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The Mississippian Section at Paddys Bluff, Crittenden County, Kentucky

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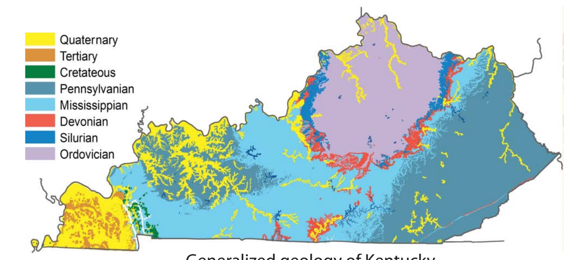

Generalized geology of Kentucky

Introduction

Paddys Bluff (Figs. 1–3) is located on the south side of the Illinois Basin on the Cumberland River, 1.7 miles downstream from Dycusburg in Crittenden County, Ky., in Carter coordinate section 23-I-16 and ecoregion 71f of the Western Highland Rim of Kentucky (Woods and others, 2002). This bluff is on a right-descending bend 18 river miles above its junction with the Ohio River at Smithland, Livingston County. The bluff (Figs. 4A, B) is locally famous as the location for a scene from the classic 1962 film, "How the West Was Won," a winner of three Academy Awards, starring James Stewart, John Wayne, and others.

We observed Paddys Bluff from the starboard Texas deck of the steamboat *Delta Queen* one rainy morning in October 2005; the thick, persistent white bed midway in the bluff especially attracted our attention (Fig. 4). Paddys Bluff is the best natural exposure of Mississippian limestone between Barkley Dam and the Ohio River, a distance of 31 river miles. The bluff, some 1,700 feet long (Fig. 4), rises 160 feet above the Cumberland River and deflects it about 16° into a long westward reach, the river removing all talus at the base of the bluff. The bluff lies in a graben between two inferred faults striking N40 to 45°E (Amos and Hayes, 1974). Readily seen in the limestones along the river at the base of the bluff is a prominent joint set parallel to these faults. This bluff is mapped on the Dycusburg geologic quadrangle map (Table 1) as the combined Salem and St. Louis Limestones (Amos and Hayes, 1974) and is capped by at least 15 feet of poorly exposed gravel of the Cretaceous Tuscaloosa Formation (Olive, 1980). Across the river less than 2 miles distant are scattered "continental deposits" of reddish brown Lafayette-type, sandy cobble-gravel (Olive, 1980), below which are outliers of the Cretaceous Tuscaloosa Formation; both cap hilltops of the same underlying Mississippian limestones.

Why is Paddys Bluff of interest? There are at least six reasons to study it. First, can the Salem and St. Louis Limestones be individually identified at the bluff? If, in fact, they can be separated, the upper boundary of sequence S4 recognized in the Lake Cumberland area of south-central Kentucky by Khetani and Read (2002, Fig. 12) extends much farther west. Still another challenge is the enigmatic, massive, fine-grained, whitish-weathering carbonate mudstone bed, unit C of our section, high in the bluff. What does it represent? How widespread is it? Why do beds below it have a strong petroliferous odor and not those above it? Why are some of the coral heads (Fig. 5) at Paddys Bluff overturned and others not? The last challenge is the bluff itself: Why is it there and how long has it been there?

The Section at Paddys Bluff

We described the section bed by bed and used 24 thin sections to supplement field observations. A gamma-ray profile was also measured, and samples for total organic carbon were collected (Fig. 5). The base of the section at river level is at 37.17851°N, 88.20599°W.

The stratigraphic reference for visitors to Paddys Bluff is its white-weathering, thick, massive, fine-grained, argillaceous lime mudstone bed (Fig. 4C), accessible either by river or by the short trail from the campground leading to the middle part of the bluff about 60 feet above river level. This trail continues downstream along the reentrant of the thick white bed, providing easy access.

There are four clearly separate limestone units (Fig. 5) at Paddys Bluff: units A and B below the thick white-weathering bed; unit C, the white-weathering bed itself; and the highest, unit D, extending above to the poorly exposed Tuscaloosa gravel at the top of the bluff.

