

**KANSAS GEOLOGICAL SURVEY**  
**OPEN-FILE REPORT 92-29**

Douglas County/Johnson County Field Trip for the  
Kansas Association of Earth Science Teachers

3 October 1992

by

Rex Buchanan  
Jim McCauley

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**KANSAS GEOLOGICAL SURVEY**  
1930 Constant Avenue  
University of Kansas  
Lawrence, KS 66047

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ASSOCIATION OF EARTH SCIENCE TEACHERS**

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## ROAD LOG

KESTA FIELD TRIP, 3 October 1992

by Rex Buchanan and Jim McCauley

Kansas Geological Survey

The following field trip runs from Lawrence to the Kansas City area, then returns to Lawrence. It focuses on Pennsylvanian formations, mostly limestones and shales, that were deposited about 300 million years ago, and will provide several opportunities to collect the invertebrate fossils that were common in those shallow Pennsylvanian seas. We also will see evidence of glacial, wind, and river deposition from the Pleistocene, during the past million years.

- 0.0        **Kansas Geological Survey.** From the Survey's parking lot, proceed south.
- 0.2        Iowa Street/U.S. Highway 59. Proceed south.
- 0.5        23rd Street. Turn west (right) onto Clinton Parkway and proceed past the Shenk Recreational Sports Complex.
- 1.0        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.
- 1.5        Kasold Drive.
- 2.7        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, of course, 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. Mount Oread replaced the hill's earlier name--Hogback Ridge. 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. Pilot Knob (which overlooks

high ground around Pleasant Grove south of Lawrence are all capped by the Oread Limestone and form part of a steep east-facing slope and a gentle west-facing slope that reflects the gentle westerly dip of the rocks.

- 3.0 Wakarusa Drive. Before development in Lawrence reached this far west, this street had the less euphonious name of Dragstrip Road.
- 3.2 The **Plattsmouth** and underlying **Toronto limestone** members of the Oread Limestone are exposed in readouts as the road descends from the Oread Escarpment.
- 3.6 **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.
- 3.8 The road climbs through the **Lawrence Formation** and much of the **Oread Formation**.
- 4.3 **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, director of the Kansas Survey from 1916 to 1954 (and after whom the Survey's headquarters is named), was one of the 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.

- 4.6 Stop sign. Turn south on County Road 13, the "Corps Road."
- 4.8 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.
- 5.1 North end of **Clinton Dam**. 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.
- 5.5 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.
- 6.2 The town of **Clinton** is three miles to the west on a peninsula between the two arms of the lake. Two miles west, now under water, is the site of Bloomington, a ghost town when the lake was constructed.
- 6.8 South end of **Clinton Dam**. Here the road again climbs briefly onto the Oread Escarpment.
- 7.0 The road climbs through the **Toronto limestone**, up to the **Plattsmouth limestone**, then descends through the same units.
- 7.2 **STOP 2**. 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.
- 7.8 Stop sign. Turn north on Douglas County road 458 , traveling across the Buck Creek Terrace of the Wakarusa River.
- 8.2 Here the road drops onto the **floodplain of the Wakarusa**.
- 8.3 T-road intersection. Turn east.
- 8.9 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.
- 9.5 **Washington Creek**. This creek begins in southwestern Douglas County and is impounded to form Lone Star Lake. Washington Creek dumps into the Wakarusa just north of here.
- 10.0 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.
- 11.5 Stop sign. Turn north on U.S. 59.

- 11.6 **Wakarusa River** has its source in eastern Wabaunsee County, where it drains part of the east face of the Flint Hills.
- 12.4 Here the highway leaves the floodplain and climbs back onto the **Buck Creek Terrace**.
- 12.8 Traffic light. Turn east (right) on 31st Street.
- 13.4 The road drops off the Buck Creek Terrace and returns to the **Wakarusa floodplain**.
- 13.8 Stop sign. Louisiana Street. For the next mile, 31st Street passes along the north edge of a large wetland that extends a mile south to the Wakarusa River.
- 14.4 To the north are several of the buildings that comprise Haskell Indian Junior College.
- 14.8 Haskell Street (Douglas County road 1055). Turn north (left).
- 15.0 **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. This outcrop displays the angled lines of crossbedding that are indicative of sediment deposited by flowing water.
- 15.8 Traffic light at intersection with 23rd Street and Kansas Highway 10. Turn east (right).
- 18.6 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 a flood in 1951, 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 during the days of Bleeding Kansas.
- 18.9 **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.
- 19.2 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.
- 20.3 **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.
- 20.8 **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.
- 20.9 **Orange glacial deposits** are exposed north of the highway.
- 22.9 The town of **Eudora**, named after the daughter of a Shawnee Indian chief, is north of the highway.
- 24.6 **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.
- 24.8 **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.
- 24.9 **Captain Creek** (elevation 785 feet). The Captain Creek Limestone Member, visible throughout the field trip, is named after this stream.
- 25.2 **Captain Creek limestone**. This is also the Douglas County/Johnson County line. Douglas County is named after 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.
- 26.4 **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 this year.
- 27.5 **Stoner Limestone Member** of the Stanton Limestone.
- 27.8 **STOP 3**. 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.
- 28.2 **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.
- 29.2 **Captain Creek limestone.**
- 29.7 Kansas Highway 285 to the town of **DeSoto**, named after the discoverer of the Mississippi River.
- 30.4 **Kill Creek** (elevation 770 feet). Kill is an old Dutch word for creek.
- 30.6-30.9 **Captain Creek limestone**, overlain by **Eudora shale**, overlain by the **Stoner limestone**, all members of the Stanton Limestone.
- 31.5-31.9 **Captain Creek limestone.**
- 32.3 **Stanton Limestone.**
- 32.7-32.9 The highway descends through members of the **Wyandotte Limestone**, which averages 60 feet in thickness in the area.
- 33.1 **Camp Creek** (elevation 780 feet).
- 33.4 **Cedar Creek.**
- 34.1 **Iola Limestone** overlain by **Lane Shale** in a roadcut along a county road to the north.
- 34.3-34.8 **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.
- 35.2 **Captain Creek limestone** (elevation 1,000 ft).

- 35.5 **Stoner limestone.**
- 35.6 **Captain Creek limestone.**
- 36.0 **Plattsburg Limestone.**
- 37.0 Kansas Highway 7 Interchange. K-7 runs 10 miles north to Bonner Springs and 7 miles south to Olathe.
- 38.7 The highway passes through the southern 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 "squirrely." 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.
- 38.8 **Stanton Limestone.**
- 38.9 **Plattsburg Limestone to the north.**
- 39.2 **Bonner Springs Shale.**
- 39.5 **Mill Creek.** The Wyandotte Limestone is exposed in the walls of the creek immediately south of the highway.
- 39.9 **Plattsburg Limestone overlain by Vilas Shale.**
- 40.1 **Stanton Limestone.**
- 40.2 **Plattsburg Limestone overlain by Vilas Shale.**
- 40.7 The **asphalt plant and quarry north of the highway** are in the Wyandotte Limestone.
- 40.8 **Bonner Springs Shale overlain by Plattsburg Limestone.**
- 41.2 Junction with I-435 headed north. The Plattsburg Limestone is exposed through this interchange, along with parts of the underlying Bonner Springs Shale and overlying Vilas Shale. This interchange is also in the midst of the Olathe Northeast oil field. Discovered in 1982, it produces from Squirrel sand of the upper Cherokee Group. The pumpjacks in this field are small because the oil here is shallow, only about 500 feet underground.
- 42.3- **Stanton Limestone.**
- 42.6
- 42.8 **Underground limestone mine to the west.**
- 43.0 **Stoner limestone.**
- 43.9 **Stoner limestone.**
- 44.4- The highway descends through the **Stoner**, underlain by the
- 44.6 **Eudora shale**, underlain by the **Captain Creek limestone**, underlain by the **Vilas Shale**.
- 44.7 The **Vilas Shale**, at the top of this roadcut, contains a white to buff sandstone and lies atop the Plattsburg Limestone.

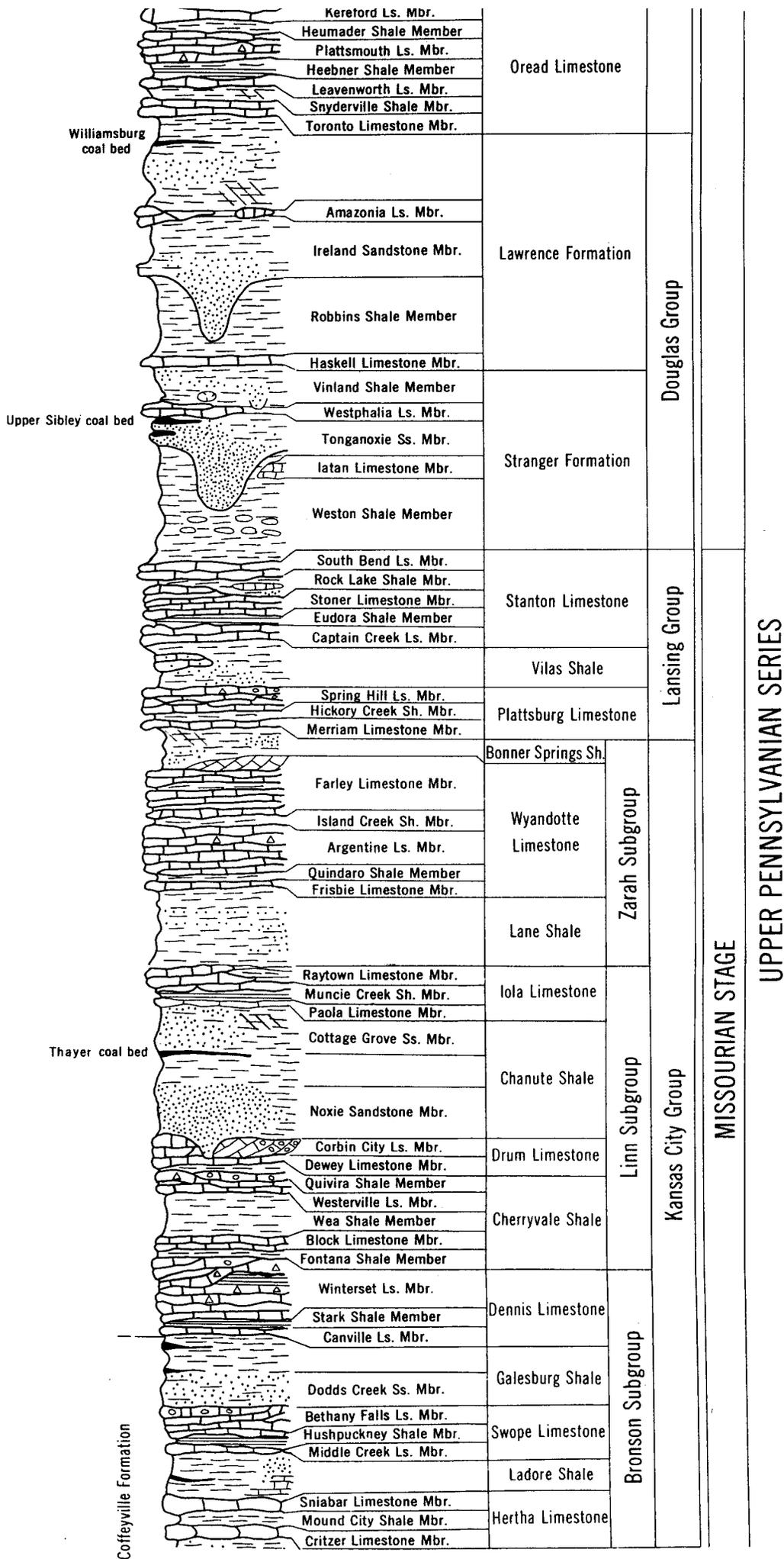
- 44.9 Upper and lower limestones in the **Farley Limestone Member** of the Wyandotte Limestone, overlain by **Bonner Springs Shale** and **Plattsburg Limestone**.
- 45.2 **Wyandotte Limestone** is exposed in the south wall of Little Mill Creek valley. The thick limestone is the Argentine limestone, above the Lane Shale.
- 45.3 **Little Mill Creek**.
- 46.0 **Bonner Springs Shale** overlain by **Plattsburg Limestone**.
- 46.2 **Plattsburg Limestone** overlain by **Vilas Shale**, which again includes layers of sandstone.
- 46.4 Kansas Highway 12/Shawnee Mission Parkway and exposures of the sandy **Vilas Shale** overlain by the **Captain Creek limestone**.
- 47.1-  
47.6 Various exposures of **Plattsburg Limestone**.
- 48.2 **Holliday Drive exit**. To the west, the Farley limestone is overlain by the Bonner Springs Shale and the Plattsburg Limestone. Here the Farley is composed of two limestone beds and a considerable amount of shale.
- 48.9 **STOP 4** 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. Holliday was a small town a mile west of here that was named after Cyrus Holliday, founder of the

Atchison, Topeka, and Santa Fe Railroad, which runs along the south bank of the Kaw, adjacent to the roadway.

