilities. Terrestrial processes would require repeated erosion without deposition, preservation of narrow channels, and repeated marine transgressions to fill the channels, each of which appears improbable even in isolation. Channelization in violent storms such as hurricanes is known (cf. Ball et al., 1967); however, it involves breaching of local barriers and does not produce elongate channels such as indicated for the Merriam. Also, deposits of violent storms are chaotic mixtures of mud and coarser clasts, typically in thin sheet-wash blankets (Hayes, 1967; Ball et al., 1967; Perkins and Enos, 1968) deposited in the upper flow regime. Storms would also fill any pre-existing channels with such chaotic deposits.

Each channel studied appears to truncate less erodible deposits, either more cohesive or coarser grained than those that fill the channel. This suggests that cut and fill were either in different environments or at different intensities. The presence of extensively bored and encrusted pebbles at the base of Merriam channels also suggests a finite period during which the channels were open before final filling. Apparently the channels were cut by rather ephemeral, strong currents and filled under different and varied sedimentary regimes. Tropical storm deposition is a possibility in the low latitudes of the Pennsylvanian in the midcontinent (Heckel, 1983; Ziegler et al., 1979). In channels filled by carbonate or argillaceous deposits, however, the muddy texture of the sediment; its resolution into a number of distinct, well-defined beds; and the occurrence of brachiopods in growth position all attest to lack of strong currents during channel fill. Processes active over long periods are also indicated by the thick sequence of low-energy deposits. It cannot be demonstrated, however, that processes of long duration cut the channels.

Tidal currents appear to be the only common submarine process capable of producing the channel forms and marine sediments developed at the Bonner Springs–Plattsburg transition. Herringbone crossbedding developed locally in the sand-filled channel supports a tidal regime. The only direct evidence of currents during the deposition of the Merriam are the large-scale inclination and toplap in the lower beds (figs. 1, 10, 13). The initial limestone beds in the Merriam drape the channel wall (figs. 1, 13, 17, 18); they do not overlap as stated by Harris (1985). Subsequent beds terminate by toplap as the Merriam thins toward the channel margins. Toplap reflects building up to a base level, presumably either local wave base or sea level. The relatively thick, crossbedded ooid grainstone lenses in Franklin County and thin lenses of grain-supported ooids and oncoids in virtually all local Merriam sections reflect at least episodic agitation by strong currents. This suggests sea level as the control rather than wave base.

Is it reasonable to infer episodic high-tidal energy in the shallow "tideless seas" (Shaw, 1964) of the midcontinent? Repeated occurrences of crossbedded oolite near the tops of upper, regressive limestones throughout the Missourian (Moore et al., 1951; Heckel, 1983) are affirmative evidence. Skeletal rudstones in the Farley Limestone show opposing current directions, indicating tidal activity, and local channels at the base of the Captain Creek Limestone contain crossbedded conglomerates, a testimony of high energy (Enos et al., in ms.).

Lunar tides are essentially lacking in many modern shallow seas, such as Florida Bay and the Bahama Banks (Ginsburg, 1956; Enos and Perkins, 1979). Wind is capable of moving large bodies of water, however, and producing rather energetic "tidal" currents (Enos and Perkins, 1979; Hardie, 1977). This was probably the prevalent condition in vast epeiric seas of the midcontinent. Wind-generated water movements would be more focused into strong currents during lowered sea levels of early transgression and late regression, where high-energy deposits are concentrated.

The uppermost shale and limestone beds in the Merriam thicken somewhat, but do not display toplap. This suggests continued presence of a shallow channel and a rise in base level with the transgression, as deduced by Heckel from the conodont assemblages (*in* Watney et al., 1985, p. 34). The persistence of channels would also explain thickening of the Hickory Creek shale and Spring Hill Limestone where the Merriam is thickest. Effective scouring of the channels almost certainly ceased early in Merriam deposition, as indicated by muddy lithologies and upward changes in bed geometry. Scouring was not a factor during maximum transgression represented by the Hickory Creek, a core shale (Heckel, 1985). Either channels were cut deep enough so that they were not completely filled during Merriam deposition, or differential compaction of the thicker channel fill maintained some relief during deposition of the other cyclothem members. Toplap in the lower Merriam indicates that the channel was filled to an effective wave base, but continued rise in sea level apparently removed this constriction.