Unit A, at the base of the section, consists mostly of poorly bedded to blocky packstones and grainstones with little internal structure and separated by gradational contacts of thin shaly limestones. Macrofossils include disarticulated crinoids (most common), followed by fenestrate and bifoliate bryozoans, plus spiriferid brachiopods and echinoid plates and spines. Microfossils include various species of endothyrid foraminifers, the most common being *Globoendothyra baileyi*, and ostracodes. Some coated grains and some calcispheres are present. Unit B is much the same as unit A, except its beds are thinner and it has more shale. We placed the contact between units A and B where limestone beds become thinner, more argillaceous, and where there is more shale. A few thin, medium gray, calcareous shales with hackly fracture are also present, as are three tempestite beds with overturned coral heads, *Acrocyathus (Lithostrotionella) proliferum* (Hall). Some lie on their sides and others are upside down in massive beds that fine upward into shaly partings (Fig. 6). Thin sections of these corals show breakage of the septa and other skeletal elements, as would be expected of storm waves. These beds occur at approximately 30, 40, and 46 feet below the base of unit C. Some upright, colonial rugose corals, *Acrocyathus (Lithostrotionella) proliferum*, are present in the lower half of unit B, about 24 feet from the base of unit C, and are all in normal, upright position. The field gamma-ray log broadly reflects this upward increase in abundance of shale in the outcrop, and has its highest counts per second just below unit C.

Unit C is a thick, massive, uniform, medium gray, argillaceous lime mudstone weathering white to light gray; petrographically, it contains less than 1 percent skeletal grains. It is totally exposed and forms a distinctive reentrant that extends the length of the outcrop. A shallow scour occurs at its base. This bed, easily seen from both the river and from the air (Figs. 4A, B), has conchoidal fracture and some poorly defined exfoliation structures. Some fine quartz silt and fine organic flecks are present. Microfossils include conodonts, sponge spicules, and possible holothurian sclerites, scolecodonts, and ostracodes. The great homogeneity of the white-weathering unit C, its general lack of stratification, and the shallow scour at its base all point to its origin as a mass-flow deposit (although this is far from certain). Thus, we tentatively think of unit C as an event bed, one that may have been deposited in a few minutes to perhaps an hour or so. A thin ball-and-pillow, soft-sediment-deformed bed found directly above the thick bed at the west end of the outcrop fits with this interpretation. Unresolved is the lateral extent of unit C beyond Paddys Bluff; we note, however, that unit C was identified in an adjacent drill core and that there is a thick deformed bed—with deformed chert—in the Salem–St. Louis unit at river level at the Dycusburg launching ramp, 1.7 miles upstream.

The overlying unit D has some of the thickest limestone beds in the section; these are incompletely exposed and hard to reach, but are cherty, lack coral heads, and occur with but one thin shale bed. Fossils include disarticulated pelmatozoan stems, fenestrate bryozoans, and brachiopods. Dark gray to black cherts are nodular and become more abundant upward. The basal bed of unit D is a hard overhanging packstone, 2 to 3 feet thick, extending continuously across the outcrop; it has a sharp contact with unit C and may somehow be related to it.

Petrographically, most of the limestones typically have 40 to 50 percent fragmental grains consisting of fine to coarse, sand-size broken fossil debris plus some calcispheres, and are mostly packstones with a few wackestones, except in unit C (with less than 1 percent sand-size debris). Micritization of carbonate debris ranges from moderate to extensive and is especially well developed on smaller fragments.

Regionally, Paddys Bluff is located in the deepest part of the middle Mississippian carbonate section of the Illinois Basin—a deep shelf or ramp (deWitt and others, 1979; Barrows and Cluff, 1984, Fig. 6). The dominance of broken skeletal debris, some tempestites, and calcispheres (derived from upramp) support this interpretation, as does the absence of typical Salem calcarenite. Units A and B represent a deepening of water depth; unit C, an event bed; and unit D, possibly shallower water. See Sable and Dever (1990, p. 55–66) for a statewide summary of Lower Mississippian rocks in Kentucky.