Proceed south on I-435 to crossover, then turn north onto I-435.

- 50.2 **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.
- 50.8 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.
- 51.2 Kansas Highway 32 underpass.
- 54.8 Interstate 70. Take the west exit. **STOP 5** 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.
- After this stop, continue west on I-70, climbing upward through the Plattsburg Limestone, Vilas Shale, to the Stoner Limestone Member of the Stanton Limestone.
- 56.5 **East Mission Creek.**
- 56.7 **Tonganoxie Sandstone Member** of the Stranger Formation.
- 57.7 **West Mission Creek.**
- 58.5 Exit for K-7 to Leavenworth and Bonner Springs. Toll booth for Kansas Turnpike.
- 59.5 **Tonganoxie sandstone.**
- 60.3 The top of the **Stanton Limestone** down through the **Vilas Shale, Plattsburg Limestone,** and the **Bonner Springs Shale.**
- 60.9 **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.
- 61.3 **Bonner Springs Shale** overlain by **Plattsburg Limestone.**
- 61.7 **Stanton Limestone.**
- 62.2 **Tonganoxie sandstone.**
- 66.8 **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.
- 67.8 **Stoner limestone.**

- 69.3 South of the highway is an exposure of a thin coal bed in the Stranger Formation. These coals were once mined in this vicinity and other parts of northeastern Kansas, but today coal mining is limited to the southeastern corner of the state.
- 70.5 **Cow Creek**, one of seven Cow creeks in Kansas.
- 70.7 **Stranger Formation** overlain by reddish Pleistocene deposits.
- 71.1 Sandstone in the **Stranger Formation**.
- 72.0 **Nine-mile Creek**.
- 73.6 Lawrence Service Area.
- 74.4 **Kent Creek**.
- 76.6 **Mud Creek**.
- 76.9 **Douglas County/Leavenworth County line**.
- 77.3 A **river channel** abandoned by the Kansas River. The slightly higher ground east of this channel is underlain by the Newman Terrace, seen early in the field trip.
- 78.4 To the north is another old **river channel**.
- 79.2 **East Lawrence Interchange**.
- 79.5 **Kansas River**. 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.
- 80.5 West Lawrence Interchange.
- 82.3 Ninth Street. This again marks the edge of the Oread escarpment.
- 83.1 15th Street. The **Toronto limestone** is exposed in the northeast corner of this intersection.
- 83.3 **Daisy Hill**. Exposure of Leavenworth and Plattsmouth limestone members of the Oread Limestone are visible in the roadcut.
- 83.4 To the west is **Pioneer Cemetery**, burial place for victims of Quantrill's raid on Lawrence in 1863. This is also the burial place of R.C. Moore.
- 83.6 Nineteenth Street. **Kansas Geological Survey**.



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

## 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).

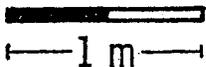
The Toronto Limestone of the Oread Formation (the lower limestone in Moore's megacyclothem classification) may represent an intermediate marine inundation separate from the transgression accounting for the Oread cyclothem (Troell, 1969). The black Heebner Shale Member of the Oread cyclothem is attributed 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.

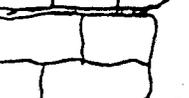
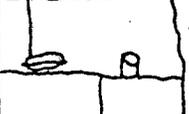
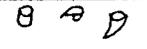
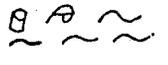
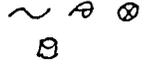
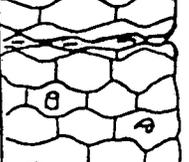
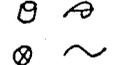
We would like you to begin the examination of the exposure with the Amazonia Limestone near the base of the slope and work your way up to the upper portion of the Plattsmouth Limestone at the crest of the exposure. The stratigraphic relationships are identified for you in the attached measured section.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

#### References Cited

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- Heckel, P.H., 1977, Origin of phosphatic black shale facies in Pennsylvanian cyclothem of Mid-Continent North America: Amer. Assoc. Petroleum Geol. Bull., v. 61, p. 1045-1068.
- Moore, R.C., 1936, Stratigraphic classification of the Pennsylvanian rocks of Kansas: Kansas Geol. Survey Bull. 22, 256 p.
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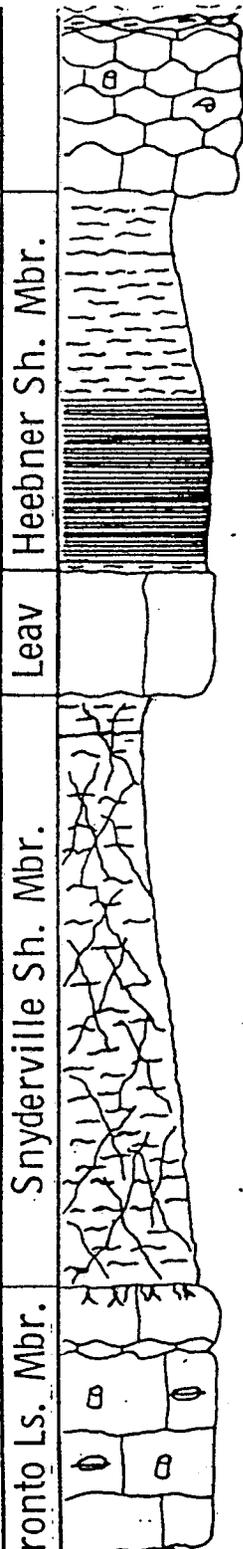
Measured Section of Clinton Spillway  
Douglas Co., Kansas

Vertical Scale :  1 m

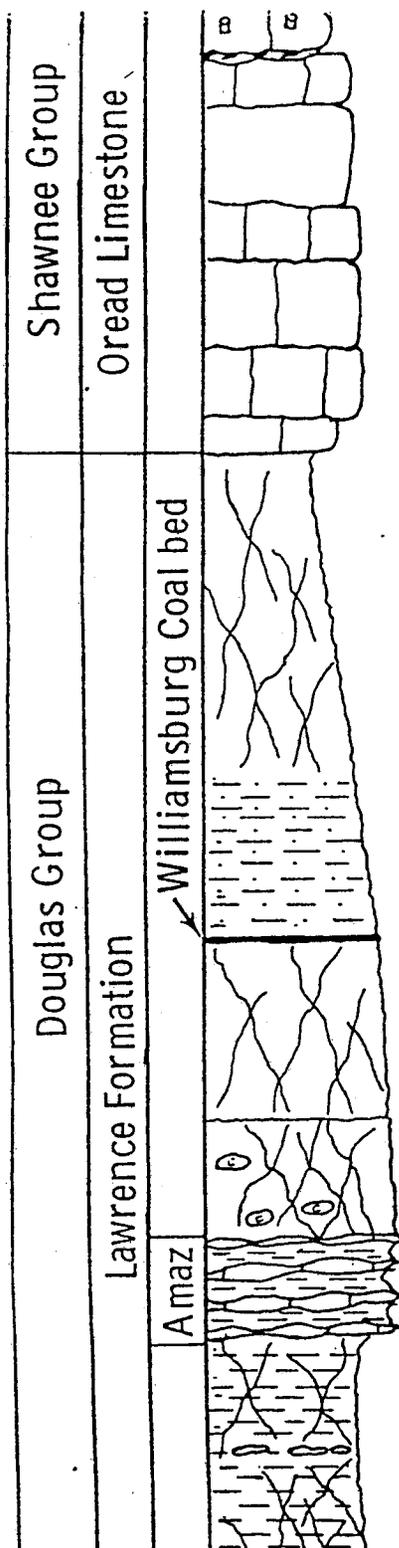
Group	Formation	Member	Lithology and Weathering Profile	Sed. Struct.	Rock Name	Fossils Particles	Color Fresh/ Weathered	Grain Size	Dia-genetic Features	Remarks
Shawnee Group	Oread Limestone	Plattsmouth Ls. Mbr.:			fusulinid packstone					
					fusulinid packstone		brown-rusty orange			
					skeletal 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

Shawnee Group

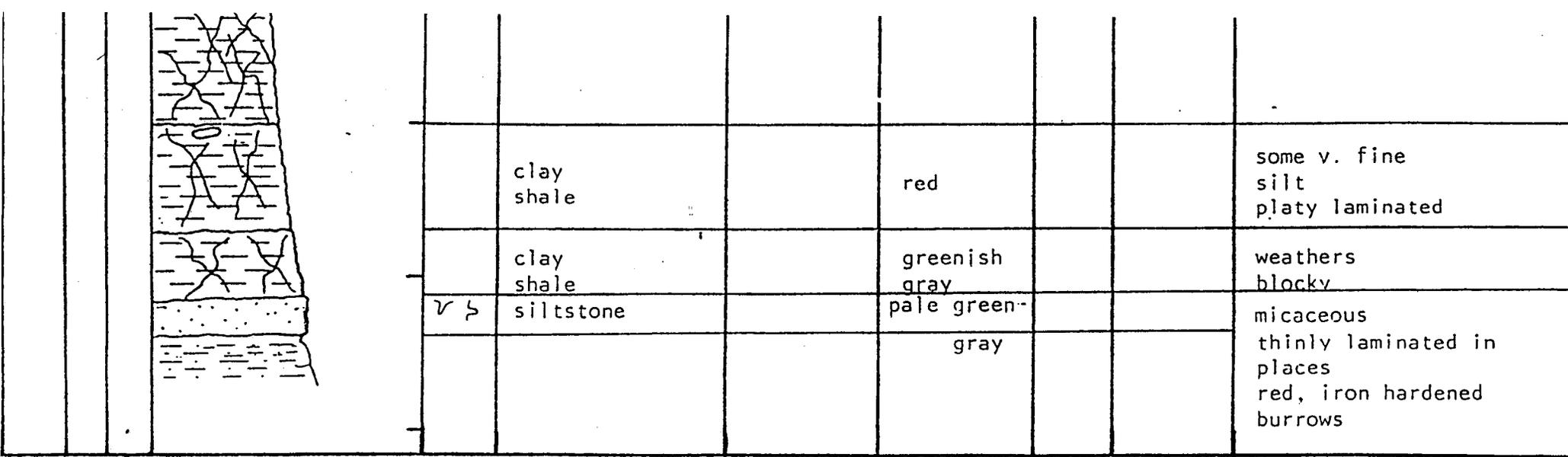
Oread Limestone



	clay shale		greenish yellow dark gray brown	clay		softer and less platy than shale below
	black shale		black		(P)	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 with shale, weather to tubes, pyrite
	crinoid/fusulinid packstone/wackestone		light gray			algal oncolites coated grains glauconite



crinoidal packstone/wackestone	B ~ B ~ A	light greenish gray			whispy shale laminations
skeletal packstone	~ B A O	light gray -orange yellow			iron stains
skeletal wackestone	B O A B	light gray			iron stains
wackestone	A ~	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