Another possible mechanism for maintaining local relief is some kind of very local subsidence. Unlikely as this may seem, it would also explain why three channels come to be superposed through the normal cyclothemic progression of depositional regimes. It could also explain a long, straight channel such as might extend from I–70/I–435 to K–10 at Cedar Creek, if some structural element such as an incipient fault controlled subsidence. However, it would not adequately explain the persistent and widespread occurrence of channels in Wyandotte and northern Johnson counties.

A more likely explanation is lateral funneling of currents by pre-existing relief developed by algal banks in the underlying Wyandotte Formation (Crowley, 1969). Crowley showed that the Bonner Springs reflects some inherited relief and this inheritance may have profoundly influenced currents and deposition even in the Stanton cyclothem that overlies the Plattsburg (Enos et al., in ms.).

The change in lithologic character of the Hickory Creek Shale with the increase in thickness at I–70/I–435 interchange also suggests a depression on the sea floor. Local bathymetric highs have been called upon to explain the loss of black color, carbon content, and fissility within core shales where they projected through a pycnocline that produced anoxic conditions elsewhere on the sea floor (Heckel, 1977). The Hickory Creek is nowhere developed as a black, fissile, carbonaceous shale, but the *Trepospirid–Paleoneilo* assemblage in the thickened Hickory Creek contains forms closely related to those that occur under dysaerobic conditions at the top of the oxygen-minimum zone (Boardman et al., 1984). With no record of a regional pycnocline, the reduction in oxygen level probably reflects stagnation in a local depression, the relict channel. This thickened Hickory Creek Shale will be pointed out on the northeast corner of the interchange.

Discussion

The concentration of channels within and at the top of the Bonner Spring Shale suggests that the simple Irwin–Shaw model of seas transgressing over an essentially planar surface (Irwin, 1965; Shaw, 1964) is not invariably appropriate to transgression in midcontinent cyclothems. Disruptions in the normal transgressive sequence at the base of the superjacent Stanton cyclothem (Enos et al., in ms.) show that such interruptions are not unique, at least in the local area of Johnson and Wyandotte counties. Other local anomalies have been documented by the detailed stratigraphy of Philip Heckel and his students (cf. Heckel, 1986) and by ongoing work of Lynn Watney and John French, Kansas Geological Survey. Even the classic layer-cake stratigraphy of the midcontinent demonstrates many responses to local conditions such as depositional relief and therefore is not all "layer-cake."

