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Robert D. Cole
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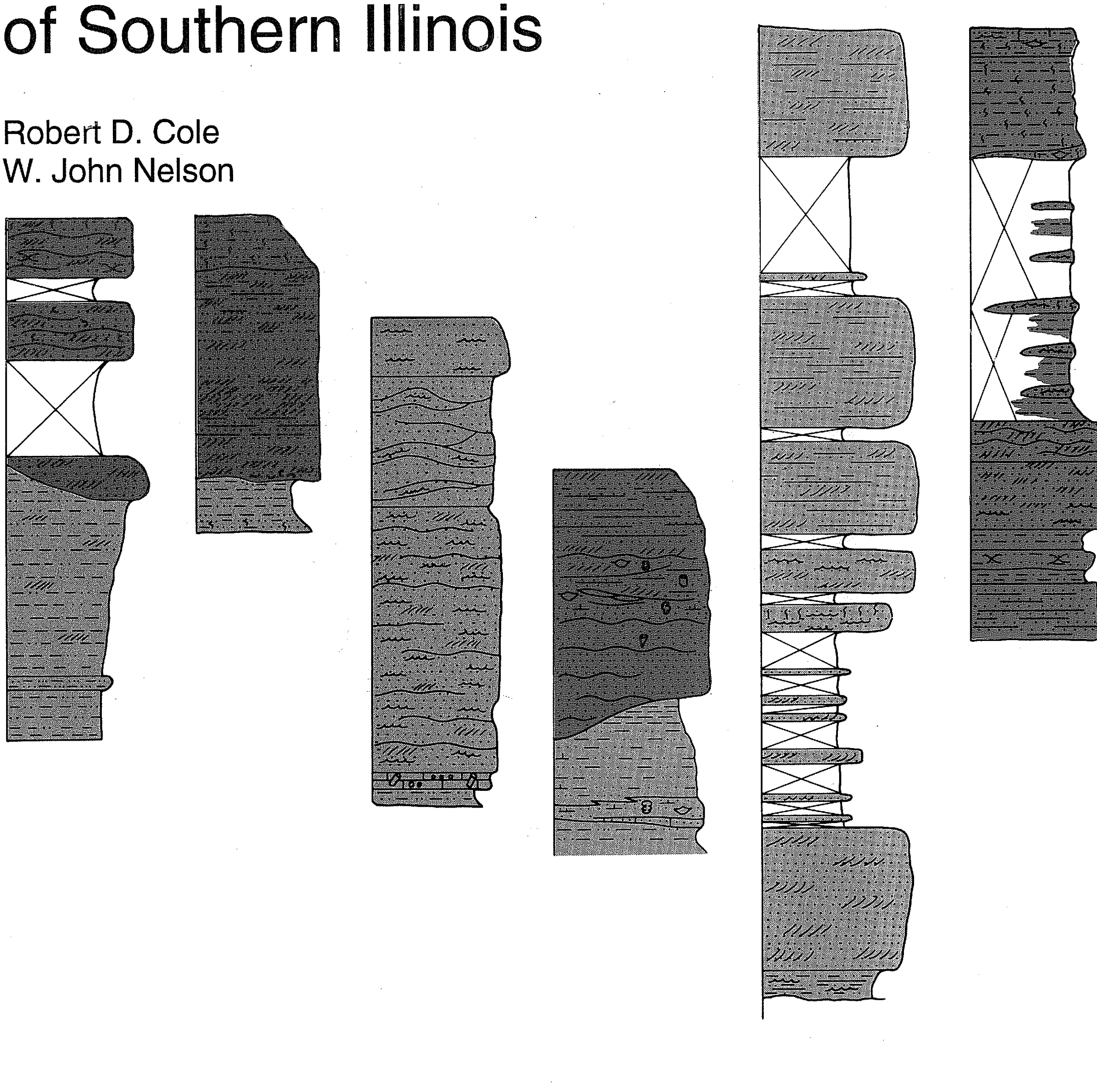

ILLINOIS STATE GEOLOGICAL SURVEY
Department of Energy and Natural Resources

Illinois Petroleum 149
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PLATE

## ABSTRACT

The Cypress Formation (Chesterian; Upper Mississippian) is a siliciclastic interval in the alternating clastic and carbonate rocks of the Pope Group. New correlations are presented herein, and existing stratigraphic nomenclature is modified. Sandstone of the lower part of the Cypress intertongues with limestone of the upper Paint Creek Formation near the western margin of the Illinois Basin. Similarly, the Bethel Sandstone (below the Cypress) is a facies equivalent of the Ridenhower Formation (shale) and part of the lower Paint Creek Formation. Where the Ridenhower is absent, the Cypress and Bethel combine into a single sandstone unit, herein named the West Baden Sandstone.

Outcrop and subsurface studies indicate that the Cypress Formation can be divided into three informal members: a thick sandstone-dominated lower member, a thin middle shaley member, and a thin upper sandstone member. Most outcrops show only the lower member. Information on the middle and upper members was derived mainly from cores and other borehole records.

The lower contact of the Cypress is conformable in some areas and erosional in others. Erosional relief appears to be slight in outcrops. The lower sandstone member was deposited under shallow subtidal conditions, probably above the fair-weather wave base. It is composed of well-sorted quartz arenite, contains marine fossils, and intertongues laterally with shallow marine limestone of the Paint Creek Formation. Lack of detrital clay indicates thorough winnowing by waves and currents. Sedimentary structures are typical of shallow subtidal deposits. Stacked or imbricate bar forms, observed in outcrops and mapped in subsurface, are analogous to tidal sand waves observed in modern shallow subtidal environments.

The middle shaley member of the Cypress locally contains coal, rooted zones, paleosols, and terrestrial plant fossils. This member reflects a regression and deposition in tidal flats (very shallow subtidal to supratidal) and in marshes. The upper sandstone member of the Cypress contains marine trace fossils associated with body fossils and sedimentary structures that indicate a return to shallow subtidal sedimentation. The upper member is overlain (conformably, in most cases) by limestone and shale of the Golconda Formation also deposited under shallow subtidal conditions.

The Cypress is thickest and merges with the underlying Bethel Sandstone along the southwest-trending West Baden clastic belt, which appears to be structurally controlled. Another clastic belt extends NNE–SSW across the Fairfield Basin of south-central Illinois. These clastic belts reflect input of sediment from source areas north and northeast of the outcrop belt. Geometry and sedimentology of sandstones in the clastic belts are comparable to those of modern tidally influenced deltas.

Sandstone bodies in the outcrop belt of the Cypress exhibit geometries similar to those of oil-producing Cypress sandstone reservoirs in the subsurface. The lower sandstone member of the Cypress yields oil at the giant Louden and Lawrence County fields, whereas sandstones in the upper member are productive in several smaller fields.

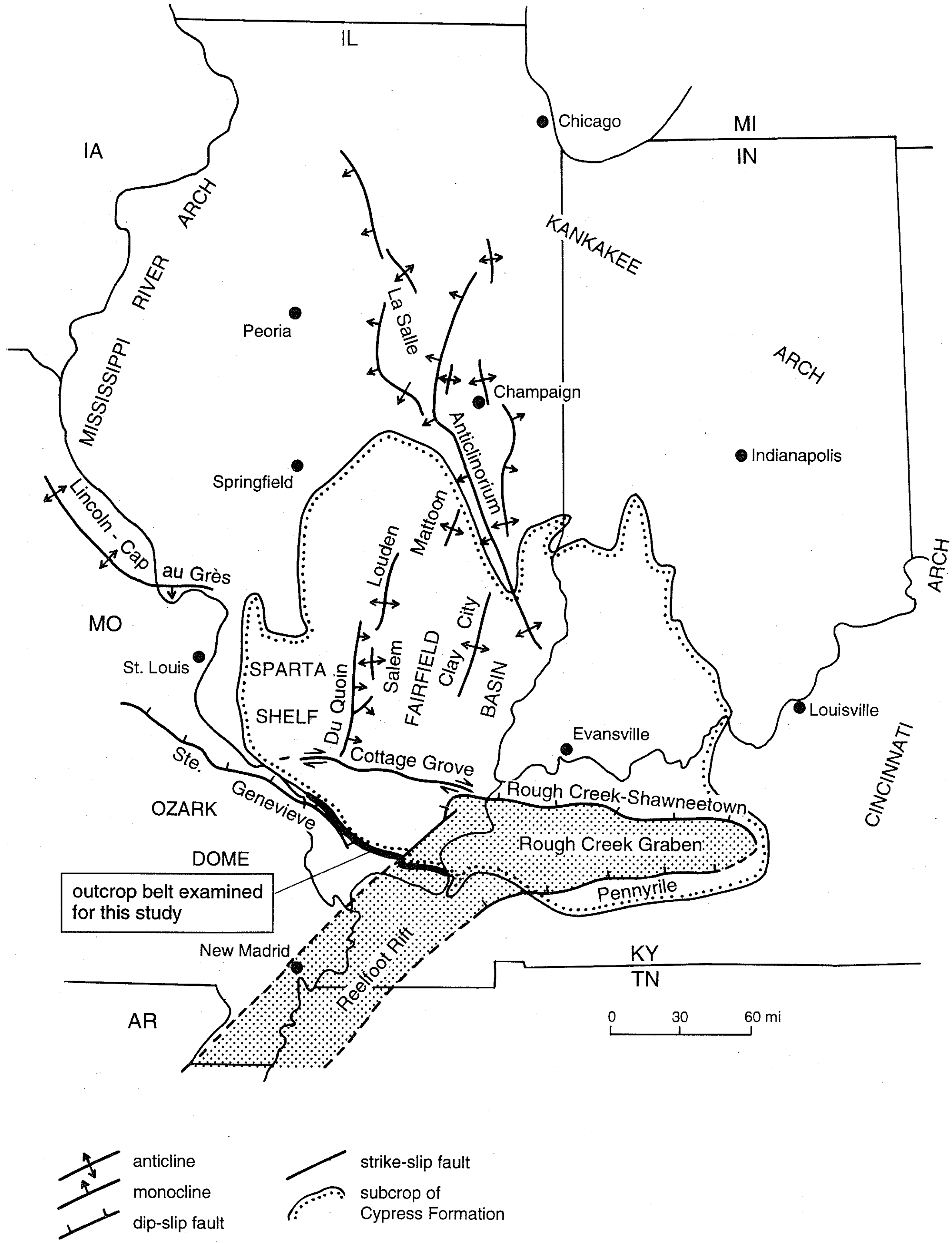



**Figure 1** Map showing the extent of the Cypress Formation and selected major structural features of the Illinois Basin and vicinity. The bold segment of the outcrop belt indicates the focus area of the study.

# INTRODUCTION

## Purpose

This study was part of a statewide investigation into methods for improving oil recovery from the Cypress Formation and the slightly older Aux Vases Formation. The study was funded by the U.S. Department of Energy and the Illinois Department of Energy and Natural Resources. The leading oil-producing formation in the Illinois Basin is the Cypress, with cumulative production of close to 1 billion barrels. It is the major reservoir rock in the giant Louden and Lawrence County oil fields, as well as in many smaller fields in central and southeastern Illinois, southwestern Indiana, and western Kentucky. In spite of the economic importance of the Cypress, little has been published about its depositional environments or reservoir geometry.

Knowledge of the geometry and trend of sand bodies is critical in implementing efficient production strategies for the Cypress. Although some reservoir geometries can be deduced empirically from borehole data, predictive modeling is enhanced through a greater understanding of the environments of deposition. Subsurface data of the type and quality needed for interpretation of depositional environments seldom are available. Only electric logs are available for most wells. The Illinois State Geological Survey (ISGS) has sample sets for fewer than 10% of the wells in the state and has cores for a much smaller percentage. Only a handful of long, continuous cores are available. Much information on rock-body geometry, lateral relationships of facies, and sedimentary structures can therefore only be obtained from outcrop study.

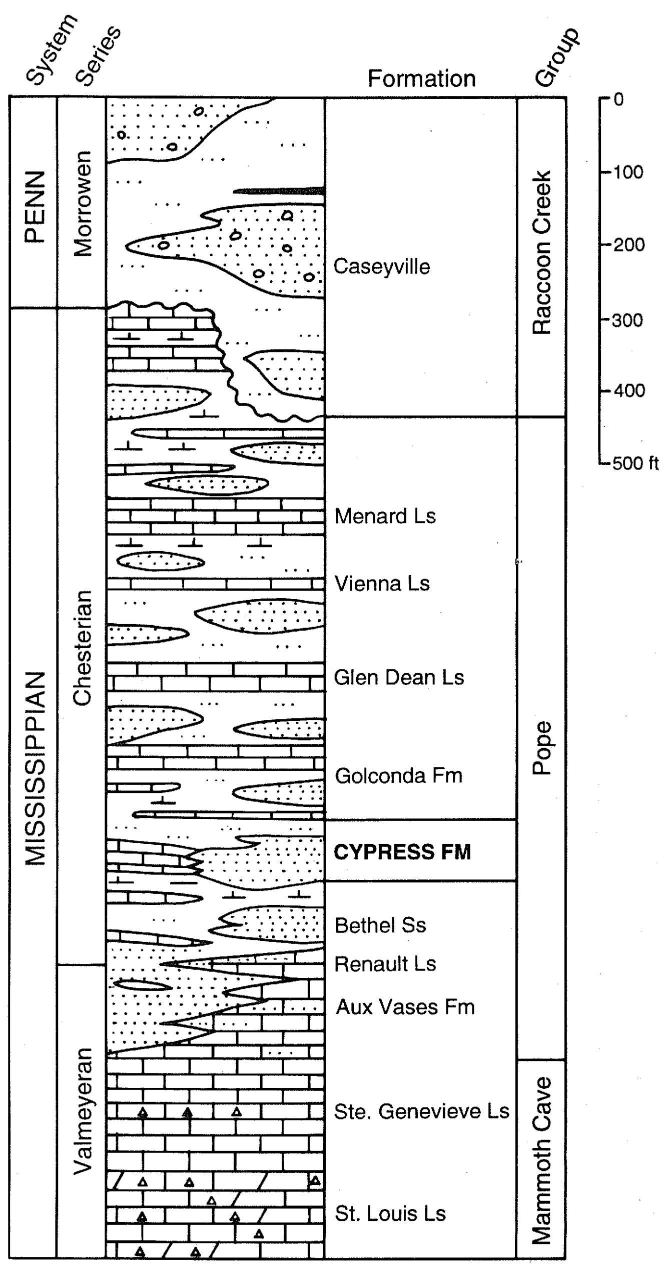
The purpose of this study was to determine depositional environments of the Cypress Formation in the outcrop belt of southern Illinois and to relate depositional facies of the outcrop to reservoir geometry.

## Geologic Setting

The study area is located in southern Illinois along the southern margin of the Illinois Basin (fig. 1). The Illinois Basin is an interior cratonic basin containing Cambrian through Lower Permian sedimentary rocks with a maximum thickness of about 23,000 feet. Broad arches and domes border the Illinois Basin. These include the Ozark Dome, Kankakee Arch, and Cincinnati Arch (fig. 1). These features were uplifted recurrently during Paleozoic sedimentation, while the proto-Illinois Basin subsided. The arches were subaerially exposed or submerged by shallow seas at various times. Southern closure of the basin, however, did not occur until late Pennsylvanian time at the earliest (Kolata and Nelson 1991a). During late Mississippian time, the proto-Illinois Basin was a broad ramp-like embayment open toward the south (Treworgy 1988).

The Illinois Basin developed from a failed rift during the Cambrian Period. The rift was composed of two connected segments: the northeast-trending Reelfoot Rift and the east-trending Rough Creek Graben (fig. 1). After Cambrian time the rift area continued to subside because of thermal contraction, isostatic adjustment, and sedimentary infill. Faults within and bordering the rift were reactivitated periodically during and after Paleozoic sedimentation. The area overlying the junction of the Reelfoot Rift and Rough Creek Graben (in extreme southeastern Illinois and the adjacent part of western Kentucky) served as a depocenter for much of Paleozoic time (Kolata and Nelson 1991a, 1991b).

In late Valmeyeran (mid-Mississippian) time, the Illinois Basin was a shallow carbonate shelf comparable to the modern Bahama Banks or Persian Gulf (Cluff and Lineback 1981). Nearly pure carbonates of the Salem, St. Louis, and Ste. Genevieve Limestones were deposited under these conditions. Near the end of the



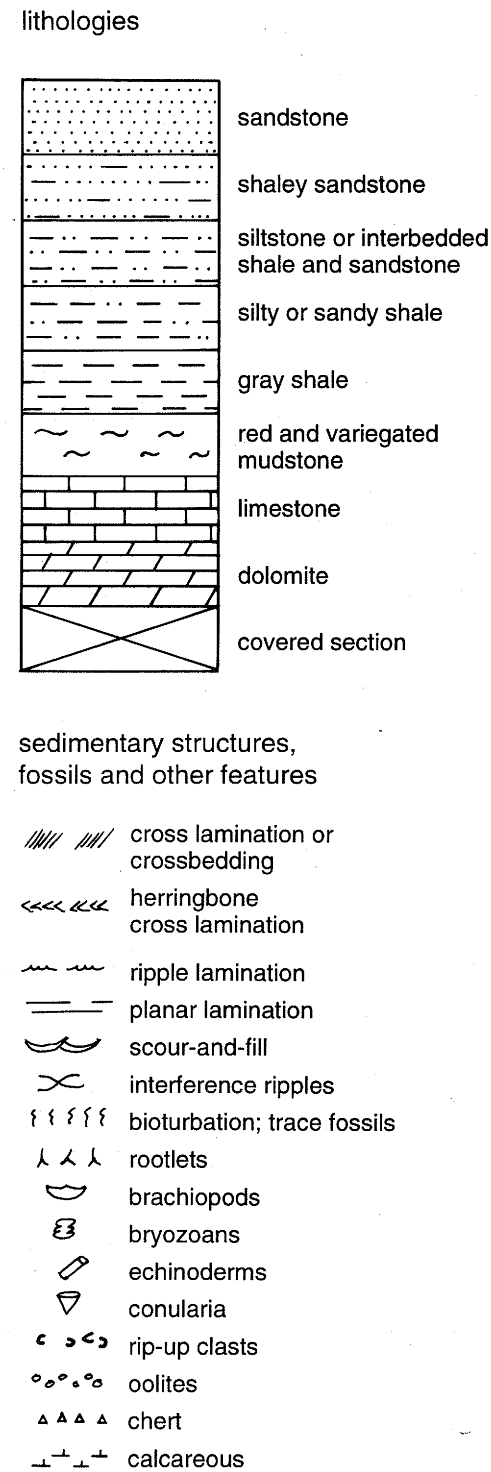




**Figure 2** Generalized stratigraphic column showing the Cypress Formation and enclosing units in southern Illinois. Not all named units are shown. The key shown applies also for figures 3 and 6 through 14.

Valmeyeran Epoch, siliciclastics entered the Illinois Basin from the northwest. These clastics make up the Aux Vases Formation (fig. 2), which intertongues with the upper part of the Ste. Genevieve (Cole 1990). For the remainder of Mississippian time, limestone and siliciclastic sedimentation alternated in the Illinois Basin area, and the Pope Group was formed (fig. 2). The Cypress Formation is a siliciclastic unit in this mixed succession.