Paleontological Study and Correlation

On the 1:24,000-scale Dycusburg geologic quadrangle map (Amos and Hayes, 1974), Paddys Bluff is mapped as a combined St. Louis and Salem unit, because the typical white calcarenite of the Salem Limestone is absent (Table 1). In a preliminary paleontological sampling of the bluff, we used corals plus conodonts (one sample) and endothyrid foraminifers (five samples) to better establish its stratigraphic units. The top of the lithostrotional coral zone (Fig. 6) was used as an indicator of the base of the St. Louis in southern Illinois (Weller and St. Clair, 1928, p. 213, 216–217), by Weller and others (1920, p. 105) in Hardin County, Ill., and by the U.S. Geological Survey in Hardin County, Ky., 120 miles to the east (Roy Kepferle, U.S. Geological Survey, personal communication, 2009). At Paddys Bluff, this top is 22 feet below unit C, the possible mudflow event bed. One sample collected from the top of unit C contains conodont elements from two species, *Synclydognathus geminus* and *Cavusgnathus unicornis*, which belong to the *Synclydognathus geminus-Cavusgnathus* Biozone of late Meramecian age (zonal name revised from Collinson and others [1971]; Rexroad and Varker [1992]). This zone is widespread in the upper St. Louis of the Mississippi Valley. The occurrence of two elements of the conodont *Taphrognathus varians* (commonly present in underlying biostratigraphic zones) suggests that this sample is from age-equivalent strata of the transition zone at the lower-upper boundary in the type area of the St. Louis Limestone. Although endothyrid foraminifers (Fig. 7) are most abundant in the Salem Limestone, the endothyra foraminifera *Eoendothyranopsis* sp., *Eoendothyranopsis scitula*, and *Globoendothyra baileyi* (identifications by Paul Brenckle of the University of Massachusetts) present in the sampled section below unit C are no longer unambiguous indicators of Salem-age beds—their range now includes the St. Louis Limestone as well as the underlying Warsaw and Keokuk Formations (Kammer and others, 1990). The shallow scour at the base of unit C, the possible mudflow bed, may be evidence of the regional sequence boundary between the Salem and St. Louis Limestones found by Khetani and Read (2002, Fig. 7) about 90 miles to the southeast. Thus, our present paleontological study leaves open the age of the limestones at Paddys Bluff—the top of the thick bed of unit C could be the boundary of the upper and lower St. Louis (based on conodont evidence) or the top of the coral zone could be the Salem–St. Louis boundary as in southern Illinois (Weller and St. Clair, 1928, p. 213, 216–217) and western Kentucky (Roy Kepferle, U.S. Geological Survey, personal communication, 2009). From a sequence-stratigraphy standpoint, the Salem–St. Louis boundary of Khetani and Read (2002, Fig. 7) might be at the base of unit C. Additional paleontological sampling and study may resolve this conflicting evidence.

Organic Geochemistry: Petroliferous Odor and Bitumen in Salem Beds

Standard procedures* were used to separate organic matter from 28 samples of shale, shaly limestones, and limestones from Paddys Bluff. This organic matter consists of bituminite and fine woody (coaly) fragments, which occur in the interstices of the rock matrix. Some organic fragments have a coal-like structure. These finely divided particles in the section at Paddys Bluff may have been in part derived from updip and closer to the shoreline. Three samples from unit D average only 0.13 percent total organic carbon: unit C averages 0.17 percent; unit B, 0.71 percent; and unit A, 0.70 percent. Thus, throughout the section, total organic carbon values are low, indicating an oxygenated ramp or slope, one that was distal, judging by its finely divided woody fragments and predominance of fragmental fossil debris. Overturned coral heads, however, show that some storm waves impinged the bottom.

Observations from both the air and hand-leveling from the river up to the base of unit C suggest that Paddys Bluff is part of a gentle anticline. This—in combination with the continuous thick, impermeable capping lime mudstone of unit C—explains the strong petroliferous odor below it and its virtual absence above unit C. The efficiency of unit C as a seal is demonstrated by both its own lack of petroliferous odor and in the beds above it. Thus, we see Paddys Bluff as a minor, now exposed, petroleum trap in a downdropped fault block, a likely model for other more deeply buried sections in the grabens of western Kentucky and southern Illinois.

A Tantalizing Question

How long has Paddys Bluff been a prominent feature on the Cumberland River? Although there is no definitive answer today, it is insightful to see how this question might be approached from regional geomorphic studies and from the cosmogenic dating of cave and sand deposits. Anthony and Granger (2006, Table 3) dated cave deposits in the headwaters of the Cumberland River and related their internal stratigraphy to the uplift history of the Cumberland watershed. They determined an age for the Lafayette-type continental deposits (Olive, 1980), such as those across the river south of Paddys Bluff, to be between 3.5 and 5.7 Ma; an age of 1.5 to 2.5 Ma for terraces cut into the Parker Strath (a much lower surface); and an age of 800,000 years for terraces above the modern floodplain of the Cumberland. Another estimate by Van Arsdale and others (2007), using a totally different methodology, estimated the age of the upland continental gravels along the Mississippi River and in the nearby Jackson Purchase Region between 5.5 and 4.5 Ma. Although neither Anthony and Granger (2006) or Van Arsdale and others (2007) applies directly to a limestone bluff at a river bend, they do point to the antiquity of the western Kentucky landscape. Could it be that Paddys Bluff first began to be exhumed as long ago as 500,000 to 800,000 years? Arguing against such an age is the fact that Paddys Bluff deflects the Cumberland River west some 16°. This implies that continuous—and much more rapid—undercutting of the base of the bluff is the most likely first-order process affecting its exposure age rather than regional responses to long-term tectonic uplift or climate change. Climbing across the bluff, we were impressed by the lack of solution rills on its beds. Hence, the age of the face of Paddys Bluff could be but a few hundred to a few thousand years old, even though the bluff itself has been deflecting the Cumberland River much longer.