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

# 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.

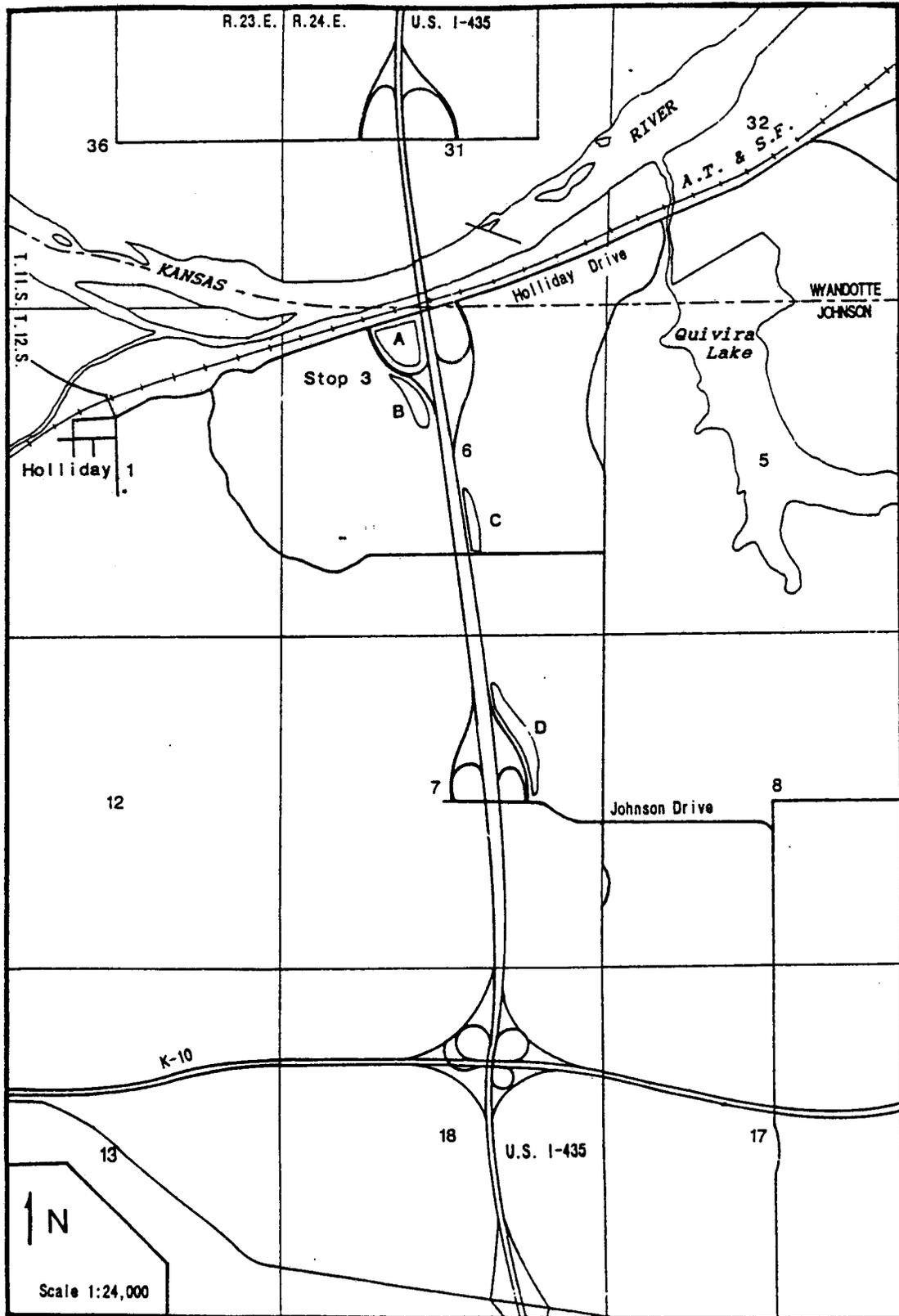
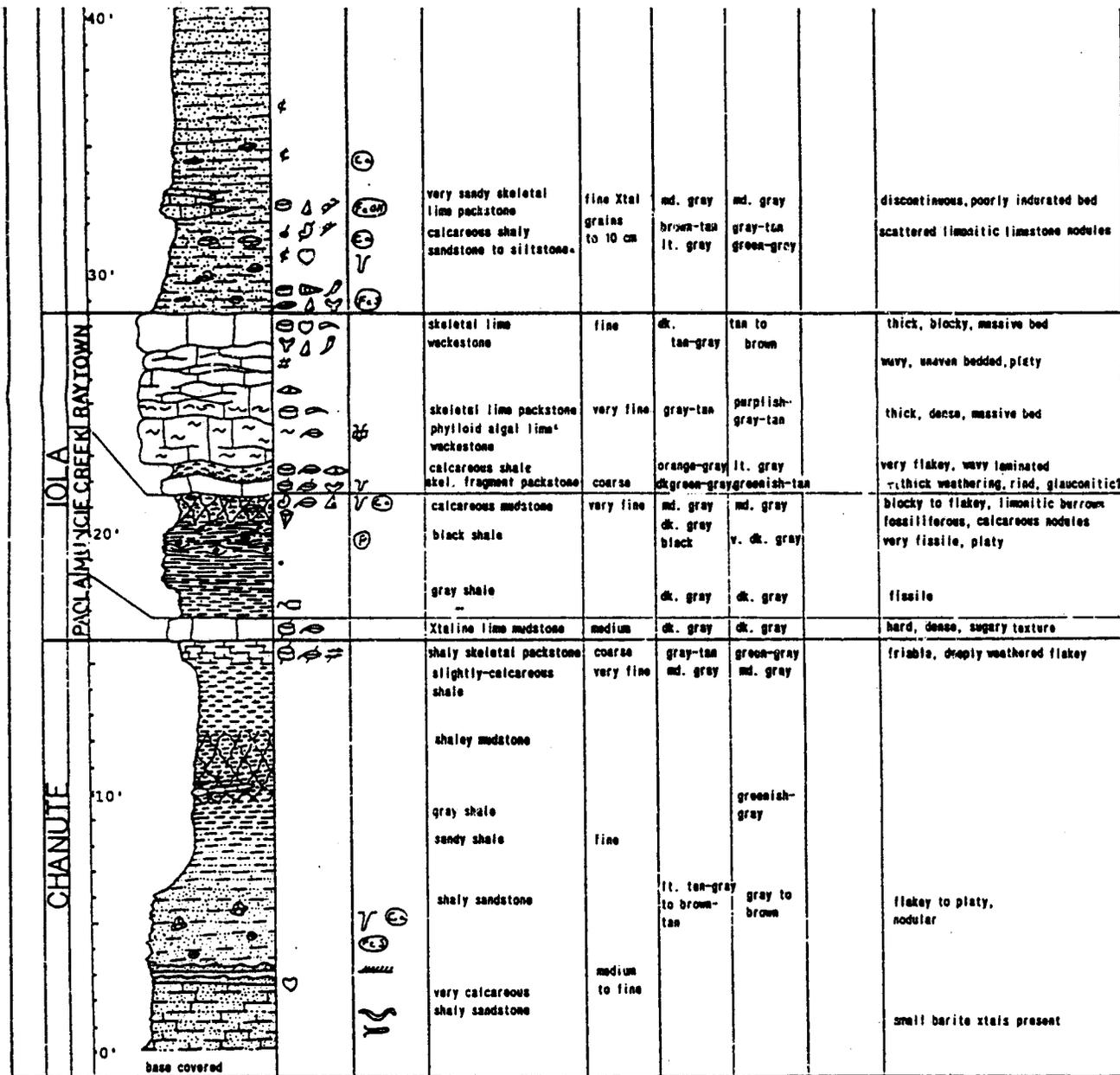


FIGURE 3-1. LOCATION MAP OF STOP 3 AND SITES A, B, C, AND D USED IN PREPARING MEASURED SECTION PROVIDED WITH STOP 3 (fig. 3-2, from Johnsgard, 1984).