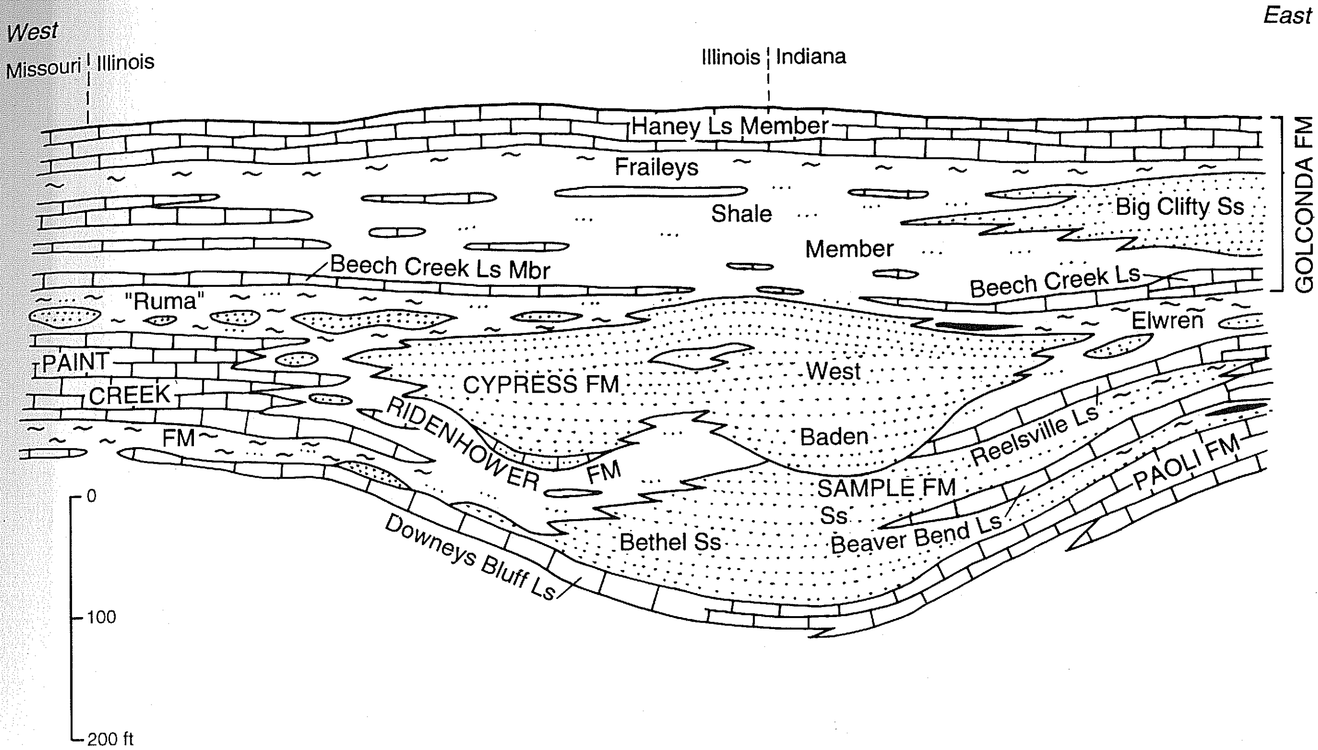



**Figure 3** Schematic east–west stratigraphic cross section following 38° N latitude across the Illinois Basin. East–west distance is approximately 150 miles.

## Nomenclature

**Cypress Formation** Englemann (1863) gave the name Cypress Sandstone to 150 feet of sandstone with shaley interbeds, exposed in bluffs along Cypress Creek in Union County, Illinois. Some subsequent workers, including Ulrich (1904), mis-correlated the older Aux Vases Sandstone with the Cypress, but later outcrop studies in southwestern Illinois (S. Weller 1913, 1920) established the separate identities of the Aux Vases and Cypress. The younger Big Clifty Sandstone was consistently misidentified as the Cypress in the outcrop belt of Kentucky and Indiana in areas where the thin intervening Beech Creek Limestone was not recognized. This mistake was rectified by Swann and Atherton (1948) and McFarlan et al. (1955).

S. Weller (1913) gave the name Ruma Formation to an interval of variegated shale and thin bedded sandstone cropping out in Monroe and Randolph Counties, Illinois (fig. 3). When further study showed the Ruma to be a lateral facies of the Cypress, the name Ruma was abandoned (S. Weller 1920). In Greene County, Indiana, Malott (1919) applied the name Elwren Formation to an interval of variegated shale and sandstone that he thought to be older than the type Cypress. Subsequent research showed the Elwren and Cypress to be equivalent. Currently, the name Elwren is applied on the outcrop in Indiana, but the name Cypress is used when referring to the subsurface.

The name Cypress Formation is used here in preference to Cypress Sandstone to emphasize that the unit also contains substantial amounts of shale and siltstone.

**Golconda Formation** The Golconda Formation is a unit of intercalated limestone, shale, and sandstone that overlies the Cypress Formation. The Golconda was named by Brokaw (1916) and defined in greater detail by Butts (1917). Swann (1963) elevated the rank of the Golconda to group, but it was revised back to a formation by Weibel et al. (1993). This change of rank was made because the Haney, Fraileys, Big Clifty, and Beech Creek are not mappable at the scale required for formational units in most of Illinois. In this report, therefore, the Golconda is classified as a formation, which is subdivided into the Beech Creek Limestone, Fraileys Shale, Big Clifty Sandstone, and Haney Limestone Members (figs. 2 and 3).

**Ridenhower Formation** The Ridenhower Formation was named by Butts (1917); the Ridenhower type section is at Indian Point (section IP, appendix A). The type Ridenhower is a unit of shale and siltstone having thin limestone interbeds; the unit separates the Cypress Formation above from the Bethel Sandstone below. Surface and subsurface mapping for this study demonstrates that the Ridenhower intergrades and intertongues eastward with the Bethel Sandstone. Westward, the Ridenhower intergrades and intertongues with carbonate rock in the upper part of the Paint Creek Formation (fig. 3, pl. 1).

Swann (1963) classified the Ridenhower Formation as part of the Paint Creek Group in Illinois. In this report, the Ridenhower and Paint Creek are recognized as separate formations that are, in part, facies equivalents. The name Ridenhower is restricted to areas where the dominant lithologies are shale and siltstone, whereas Paint Creek is used in areas where limestone dominates.

**Bethel Sandstone** The Bethel Sandstone was named by Butts (1917) for exposures in Crittenden County, Kentucky. In southern Illinois the Bethel is a unit of sandstone that partly underlies and partly is laterally equivalent to the Ridenhower Formation (fig. 3, pl. 1).

**West Baden Sandstone (revised)** The term West Baden Group was introduced in southern Indiana by Cumings (1922) and reintroduced after long disuse by Gray et al. (1960). As defined therein, the West Baden Group comprises the Bethel Sandstone, the Ridenhower Formation and equivalent units, and the Cypress Formation. The name is generally restricted to areas where Cypress and Bethel sandstones are directly superimposed and not readily distinguished from one another. This situation occurs chiefly along a sinuous, bifurcating belt that extends southwestward from west-central Indiana into southern Illinois. The name West Baden clastic belt is given to this belt of sandstone (Sullivan 1972).

Because the West Baden "Group" cannot be divided into formations, it does not fit the definition of a group as given in the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature 1983). We are therefore revising the West Baden Group to a formation, the West Baden Sandstone. Use of the name West Baden Sandstone should be restricted to areas where the Cypress-Ridenhower-Bethel interval is predominantly composed of sandstone and not divisible into smaller formations. In other areas of the basin, where shale or limestone formations separate the Cypress from the Bethel, West Baden should not be used. No logical reason exists to combine the Cypress, Ridenhower, and Bethel into a group or subgroup distinct from the remainder of the Pope Group.

**Paint Creek Formation (revised)** The Paint Creek Formation was defined by S. Weller (1913) in Randolph County, southwestern Illinois, and elevated to a group by Swann (1963). Under Swann's classification, the Paint Creek Group comprises the Downeys Bluff Limestone (oldest), Bethel Sandstone, and Ridenhower Formation.

In its type area the Paint Creek is composed largely of limestone. An interval of red claystone near the base of the Paint Creek is approximately equivalent to the Bethel Sandstone (pl. 1). However, this claystone and the underlying limestone (Downeys Bluff equivalent) are too thin to be mapped at the scale of formations in southwestern

Illinois. Moreover, the part of the Paint Creek that is equivalent to the Ridenhower is greatly different in lithology from the type Ridenhower. The use of a different name is appropriate because of the change in lithology. According to the North American Commission on Stratigraphic Nomenclature (1983), the Paint Creek is not a group because it is not divisible into mappable formations. Therefore, we are revising the Paint Creek Group back to Paint Creek Formation in this report. Use of the name Paint Creek should be restricted to areas where the interval is composed primarily of limestone and where the Bethel Sandstone is absent or not mappable.

## Previous Research

Many geologists have studied the Cypress Formation. Early studies established the areal distribution, stratigraphy, and paleontology of the Cypress and enclosing strata (S. Weller 1913, 1920, Sutton and Weller 1932, Sutton 1934, J.M. Weller 1940, 1948, Workman 1940, Dana and Scobey 1941, Atherton 1947, Swann and Atherton 1948, McFarlan et al. 1955). Geologic maps showing the outcrop belt of the Cypress in southern Illinois were published by S. Weller and J.M. Weller (1939), S. Weller and Krey (1939), and J.M. Weller and Ekblaw (1940).

J.M. Weller and Sutton (1940, p. 844–846) stated that evidence on the source of Chesterian sediments is "contradictory": thickness and facies patterns indicated different source areas for different sandstones. They suggested that much Chesterian siliciclastic sediment came from "Llanoria," a postulated landmass in the Gulf Coastal region. The presence of marine invertebrates and terrestrial plant fossils in Chesterian siliciclastic units enabled them to deduce that marine (shallow marine and estuarine) and nonmarine (alluvial or coastal-plain) deposits were represented. They viewed Chesterian limestone-shale intervals as entirely marine on the basis of abundant faunal evidence. Weller and Sutton further characterized Chesterian strata as cyclic: marine limestone-shale units alternating with partly continental siliclastic units. Siever (1953) studied petrology and sedimentation of upper Chesterian sandstones (above the Cypress). He regarded Chesterian strata as cyclic, similar to Pennsylvanian cyclothems; cyclicity was attributed to repeated shifts of the strandline. Sandstones, according to Siever, were partly shallow marine, partly terrestrial. Siever favored multiple source areas for upper Chesterian siliciclastics. He proposed that the principal source areas were the Transcontinental Arch northwest of the Illinois Basin and the Canadian Shield north of the basin. A secondary source area northeast of the basin (Appalachian orogen?) and a minor contribution from the Ozark Dome also were postulated.

Smoot (1960) noted that the lower part of the Cypress Formation contains marine fossils and occasional limestone beds, whereas the middle and upper Cypress contain terrestrial plant fossils and local coal. Accordingly, Smoot characterized the lower Cypress as marine and the upper part as nearshore to terrestrial.

Current views of Chesterian sedimentation in the Illinois Basin are heavily influenced by the work of Paul E. Potter and David H. Swann. Potter's views of Chesterian paleogeography are presented in a series of papers (Potter 1962, 1963, Potter and Pryor 1961, Potter et al. 1958). His interpretations were made mainly on the basis of petrography of the sandstones, geometry of sand bodies in subsurface, and paleocurrent data (principally from crossbedding). Potter inferred that the Illinois Basin area was a southwest-sloping ramp in Chesterian time and that the primary source of siliciclastics lay to the northeast. He envisioned a large river system that built deltas, similar to the modern Mississippi delta. According to Potter, Chesterian sandstones were deposited in a variety of fluvial, deltaic, and shallow marine environments.

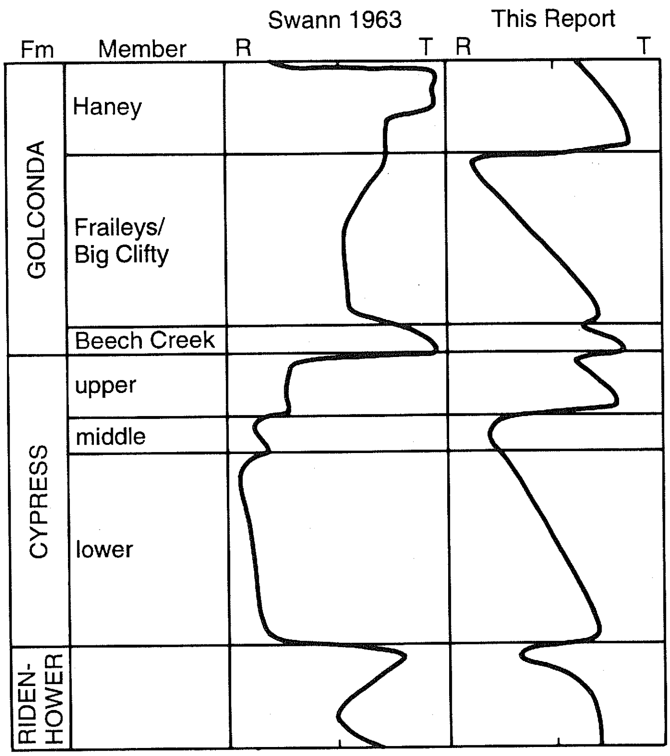



**Figure 4** Diagram showing contrasting interpretations of relative sea-level changes during early Chesterian time. Swann's (1963) interpretation is shown on the left and ours is on the right. T= transgression, R= regression.

Swann (1963, 1964) concurred with Potter's model and named the postulated fluvial system the "Michigan River" (fig. 4). According to Swann (1963), the Michigan River deposited the lower Valmeyeran Borden Siltstone, but its delta retreated far to the northeast when sea level rose at the onset of deposition of carbonates of the Mammoth Cave Group. Sea level dropped in late Valmeyeran time, the Michigan River delta prograded, and siliciclastic deposition in the Illinois Basin area was renewed. Throughout Chesterian time, the delta repeatedly advanced and retreated, and it also shifted laterally along the northwest-trending coastline. According to Swann, each Chesterian limestone represented a transgression and each siliciclastic unit a regression.

More specific environmental interpretations were presented by Swann (1964). Large sand bodies were interpreted as distributary-channel and "bar finger" (distributary-mouth bar) deposits. Small sandstone bodies were attributed to similar environments or to reworking of abandoned deltas by marine currents and tides. Shales were interpreted as representing prodelta, interdistributary bay, overbank, and marsh environments. Swann proposed that climate, rather than eustasy, was the primary control on Chesterian "rhythmic" sedimentation. During dry periods, sediment transport increased and the delta prograded. In wet periods, greater plant cover baffled sediment transport and limestone was deposited (Swann 1964).

More recent papers on the Chesterian of the Illinois Basin include regional summaries (e.g., Atherton and Palmer 1979, Sable 1979, Treworgy 1991) and detailed analyses of individual units in small areas (e.g., Treworgy 1988, Wilsey 1984, Cluff and Lasemi 1980). A field guidebook by Seyler (1982) included information on outcrops of the Cypress Formation in southern Illinois, including several that were reexamined for our study. Seyler interpreted these Cypress outcrops in the framework of a fluvially dominated delta, as postulated previously by Swann. Treworgy (1988) focused on the Golconda Formation (immediately overlying the Cypress) and characterized the Illinois Basin as a tidally influenced ramp. Wilsey's interpretation of Cypress sedimentation in White and Gallatin Counties, Illinois, is similar to interpretations by Potter and Swann. Wilsey assigned sandstones of the Cypress to fluvial and deltaic settings under marine regression. Pryor et al. (1991) relied on Wilsey in their treatment of Mississippian reservoir rocks of the Illinois Basin. One of the few papers to diverge from the Michigan River model was Cluff and Lasemi (1980). Using subsurface data, Cluff and Lasemi interpreted the Cypress in the Louden oil field as barrier-island, lagoonal, and dune deposits transected by tidal channels on the crest of a rising anticline.

## Methods

Outcrop study for this project was conducted by Cole from 1990 to 1992. Thirty stratigraphic sections of the Cypress Formation and adjacent strata were measured along the outcrop belt from eastern Pope County to Union County, Illinois. Locations of measured sections are given (fig. 5, appendixes A and B), and graphic columns of 21 of the sections are presented (figs. 6–14). Sedimentary structures were described and fossils identified at each outcrop, and samples were collected for petrographic study. In addition, Nelson mapped the outcrop belt of the Cypress and adjacent formations in parts of Johnson, Massac, and Pope Counties (fig. 5). Information from this mapping was used to correlate the measured sections.

Thin sections of 70 sandstone specimens were prepared and examined under the petrographic microscope. Clay mineralogy of sandstone samples was determined using X-ray diffraction performed by D.M. Moore of the ISGS. Porosity and permeability of sandstone samples from the I-57 section were determined by D.J. Haggerty, also of the ISGS.

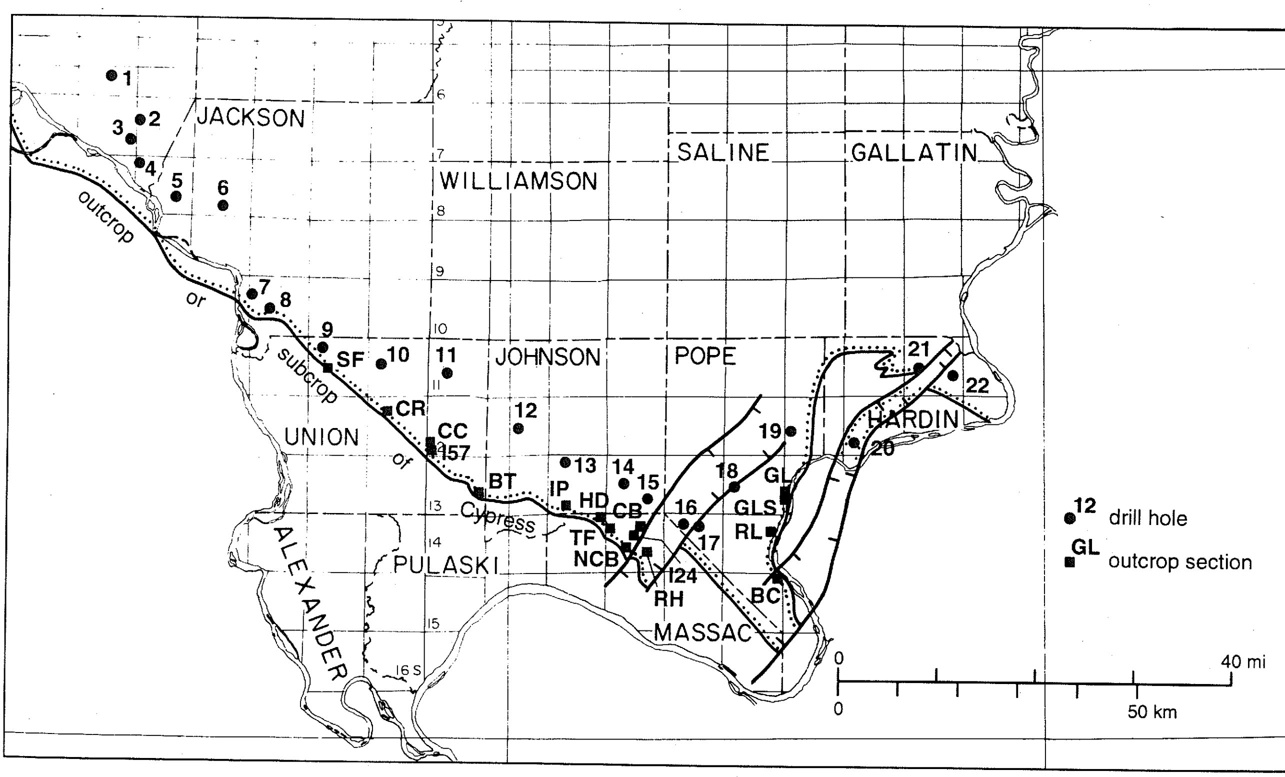



**Figure 5** Map showing locations of outcrop sections mentioned in this report and drill holes used for plate 1 (see appendix A for explanation of outcrop identification and appendix B for records of drill holes).

Subsurface study for this report was conducted mainly by Nelson as part of a regional investigation of the Pope Group in the southern part of the Illinois Basin. All available well records (about 60) were examined in a belt about 5 miles wide along the outcrop from Hardin County on the east to Randolph County on the west. Available cores and well cuttings were reexamined when adequate descriptions did not exist. A cross section (pl. 1) was constructed using the records from 22 wells, including eight continuous cores. Wells used in the cross section are listed in appendix B.