Acknowledgments

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*Carbon data were determined by ultimate analysis, a test designed to measure the carbon, hydrogen, nitrogen, and sulfur in coal (and determine oxygen by difference). All carbon, organic and inorganic, was measured in this test. Organic carbon was determined by subtracting mineral carbon from total carbon. Tests were run by the University of Kentucky Center for Applied Energy Research, Lexington, Ky.

Map layout, design, and cartographic editing by Terry Hounshell

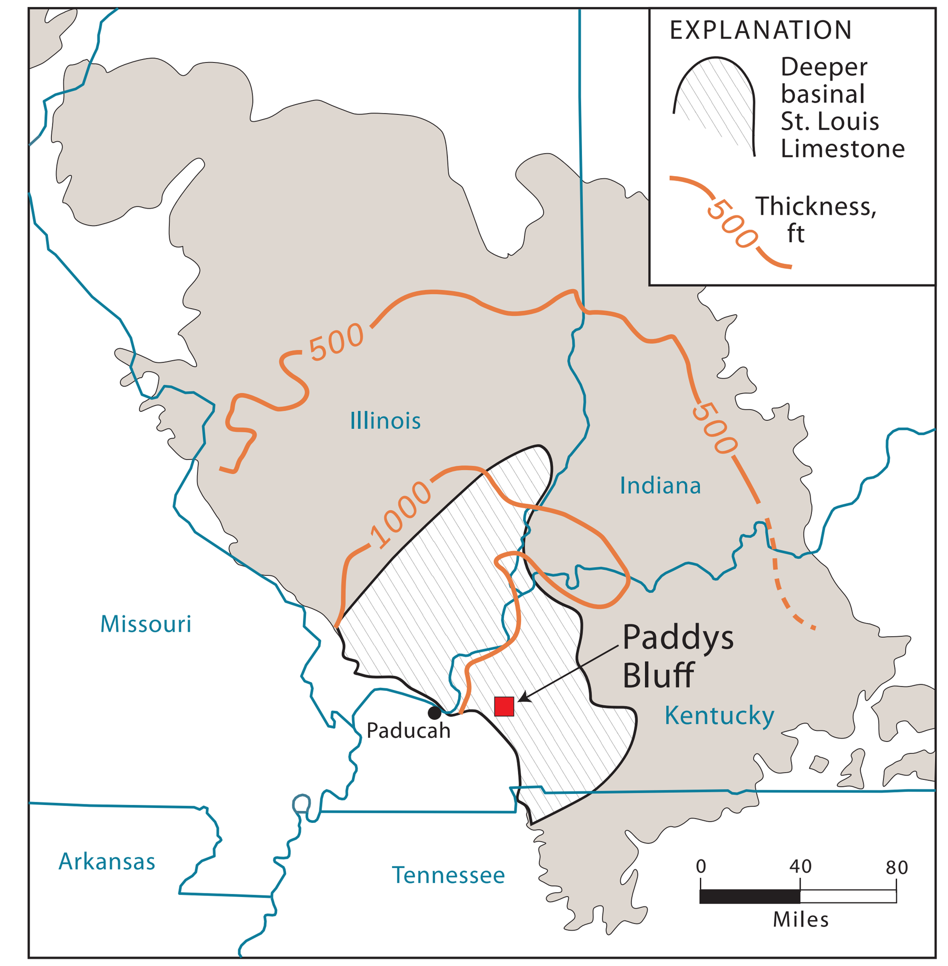

Figure 1. Middle Mississippian carbonate section of the Illinois Basin. After Pryor and Sable (1974, Fig. 7) and deWitt and others (1979, Fig. 92).