a

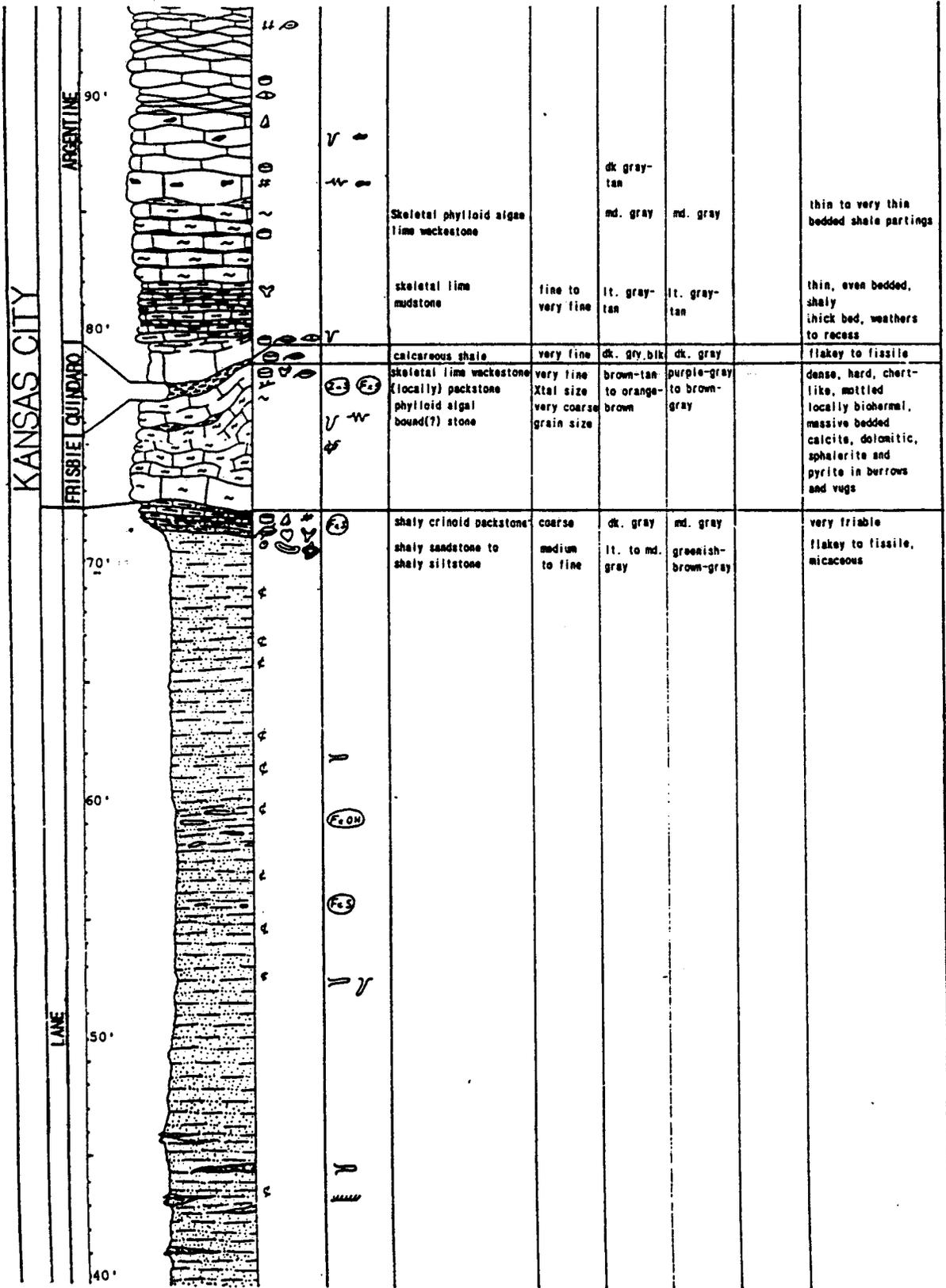


KEY TO SYMBOLS

FOSSILS	FOSSILS	PARTICLES	SED. STRUCT.	DIAGEN. FEAT.
Conal Stromat. Algae	Brachiopod, General	Limestone Lithoclast	Imbricate Grains	Stylolites
Green, Codiocian Algae	Spirifer Brachiopod	Shale Lithoclast	Vertical Burrow	Dolomitized Burrow
Phylloid Algae	Productid Brachiopod	Palletoid	Horizontal Burrow	Dolomite Xtals
Plant Fragments	Lingulid Brachiopod	Calcite Grains	Boring	Chert Nodules
Fossiloid	Coiled Cephalopod	Ooid	Rippled Scale X-lamin.	Selenite Xtals
Encrusting Wbrm	Nautiloid	Onkolith	Groove	Manganese Dendrites
Conularid	Gastropod	Coated Grain	Prod/Bounce	Phosphate Nodule
Solitary Coral	Bivalve	Shells	Flute	Calcium Carbonate Mod.
Fenestrate Bryozoa	Crinoid	Fossil Fragments	Load Cast	Sphalerite
Ramose Bryozoa	Echinoid		Tracks and Trails	Pyrite/Marcasite
Encrusting Bryozoa	Shark Tooth		Feeding Trace	Limonite Nodules

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



C

BONNER SPRINGS	150'		shaly sandstone	fine	md. gray	pink-gray	platy to fissile
			sandy lithoclastic mollusc lim packstone	very coarse	md. brown	lt. gray	blocky, limoalitic 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
	FARLEY	120'		skeletal phylloid algae lim wackestone to packstone	very fine	gray-tan	pale pink-tan
			stromatolitic(?) skeletal lim 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, persistent bed
			shaly sandstone	fine	md. gray	lt. gray	flakey to fissile
			shaly mudstone calcareous shale stromatolitic skeletal lim wackestone	very fine fine medium	dk. brown orange to tan-gray	lt. brown orange-tan	wavy to nodular bedded, domal stromatolitic(?) laminae
			phylloid algal lim mudstone	fine	pink-tan to gray	pale pink-gray	sparse ooids & calcite grains
WANDOTE ISLAND CREEK		100'		shaly sandstone	very fine	lt. gray	lt. gray
			coated grain packstone skeletal wackestone	very fine Xtal size very coarse grain size	tan-gray	brown-tan	3 even, distinct beds shells w/calcite, dolomite Xtals
			coated grain packstone skeletal lim mudstone	very fine		gray-tan	wavy bedded, "clay seams" present

d

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

a

STOP 3 HOLLIDAY DRIVE

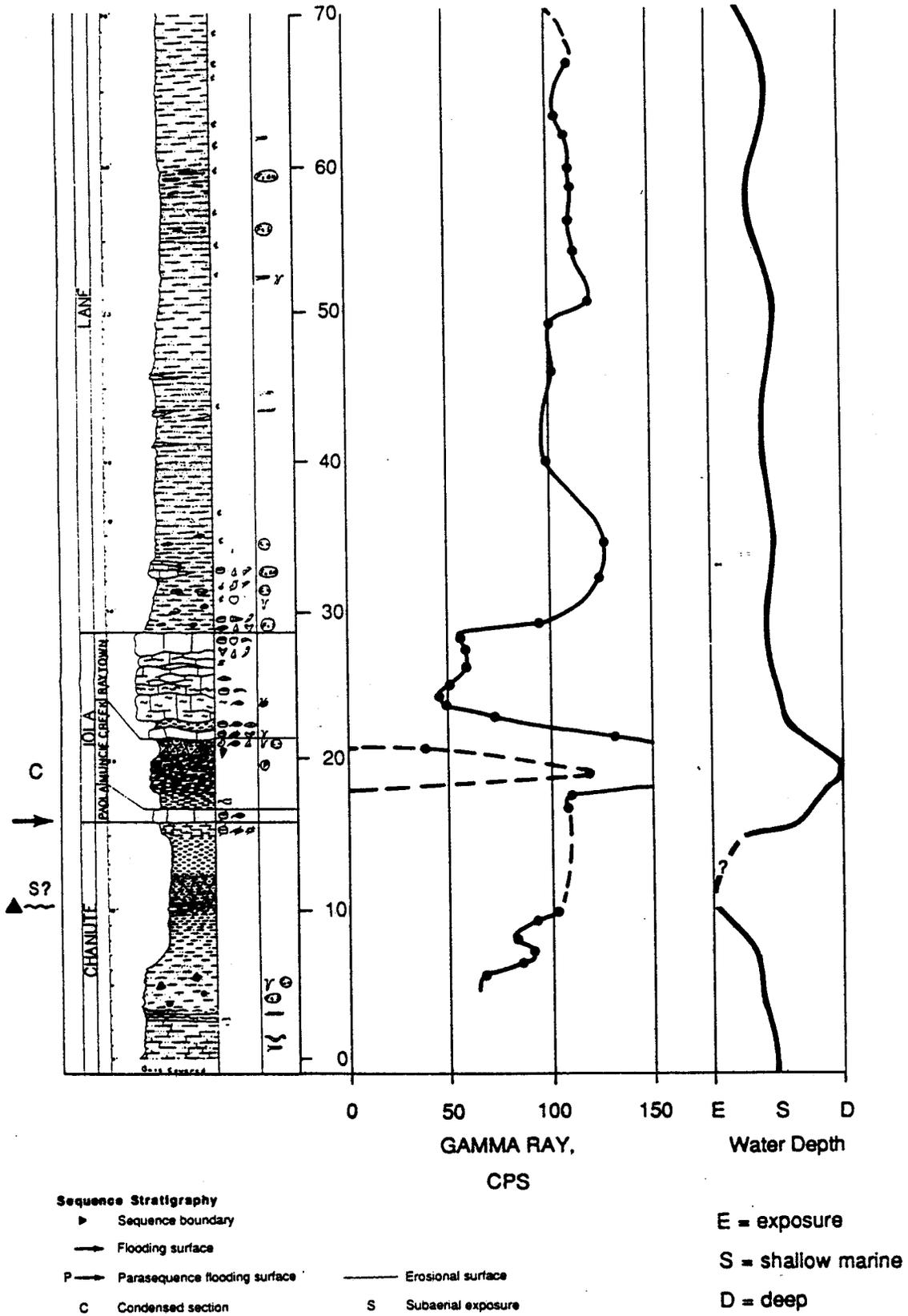
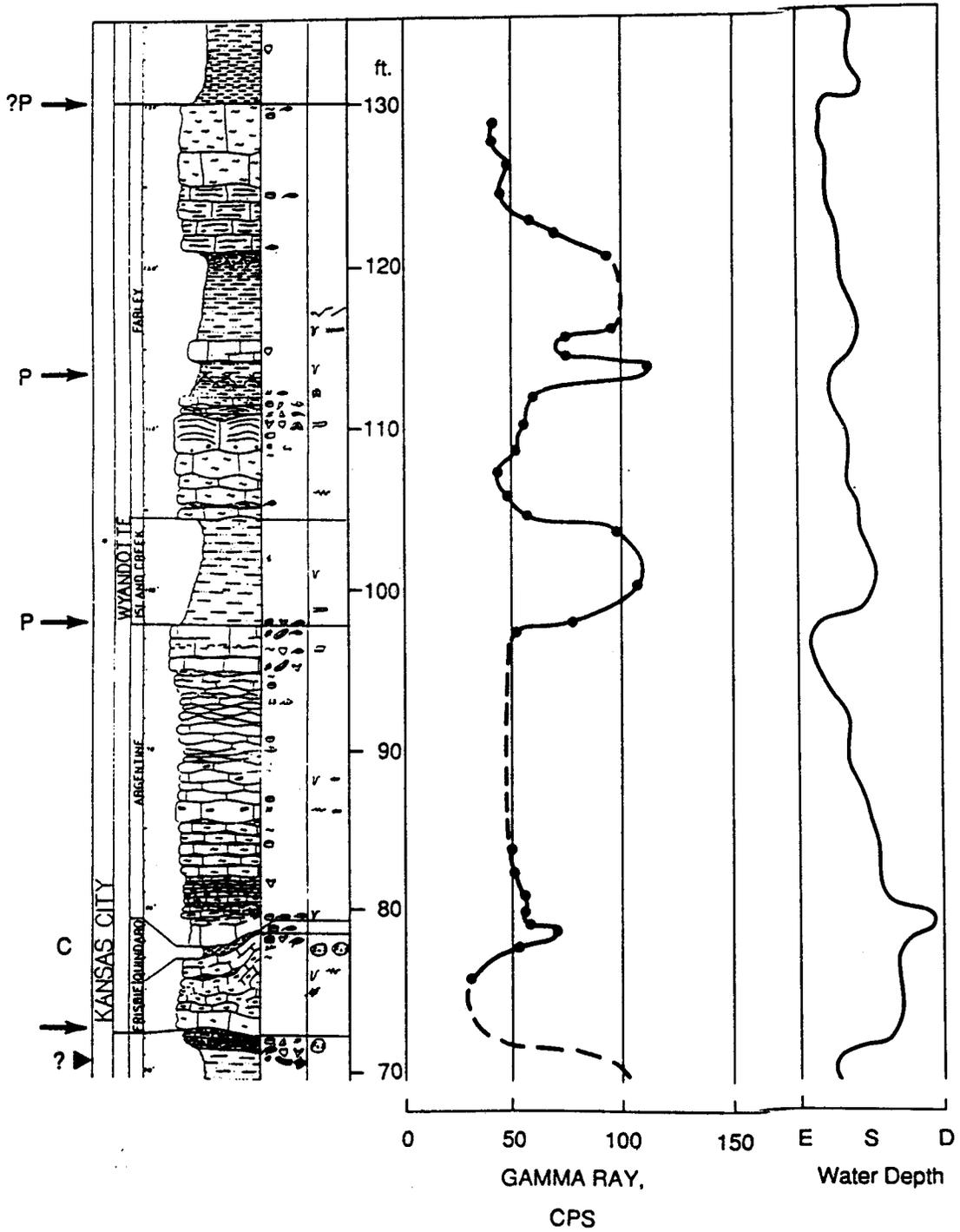


FIGURE 3-3 (A AND B)—STRATIGRAPHIC SECTION NATURAL GAMMA-RADIATION PROFILE, WATER-DEPTH CURVE, AND SEQUENCE CLASSIFICATION (extreme left) for lower portion of measured section in fig. 3-2.