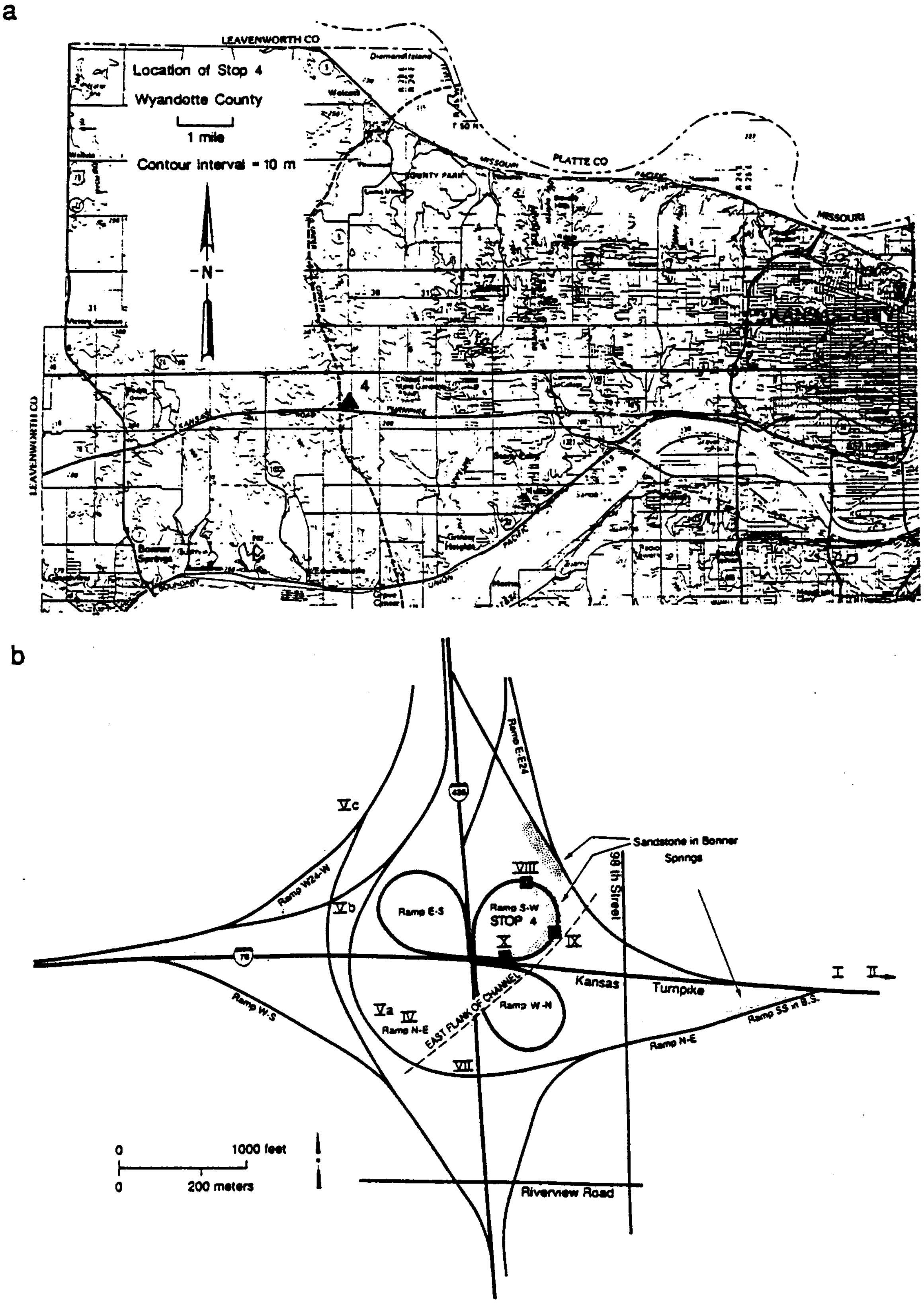


FIGURE 4-1(A and B)—Location map for Stop 4 in Wyandotte County (A) and index map showing intersection with location of Stop 4 along northeastern cloverleaf of interchange of I–70 and I–435 and location of measured sections used in cross section (fig. 4-2a and b) identified with Roman numerals. Stippled pattern represents sandstones of Bonner Springs.