Patterns of outcrop and core availability introduced unavoidable bias to this study. Cypress outcrops in southern Illinois are predominantly bluff-forming, thickly bedded sandstone in the lower part of the formation. Shale, mudstone, siltstone, and interlaminated sandstone-shale of the middle and upper Cypress rarely crop out. Nearly all of the available cores of the Cypress near the outcrop belt were taken from fluorspar-exploration boreholes in Hardin and Pope Counties. These cores sample the Cypress at its thickest and sandiest. At the eastern and western margins of the Illinois Basin, the Cypress becomes thin and shaley. Data for the western margin are scarce, however, and the eastern margin lies outside the study area. Hence, we were forced to focus on the sandstone-dominated lower portion of the Cypress Formation in the basin interior. To achieve a more balanced, basin-wide synthesis of Cypress sedimentation will require an intensive search for shaley outcrops and a dedicated program of subsurface mapping.

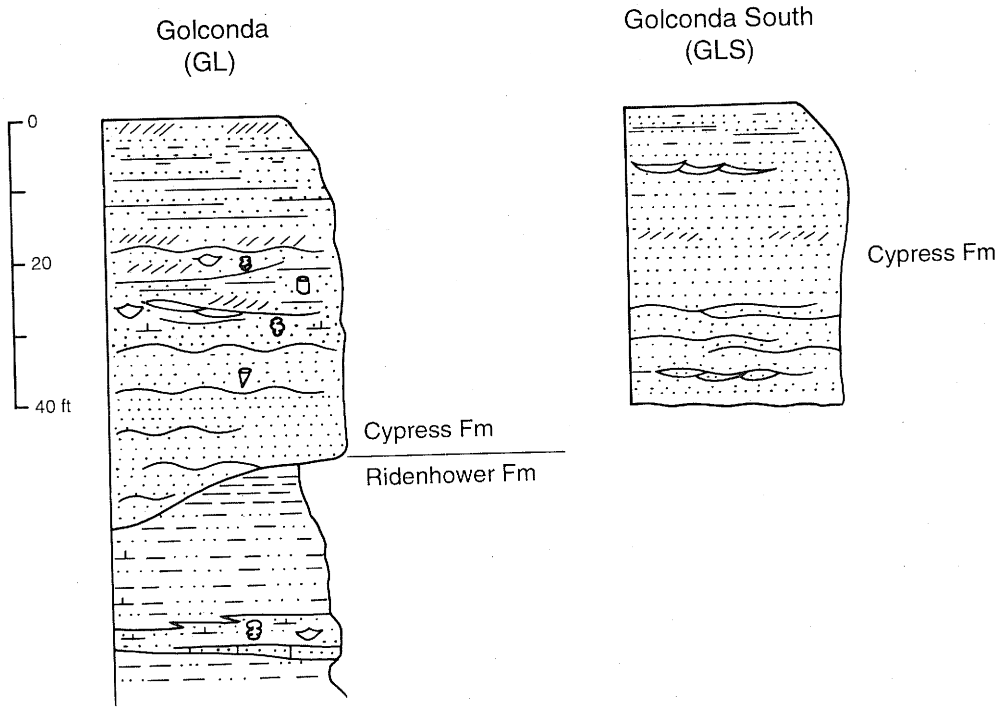



**Figure 6** Graphic columns of Golconda and Golconda South sections.

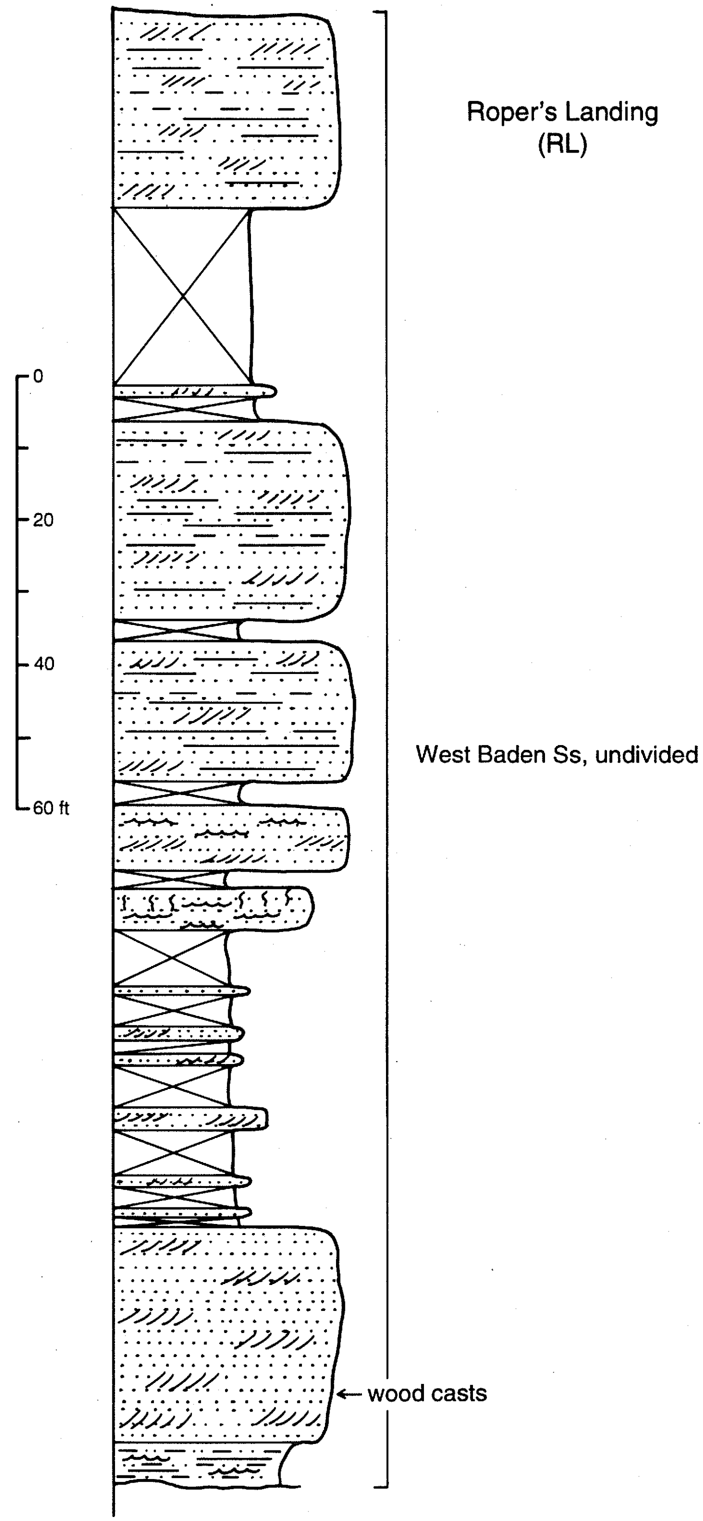



**Figure 7** Graphic column of Roper's Landing section.

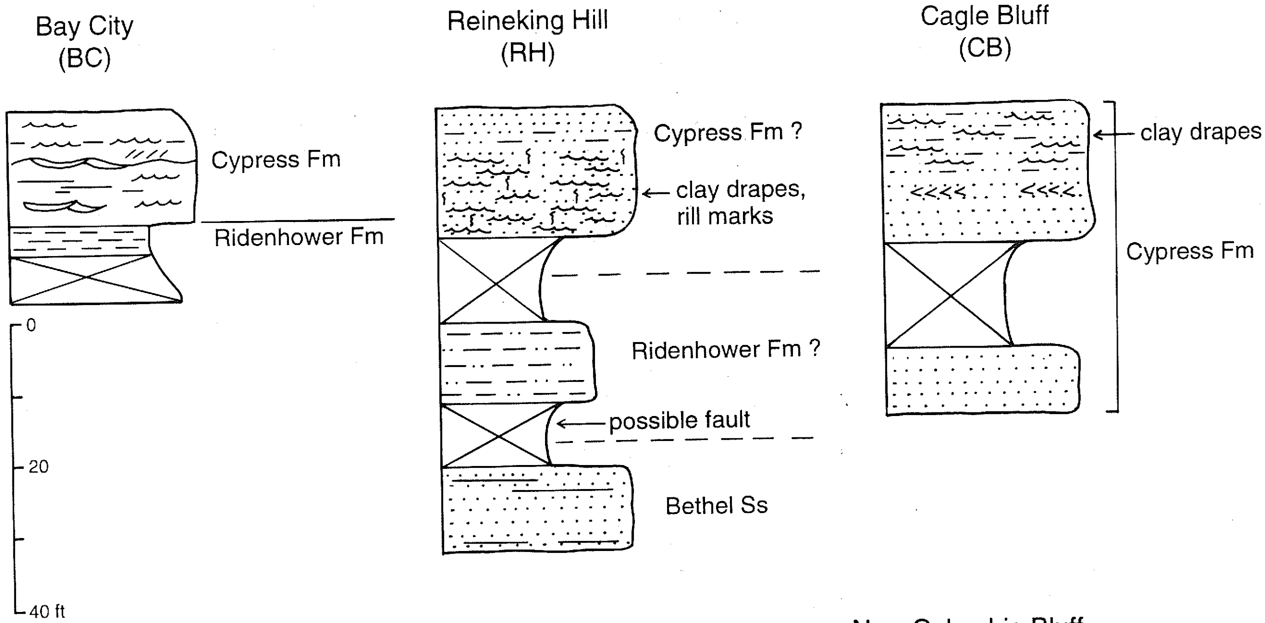
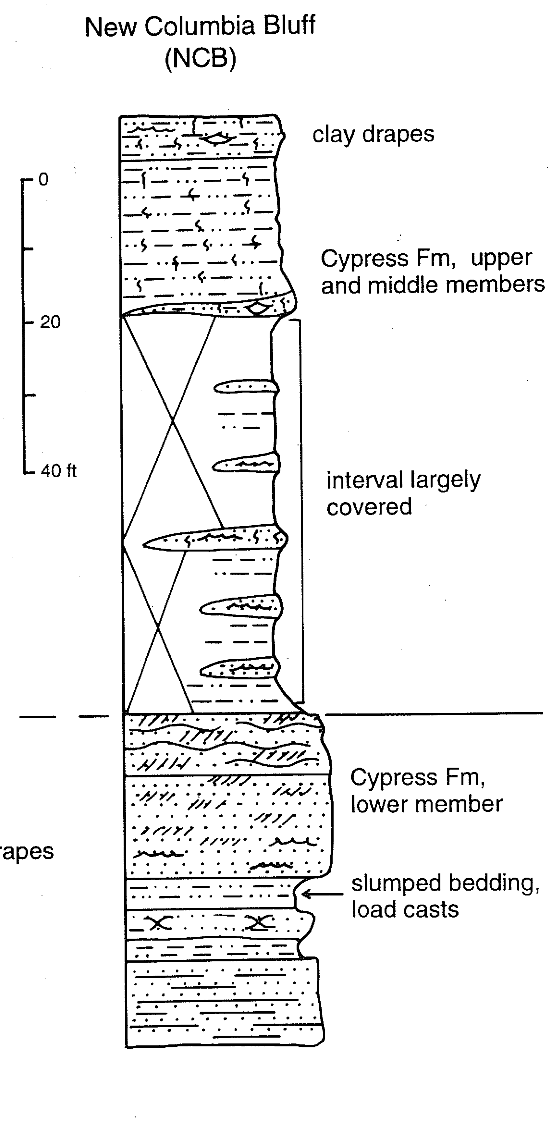



**Figure 8** Graphic columns of Bay City, Reineking Hill, and Cagle Bluff sections.



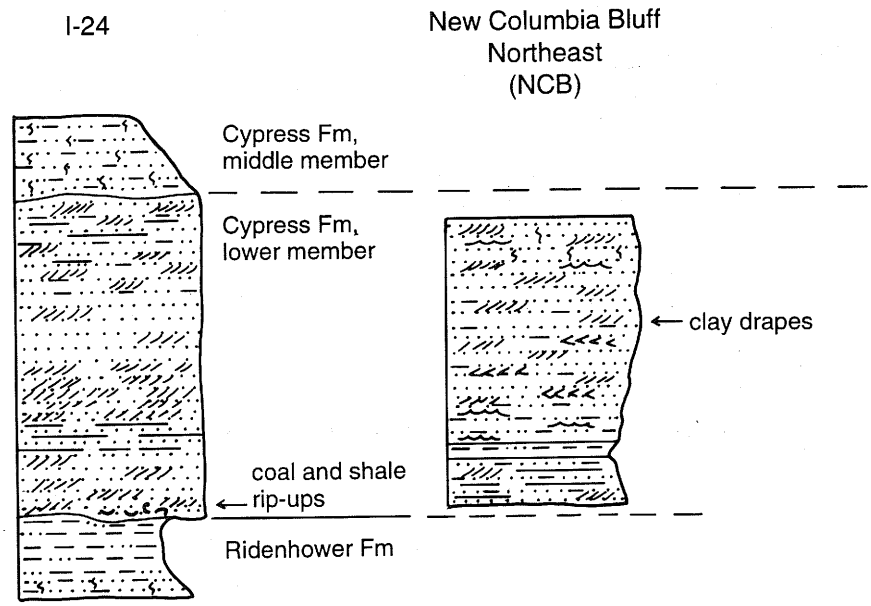




**Figure 9** Graphic columns of I-24, New Columbia Bluff NE, and New Columbia Bluff sections.

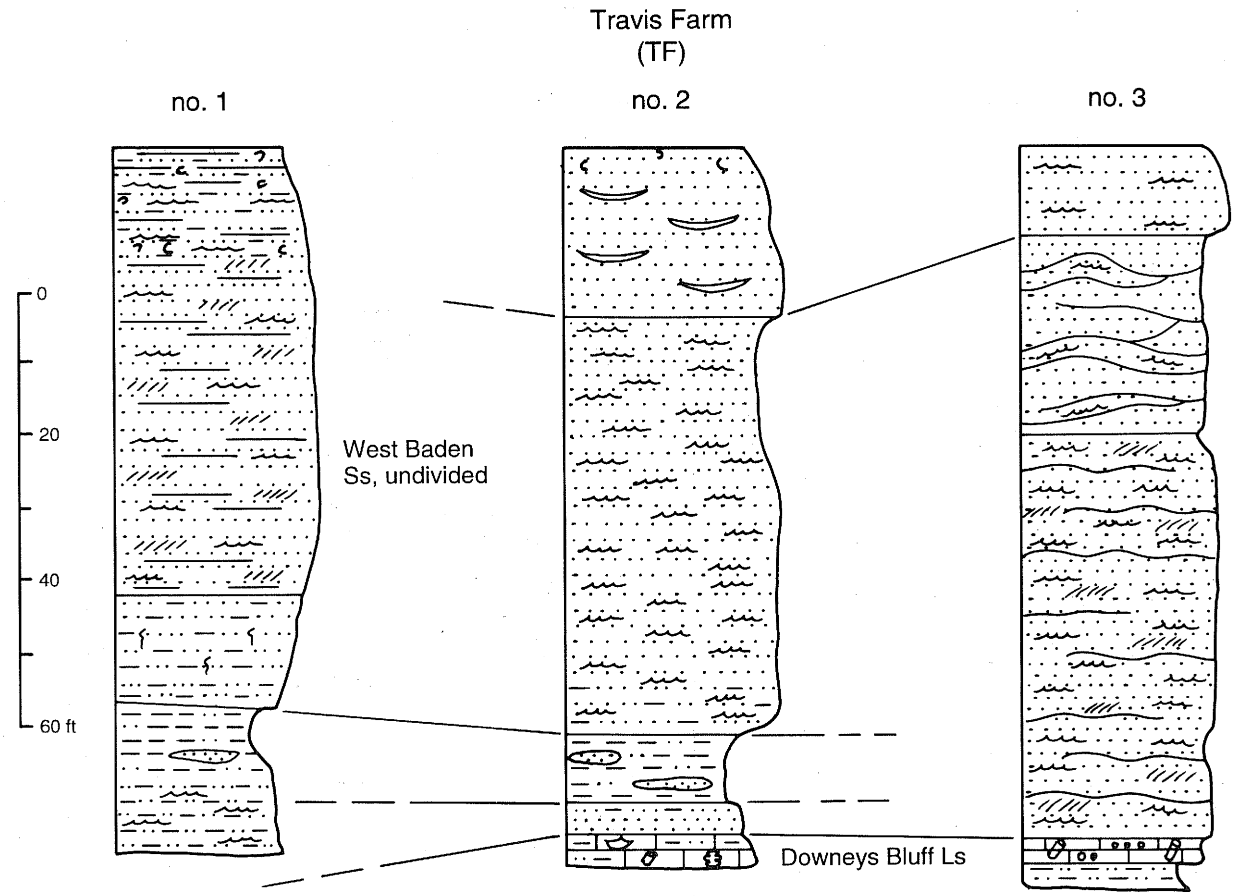



**Figure 10** Graphic columns of Travis Farm no. 1, no. 2, and no. 3 sections.

# FINDINGS

## Regional Relationships

**Distribution and thickness** The Cypress Formation underlies a large area of central and southern Illinois, southwestern Indiana, and western Kentucky (figs. 1, 15). The northwestern, northern, and northeastern limits of the Cypress are defined by pre-Pennsylvanian erosion. The only area where it was not deposited is at the southeast corner of the basin in Kentucky.

Thickness trends of the Cypress are known only in a general way. No regional isopach map of the Cypress in Indiana or Kentucky has been published. A small-scale, generalized isopach map of the Cypress in Illinois appears in Willman et al. (1975, p. 155). Additional information was gleaned from various published reports, geologic maps, and cross sections. These sources indicate that the Cypress is thickest in the central and east-central parts of the Illinois Basin, thinning markedly on the western and southeastern margins. In Indiana the Cypress is thickest along a NNE-trending, bifurcating belt called the West Baden clastic belt (Sullivan 1972). Within the West Baden belt, sandstones of the Cypress Formation merge with the underlying Bethel Sandstone to form a single undifferentiated unit, the West Baden Sandstone, which is as thick as 300 feet (Sullivan 1972).