b

STOP 3 HOLLIDAY DRIVE



E = exposure  
S = shallow marine  
D = deep

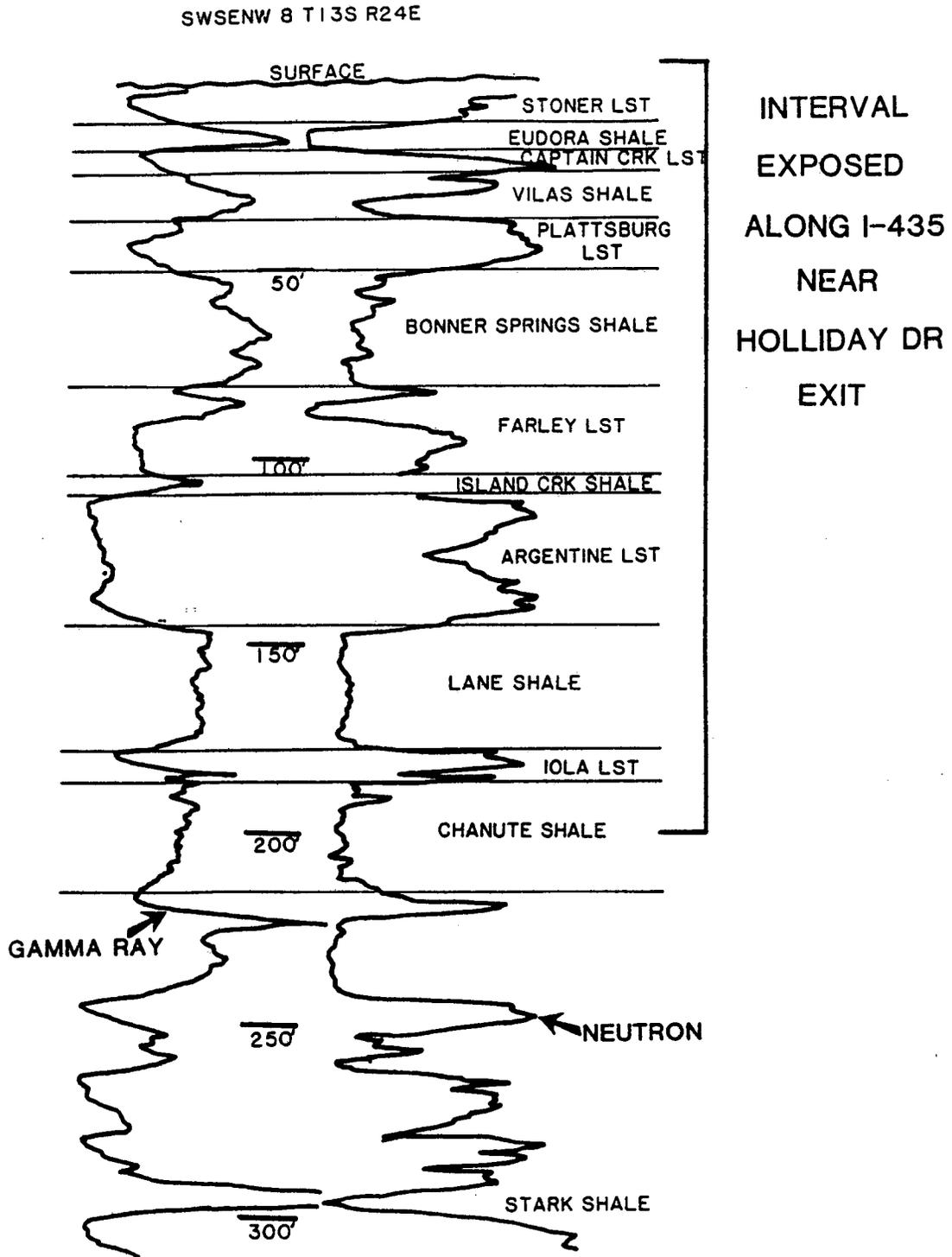


FIGURE 3-4—CORRELATION OF FORMATIONS IN LANSING AND KANSAS CITY GROUPS BASED ON GAMMA RAY-NEUTRON LOG OF WELL LOCATED NEAR STOP 3.

# 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  $\pm 0.32$  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  $7.95 \pm 2.36$  m ( $26.2 \pm 7.8$  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 pectens,

*Composita* and spiriferid brachiopods, high-spined 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* traces 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  $0.88 \pm 0.33$  m ( $0.9 \pm 1.1$  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 ooid 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  $18.1 \pm 5.7$  cm ( $7.2 \pm 2.3$  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  $4.1 \pm 1.2$  m ( $13.5 \pm 4$  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-spined 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-spined 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*, *Echinochonus*, 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, platy to flakey, calcareous shale. A low-diversity fauna of low-spired gastropods (*Trepostira* and, rarely, bellerophon-tids), 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 top lap 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 top lap 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 be 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 top lap 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 top lap as the Merriam thins toward the channel margins. Top lap 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 mid-continent? 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 top lap. 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. Top lap 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 cyclothem 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.).

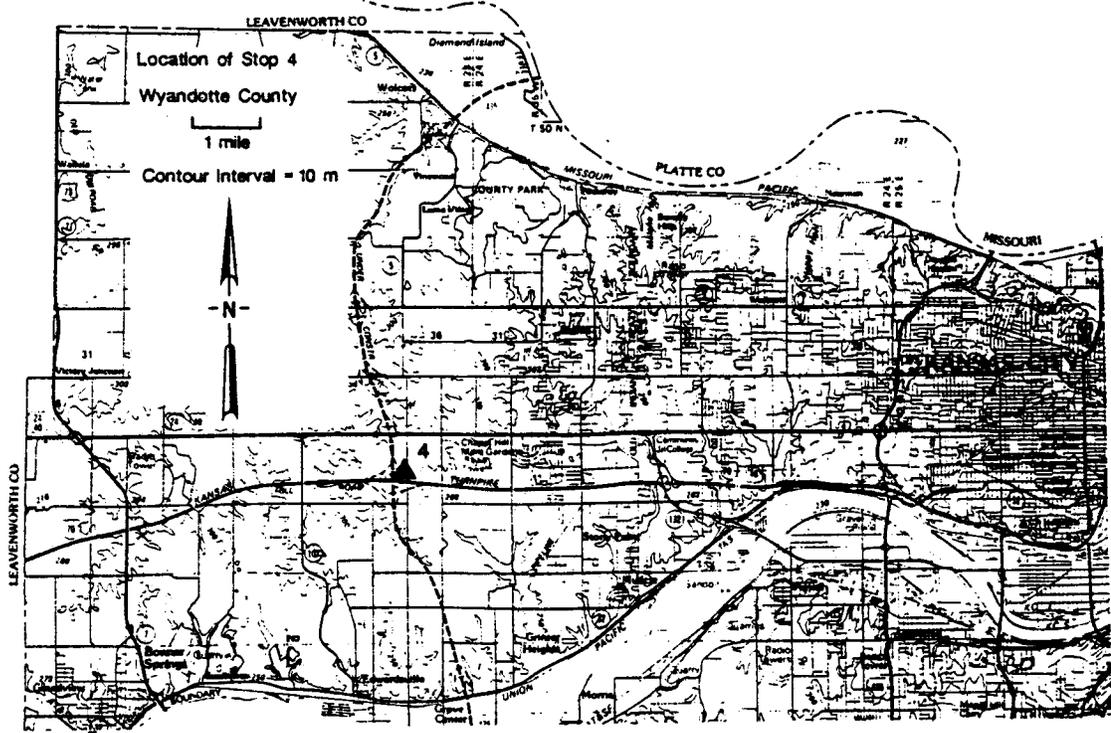
The change in lithologic character of the Hickory Creek Shale with the increase in thickness at I-70/I-435 interchange also suggests a depression on the sea floor. Local bathymetric highs have been called upon to explain the loss of black color, carbon content, and fissility within core shales where 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 *Trepostirid-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 cyclothem. 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."

a



b

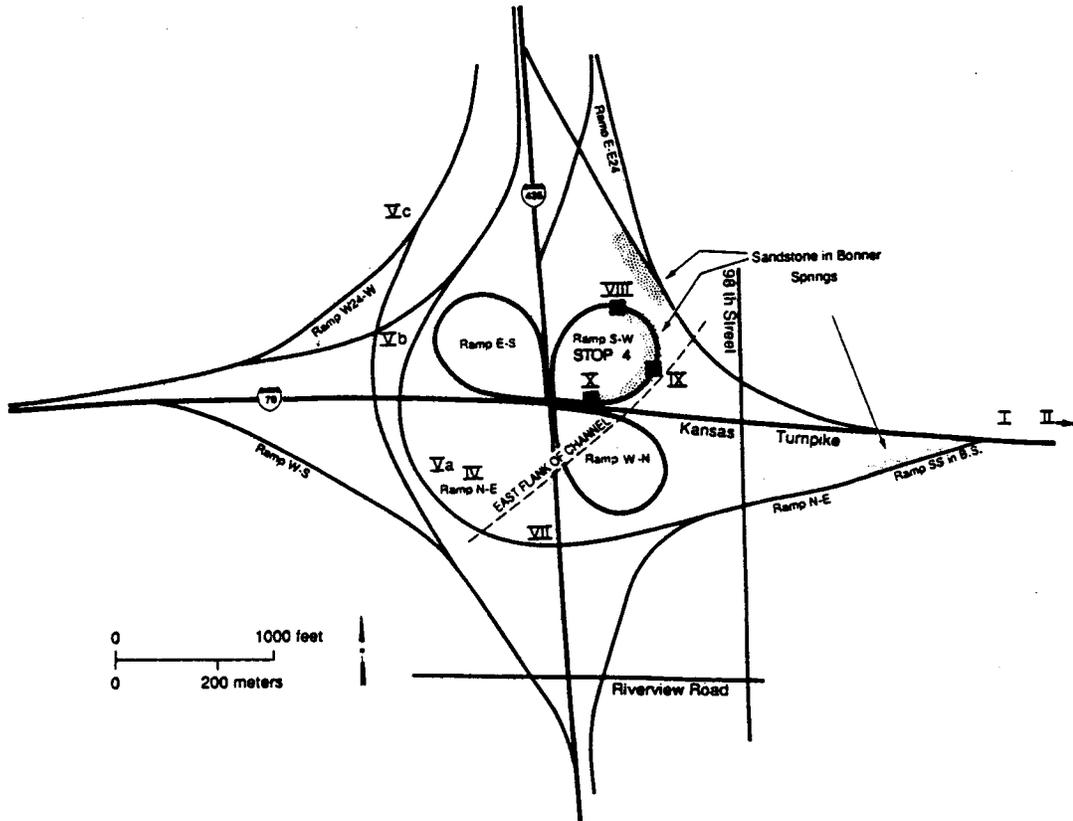


FIGURE 4-1(A and B)—Location map for Stop 4 in Wyandotte County (A) and index map showing intersection with location of Stop 4 along northeastern cloverleaf of interchange of I-70 and I-435 and location of measured sections used in cross section (fig. 4-2a and b) identified with Roman numerals. Stippled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