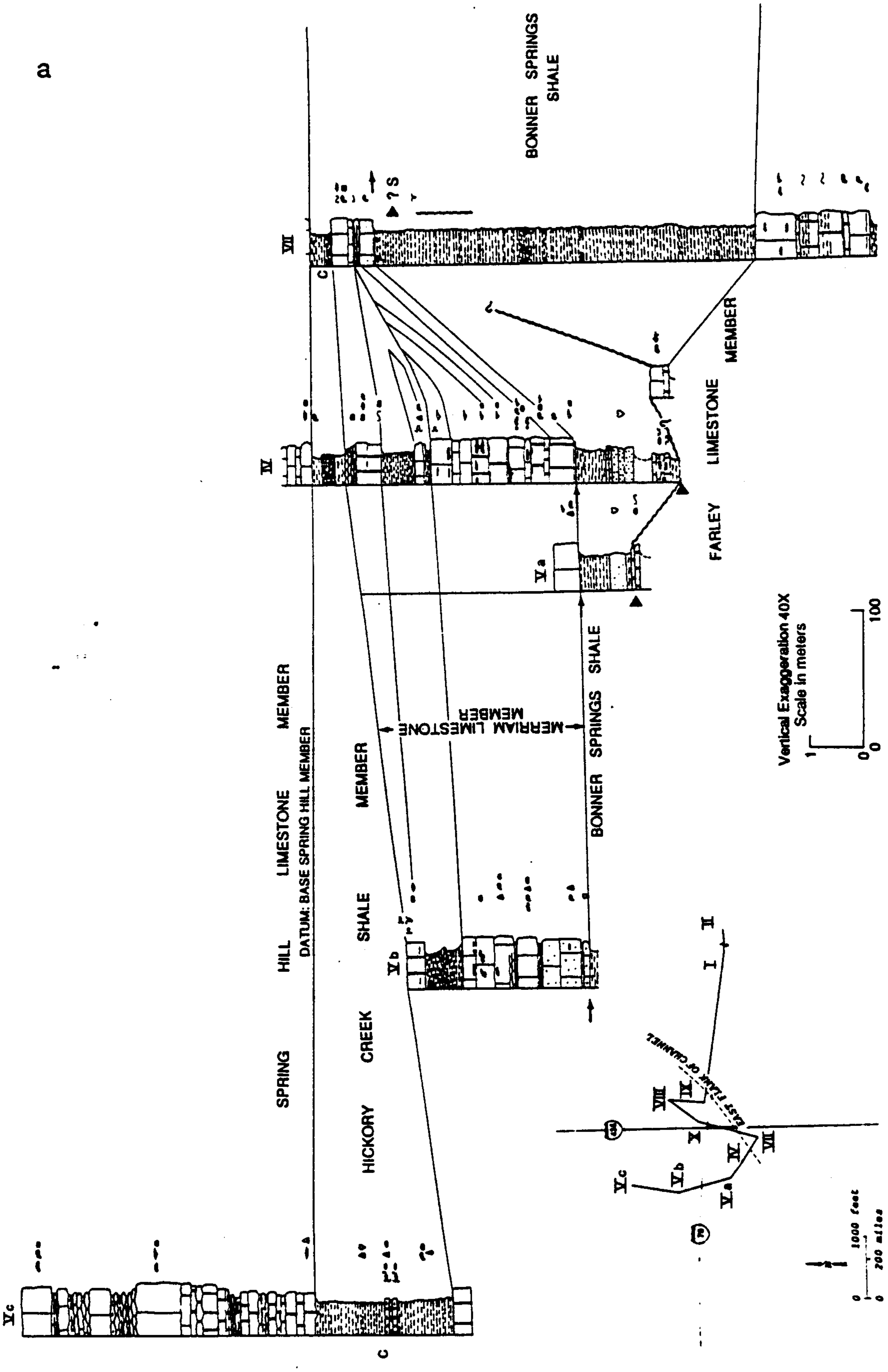


FIGURE 4-2(a and b)—Northwest-to-east stratigraphic cross section through I-70/I-435 interchange area based on measured sections and interpretations (less sequence interpretations) by Enos and Herman, in ms. Datum for the cross section is the base of the Spring Hill Limestone. Uppermost Farley Limestone, Bonner Springs Shale, Merriam Limestone, Hickory Creek Shale, and Spring Hill Limestone are included in section.