Our outcrop and core study, as well as stratigraphic columns on published geologic quadrangle maps, show that the West Baden clastic belt continues into extreme southeastern Illinois and the adjacent part of western Kentucky (fig. 15). The thickest

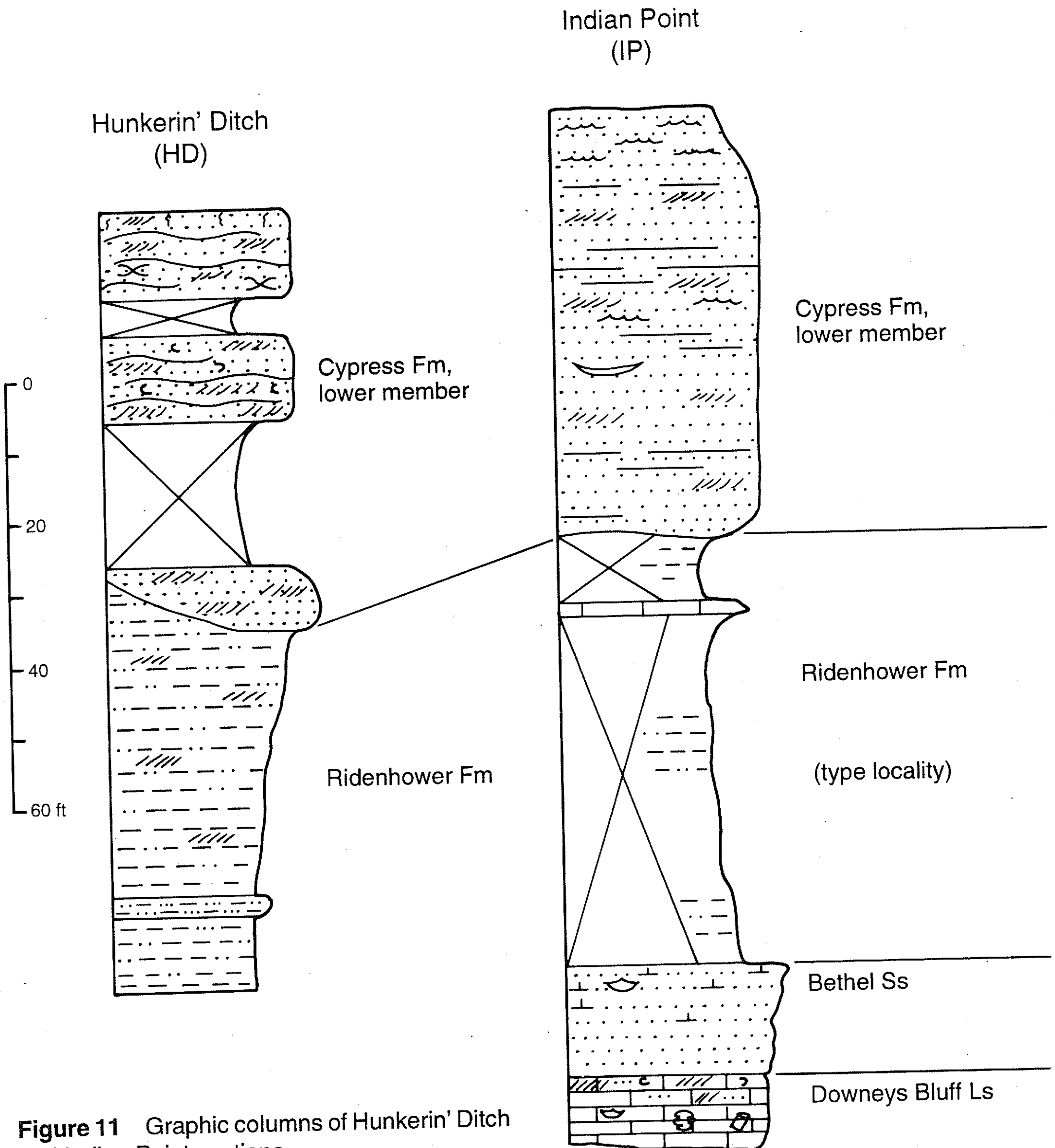



**Figure 11** Graphic columns of Hunkerin' Ditch and Indian Point sections.

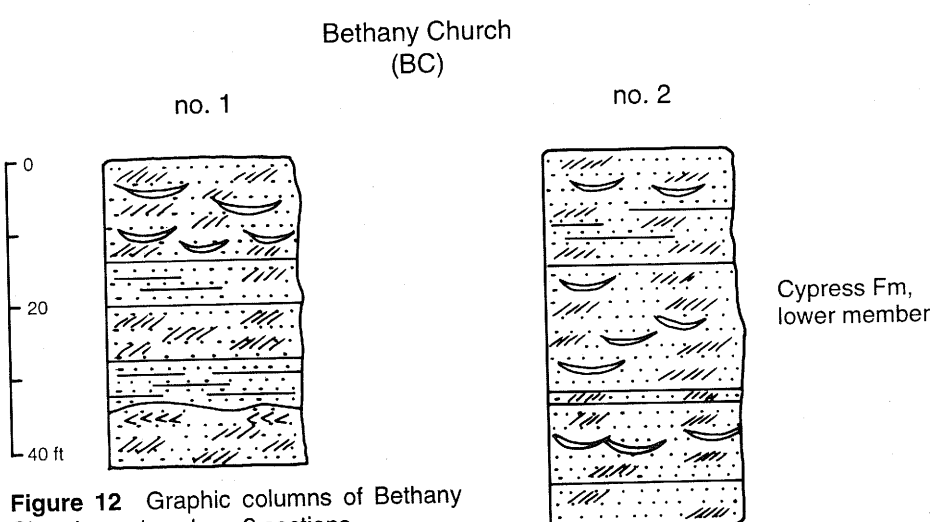



**Figure 12** Graphic columns of Bethany Church no. 1 and no. 2 sections.

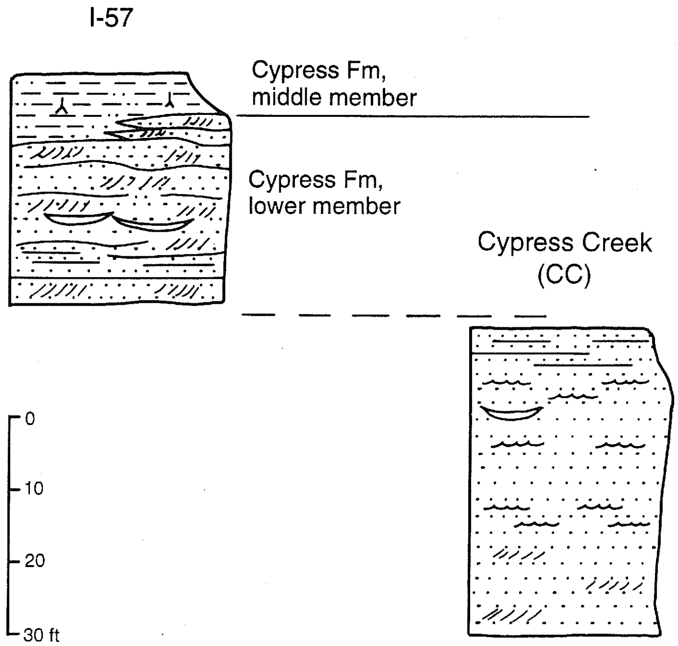



**Figure 13** Graphic columns of I-57 and Cypress Creek sections.

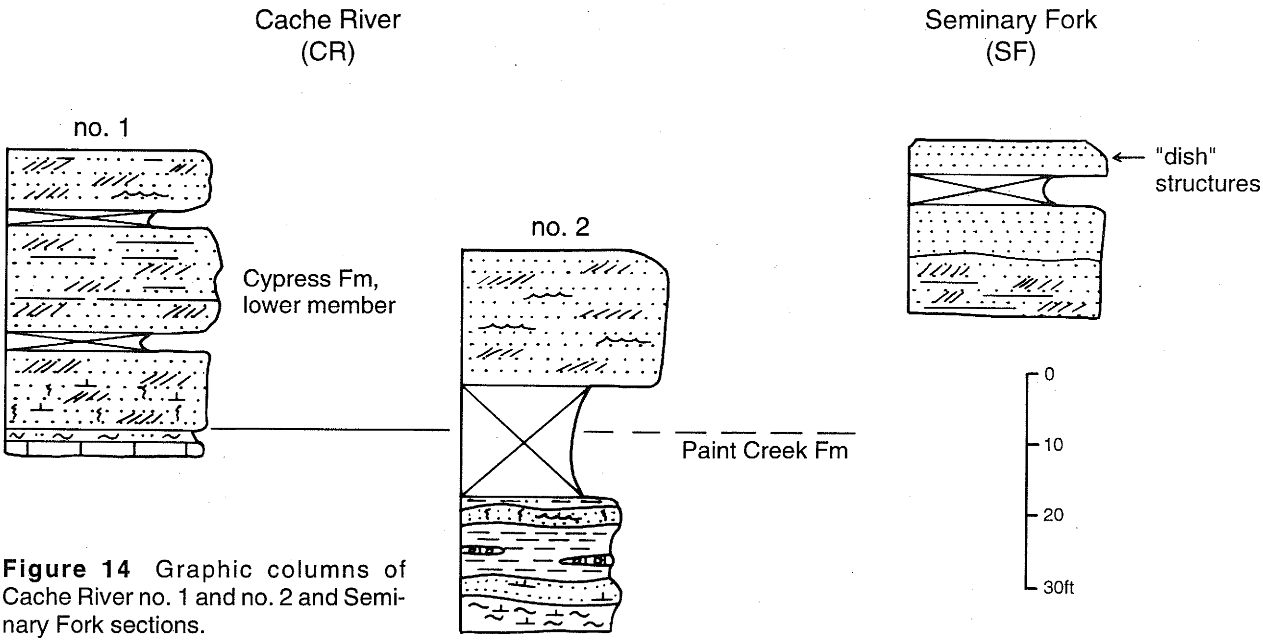



**Figure 14** Graphic columns of Cache River no. 1 and no. 2 and Seminary Fork sections.

part of the clastic belt in Illinois follows the Dixon Springs Graben, a structure that was active in both pre- and post-Mississippian time (Kolata and Nelson 1991a). In southwestern Indiana, part of the West Baden belt parallels the Wabash Valley Fault System, indicating tectonic control there also.

The Cypress is also thick in part of the Fairfield Basin of south-central Illinois, west of the West Baden clastic belt. The Cypress is at least 120 feet thick along a broad belt that trends NNE from the outcrop in Union and Johnson Counties to the northern subcrop of the Cypress in Jasper and Cumberland Counties (Willman et al. 1975, fig. M-37). Well data show that the Cypress is as thick as 200 feet in parts of Perry

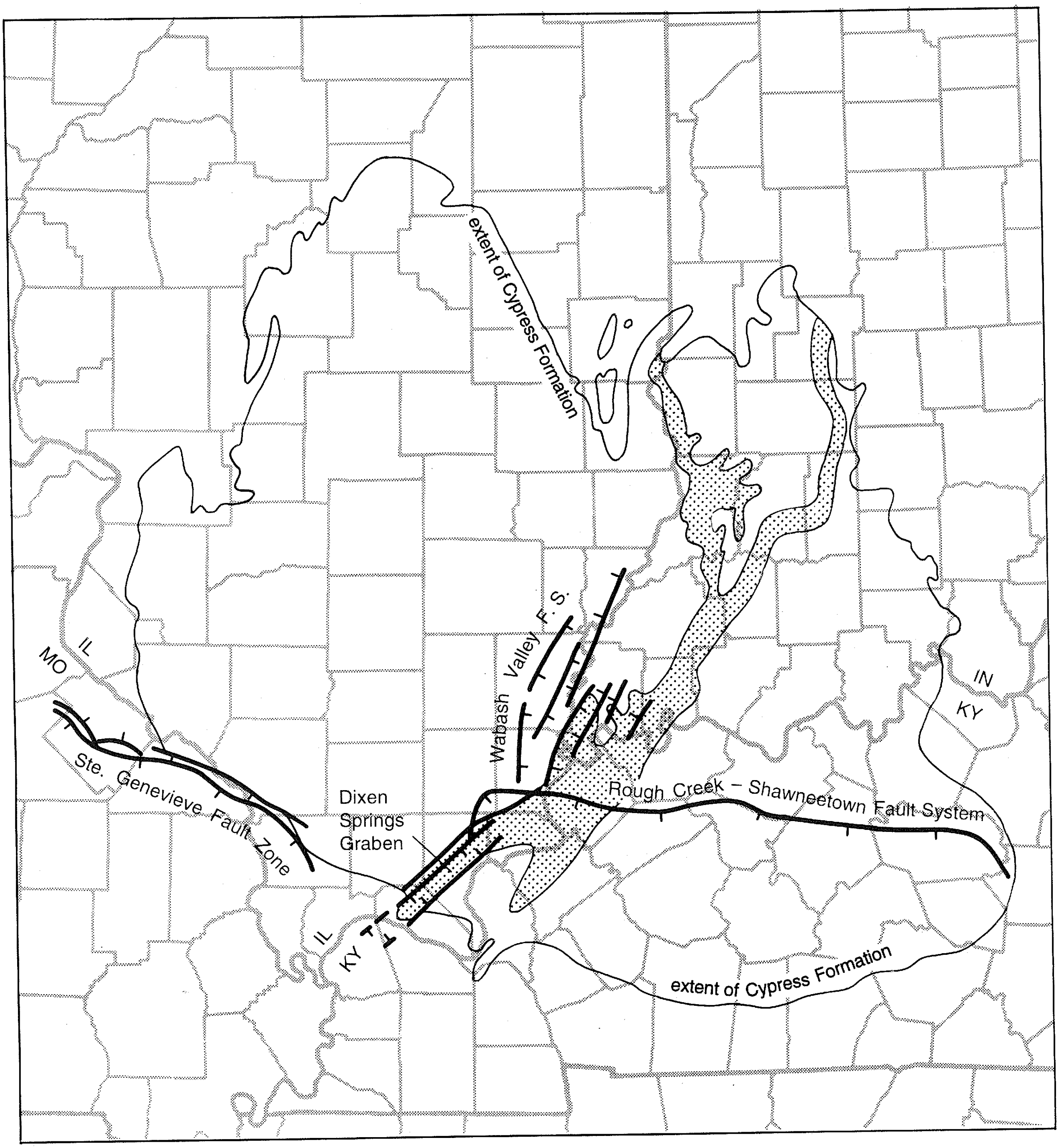



**Figure 15** Map showing the extent of Cypress Formation, West Baden clastic belt (stippled), and selected faults. The clastic belt in Indiana is taken from Sullivan (1972); in Illinois and Kentucky, it is from various sources. Paleostructural control of the clastic belt by the Wabash Valley Fault System and Dixon Springs Graben is indicated.

and Franklin Counties in southern Illinois. As in the West Baden clastic belt, the thick Cypress merges with the Bethel in some areas. In most of the outcrop belt in southern Illinois away from the West Baden clastic belt, however, the Bethel is thin or absent where the Cypress is thick. Additional detailed subsurface mapping clearly is needed to outline thickness and distributional patterns of the Cypress Formation in the Fairfield Basin.

The Cypress thins rapidly west of the Fairfield Basin. It averages about 40 feet thick along the northwestern subcrop (Willman et al. 1975) and thins to less than 20 feet on the flank of the Ozark Dome. The Cypress also tapers southeastward from the West Baden clastic belt. Farthest from the clastic belt, in the southeastern part of the western Kentucky outcrop belt, the Cypress is reduced to discontinuous bodies of shale and sandstone within the Girkin Limestone (McFarlan et al. 1955).

**Lithofacies patterns** The Cypress Formation in the outcrop belt is dominated by sandstone where the formation is thick and by shale where it is thin. Abrupt lateral lithofacies changes, however, are evident throughout the outcrop belt.

The Cypress commonly can be divided into three informal members where it is thick. These members comprise a lower sandstone member, a middle shaley member, and an upper sandstone member. The lower member commonly represents two-thirds to three-quarters of the thickness of the formation in the outcrop belt. It is composed predominantly of bluff-forming sandstone containing occasional laminae and thin interbeds of dark gray shale and siltstone. Most outcrops of the Cypress in southern Illinois reveal only the lower member. The middle shaley member of the Cypress is composed mostly of shale and mudstone, as well as thin interbeds of siltstone and sandstone. These rocks are largely medium to dark gray, but red and green variegated mudstone occurs in the middle member in some areas. Coal and carbonaceous shale are also widespread in the middle member, particularly at or just above the base of the member. The upper member of the Cypress is largely thin bedded sandstone with interbeds of shale and siltstone; lenses of thick bedded sandstone occur in this member.

Where the Cypress is thin, on the eastern and southwestern margins of the Illinois Basin, it is largely shale containing lenses of sandstone. Dark gray, well laminated shales are present, as are red and green variegated mudstones. The sandstone is mostly very fine grained and laminated to thinly bedded. Sandstone in some areas of Todd County, Kentucky, fills small channels incised into underlying limestones (Shawe 1967). Thin lenticular limestones occur near the southeastern pinch-out of the Cypress in Kentucky. The thin, shaley Cypress of the Sparta Shelf in southwestern Illinois and the adjacent part of Missouri (Ruma Formation of S. Weller 1913) is poorly exposed and has been little studied. Variegated shale or claystone and thin bedded siltstone and sandstone are reported to be the principal rock types in that area (S. Weller 1913, Thompson 1986).

**Relationships to adjacent units** In most of the Illinois Basin, the Beech Creek Limestone Member of the Golconda Formation (commonly called the "Barlow lime") conformably overlies the Cypress Formation (fig. 3). The Cypress–Beech Creek contact typically is sharp; however, in places, calcareous sandstone containing fossil fragments grades upward into sandy limestone through an interval a few feet thick. Locally a shaley facies of the Beech Creek ("false Barlow") fills channels eroded into the upper Cypress (Cluff and Lasemi 1980). The Beech Creek is discontinuous where the Cypress is thickest, especially in the West Baden clastic belt. Where the Beech Creek is absent, sandy beds of the upper Cypress grade into fissile clay-shales of the Fraileys Shale Member of the Golconda.

The lower contact of the Cypress is commonly disconformable near the West Baden clastic belt. The Cypress overlies the Ridenhower Formation and has erosional contacts at the Golconda (fig. 6), Bay City (fig. 8), I-24 (fig. 9), and Hunkerin' Ditch (fig. 11) sections, in addition to several outcrops near these sections. Erosion is indicated by locally truncated laminations in the Ridenhower and by rip-up clasts of shale and siltstone, derived from the Ridenhower, in the basal Cypress. At the I-24 section, the basal Cypress contains coal stringers as well as shale clasts. Relief on the contact is slight, no more than a few feet. At most outcrops one must search to find clearly truncated laminae in the Ridenhower. Layering in the Ridenhower typically undulates more or less parallel with the base of the Cypress, indicating loading but little scouring. No deeply incised channels, such as those reported at the base of the Bethel Sandstone in western Kentucky (Sedimentation Seminar 1969), are known to occur at the base of the Cypress.

Farther from the West Baden clastic belt, in Johnson and Union Counties, the lower contact of the Cypress appears to be conformable. Sandstone of the Cypress directly overlies a thin limestone bed at the top of the Ridenhower in many places (pl. 1, wells 9–13). The limestone bed commonly is sandy, indicating lithologic transition to the Cypress.

Cypress siliciclastics intertongue westward with limestone of the Paint Creek Formation in northern Union and southern Jackson Counties (pl. 1, wells 7–9). The Cypress in the transition zone is shaley and calcareous, and contains interbeds of red or variegated mudstone. In the core of COGEOMAP borehole CB-1, an 11-foot-thick limestone tongue of the Paint Creek separates intervals of burrowed, calcareous sandy shale and sandstone (pl. 1, well 9). Only the uppermost tongue of the Cypress, about 20 feet thick, extends across the top of the Paint Creek Formation northwestward into Randolph and Monroe Counties (pl. 1, wells 1–6).

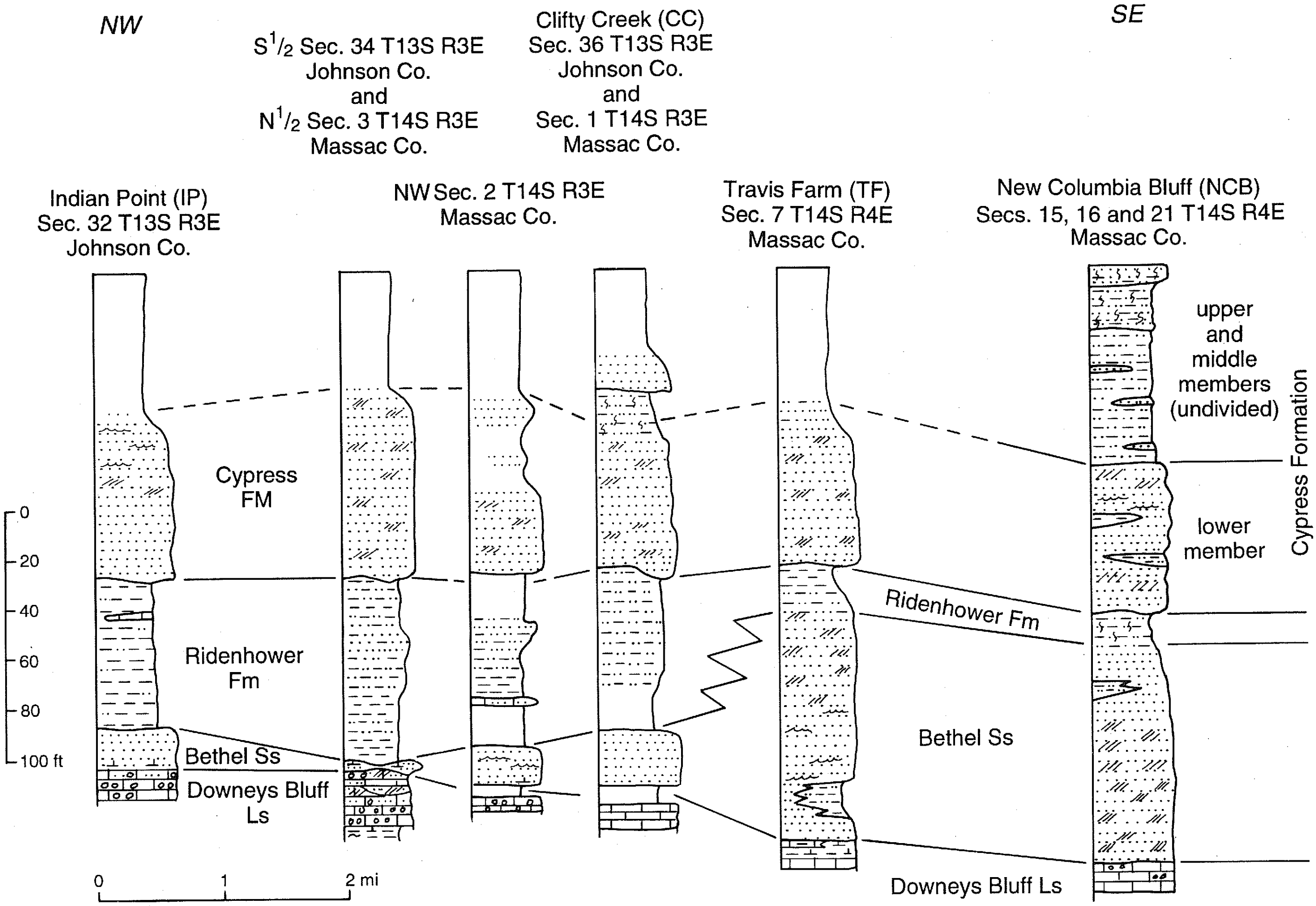



**Figure 16** Cross section made from composite outcrop sections in Johnson and Massac Counties, Illinois. The section illustrates lateral intergradation of the Bethel Sandstone and Ridenhower Formation along the western margin of the West Baden clastic belt.