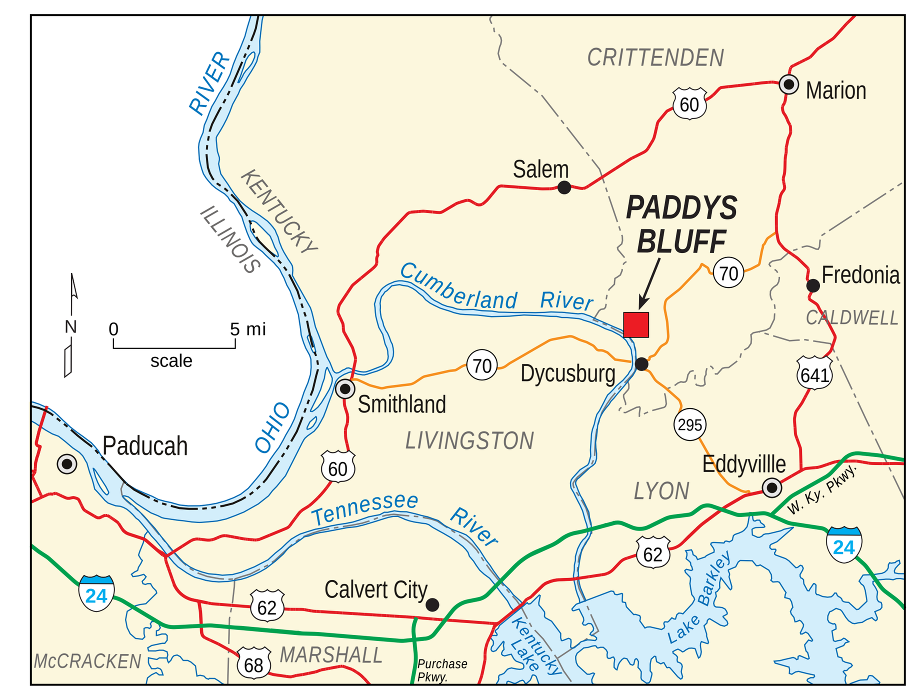

Figure 2. Location of Paddys Bluff.

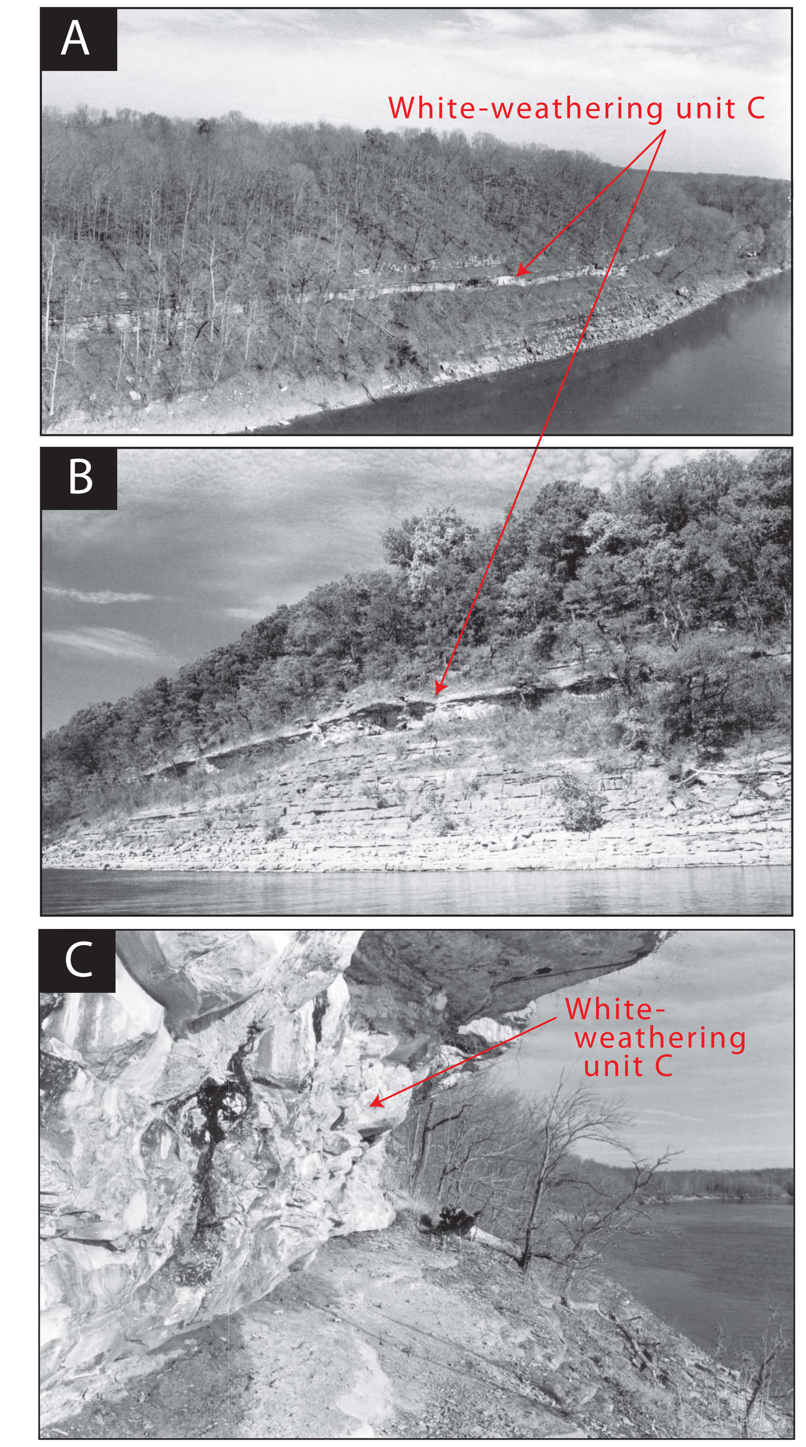

Figure 4. Paddys Bluff (A) as seen from the air and (B) as seen from the Cumberland River. (C) Close-up of unit C.