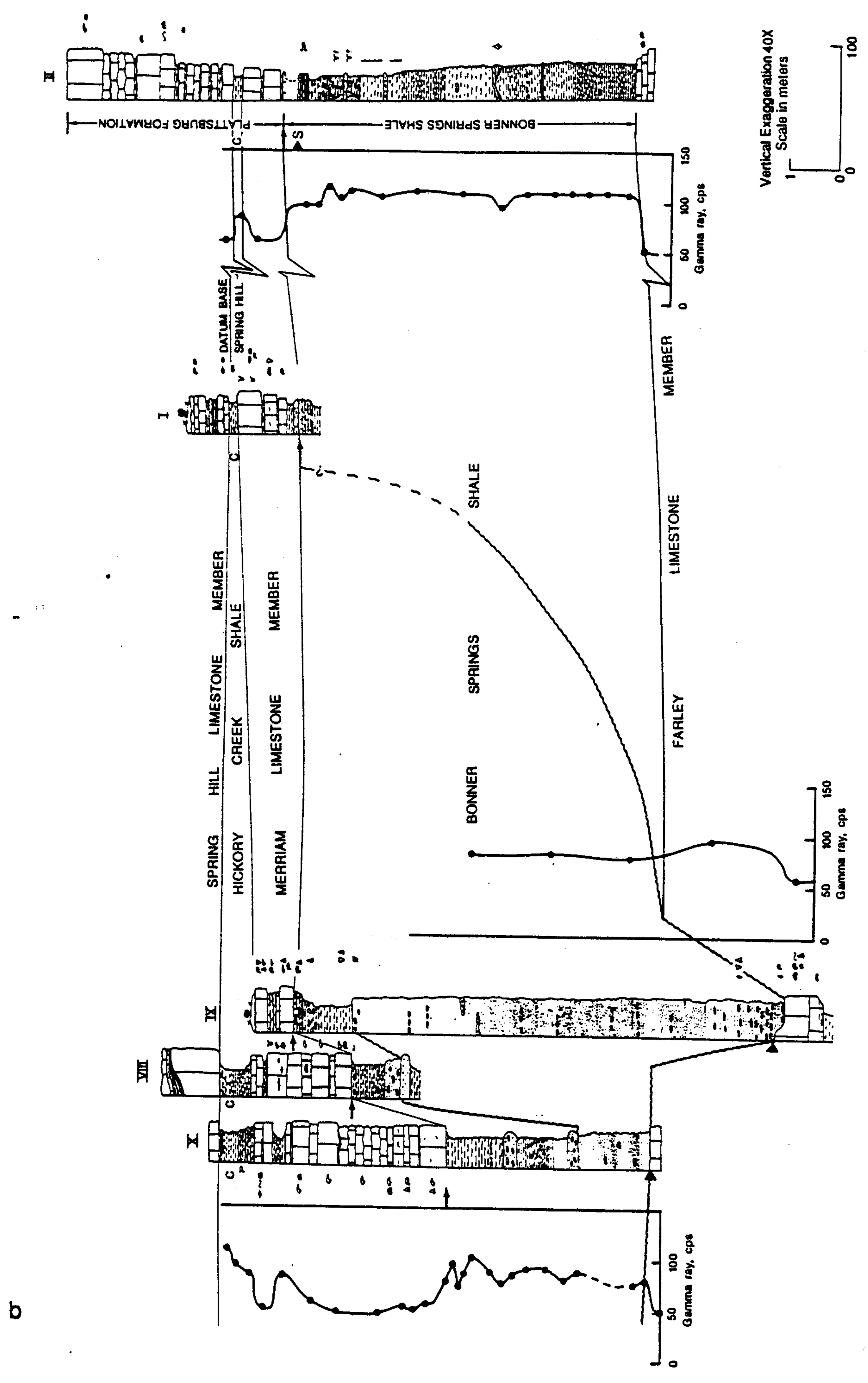
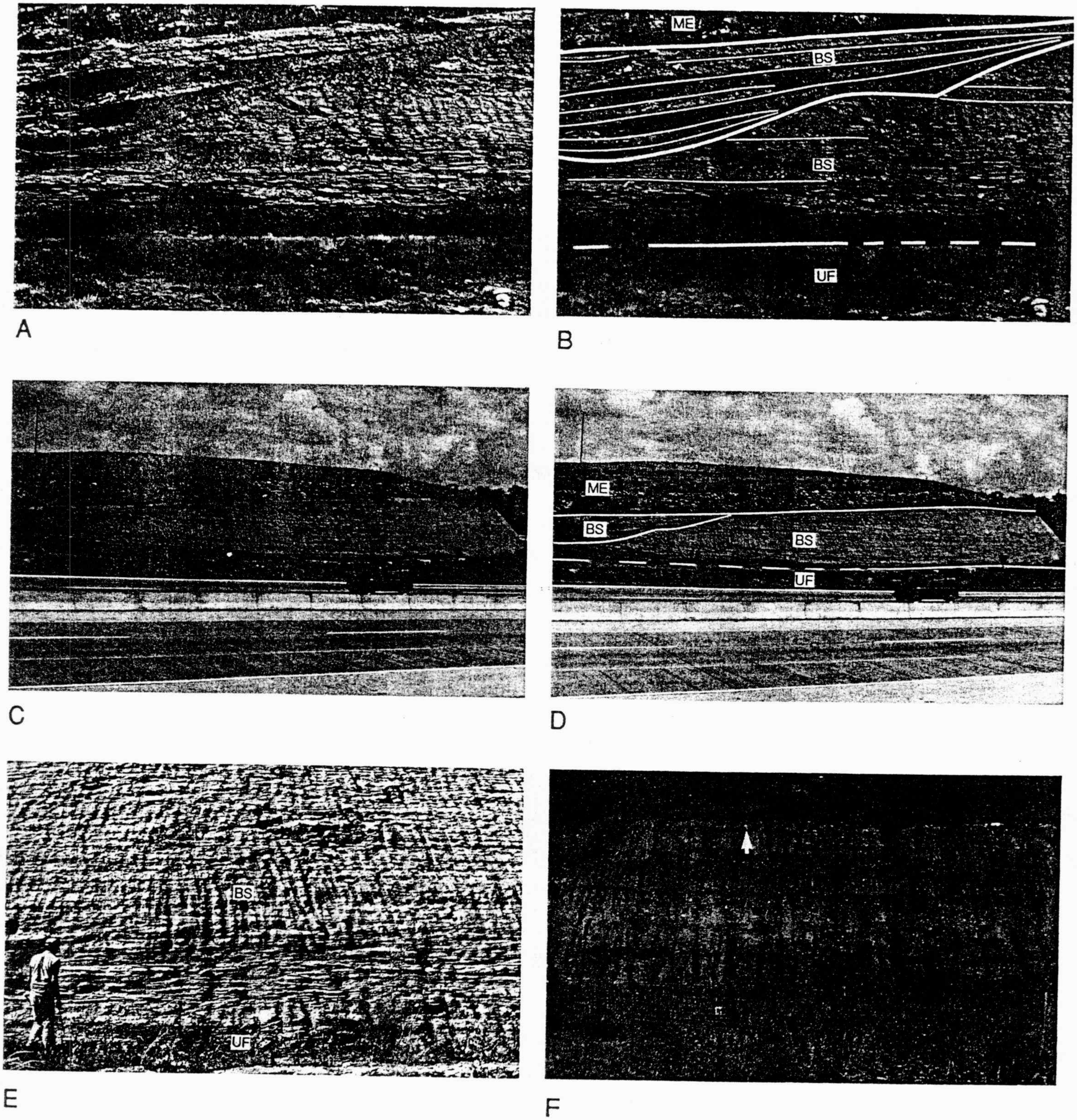