This upper tongue of the Cypress (Ruma Formation of S. Weller 1913) is composed largely of variegated shale and claystone with lenses of calcareous sandstone.

The West Baden Sandstone on the outcrop belt in southern Illinois ranges from about 210 to 300 feet thick. The interval is predominantly sandstone and shaley sandstone, but lenses of shale and thin, sandy limestone occur at various stratigraphic positions. Variegated claystone is present near the top in places (e.g., wells 19 and 20 on pl. 1). The contact of West Baden clastics with the underlying Downeys Bluff Limestone is generally disconformable. Many cores and outcrops show a basal conglomerate of shale and limestone clasts, quartz granules, and invertebrate fossil fragments (Baxter and Desborough 1965, Baxter et al. 1963, 1967, Trace and Amos 1984). Little erosion of the Downeys Bluff has taken place however. Although the Downeys Bluff is only 20 to 30 feet thick, it is rarely, if ever, completely eroded in Illinois. Farther east in Kentucky, the Bethel Sandstone fills channels incised as much as 250 feet into underlying limestones (Sedimentation Seminar 1969).

The Bethel Sandstone in Johnson County, Illinois, is a westward-thinning tongue of the West Baden Sandstone (fig. 16, pl. 1). Upper sandstone beds of the Bethel progressively pinch out and grade into shale and siltstone of the Ridenhower Formation. The Bethel is reduced to discontinuous lenses of sandstone in western Johnson and Union Counties (figs. 3, 16). Farther northwest in Jackson and Randolph Counties, red and variegated mudstone overlie the Downeys Bluff at the expected position of the Bethel (pl. 1).

The lower contact of the Bethel is generally conformable west of the West Baden clastic belt. Sandy limestone and calcareous sandstone alternate and intertongue through an interval several feet thick in the NW, Sec. 3, T14S, R3E, Johnson County. Within the transition interval are local, shallow channels filled with intraformational conglomerates. The abundant marine fauna and herringbone crossbedding in these rocks imply that the channels were scoured by tidal or wave-generated currents.

## Paleontology

Although not richly fossiliferous, the Cypress Formation contains a variety of fossil evidence suitable for environmental interpretation. These include fragmentary and whole body fossils of marine invertebrates, several types of trace fossils, and casts and carbonized impressions of terrestrial plants, including in situ root casts.

Marine body fossils occur in the lower sandstone member of the Cypress, particularly near the base. Spiriferid brachiopods, fenestrate bryozoans (including *Archimedes* sp.), conularids, and echinoderm fragments were collected from the lower part of the sandstone at Golconda (fig. 6). Fragments of brachiopods, bryozoans, and echinoderms occur in thin sections from near the base of the Cypress at I-24 (fig. 17) and from near the top of the bluff-forming sandstone at Indian Point (fig. 18). Productid brachiopods were found in the core from COGEOMAP borehole CB-1 (pl. 1, well 9) in the lower part of the sandstone that overlies a limestone tongue of the Paint Creek Formation. The limestone in this core also contains marine fossils.

Several previous authors reported marine fossils from the Cypress, but they generally did not specify which part of the formation is fossiliferous. J.M. Weller and Sutton (1940) reported the brachiopod *Camarophoria explanata* in the Cypress in both southern Illinois and western Kentucky. Marine faunal grains have been identified in core from Lawrence County (Grube and Cole 1992), from sample sets in Clinton County (Whitaker and Finley 1992), from sample sets and core biscuits in Clay County (J. Xu, ISGS, personal communication, 1992), and from samples from the Louden oil field in Fayette County (D. Horowitz, Exxon, Houston, Texas, personal communication, 1991).

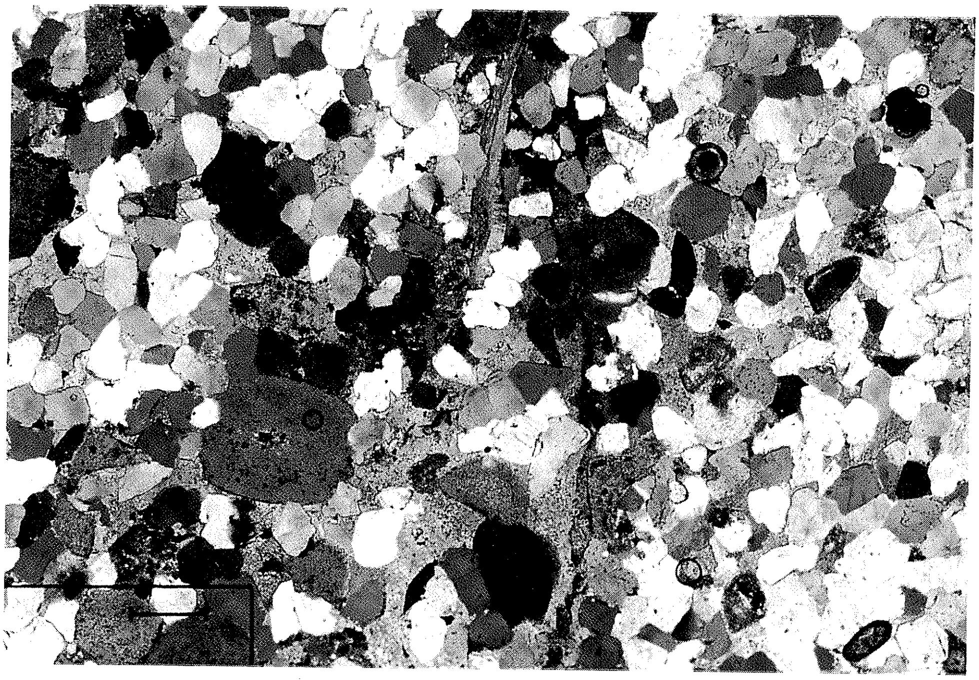


**Figure 17** Photomicrograph showing a brachiopod fragment (top center) and several echinoderm fragments (large, cloudy, or stippled grains mostly left of center) in sandstone from the lower member of the Cypress at the I-24 section. Calcite cement (cloudy, yellowish brown) is also apparent in this slide. Bar scale is 1 mm.

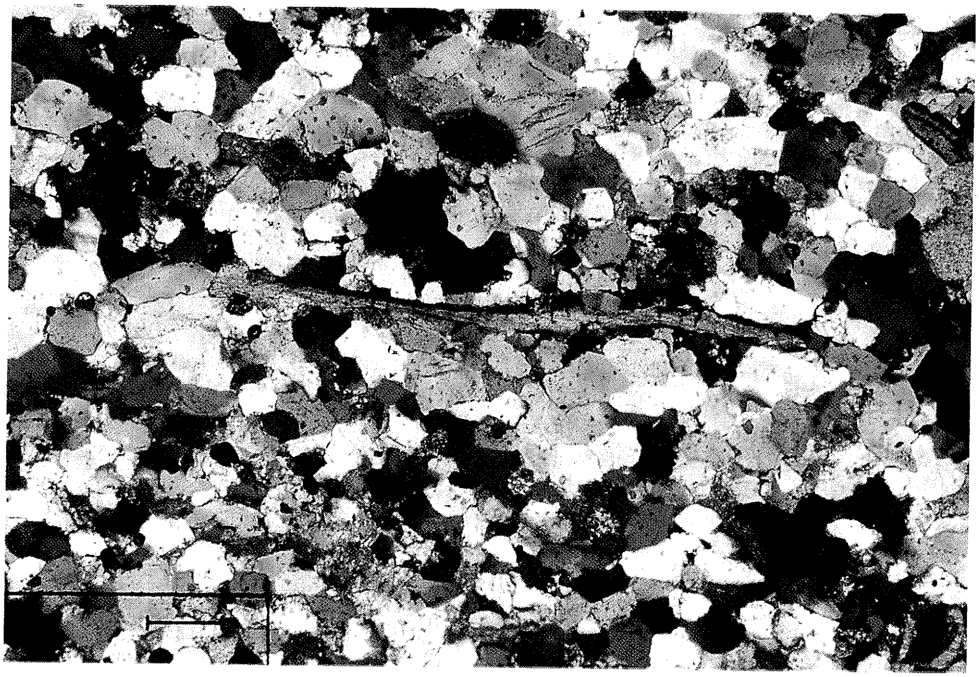


**Figure 18** Photomicrograph showing a large punctate brachiopod fragment (center) and an echinoderm plate (right edge, above center) in sandstone of the lower member of the Cypress at the Indian Point section. Bar scale is 1 mm.

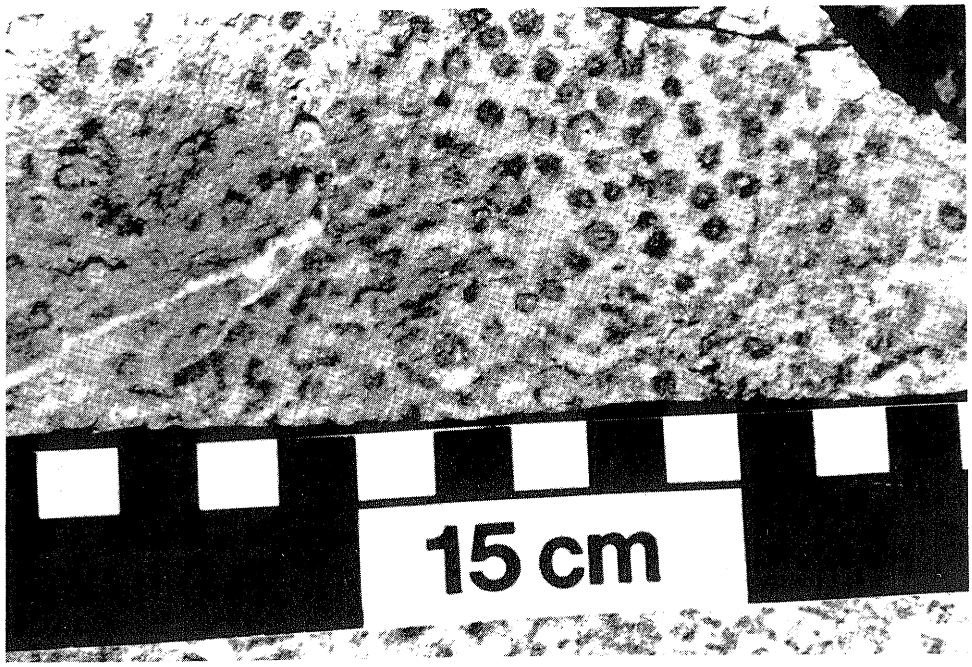



**Figure 19** Vertical burrows *(Skolithos)* on a bedding surface of thin bedded sandstone from the upper member of the Cypress, New Columbia Bluff section. Photograph by K.R. McGee.

Marine fossils also occur in the uppermost part of the Cypress. Crinoid columnals as well as derbyid, productid, and spiriferid brachiopods were identified in shaley sandstone from near the top of the Cypress at New Columbia Bluff (fig. 9). Cores of sandstone from the upper Cypress of the Bartelso oil field, Clinton County, contain scattered fossil fragments (Whitaker and Finley 1992). Productid brachiopods were noted in a core of the upper Cypress from Union County. Marine fossils and calcareous beds are most common within a few feet of the contact with the overlying Beech Creek Limestone.

Trace fossils are fairly common in sandstones near the top of the Cypress, and they are also present in the lower bluff-forming sandstone. Bedding-plane tracks and trails, along with vertical burrows, occur in sandstone thought to be basal Cypress in the Reineking Hill section (fig. 8). A diverse assemblage of ichnofossils was described from shaley sandstone near the top of the New Columbia Bluff section (fig. 9). Vertical burrows *(Skolithos)* perforate the thin sandstone layers (fig. 19); cylindrical horizontal burrows are abundant on bedding surfaces (fig. 20). Also present are *Lockeia*, a bivalve resting trace; *Olivellites plumeri*, a crawling trace; *Ucherites*, a bivalve crawling trace; *Aulichnites* sp., a trackway; *Scalarituba missouriensis*, the trace of a polycheate worm; an unnamed shrimp resting trace; and plug-shaped *domichnia* (J.A. Devera, ISGS, personal communication, 1991). The above traces belong to the *Cruziana* ichnofacies, typical of open marine waters of the upper subtidal to lower intertidal realm (Frye 1975).

Plant remains are widespread in the Cypress Formation, but they are generally fragmentary and difficult to identify. Casts of *Lepidodendron* sp. are reported to be common in the "Ruma" (upper Cypress) of southwestern Illinois (Weller and Sutton 1940). As noted by Seyler (1982), casts of *Lepidodendron* logs and bark fragments are common in sandstones of the Cypress, and bits of carbonized stems and foliage occur in shales. Such material may have been transported far from its source and does not necessarily indicate deposition in a terrestrial or nearshore environment. In situ root casts of land plants are present in the Cypress, although few examples

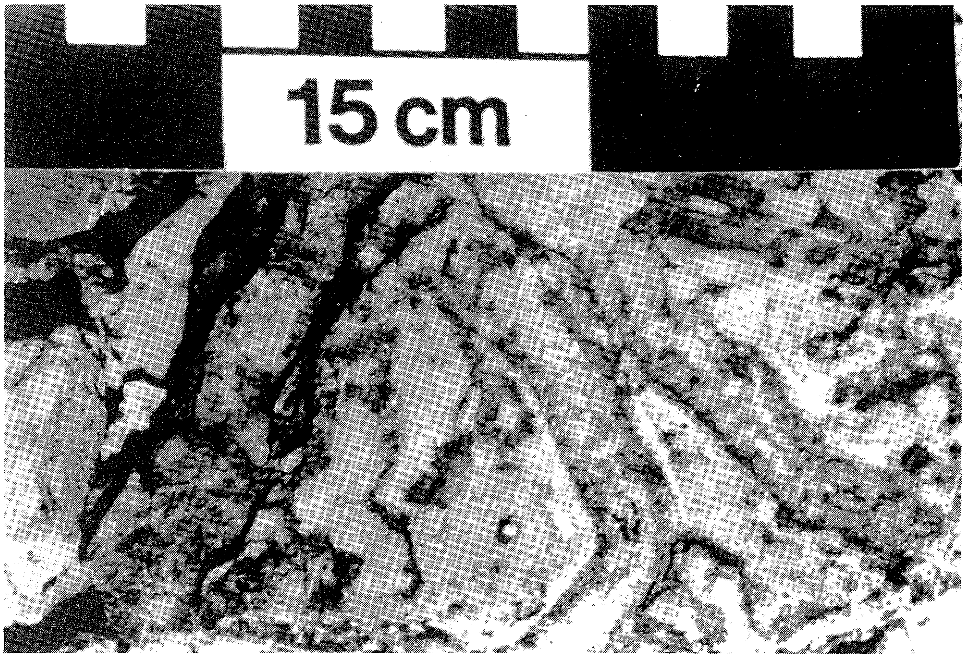



**Figure 20** Cylindrical horizontal burrows on a bedding surface of thin bedded sandstone from the upper member of the Cypress, New Columbia Bluff. Photograph by K.R. McGee.

have been documented. Well preserved roots were observed in a core from Hardin County. Shale at the base of the middle shaley member of the Cypress in the I-57 section contains poorly preserved root casts (fig. 13). Carbonaceous, illitic "underclay" (rooted?) and coal occur at the base of the middle member in the Salem Quadrangle, Kentucky (Trace 1962).

## Petrology

Petrology of sandstone from the Cypress Formation in the outcrop belt of southern Illinois differs significantly from petrology of Cypress sandstone from subsurface cores, as reported by other workers. Differences between outcrop and subsurface petrology are largely attributable to weathering.

Sandstone of the Cypress from the outcrop is predominantly very fine to fine grained (rarely medium grained), moderately to well sorted quartz arenite. Monocrystalline quartz composes 95% or more of the grains in nearly all thin sections examined. Quartz grains are predominantly angular to subrounded; only a few grains are rounded. Plagioclase feldspar is a minor component, making up 1% to 3% of most samples. Feldspar grains are commonly decomposed. Accessory and trace minerals include muscovite, chert, and zircon. Most grains are randomly oriented, but some are aligned along microscale cross laminae. A few thin sections exhibited microscale truncation surfaces.

Cypress sandstone from the subsurface in Illinois is typically quartz arenite, but a few samples are classified as subarkose or sublitharenite. Bosse (1986) classified 32 out of 35 sandstones taken from cores in producing oil fields as quartz arenite; the other three were subarkose or sublitharenite. In another study of sandstone from producing oil fields, D.M. Moore and R.E. Hughes (written communication, 1994) reported average values of $0.8 \pm 2.0\%$ for K-feldspar and $5.2 \pm 7.0\%$ for plagioclase. The figures for plagioclase include many samples containing less than 5% plagioclase and a few containing unusually high amounts of this mineral (as great as 34% in one sample from the Tamaroa oil field in Washington County). If we disregard the few very high values, samples from the subsurface contain only slightly more plagioclase than samples from the outcrop. Considering the degraded condition of most feldspar grains in thin sections from outcrop samples, we surmise that feldspar was selectively removed from the outcrop by weathering. Similarly, calcareous fossil grains and calcite cement are rare in thin sections prepared from outcrop samples, but they are more common in sandstone from the subsurface. Among the few calcareous sandstones found in outcrop are those from the Cache River no. 1 section. Petrographic study showed that part of this sandstone contains calcite cement, whereas other parts contain open pore space and no cement. At the Golconda section, molds of calcareous bioclasts (echinoderms, brachiopods, and bryozoans) were observed in highly porous sandstone. This sandstone probably had calcite cement originally; both bioclasts and cement were leached away. Calcite cement and fossil fragments are common in cores of Cypress sandstone from north of the outcrop belt. Bosse (1986) observed patchy calcite cement in 21 out of 35 thin sections, representing cores from 9 oil fields. Among these thin sections, 18 contained less than 4% calcite cement, but 3 contained 16% to 20% calcite cement. D.M. Moore and R.E. Hughes (written communication, 1994) also reported great variability in percentage of calcite in Cypress sandstone from the subsurface. Calcite bioclasts generally constitute less than 1% of the grains in sandstone from the subsurface, but they constitute up to several percent in some cases. Pelmatozoan fragments are the most abundant bioclasts, followed by brachiopod and bryozoan fragments. Bioclasts range from fine fragments the size of sand to whole fossils (figs. 17, 18). Some bioclasts are worn, but others appear little abraded.

Clay minerals constitute less than 5% of sandstone volume in outcrop samples but average more than 6% in sandstone samples from cores. In outcrop samples, kaolinite and illite (containing a small amount of interlayered expandable clay) are present; chlorite is absent. The kaolinite content is greater than or roughly equal to the illite content in outcrop samples (D.M. Moore and R.E. Hughes, written communication, 1994). In contrast, Cypress sandstone from cores contains illite, mixed-layer illite/smectite, iron-rich chlorite, and kaolinite (Smoot 1960, Bosse 1986). Moore and Hughes found the average clay-mineral content of sandstone from cores to be as follows: kaolinite, 30%; illite, 30%; illite/smectite, 20%; and chlorite, 20%. Kaolinite is commonly a product of ancient or modern weathering under a humid climate (Hughes at al. 1992). Thus, modern weathering (of feldspar) is a probable cause of the increased kaolinite in outcrop samples when compared with core samples.