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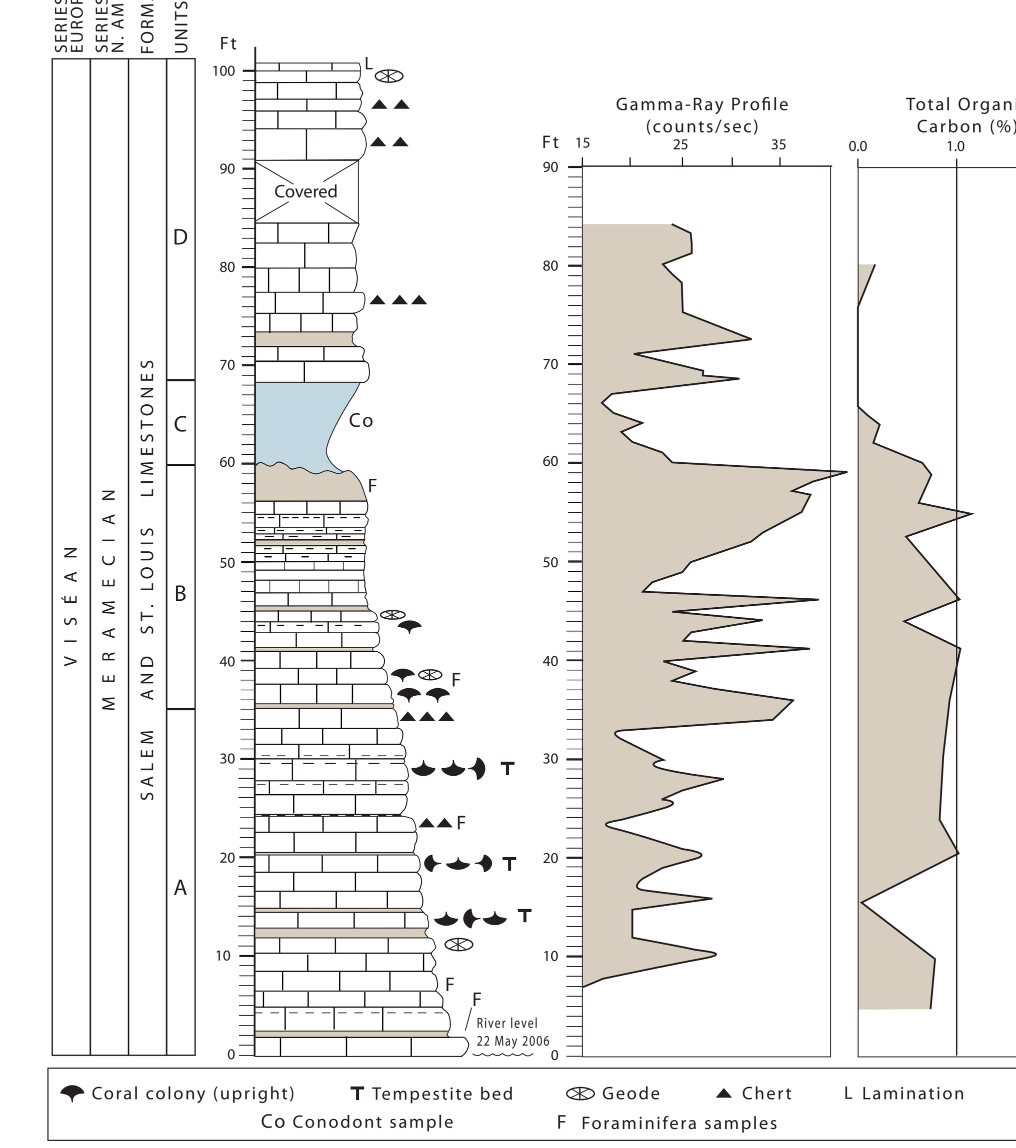

Figure 5. Geologic section, profiles of gamma radiation, and total organic carbon. Base of section is at 37.17851°N, 88.20599°W, and includes the widespread coral zone (see Fig. 6) that extends around the southern part of the Illinois Basin (St. Louis, Mo., to Elizabethtown, Ky.).