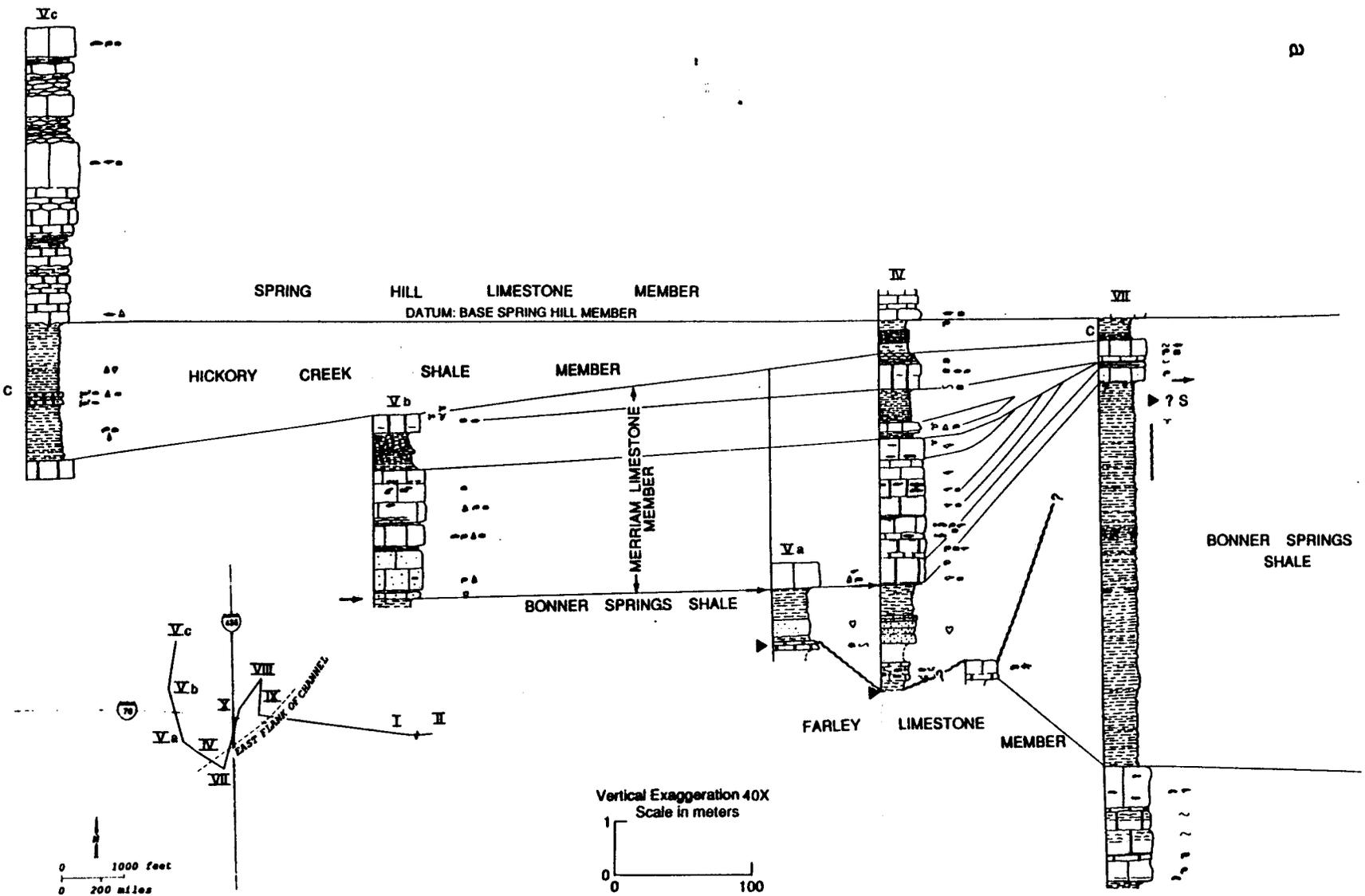


FIGURE 4-2(a and b)—Northwest-to-east stratigraphic cross section through I-70/I-435 interchange area based on measured sections and interpretations (less sequence interpretations) by Enos and Herman, in ms. Datum for the cross section is the base of the Spring Hill Limestone. Uppermost Farley Limestone,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

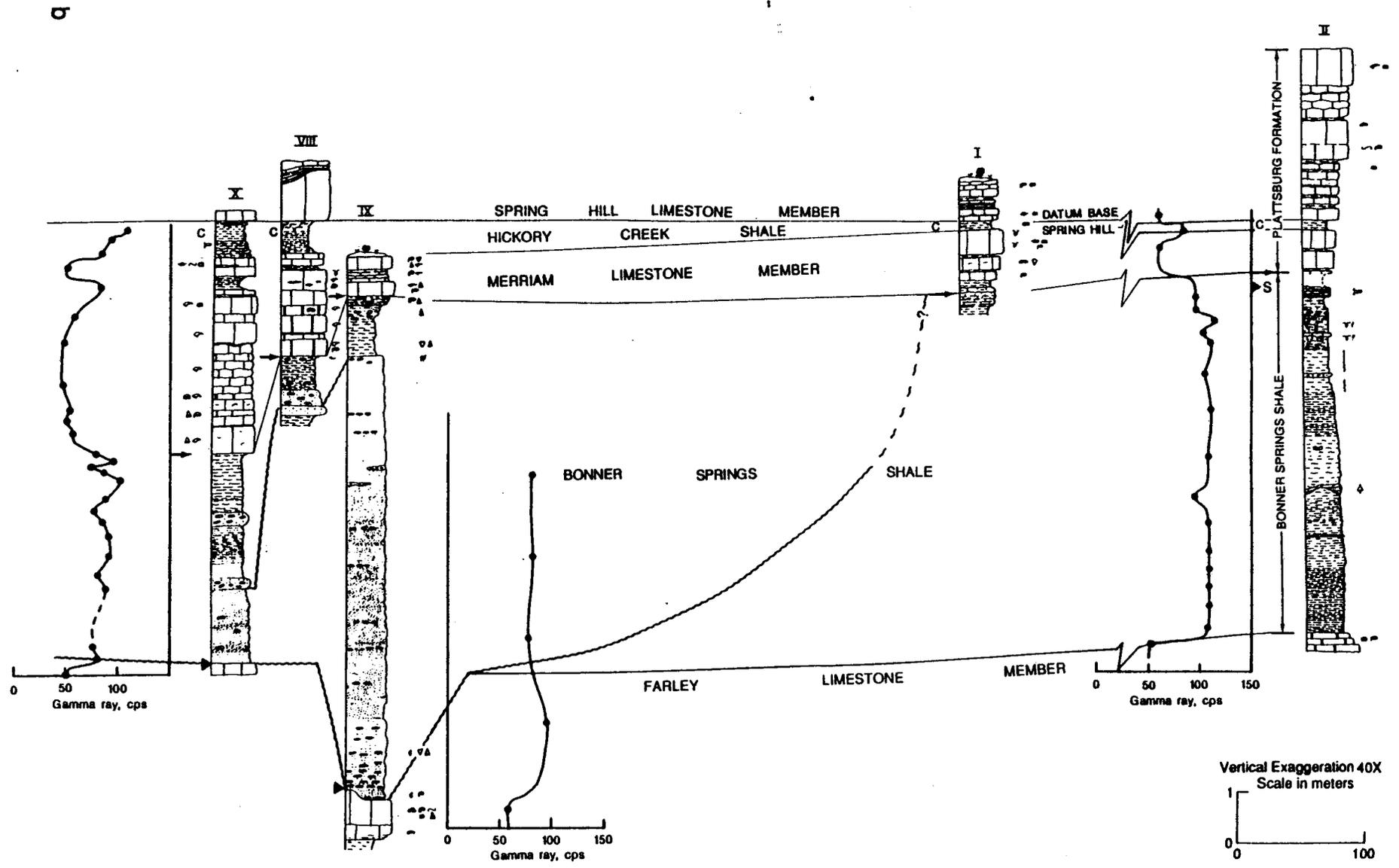
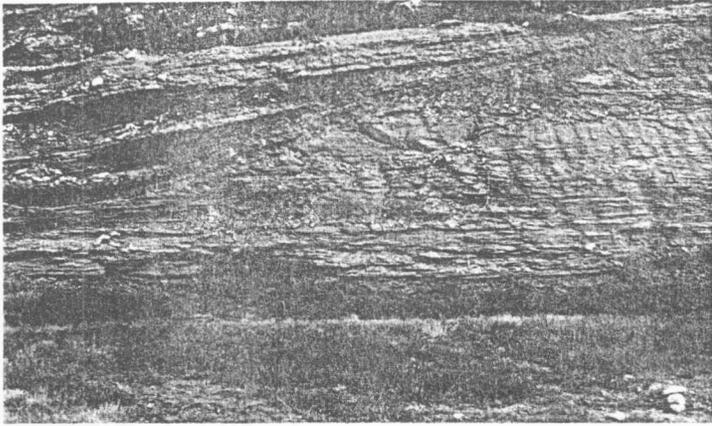


FIGURE 4-3(A and B)—Bonner Springs Shale at Stop 4 showing sandstone of Bonner Springs (BS) resting on locally eroded upper Farley Limestone (UF) near section X. Sandstone is cut by erosional surface beneath a hemi-channel form which extends up to near the base of the Merriam Limestone (ME). Hemi-channel is filled with sandstone. 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]).

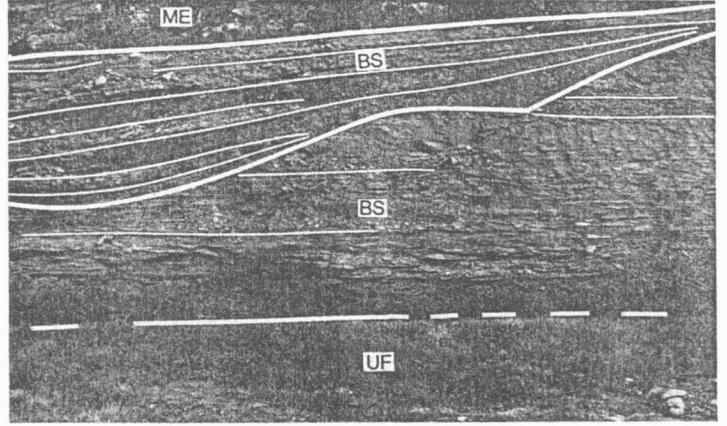
FIGURE 4-3(C and D)—South side of Stop 4, northeast clover-leaf of intersection of I-70/435, between sections X and IX. Large channel-form sandstone in Bonner Springs Shale passes diagonally (northeast-to-southwest) through this exposure. Sandstone is cut by deep erosional surfaces beneath hemi-channel 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.