Silica (in the form of quartz overgrowths) and calcite are the two major cementing agents in sandstone. Diagenetically generated clays and iron oxides also provide some minor, local cementation (D.M. Moore, personal communication, 1992).

Porosity of sandstone from the lower sandstone member of the Cypress from the I-57 section ranges from 13.1% to 21.4%. These figures are similar to those determined for sandstone of the Cypress Formation from several oil fields in southern Illinois (typically 12% to 21%). Permeability of sandstone from I-57 ranges from 0.3 to 915.3 millidarcies. The range of permeability from these outcrop specimens is considerably greater than that encountered in the subsurface. Studies from six producing oil fields show average permeability ranging from 49 to 98 millidarcies; extreme values generally range between 5 and 200 millidarcies (D.J. Haggerty, personal communication, 1994). Evidently, weathering at the outcrop increases the range of permeability, while having relatively little effect on porosity.

In summary, sandstone of the Cypress from the outcrop belt is very fine to fine grained, moderately to well-sorted quartz arenite. Some sandstone originally was

**Figure 21** Linguloid ripple marks from a thin bedded sandstone in the lower member of the Cypress, New Columbia Bluff. Ripple crests average about 4 inches apart. Photograph by K.R. McGee.

subarkose, but much feldspar has been altered to kaolinite. Calcareous bioclasts and calcite cement occur in unweathered samples, such as those from cores. Porosity is relatively consistent, but permeability of the sandstone varies markedly within short distances.

## Sedimentary Structures

The lower, middle, and upper members of the Cypress contain distinct suites of sedimentary structures. Observations are more complete for the lower member than for the poorly exposed middle and upper members. Sedimentary structures of the middle and upper members are known mainly from cores.

**Lower sandstone member** Low-angle cross lamination and crossbedding, ripple lamination, and planar lamination are the most common sedimentary structures in the lower member of the Cypress. Sandstone bodies commonly take the form of stacked or imbricated bar-form lenses. Shallow scour-and-fill structures, slumped or contorted bedding, amalgamated laminae, and possible tidal laminations are present in some areas.

Planar and wedge-planar cross lamination or crossbedding are present in nearly every outcrop of the lower sandstone member. Crosslamination is predominantly low angle, and medium-angle crossbedding is uncommon. At the Roper's Landing section, low-angle cross lamination occurs in nearly every sandstone interval through more than 200 feet of strata, representing nearly the full thickness of the West Baden clastic belt (fig. 7). At other sections, cross laminated sandstone alternates with intervals of planar- and ripple-laminated sandstone. Herringbone cross lamination was observed near the top of the lower member at the Cagle Bluff (fig. 8) and New Columbia Bluff Northeast (fig. 9) sections.

Ripple laminations were observed in most outcrops of the lower member. Common ripple types are asymmetric (current) ripples and interference ripples. At the Golconda section (fig. 6) asymmetric ripples have truncated crests. The sandstone

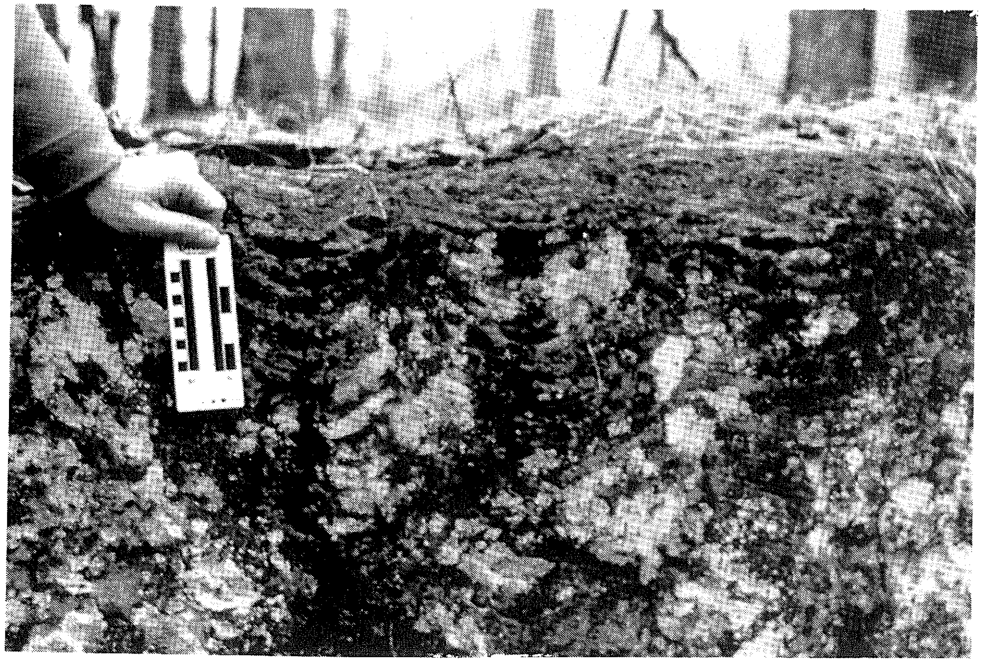


**Figure 22** Stacked, concave-upward "dish" structures at the top of the exposed sandstone, Seminary Fork section. These features are interpreted to be the product of expulsion of pore water from the sand before it lithified.

above the medial shale in the Reineking Hill section (fig. 8) has ripple laminations with clay drapes, flaser bedding, and burrows. Ripples contain clay drapes at several other sections studied. Climbing ripples occur in the I-57 section in some places (fig. 13). Linguloid ripples are well developed at the New Columbia Bluff section (fig. 21). The Bethel Sandstone in the Reineking Hill (fig. 8) and Travis Farm (fig. 10) sections contains intervals of bluff-forming, shale-free, ripple-laminated sandstone as thick as 50 feet.

Planar-laminated sandstone occurs at most measured sections as relatively thin intervals that alternate with cross laminated and rippled sandstone. In the Golconda, Golconda South (fig. 6), and I-24 (fig. 9) sections, intervals of planar-laminated sandstone are several feet thick and have undulating upper and lower contacts. Amalgamated planar laminations alternating with ripple laminations were observed in sandstone of the lower Cypress in the Cypress Creek section (fig. 13). The 60-foot interval of Cypress exposed at Indian Point (fig. 11) displays amalgamated laminations alternating with a few thin intervals of planar- and ripple-laminated sandstone.

Small-scale, soft-sediment deformation was found at several sections. Deformed cross lamination—overturned in some places—occurs in sandstone near the base of the Cypress at the Cache River no. 1 section (fig. 14). Contorted bedding and small-scale "dish" structures (fig. 22) occur near the top of the sandstone exposed at the Seminary Fork section (fig. 14). The features at Seminary Fork most likely are products of rapid dewatering of the sediment. Large-scale contorted bedding in sandstone near the Bethany Church section also may be a product of dewatering or, alternatively, of slumping before the sand was lithified. Small-scale load casts (fig. 23) are common in thin bedded sandstone. Ball-and-pillow structures and contorted laminations occur (fig. 24).

Small, shallow channels or scour-and-fill structures are present at many outcrops, notably Golconda (fig. 6), Cache River no. 1, and Seminary Fork (fig. 14). The

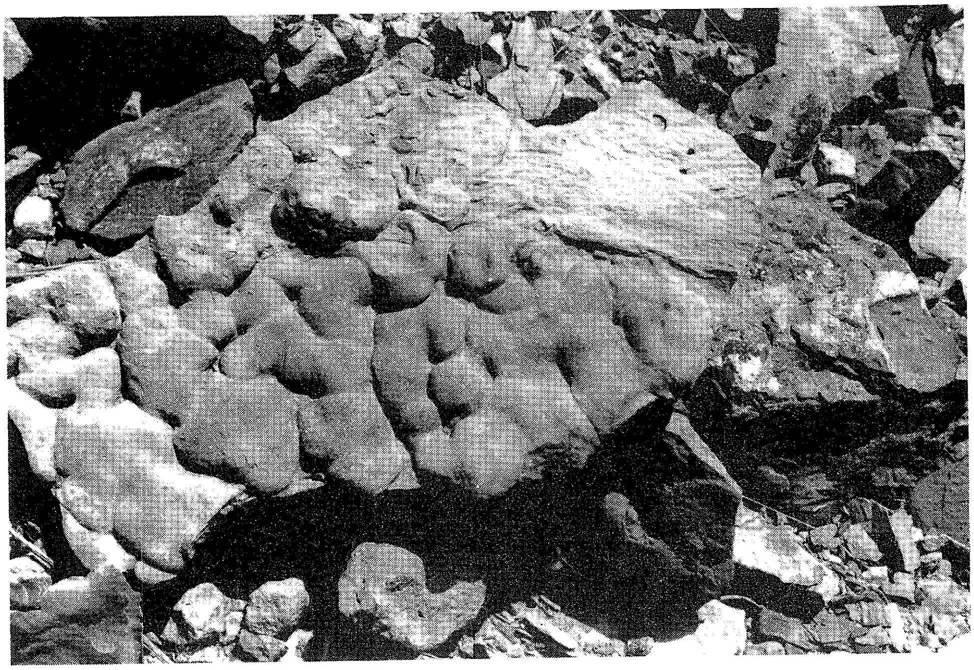


**Figure 23** Load casts on the base of a sandstone bed in an interbedded sandstone-shale interval within the lower member of the Cypress, New Columbia Bluff. The slab is about 2 feet long. Photograph by K.R. McGee.


**Figure 24** Contorted bedding and ball-and-pillow structures in an interbedded sandstone-shale section in the lower member of the Cypress, New Columbia Bluff. Photograph by K.R. McGee.

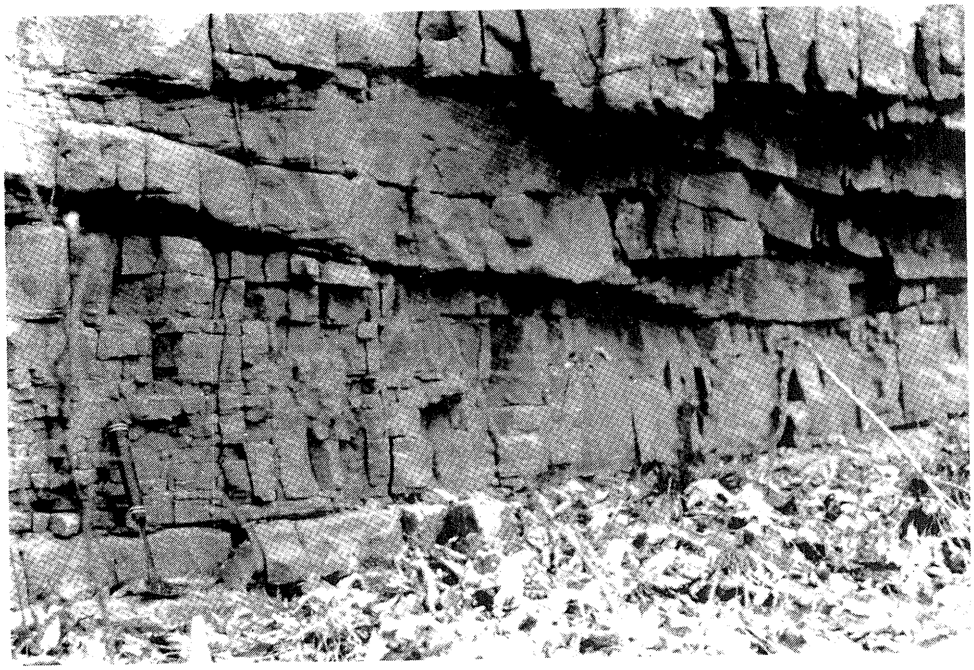


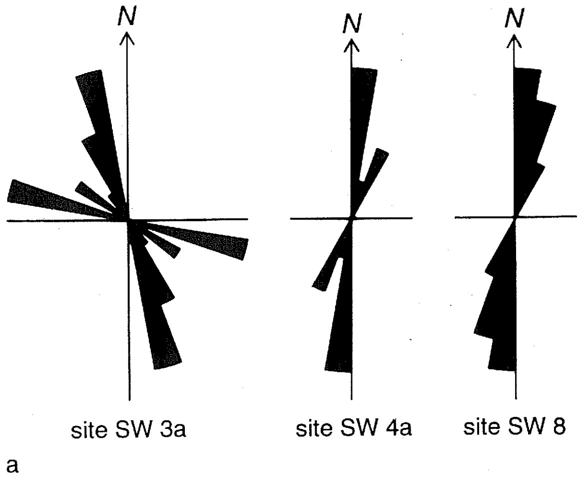
**Figure 25** Shallow cut-and-fill structure in sandstone at Roper's Landing. Note how the bedding in the unit above the scour surface onlaps toward the left. The hammer in the lower left corner shows the scale.

Roper's Landing section also contains good examples (fig. 25). Most channels have amplitudes of less than 5 feet and gently dipping margins.

Alternating thin and thick laminations occur in sandstone near the top of the Roper's Landing (fig. 7) and Bethany Church no. 2 (fig. 12) sections, and in sandstone at the base of the exposure at Bethany Church no. 1 (fig. 12). These laminations resemble tidal couplets described by Kvale and Archer (1989), but they were too poorly developed for definitive interpretation.

Some lenticular sandstone bodies observed in outcrop are convex upward and downward and indicative of bars. The sandstone exposed at the I-57 section appears to consist of several coalescing lenses that are convex upward and thicker than 30 feet. The bases of the sandstone lenses are below road level. The lens form is most evident near the north end of the cut for the northbound lanes, where shale (on the north) appears to intertongue with sandstone (on the south). Similar lenses, which appear to be elongate north–south, are at the Cache River no. 1 and no. 2 sections (fig. 14). Lenticular sandstone bodies, which are convex upward and downward and separated by covered (probably shaley) intervals, are visible on the face of New Columbia Bluff when the leaves are off the trees. An isolated bar-form lens of cross laminated sandstone about 8 feet thick is at the top of the Golconda section.

Paleocurrent measurements were made at several sites. Only asymmetric ripple marks and three-dimensional exposures of cross laminations or accretionary bedding were considered reliable current indicators. The strike trends of accretionary bedding from the I-57 section are summarized in a series of rose diagrams (fig. 26). As a result of the accretionary bedding, the paleocurrent was assumed to have been parallel with the strike of the inclined beds rather than downdip as would be the case with foreset laminae. Hence, two possible paleocurrent trends, 180° apart, have been plotted on the rose diagrams. The diagrams indicate a prevalent north or south current trend and a secondary trend oriented either N80° W or S80° E. Measure-



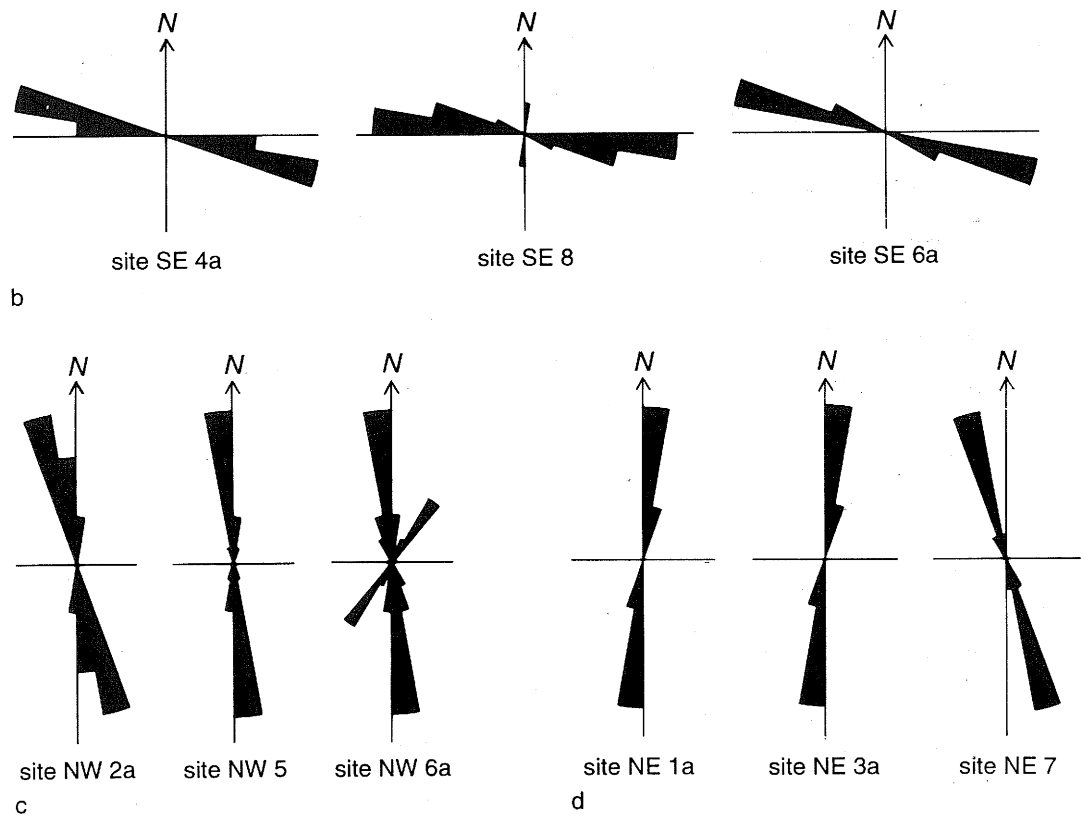




**Figure 26** Rose diagrams depicting the strike of the accretionary bedding in the I-57 section. Paleocurrent is presumed to have been parallel to strike, but each reading represents two possible paleocurrent trends that are 180° apart.

ments of accretionary bedding at the Bethany Church no. 1 and no. 2 sections indicated northeast or southwest paleocurrents. Herringbone cross lamination at the Cagle Bluff and New Columbia Bluff NE sections indicated bidirectional NE–SW to NNE–SSW paleocurrents.

Bedding of sandstone at the I-57 section takes the form of elongate lenses that are typically 1 to 3 feet thick. In several parts of the roadcut, lenticular beds overlap one another in shingled or imbricate fashion (fig. 27). Shingled lenses are inclined at a very shallow angle to overlying master bedding surfaces. Seyler (1982, p. 27) described this as "very large-scale cross-bedding with smaller trough cross-bedding superimposed." The tilt of shingled sandstone lenses indicates that sediment transport was southward in part of the exposure but northward elsewhere. As stated above, other paleocurrents at this section ran nearly east–west.

Shale and siltstone in the lower member of the Cypress commonly display planar laminations, discontinuous siltstone or sandstone lenses, ripple lamination, ripple cross lamination, and flaser bedding. Small-scale slumped and contorted bedding, load structures, and ball-and-pillow structures occur in shaley intervals, as seen at the New Columbia Bluff section (fig. 9).