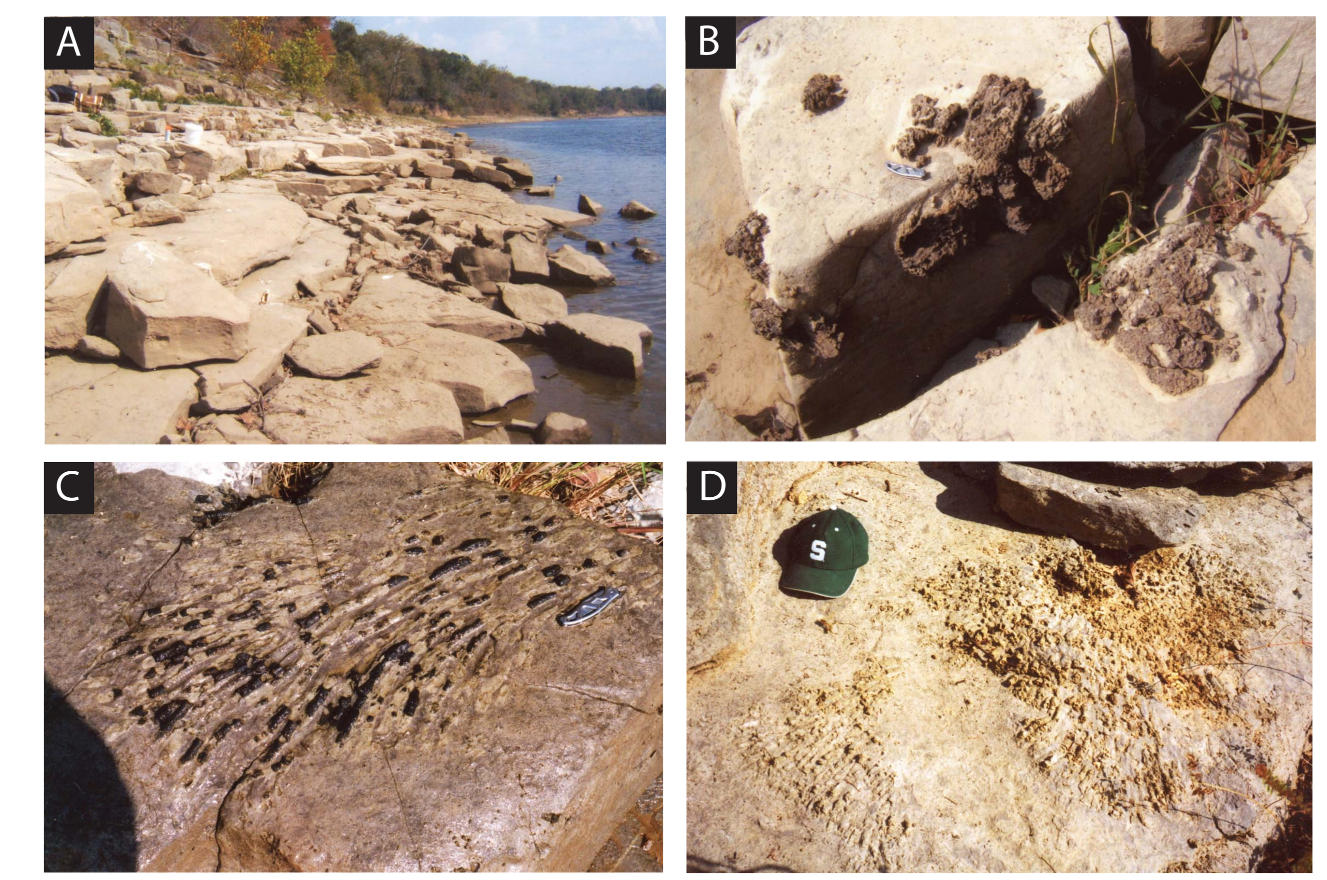
Figure 6. Coral heads at Paddys Bluff. (A) Beds with abundant coral heads exposed near river level at low water. (B) Silicified fragmental coralline debris. (C) Large single coral lying on its side. (D) Overturned coral head.