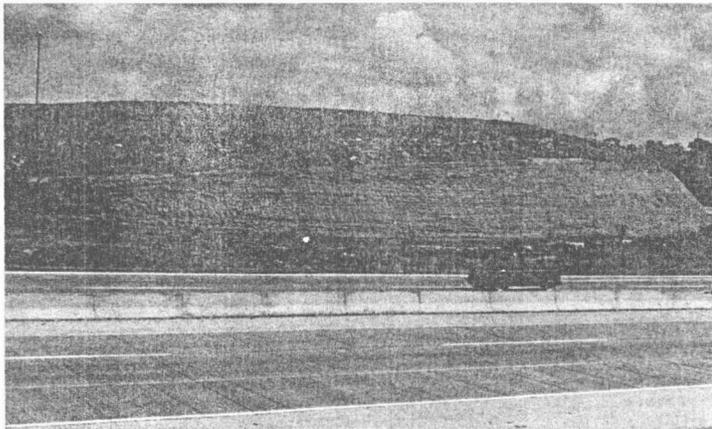
FIGURE 4-3 (F)—Typical Bonner Springs Shale (section II) shown in fig. 4-2(b). Upper portion commonly contains maroon interval (beneath base of arrow) that is overlain by a calcareous paleosol horizon (point of arrow). The maroon interval is clearly truncated near section VII, on the southwest side of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



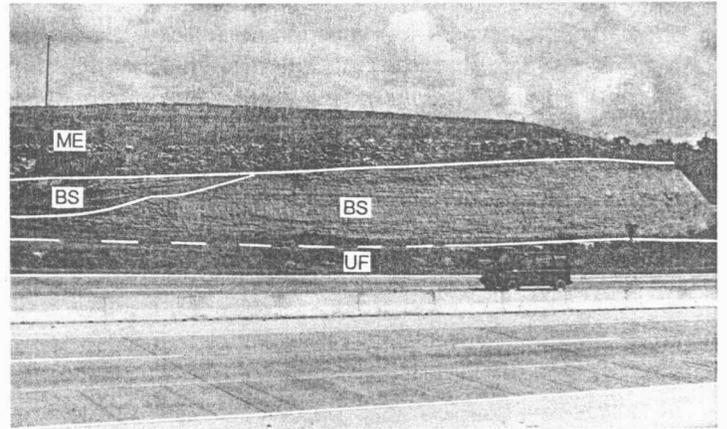
A



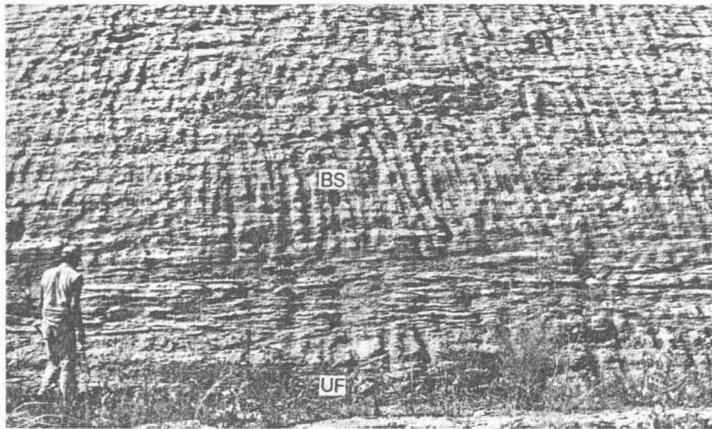
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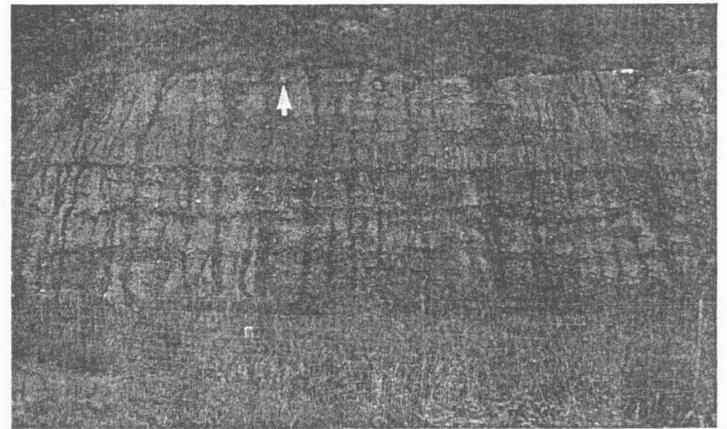
C



D



E



F

## 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 cyclothem 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 cyclothem 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

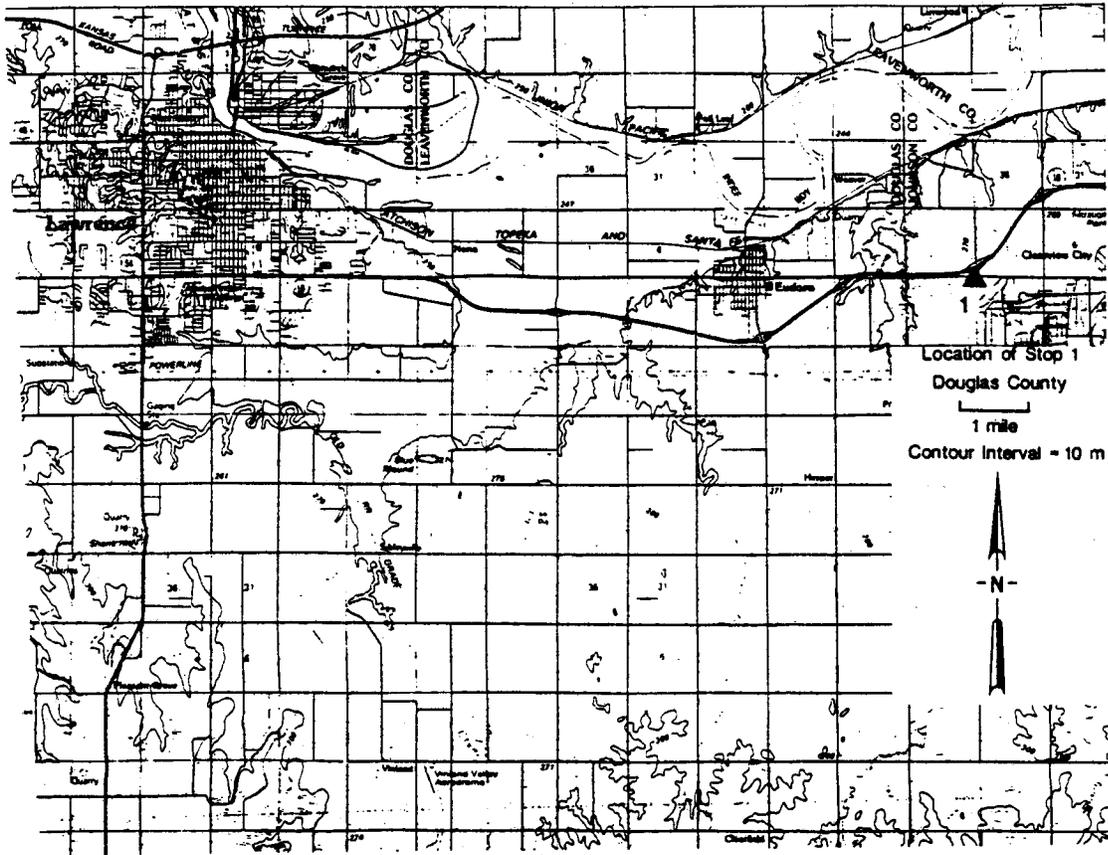


FIGURE 1-1—LOCATION MAP FOR STOP 1, EDGERTON EXIT ON HIGHWAY 10 EAST OF LAWRENCE.

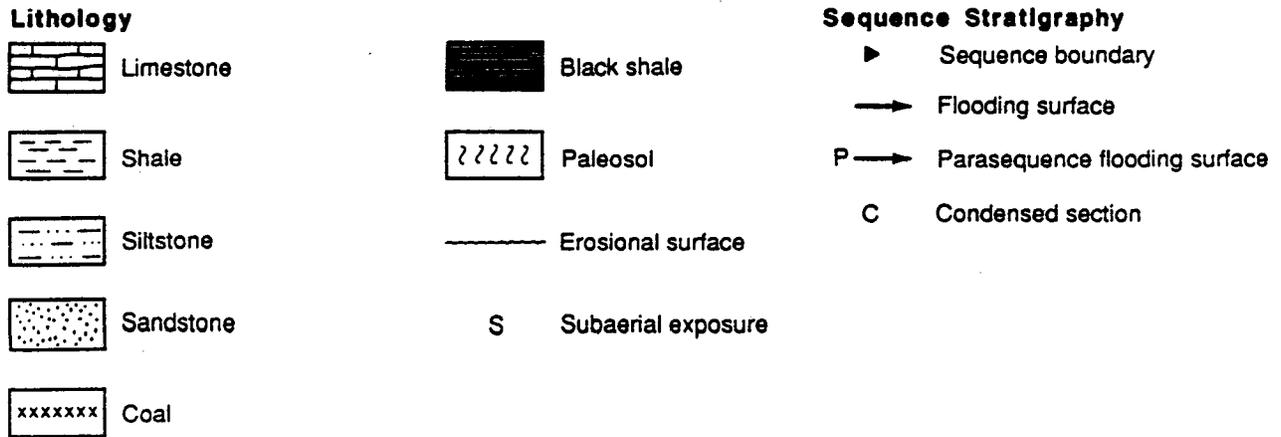


FIGURE 1-2—LEGEND WITH MAJOR LITHOLOGIES, SURFACES, AND SEQUENCE-STRATIGRAPHIC TERMS.

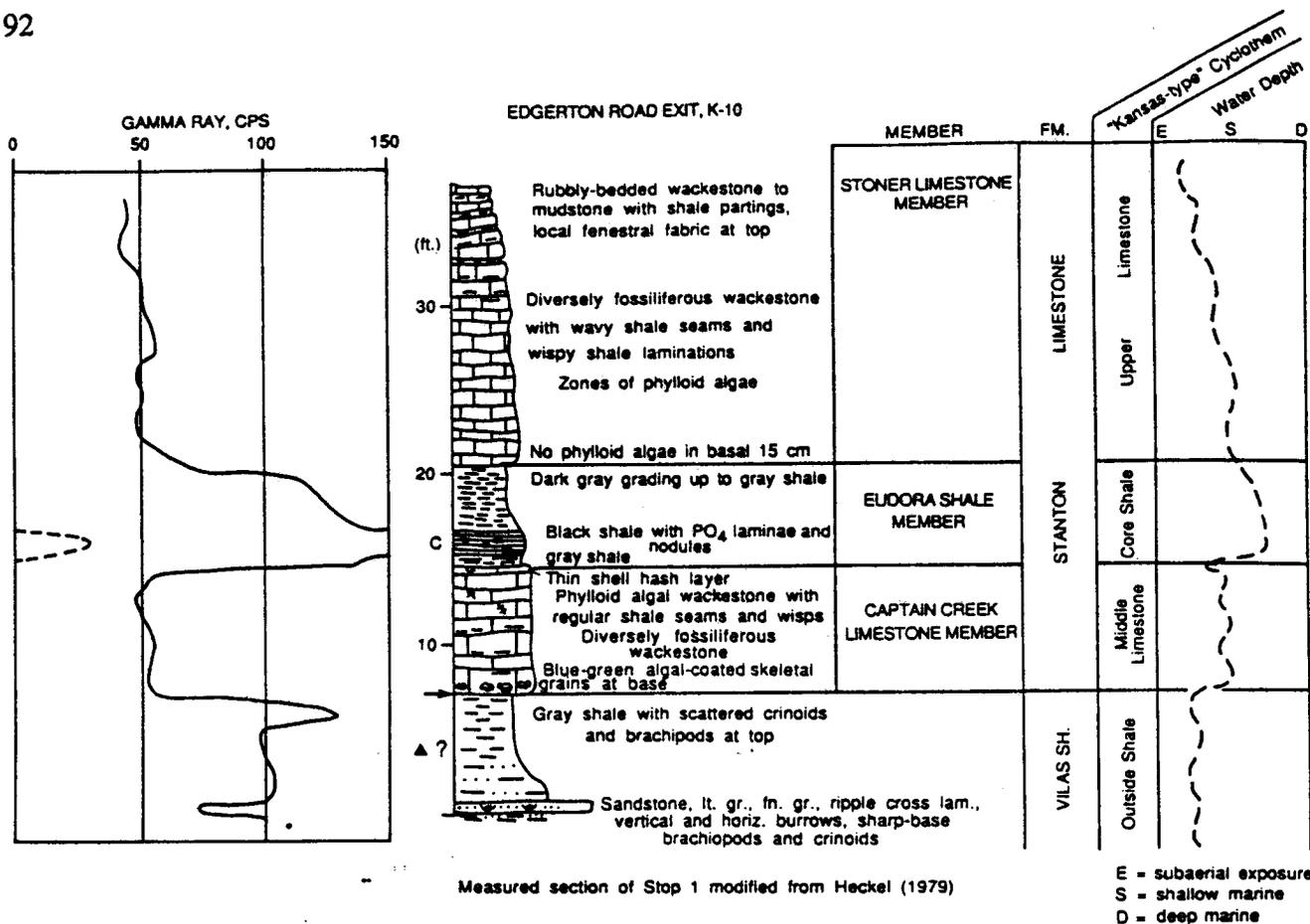


FIGURE 1-3—MEASURED SECTION OF STANTON LIMESTONE AT STOP 1. Natural gamma-ray profile obtained with hand-held gamma scintillation counter. Symbols used in graphic columns are shown in fig. 1-2.