b
II
I
IX
VIII
X
PLATTSBURG FORMATION
BONNER SPRINGS SHALE
DATUM BASE
SPRING HILL
SPRING HILL LIMESTONE MEMBER
HICKORY CREEK SHALE
MERRIAM LIMESTONE MEMBER
BONNER SPRINGS SHALE
FARLEY LIMESTONE MEMBER
C
S
0
50
100
150
Gamma ray, cps
Vertical Exaggeration 40X
Scale in meters
1
0
0
100

FIGURE 4-3(A and B)—Bonner Springs Shale at Stop 4 showing sandstone of Bonner Springs (BS) resting on locally eroded upper Farley Limestone (UF) near section X. Sandstone is cut by erosional surface beneath a hemi-channel form which extends up to near the base of the Merriam Limestone (ME). Hemi-channel is filled with Photos are close-up of left portion of fig. 4-3(C and D). Note hammer left of center for scale (1 ft [0.32 m]).

FIGURE 4-3(C and D)—South side of Stop 4, northeast clover-leaf of intersection of I–70/435, between sections X and IX. Large channel-form sandstone in Bonner Springs Shale passes diagonally (northeast-to-southwest) through this exposure. Sandstone is cut by deep erosional surfaces beneath hemi-channel forms. Merriam Limestone, ME, thickens to left into hemi-channel form seen on opposite side of this clover-leaf. UF, upper Farley Limestone, resides at the base of the Bonner Springs Shale. It is locally eroded beneath the sandstone, losing elevation quickly to the lower right of this photo.

FIGURE 4-3(E)—Close-up of east face of sandstone in Bonner Springs Shale at Stop 4 (section IX). The sandstone includes a few festoon cross sets up to 30 cm thick and herringbone cross-bedding near the base.

FIGURE 4-3 (F)—Typical Bonner Springs Shale (section II) shown in fig. 4-2(b). Upper portion commonly contains maroon interval (beneath base of arrow) that is overlain by a calcareous paleosol horizon (point of arrow). The maroon interval is clearly truncated near section VII, on the southwest side of I–70/435 intersection.


A
ME
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