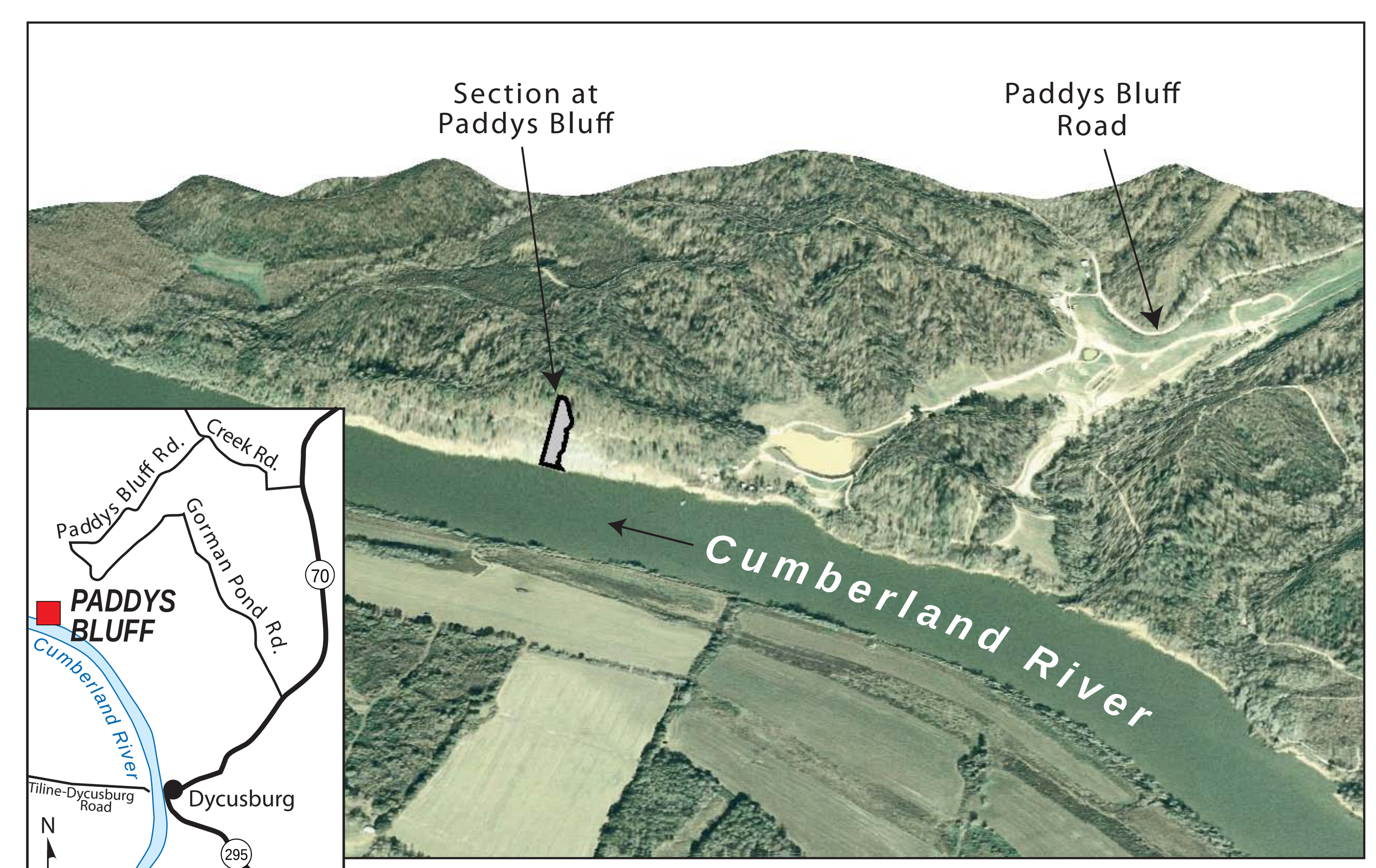

Figure 3. Looking northeast at an oblique digital terrain view of Paddys Bluff. The shoreline along the northeast bank of the Cumberland River is about 1 mile long. Although Ky. 70 is present on both sides of the river, no ferry connects its two boat ramps.

Table 1. Nomenclature of Salem and St. Louis Limestones of nearby 7.5-minute quadrangle geologic maps.

Cave in Rock and Salem quadrangle maps	Dycusburg and adjoining quadrangles to the southwest, south, and southeast	
St. Louis Limestone	Mapped as Salem and St. Louis Limestones	Upper Member of the St. Louis Limestone
*Salem Limestone		Lower Member of the St. Louis and Salem Limestones

*Recognized in Kentucky in these two quadrangles by the presence of crossbedded, white calcarenites (formation pinches out to the southwest, south, and southeast).

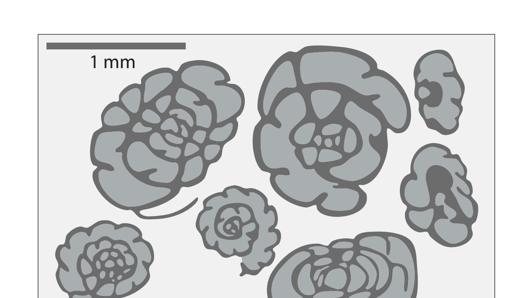

Figure 7. Endothyrid foraminifers from Paddys Bluff. Drawing by Evelen Pence.

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