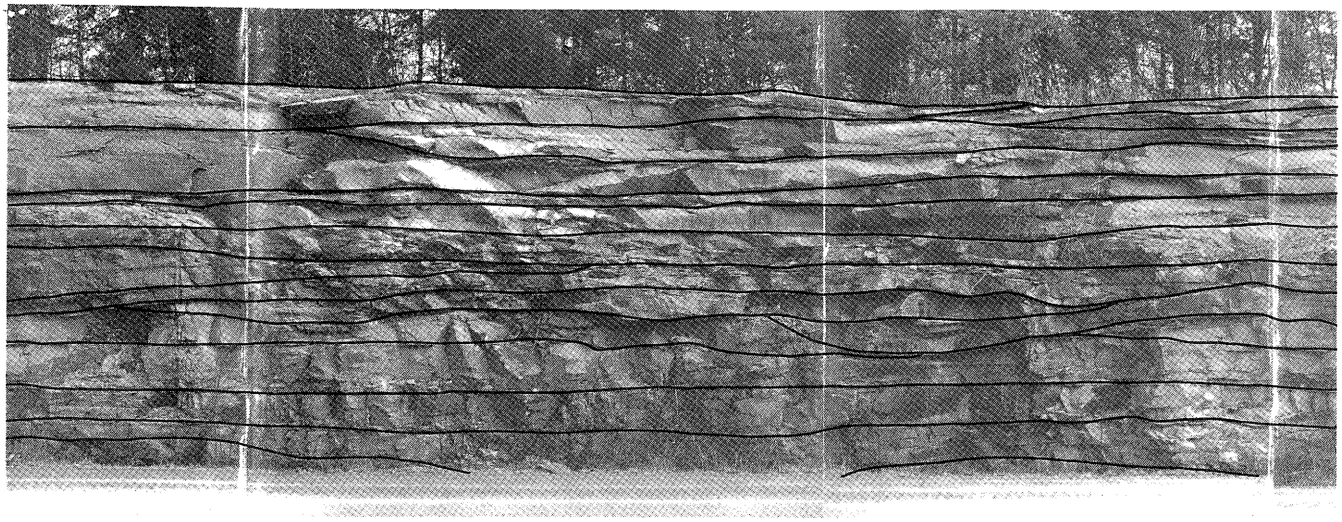
Shale and siltstone intervals in the lower member of the Cypress vary from a fraction of an inch to several tens of feet thick, but most are a few inches to about 2 feet thick. Shale units are lenticular and pinch out abruptly, or they grade laterally to sandstone. Well-defined sequences that become more fine or coarse upward are seldom found in the Cypress. Shale, siltstone, and sandstone of the lower Cypress alternate in seemingly random fashion at most exposures.

**Middle shaley member** The middle member of the Cypress contains features indicative of subaerial exposure. Specifically, there is variegated mudstone that appears to be a paleosol as well as coal and carbonaceous shale with rooted underclay.

Variegated mudstone occurs in the middle member at many places in southern Illinois (pl. 1). This lithology is most common away from the West Baden clastic belt. On the eastern and western margins of the basin, multicolored mudstone is a major constituent of the Cypress. Early geologists called these rocks the Ruma Formation when referring to the western margin of the basin in southwestern Illinois (S. Weller 1913, 1920) and the Elwren Formation for the eastern margin of the basin in Indiana and Kentucky (Malott 1919). Both "Ruma" and "Elwren" are composed of thin, lenticular sandstones overlain by red, green, and gray variegated claystone and siltstone.

Mudstone of the middle Cypress (and "Ruma" and "Elwren") is mottled in shades of gray, greenish gray, and dark red. It ranges from claystone through silty mudstone and siltstone. Some mudstone is blocky or massive and slickensided, lacking any trace of lamination. Other mudstone is slightly to moderately laminated clay shale, silty shale, and siltstone. Small nodules of impure limestone or dolomite occasionally occur in variegated mudstone, particularly near the base. In Indiana, Ambers and Petzold (1992) described root traces, salt crystal molds, mudcracks, terrestrial plant debris, brecciated fabrics, tidal laminations, columnar pedogenic structures, caliche fabrics, and rare paleosol horizon formation. All of these features signify very shallow subtidal to supratidal conditions.

Coal and carbonaceous shale are widespread in the middle member of the Cypress in both Illinois and western Kentucky. Coal is common in the upper part of the Cypress east of the West Baden clastic belt in parts of Crittenden, Caldwell, and Livingston Counties of Kentucky. Coal is typically found directly overlying the lower bluff-forming sandstone, but thin coal and carbonaceous shale also occur near the top of the Cypress (Amos 1966, 1974, Amos and Hays 1974, Trace 1962, 1966, 1976). The thickest coal bed reported in the Cypress in Kentucky was 4 feet thick; this may be the thickest Mississippian coal in the Illinois Basin (Rogers and Hays 1967). In Illinois, coal in the Cypress is thin and sporadic but widely distributed. Coal and shale containing plant fossils were found in samples from the middle member in the Comanche no. 1 Branham well (pl. 1, well 14). Whitaker and Finley (1992) reported coal in samples from the mid-upper Cypress of the Bartelso oil field in Clinton County. Two thin coal beds were reported in parts of Clay, Richland, and Wayne Counties of southeastern Illinois (Workman 1940). As many as three separate thin, black, carbonaceous shale units or impure coals were observed in cores of the middle Cypress from Pope and Hardin Counties (in the West Baden clastic belt).



Rooted underclays occur in the middle Cypress. A core from Hardin County contained four or possibly five paleosols consisting of slickensided mudstone that contains root traces and small, irregular siderite nodules. Carbonized root casts were observed in mudstone directly overlying the lower Cypress sandstone at the I-57 section (J.A. Devera, ISGS, personal communication, 1992). Trace (1962) reported underclay beneath a Cypress coal in the Salem Quadrangle, Kentucky.

Coal, paleosol, and rooted zones are absent or poorly developed in the West Baden clastic belt in southern Illinois (fig. 9, pl. 1). Sandstone extends nearly to the top of the Cypress in some areas of the clastic belt, and the members cannot be recognized. Where present, the middle member in the clastic belt is composed of medium to dark gray, laminated shale having laminae, lenses, and interbeds of siltstone and sandstone.

**Upper sandstone member** The upper member of the Cypress is a thin, poorly exposed interval of shale, siltstone, and shaley sandstone. We found it outcropping only in the New Columbia Bluff section and a few small, nearby exposures. The upper member also is known from cores in Hardin and Pope Counties, one core in Union County, and to a lesser degree from sample studies (cuttings) of wells north of the outcrop belt.

In the New Columbia Bluff section and nearby outcrops (fig. 9), the upper member is composed largely of thinly bedded, burrowed sandstone interlaminated with silty shale and siltstone. Lenses of thick bedded sandstone as much as 2 feet thick occur within the upper Cypress along the bluff face. Lamination of this rock is largely obliterated by burrowing. Near the top of the exposed section, diverse shallow-marine trace fossils were identified, along with fragments of brachiopods and echinoderms.

Cores of the upper member reveal a generally upward-fining succession that has shaley, very fine grained sandstone at the base that grades upward through interlaminated siltstone and sandstone to clay shale at the top. This interval is as much as 30 feet thick, but normally it is 5 to 15 feet thick. In some cases the uppermost Cypress strata consist of calcareous shale that contains marine fossils and thin interbeds or lenses of limestone grading into the overlying Beech Creek. In other cases the uppermost Cypress is sandstone, which either grades into or is sharply overlain by the Beech Creek. Sedimentary structures of the uppermost Cypress include planar, lenticular, and flaser laminations, cross lamination, small-scale slump structures, ball-and-pillow structures, contorted lamination, and

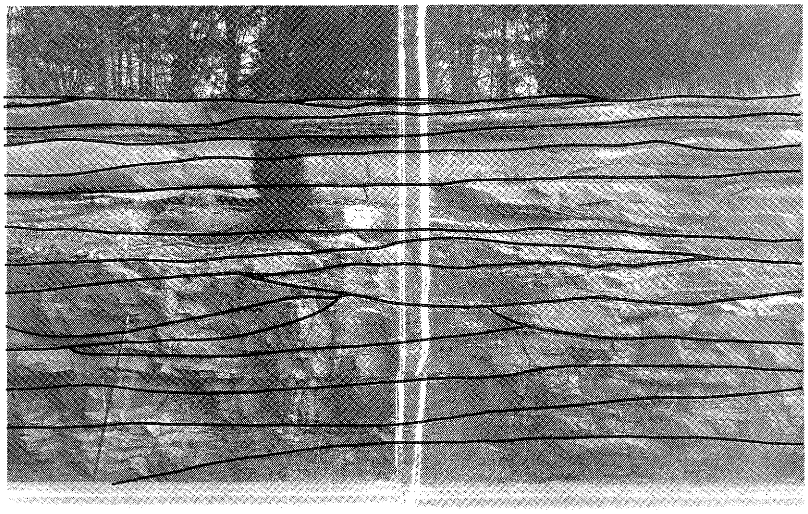


**Figure 27** Photomosaic of part of the I-57 section shows gently inclined, shingled, or imbricate beds within a large lenticular, bar-form sandstone body (the entire exposure).

burrowing. The upper Cypress from a core in Hardin County contains siltstone with well developed tidal rhythmites, similar to those described by Kvale and Archer (1989). These features are consistent with shallow subtidal sedimentation.

## DISCUSSION

### Environments of Deposition

**Lower sandstone member** The marine origin of the lower sandstone member is indicated by at least five factors: mineralogical and textural maturity, presence of marine body fossils (some of which are whole and unabraded), lateral facies relationships, sedimentary structures, and geometry of sandstone bodies.

Sandstone of the lower member is well-sorted quartz arenite to borderline subarkose. Petrology indicates provenance largely from recycled older Paleozoic sandstones, extensive deposits of which lay north of the Illinois Basin during Chesterian time. These older sandstones are largely quartz arenites, although some Cambrian sandstones, notably the Mt. Simon, are feldspathic (Willman et al. 1975, Mossler 1987). The scarcity of clay and silt matrix in sandstone of the Cypress implies extensive reworking and winnowing by currents. Such reworking and winnowing typically takes place in shallow marine environments; fluvial processes generally do not remove much of the fine grained fraction (Reineck and Singh 1975).

Articulate brachiopods, pelmatozoans, bryozoans, and conularids that occur in the lower member imply shallow, clear marine water of normal salinity (not deltaic, tidal flat, estuary, or other brackish water settings). Although broken, abraded bioclasts might have been transported by storms or high winds or reworked from older formations, whole fossils and large, well preserved fragments of delicate bryozoans probably represent organisms that lived in or near the site of deposition. Presence of such fossils also indicates currents of low to moderate energy.

The lower member of the Cypress is laterally equivalent to limestone of the Paint Creek Formation, which contains a rich and diverse marine fauna. This facies change takes place near the border between the Sparta Shelf and the Illinois Basin (pl. 1). Relatively thin limestone of the Paint Creek was deposited on the shelf while thicker sandstone of the Cypress accumulated in the basin. The thickness change indicates that the basin was subsiding more rapidly than the shelf. Water depth probably was no greater on the shelf than in the basin. Evidently, deposition of carbonates versus siliciclastics was controlled by sediment supply rather than water depth. Siliciclastic sediment was funneled along the axis of the Illinois Basin during Cypress time. The Sparta Shelf was far enough from the source of siliciclastics to allow deposition of limestone.

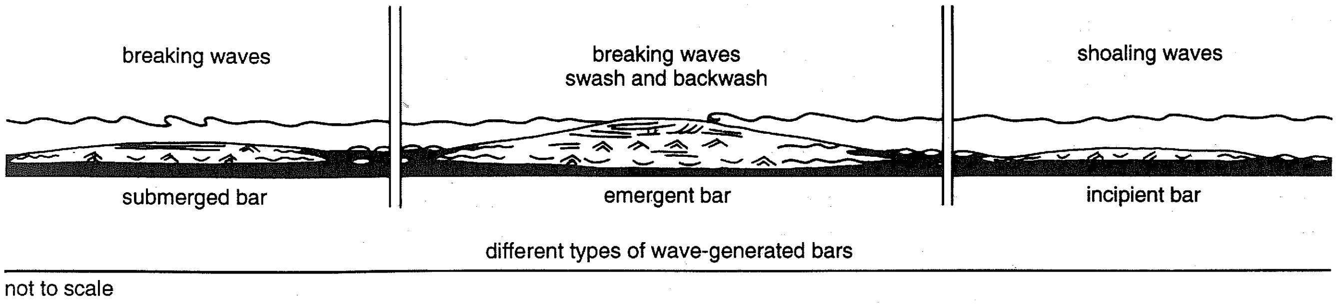
Sedimentary structures of the lower member are consistent with tidally influenced, shallow marine environments. Paleocurrent trends measured on Cypress outcrops indicate bidirectional currents. Herringbone cross lamination, in particular, strongly indicates tidal action. Ripples that bear clay drapes, common in the Cypress, are another reliable indicator of tidal activity (Klein 1970, 1977). Moreover, the style of ripple lamination in the lower Cypress is quite similar to that attributed to shallow marine environments by de Raff et al. (1977). The chevron form of many Cypress ripples indicates tidally induced oscillating currents. Also, ripple crests commonly are absent, indicating truncation by a subordinate current moving in an opposite direction to the original transporting current.

The lower Cypress lacks sedimentary sequences indicative of deposition by rivers or by fluvially dominated deltas. The lower contact is typically erosional, but no deep channels have been identified. Only a few small, shallow channels were observed during this study. The Cypress lacks the upward-fining sequences typical of fluvial or distributary channels, and it also lacks the upward-coarsening sequences that characterize prograding fluvially dominated deltas. Shale and siltstone intertongue with sandstone in seemingly random fashion, with no consistent vertical succession.

Many sandstone bodies in the lower member take the form of bars, linear in plan view and convex-upward in side view. Low-angle cross laminae, plane laminae, both asymmetric and symmetric ripples, and local flaser bedding near the base are the most common sedimentary structures. de Raff et al. (1977) illustrated three different types of wave-generated bars in their study of Lower Carboniferous rocks in Ireland (fig. 28). We have observed sedimentary structures and sequences in the Cypress resembling all three types of bars illustrated by de Raff et al.

Intervals of sandstone bearing sets of planar or gently inclined laminae occur between or adjacent to bar-form sand bodies of the lower member. These sets of laminae are separated by distinct undulatory upper and lower surfaces. Such sand, according to Davis (1983), was probably deposited in swales between bars. Littoral and nearshore currents transport sand parallel to bars and deposit it at the down-current end. Depositional lows are thus passively and calmly filled.

Sandstone at the I-57 section displays cross strata with sharp set boundaries, parallel laminae, reactivation surfaces, local flaser bedding, clay drapes in ripples, interference and asymmetric ripples, convolute bedding, and load casts. Each of these features is common in tidal settings (Klein 1970, 1977). Klein attributes sharp set boundaries and parallel laminae to the reversal of tidal current bedload transport and tidal current phases of subequal flow velocity. Reactivation surfaces are the result of time-velocity asymmetry. Transport of tidal current bedload combined with an alternating tidal current velocity leads to bar migration and the production of cross strata. Subordinate tidal phases produce reactivation surfaces. Flaser bedding and clay drapes in ripples reflect transport of tidal current bedload and deposition of mud from suspension during periods of slackwater at both high and low tides. Interference ripples are generated during late-stage runoff, usually during ebb tide. Asymmetric ripples are formed during dominant tidal phases, although the crest of the ripple may be truncated during the subordinate tidal phase. Convolute bedding and load casts develop by differential loading and subsequent compaction during rapid deposition (Klein 1977). Although all of these structures may form in environments other than tidal, the close association of so many such features strengthens the case for hypothesizing tidal processes in the lower member of the Cypress.




| Structure | Process | Structure | Process |
|---|---|---|---|
| low angle bedding | highest energy level, swash and breaker zone | asymmetrical wave ripples | half-stationary wave oscillation, waves in close touch with bed |
| cross-bedding | high energy, mega ripples in runnels and on ridges | symmetrical wave ripples | stationary wave oscillation |
| parallel lamination | suspension fall out after whirling up by waves | flaser bedding | intermittent wave action |
| cross lamination | wave-derived current e.g., in runnels and rips | linsen beds | intermittent wave action |

**Figure 28** Three bar-shoal types and their supposed relative depths of deposition and degree of wave agitation are illustrated (from de Raff et al. 1977).

Some sandstone bodies in the lower member of the Cypress appear to be bar-form lenses that are convex both upward and downward and 10 to more than 30 feet thick. The larger bar forms partly coalesce at the I-57 section and contain elongate lenticular, very gently inclined, shingled or imbricated bedding (fig. 27). Likely modern analogues of these bar-form sandstones are tidal sandbars. Off (1963) described two types of tidal sandbars: tidal sand ridges and sand waves. Tidal current sand ridges typically are large features; they are 25 to 100 feet high, 5 to 40 miles long, and are spaced 1 to 6 miles apart. They are oriented parallel to tidal currents and are best developed near the heads of bays in broad, shallow shelves and embayments such as the North Sea, Bay of Korea, and Persian Gulf. Such embayments commonly have tidal ranges greater than 4 meters (13 ft) and tidal currents of 1 to 5 knots. Sand waves are smaller, mostly 10 to 20 feet high, but they can reach 40 feet under favorable conditions. They are essentially giant current ripples oriented perpendicular to tidal currents. Tide ranges and current velocities associated with sand waves are smaller than those associated with tidal sand ridges. Off (1963) suggested that certain Chesterian sand bodies in the Illinois Basin might be tidal current ridges. In most cases, however, sandstone lenses in the Cypress have dimensions closer to those of sand waves rather than those of sand ridges.

The tidal-bar model is strengthened by subsurface mapping in Lawrence County, Illinois, where the lower member of the Cypress produces oil. Here the lower member is composed of stacked or coalescing lenticular sand bodies that are about 800 to 2,000 feet long, 300 to 600 feet wide, and 10 to 15 feet thick. The long axes of these sand bodies strike northeast to north-northeast (J.P. Grube, ISGS, personal communication, 1994). The dimensions of the lower Cypress sand bodies in Lawrence County are similar to those of modern tidal sand waves described by Off (1963).

Sandstones above and below the Cypress exhibit similar geometries, and likewise have been interpreted as tidal bar deposits. Below the Cypress, the Aux Vases Formation in the Energy oil field of Williamson County in southern Illinois, comprises upper and lower sandstone units separated by a thin, shaley, impermeable zone. Both sandstones occur as lenses that are convex upward and are interpreted as marine bars (Huff 1993). Above the Cypress, the Big Clifty Sandstone Member of the Golconda Formation occurs as lenses that have general northeast orientation and are interpreted as offshore tidal bars (Treworgy 1988).

A possible ancient analog for the lower member of the Cypress is the Viking Formation (Lower Cretaceous) of Saskatchewan. Evans (1970) described the Viking as a widespread sheetlike sandstone about 45 feet thick. Evans found that the Viking is composed of imbricated sandstone bodies and that each successive package of rock overlaps the underlying sandstone in a southward direction. Evans interpreted the sandstones to have been deposited in a shoreline and offshore bar environment.

Portions of the lower member of the Cypress may have been deposited in tide-dominated deltas. Modern tide-dominated deltas studied by sedimentologists include the Gulf of Papua (New Guinea; Miall 1979) and the Klang (Malaysia) and Ord and Burdekin deltas (Australia; Coleman 1976, Coleman and Prior 1980, 1982). Features of these modern examples include clean, well-sorted sands, sand units having erosional bases, common marine fossils, common herringbone and bidirectional cross lamination, flaser bedding and planar lamination of the upper flow regime, and absence of well defined coarsening- and fining-upward sequences. Parallel tidal sand ridges develop within and seaward of the broad, funnel-shaped distributary mouths (Coleman and Prior 1982). The tops of tidal sand ridges may be vegetated, and peat develops on top of sand bodies under humid climates.

The West Baden clastic belt may comprise deposits of tide-dominated deltas and associated offshore tidal sand waves, or possibly sand ridges. Isopach and net-sand thickness maps by Sullivan (1972) display linear and bifurcating sand bodies that may represent distributaries. This conclusion is supported by Hrabar and Potter's (1969) study of the West Baden Sandstone at the northern outcrop of the clastic belt in Indiana. Hrabar and Potter mapped a south-trending, bifurcating, linear sand body in which paleocurrents indicated southerly transport. This sandstone, interpreted as a distributary-channel deposit, overlies a thinner fine grained sandstone in which sedimentary structures and paleocurrents imply tidal currents. The West Baden Sandstone in Indiana also intergrades laterally with marine limestones and shales (Hrabar and Potter 1969, Sullivan 1972).

The West Baden clastic belt follows grabens in the Wabash Valley Fault System and Dixon Springs Graben (fig. 15). The Dixon Springs Graben is a segment of the Cambrian-age Reelfoot Rift in which faults have been reactivated repeatedly (Kolata and Nelson 1991a). Although mapped faults in the Wabash Valley system are post-Pennsylvanian, this fault system may have earlier ancestry. In any event, the axis of maximum subsidence during Cypress deposition lay along this trend. Thus, siliciclastics were funneled into this area.