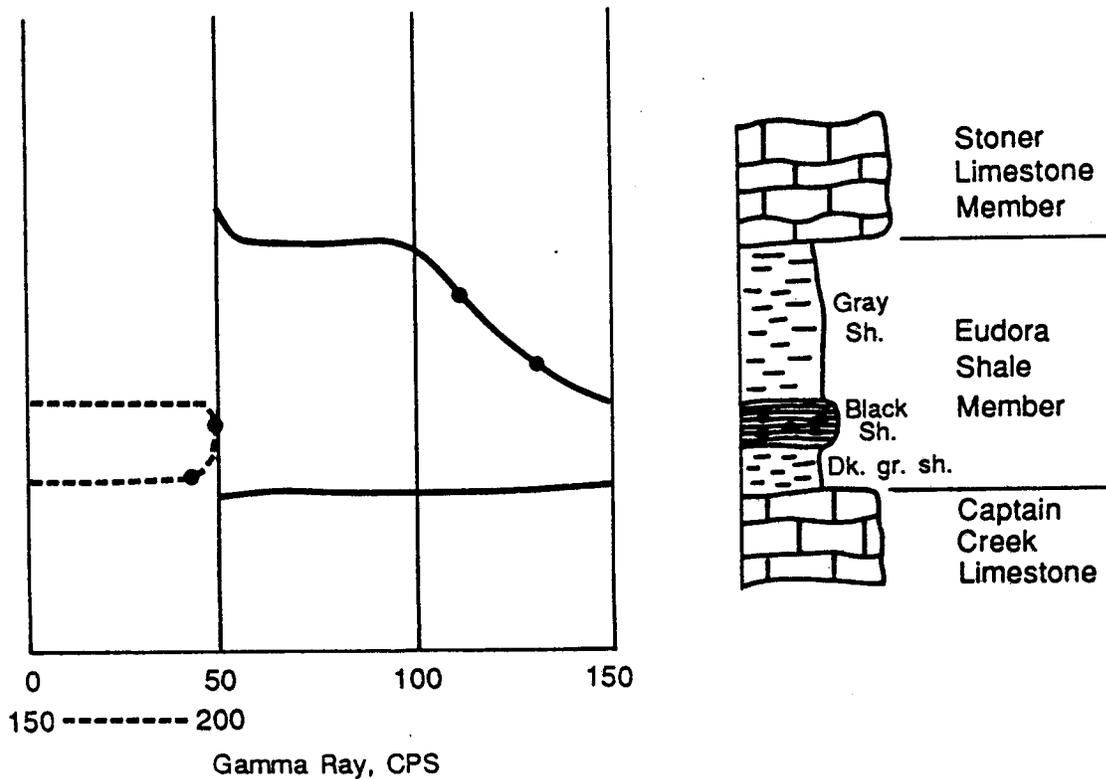


FIGURE 1-4—FOUR-FOOT (1.2-M)-THICK SECTION OF EUDORA SHALE EXPOSED ALONG I-435, 14 mi (23 km) east of Stop 1. Section is very similar to that seen at Stop 1.

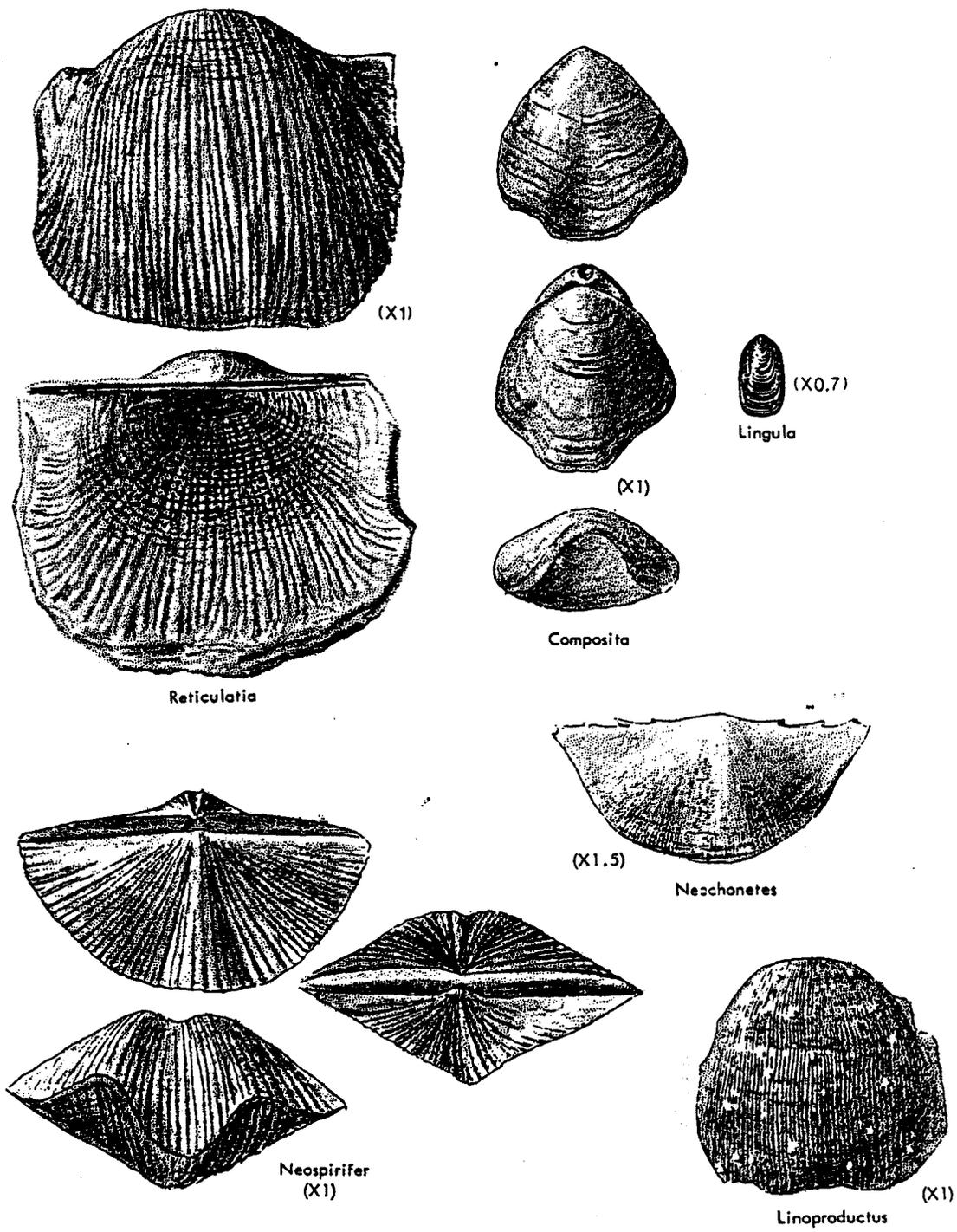


FIGURE 1-5—COMMON MACROFOSSILS OCCURRING IN UPPER PENNSYLVANIAN STRATA (from Moore, 1964).

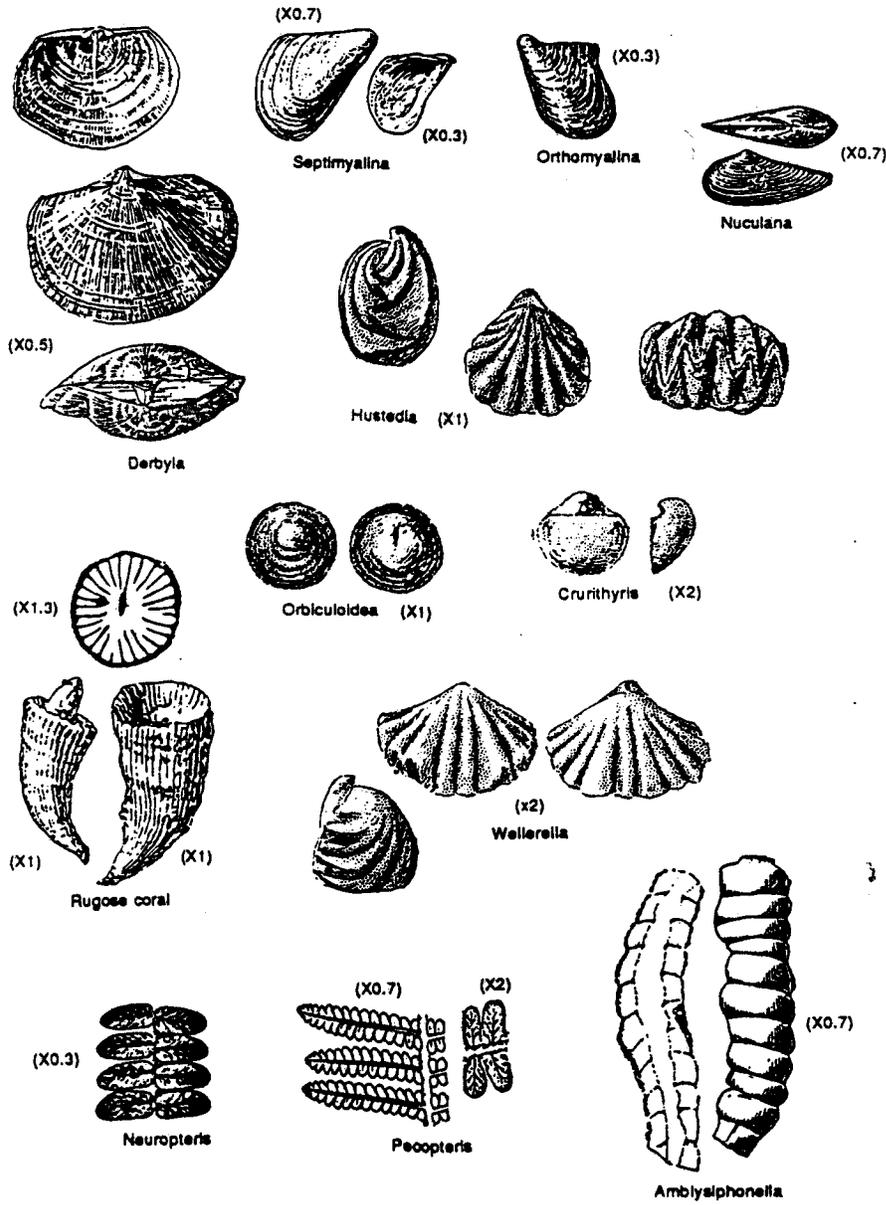


FIGURE 1-6—COMMON MACROFOSSILS OCCURRING IN UPPER PENNSYLVANIAN STRATA (from Moore, 1964).