Sea level probably was high during deposition of the Ridenhower Formation and the equivalent part of the Paint Creek Formation (fig. 4). The widespread disconformity at the base of the Cypress indicates lowering of sea level but not subaerial exposure. No exposure features such as deeply incised paleovalleys, paleosols, or rooted zones are known. The sub-Cypress surface was probably scoured by wave- and tide-generated currents. Deposition of the lower member of the Cypress took place under shallow subtidal conditions, certainly above the storm wave base and probably above the fair-weather wave base.

**Middle shaley member** The middle shaley member of the Cypress contains evidence of widespread subaerial exposure, including the presence of coal, thick carbonaceous shales with fossil land plants, underclay with root casts, and variegated mudstone that appears to be paleosols. Depending upon presumed compaction ratios, a 4-foot coal bed represents 12 to 40 feet of peat. Widespread occurrence of relatively thick coal and rooted underclays implies that some, if not all, of the Cypress coal represents in situ peat accumulation in swamps rather than rafts of transported plant debris.

Red and green mudstone commonly occurs in the middle member along the southwestern and southeastern margins of the basin, where the Cypress is thin. Ambers and Petzold (1992) found many sedimentary features indicative of very shallow subtidal, intertidal, and supratidal (subaerial exposure) in variegated mudstone of the Elwren (Cypress) Formation of southern Indiana. Similarly, Weimer et al. (1982) attributed variegated mudstone of the Aux Vases Formation in southern Illinois to upper tidal-flat and marsh sedimentation.

We infer that during deposition of the middle member of the Cypress, most of southern Illinois was a tract of tidal mudflats dotted by stands of vegetation (fig. 4). Little new sedimentation took place. Sediments, including previously deposited marine sediments, were altered by subaerial exposure under an arid climate (Ambers and Petzold 1992). Subtidal sedimentation apparently persisted along the West Baden clastic belt as a result of more rapid subsidence in the underlying Dixon Springs Graben.

Other siliciclastic units in the Pope Group contain intertidal to supratidal deposits analogous to the middle member of the Cypress. In the Energy oil field of Williamson County, the Aux Vases Formation contains a thin middle zone of shale, siltstone, and very fine algal sandstone, interpreted as sediments of intertidal flats. The middle intertidal zone separates upper and lower sandstone bodies thought to be subtidal bars (Huff 1993). A widespread interval of variegated mudstone occurs at the top of the Big Clifty Sandstone Member of the Golconda Formation (pl. 1). Treworgy (1988) described features indicative of paleosol and supratidal deposition in this mudstone.

**Upper sandstone member** The upper member of the Cypress Formation records a return to subtidal sedimentation (fig. 4). Ichnofossils and body fossils at the New Columbia Bluff section indicate shallow, open marine conditions. Sedimentary structures also are consistent with subtidal sedimentation. Thin, lenticular sand bodies in the upper member may be marine sandbars. The general upward fining of sediments and locally gradational contact with the overlying Beech Creek Limestone reflects a gradual cutoff of siliciclastic sediment. In the West Baden clastic belt, siliciclastics were still entering during deposition of the Beech Creek, thus inhibiting deposition of the limestone there. The Beech Creek itself is interpreted (fig. 4) to represent a rapid initial transgression, followed by gradual regression (Harris 1992).

In oil fields north of the outcrop belt in Illinois, the upper member of the Cypress contains lenticular sandstone bodies that have northeast to east-northeast orientation and are interpreted to be tidal sandbars. Such bars are present in the Bartelso Field of Clinton County (Whitaker and Finley 1992) and are particularly well documented in the Tamaroa and Tamaroa South Fields in Perry County (Grube 1992).

## Sediment Source

Most previous authors, including Siever (1953), Potter (1962 and 1963), and Swann (1963 and 1964), postulated that Chesterian clastics were dominantly derived from areas north of the Illinois Basin. Surprisingly, little direct evidence exists to support that conclusion. Thickness and lithofacies patterns of the Cypress Formation indicate that siliciclastic sediment entered the basin along an axis trending north–south to northeast–southwest. The central Illinois clastic belt follows a north–south trend, whereas the West Baden clastic belt trends northeast–southwest. The Cypress thins markedly on both the western and southeastern margins of the basin, and its sand content also sharply decreases. Neither the Ozark Dome to the west nor the Cincinnati Arch to the east and southeast seem tenable as sources of Cypress siliciclastics.

Petrologic maturity of the Cypress is consistent with provenance from older Paleozoic sandstones on the Transcontinental Arch, Canadian Shield, and northern Alleghenian orogen. However, this observation alone does not rule out other potential source areas. Detailed mineralogical studies that might link Cypress sediment with specific source areas have not been conducted. Paleocurrent data are also not very revealing. Paleocurrent trends in the outcrop belt of southern Illinois generally are bidirectional, reflecting tidal ebb and flood.

A potentially more relevant paleocurrent study was conducted by Hrabar and Potter (1969) at the northeastern outcrop of West Baden clastics in Indiana. These authors found prevailing southbound paleocurrent indicators in sandstones of the lower (Bethel) part of the West Baden clastic belt, evidence that implies at least some West Baden sediment came from the north.

Paleogeographic evidence militates against a southern source of sand for the Cypress. During Chesterian time, the deep Ouachita trough and flanking foreland Arkoma and Black Warrior Basins separated the Illinois Basin area from possible sources of terrigenous sediment on the south (Houseknecht 1983). Sandstones of Cypress age on the northern margins of the Arkoma and Black Warrior Basins are much thinner than the Cypress Formation in Illinois. The Batesville Sandstone is the approximate time-equivalent of the Cypress north of the Arkoma Basin on the southern flank of the Ozark Dome in northern Arkansas. This thin, shallow-marine sandstone pinches out southward into thick deep-water shales of the Arkoma Basin (Handford and Manger 1993). The only sandy unit of approximate Cypress age in northern Alabama is the upper sandstone member of the Pride Mountain Formation. This again is a thin, discontinuous shallow-water unit that pinches out southward into thick shales of the Black Warrior Basin (Thomas 1972). The Batesville and Pride Mountain sandstones are distal, seaward counterparts of the thicker, nearshore Cypress sandstones of the Illinois Basin.

The sand of the Cypress Formation probably was derived from source areas north and northeast of the Illinois Basin. This conclusion is made more on the basis of elimination of other possible source areas than on direct positive evidence.

## Analogs for Hydrocarbon-Producing Zones

Because sandstones of the Cypress Formation are major petroleum reservoirs, a goal of this study was to relate characteristics of the outcrop belt to those of the producing oil fields. Several concurrent subsurface studies conducted by the ISGS provide a framework to delineate depositional facies of pay zones in the Cypress. These studies indicate that characteristics of the producing fields are closely similar to those of the outcrop belt.

The lower sandstone member of the Cypress yields oil in Lawrence County, Illinois. The lower member here is composed of stacked, elongate, lenticular sandstone bodies that are each 10 to 15 feet thick and trend northeast–southwest. These sandstone bodies probably are tidal bars. Overlying the lower member in Lawrence County is an interval of variegated mudstone that contains features characteristic of subtidal to upper intertidal depositional environments (Grube and Cole 1992, J.P. Grube, personal communication, 1994).

Another major field having production from the lower sandstone member is the Louden oil field in Fayette County. Here the lower member is composed of lenticular sandstone bodies as thick as 60 feet, encased in and grading laterally to shale. The sandstone is slightly calcareous and contains scattered bryozoan, brachiopod, and crinoid fragments. Overlying the productive lower member is a shale-dominated interval that includes red and green shale (Cluff and Lasemi 1980). Together, the Lawrence County and Louden fields probably account for more than half of the total oil production from the Cypress in the Illinois Basin.

Studies of upper Cypress reservoirs by Grube (1992), Whitaker and Finley (1992), and Xu and Huff 1995 all showed successions of stacked or imbricated sandstone bodies, which are separated by thin shales, in the upper Cypress. The sandstone bodies are lens shaped in map view; the long axes of the lenses generally trend northeast–southwest. In the Mattoon oil field of Coles County, Illinois, sandstone bodies in the upper Cypress trend generally north–south (McGee, in preparation).

The main hydrocarbon-producing facies are apparently stacked or imbricated offshore-bar sandstone bodies that prograded southward, down the gentle paleoslope of the basin. Generally, structural closure is necessary to create a trap in such sandstones. Plane- and ripple-laminated sandstone also may be productive, if petrophysical properties are favorable and structural closure is present.

To summarize, outcrops of the Cypress Formation provide analogs for hydrocarbon-producing zones in the deeper part of the basin. An understanding of depositional facies trends, areal distribution, and internal architecture can enhance success of exploration for these reservoirs. This understanding is best achieved through coordinated studies of the outcrop and subsurface.

## CONCLUSIONS

Deposition of the Cypress Formation took place in a shallow marine, ramp-like embayment that was open to the south. The principal source of terrigenous detritus lay to the north and northeast. The Ozark Dome and Cincinnati Arch were shoal areas that contributed little or no sediment. Sediment was funneled into an elongate, broad, and shallow trough that ran south-southwest from west-central Indiana to southern Illinois. Subsidence of this trough may have been structurally controlled by the ancestral Wabash Valley Fault System and Dixon Springs Graben.

Limestone and shale of the Paint Creek and Ridenhower Formations were deposited in shallow, open marine environments. Widespread erosion took place prior to Cypress sedimentation, but the erosion surface had little relief. A major influx of siliciclastic sediment, largely sand, then entered the proto-Illinois Basin, forming the lower sandstone member of the Cypress. This sandstone was deposited in tide-dominated deltas and in shallow offshore, open marine settings. Evidence for these conclusions includes the following points.

- Normal marine fauna (e.g., filter-feeding brachiopods, echinoderms, and bryozoans) are present.
- The lower Cypress intertongues westward with marine limestone of the upper part of the Paint Creek Formation.
- Sedimentary structures throughout the Cypress imply active, but relatively gentle, current activity. The structures are typical of those reported in the literature for shallow subtidal settings.

- Bidirectional and herringbone crossbedding and possible tidal couples indicate tidal ebb and flood, particularly at the top of the interval.
- Parallel swarms of stacked or imbricate bars are present and analogous to the tidal sand waves described by Off (1963).
- Vertical grain-size and bedform trends are variable, as found in modern tide-dominated deltas. River- or wave-dominated deltas typically exhibit well-developed, coarsening-upward cycles.

The middle shaley member of the Cypress records a regression that led to subaerial exposure and deposition in very shallow subtidal to supratidal and marsh environments. These deposits include coal (as much as 4 feet thick), carbonaceous shale with terrestrial plant fossils, underclay with root casts, and red and green variegated mudstone with features indicative of subaerial exposure. Such features are best developed away from the West Baden clastic belt and near the margins of the Illinois Basin. Within the clastic belt, subsidence may have been rapid enough to prevent exposure.

The upper member of the Cypress reflects a return to shallow subtidal conditions, as signified by the laminated, upward-fining sediments that contain marine body fossils and trace fossils. Siliciclastic input gradually waned, allowing deposition of the Beech Creek Limestone except in some places in the West Baden clastic belt. By this time, tectonic subsidence appears to have stabilized over most of the basin—the rift area no longer subsided more rapidly than surrounding areas.

The above model differs from the fluvially dominated "Michigan River" delta model of Swann (1963, 1964) and Potter (1962, 1963). Although the middle member contains nonmarine strata, the bulk of the Cypress is a subtidal deposit. The Cypress was deposited in shallow shelf, tide-dominated delta, estuarine, and tidal-flat settings.

Although Cypress siliciclastics came from the north or northeast, evidence of a long-lived Michigan River system is lacking. Clastic sources for the Pope Group periodically shifted to different areas of the basin. The older Aux Vases Sandstone had a source west or northwest of Illinois (Cole 1990), whereas the younger Big Clifty Sandstone had a source east of the basin (Sable and Dever 1990).

Instead of a single regression, as indicated by Swann (1963), the Cypress reflects two episodes of relatively high sea level separated by an episode of low sea level for the middle member (fig. 4). Siliclastic and carbonate rocks were deposited simultaneously in different parts of the basin during Cypress time. As suggested by Swann (1964), sediment supply, not water depth, probably was the major factor that controlled siliciclastic versus carbonate sedimentation. Sand was funneled toward the tectonically controlled, NNE–SSW-trending axis of the basin, where subsidence was greatest. Little sand reached the stable eastern and western margins of the basin.

Bar-form sandstone bodies made up of tidal current ridges or sand waves are the most favorable facies for hydrocarbon production from the Cypress in Illinois. Such bars can form stratigraphic traps with no structural closure necessary. Ripple-laminated and planar-laminated sheet sandstones can be productive, but structural closure generally is required. Both types of sandstones commonly have good porosity, but permeability varies greatly in response to diagenetic history.

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## APPENDIX A OUTCROP SECTIONS

List of outcrop sections used in this study. Symbols for outcrop sections are keyed to figure 5.

BC Bay City, roadcut in bluff, SW NW NE, Sec. 1, T15S, R6E, Pope County, Smithland Quadrangle.

BT Bethany Church no. 1 and no. 2, both along southwest-facing bluff in W½ SE NE, Sec. 24, T13S, R1E, Union County, Cypress Quadrangle.

CB Cagle Bluff, southeast-facing bluff, SE NW, Sec. 10, T14S, R4E, Massac County, Mermet Quadrangle.

CC Cypress Creek, streambanks and bluffs along Cypress Creek just east of Interstate Highway 57, E½ SW, Sec. 30, T12S, R1E, Union County, Anna Quadrangle.

CR Cache River no. 1 and no. 2. Cache River no. 1 is streambed, banks, and bluffs of Cache River in NW NE NW, Sec. 9, T12S, R1W, Union County, Anna Quadrangle. Cache River no. 2 is streambank and bluffs along Cache River in NW SE NW, same section.

GL Golconda, Ohio River bluff, NE SE NW, Sec. 30, T13S, R7E, Pope County, Golconda Quadrangle.

GLS Golconda South, Ohio River bluff, NW NE NW, Sec. 31, T13S, R7E, Pope County, Golconda Quadrangle.

HD Hunkerin' Ditch, ditch and natural exposures on north side of county road in SE NE, Sec. 1, T14S, R3E, Massac County, Mermet Quadrangle.

I-24 Interstate 24, roadcut along Interstate Highway 24, NE NE SW, Sec. 10, T14S, R4E , Massac County, Mermet Quadrangle.

I-57 Interstate 57, box cuts along Interstate Highway 57 in NW SW and SW NW, Sec. 31, T13S, R1E, Union County, Anna Quadrangle.

IP Indian Point, railroad cut and south-facing bluff in S½ SE, Sec. 32 and S½ SW, Sec. 33, T13S, R3E, Johnson County, Karnak Quadrangle.

NCB New Columbia Bluff NE, New Columbia Bluff, and New Columbia Bluff SW (sections too closely spaced to separate at the scale of fig. 6). New Columbia Bluff NE is southeast-facing bluff in NW NE NW, Sec. 15, T14S, R4E, Massac County, Mermet Quadrangle. New Columbia Bluff is roadcut and adjacent bluff face in W½ SE NW, same section. New Columbia Bluff SW is bluff face in SW SW NW, same section.

RH Reineking Hill, cut along east side of Illinois Central Railroad, SE SE NE, Sec. 23, T14S, R4E, Massac County, Reevesville Quadrangle.

RL Roper's Landing, Ohio River bluff, SE NE NE, Sec. 14, and NW NW, Sec. 13, T14S, R6E, Pope County, Brownfield Quadrangle.

SF Seminary Fork, northeast bank and bluffs of Seminary Fork in NW SE SE, Sec. 16, T11S, R2W, Union County, Cobden Quadrangle.

TF Travis Farm no. 1, no. 2, and no. 3. Travis Farm no. 1 is west-trending ravine in NE NW SE, Sec. 7, T14S, R4E, Massac County, Mermet Quadrangle. Travis Farm no. 2 is west-trending ravine in NE SW SE, same section. Travis Farm no. 3 is west-trending ravine in SW SW SE, same section.

## APPENDIX B BOREHOLE RECORDS USED FOR PLATE 1

1 Badger Oil and Gas Co. no. 1 Schroeder, SW NW NW, Sec. 27, T6S, R5W, Randolph County, ISGS county no. 635, sample study by J.N. Payne.

2 Gretzmacher no. 1 Lindenburg, SW NE NW, Sec. 18, T7S, R5W, Randolph County, ISGS county no. 2132, sample study by H.M. Bristol and E. Atherton.

3 Christian and Waggoner no. 1 Waltemate, NE NW NE, Sec. 25, T7S, R6W, Randolph County, ISGS county no. 1918, electric log and sample study by F.E. Tippie.

4 Andrews no. 1 Fraser, SW NE SW, Sec. 6, T8S, R5W, Randolph County, ISGS county no. 1919, electric log and sample study by W.J. Nelson.

5 F.L. Rigney no. 1 Gutermuth, NE NE NE, Sec. 26, T8S, R5W, Jackson County, ISGS county no. 1165, electric log and sample study by E. Atherton and D.B. Saxby.

6 Walter Willis no. 1 Cleiman Heirs, NW NW SE, Sec. 34, T8S, R4W, Jackson County, ISGS county 1162, electric log and sample study by E. Atherton.

7 Phillips Petroleum no. 1040-6, NW NE SW, Sec. 18, T10S, R3W, Jackson County, ISGS county no. 1514, electric log and sample study by R.H. Howard.

8 Phillips Petroleum no. 1040-7, SW NW SE, Sec. 21, T10S, R3W, Jackson County, ISGS county no. 1513, electric log and sample study by R.H. Howard.

9 Illinois State Geological Survey, COGEOMAP test hole CB-2, SE SE SE, Sec. 6, T11S, R2W, Union County, continuous core described by R.D. Cole and J.A. Devera.

10 Presley Tours no. 2 Wayman, SE SE SW, Sec. 17, T11S, R1W, Union County, ISGS county no. 20477, gamma ray-neutron log and sample study by W.J. Nelson.

11 Monjeb Minerals no. 1 Richards, NW NW SW, Sec. 21, T11S, R1E, Union County, ISGS county no. 20472, electric and gamma ray-density logs and sample study by company geologist.

12 Zeppa & Coates no. 1 Albright, NW NW SE, Sec. 22, T12S, R2E, Johnson County, ISGS county no. 29, electric log and sample study by E. Atherton and F.E. Tippie.

13 Cunningham well, Vienna courthouse square, NE SE, Sec. 5, T13S, R3E, Johnson County, ISGS county no. 48, anonymous sample study.

14 Comanche Oil Co. no. 1 Branham, NE NE NW, Sec. 21, T13S, R4E, Johnson County, ISGS county no. 20282, gamma ray-neutron log and sample study by W.J. Nelson.

15 Glass no. 1 Cummins, SW SW SW, Sec. 25, T14S, R4E, Johnson County, ISGS county no. 55, sample study by W.J. Nelson.

16 Boyer Drilling Co. no. 1 Ditterline, SW SE SW, Sec. 9, T14S, R5E, Pope County, ISGS county no. 20306, continuous core described by J.W. Baxter and J.D. Treworgy.

17 Milo Ditterline no. 2, SE SW SE, Sec. 10, T14S, R5E, Pope County, ISGS county no. 20307, continuous core described by J.W. Baxter and W.J. Nelson.

18 Abner Field no. 1, NW SE SE, Sec. 19, T13S, R6E, Pope County, ISGS county no. 108, continuous core described by L.E. Workman.

19 Ozark-Mahoning CT-1S, NW SE, Sec. 19, T12S, R7E, Pope County, ISGS county no. 20330, continuous core described by R.D. Cole and W.J. Nelson.

20 Ozark-Mahoning KT-19S, NE NE, Sec. 31, T12S, R8E, Hardin County, ISGS county no. 20794, continuous core described by J.D. Treworgy and W.J. Nelson.

21 Ozark-Mahoning USHC-55S, SE NW NW, Sec. 17, T11S, R9E, Hardin County, ISGS county no. 20795, continuous core described by J.D. Treworgy, Z. Lasemi and R.D. Cole.

22 Ozark-Mahoning no. 43M, SW NE NW, Sec. 24, T11S, R9E, Hardin County, ISGS county no. 161, samples (well cuttings) described by D.B. Saxby.