Stratigraphic and Structural Framework along the 11:30 O'Clock Cross Section in the Illinois Basin: Wayne County, Illinois, to Stephenson County, Illinois

Janis D. Treworgy, Stephen T. Whitaker, and Zakaria Lasemi

Open File Series 1994-6

ILLINOIS STATE GEOLOGICAL SURVEY
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Cross sections available in the series

Vertical scale is 1 inch = 400 feet; horizontal scale is 1:250,000 (1 inch = about 4 miles)

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Northwest-Southeast Cross Section in the Illinois Basin, Sparta Shelf, Southern Illinois, to Rough Creek Graben, Western Kentucky, by Stephen T. Whitaker, Janis D. Treworgy, Michael L. Sargent, and Martin C. Noger, ISGS Open File Series 1992-3.

West-East Cross Section in the Illinois Basin, Ozark Dome, Missouri, to Rough Creek Graben, Western Kentucky, by Michael L. Sargent, Janis D. Treworgy, and Stephen T. Whitaker, ISGS Open File Series 1992-4.

INTRODUCTION

This report accompanies the *11:30 O'Clock Cross Section in the Illinois Basin,* one of a network of regional cross sections that portray the structural and stratigraphic framework of the Illinois Basin. Most of the cross sections radiate from the UNOCAL no. 1 Cisne drill hole in Wayne County, Illinois, the approximate geographic center of the basin. These structural cross sections, which include wireline logs of deep tests, traverse significant geological features in Illinois, Indiana, and Kentucky, and portray the entire Phanerozoic section.

The line of the *11:30 O'Clock Cross Section in the Illinois Basin* extends from the center of the Illinois Basin in south-central Illinois to the southern end of the Wisconsin Arch at the Wisconsin border in northwesternmost Illinois. The cross section is generally perpendicular to the depositional slope of the basin and portrays major facies relationships along that trend. Only unconformities at the sequence boundaries, as defined by Sloss (1963), are indicated on the cross section. Additional detailed descriptions of the lithologies and facies relationships can be found in Willman et al. (1975) and Leighton et al. (1991). The principal drill holes shown on the cross section are referred to in the text by farm name and reference letter; infill drill holes are numbered consecutively from south to north.

Geologic History of the Illinois Basin

The origin and evolution of the Illinois Basin is linked to an aulacogen that formed during breakup of a supercontinent during the late Proterozoic through the Middle Cambrian (Kolata and Nelson 1991a). This aulacogen, known as the Reelfoot Rift/Rough Creek Graben, is situated in the southern part of the present Illinois Basin, south of the line of cross section. By Late Cambrian time, the proto-Illinois Basin was a broad cratonic embayment that was open to the south. During the Paleozoic, tectonic subsidence was more rapid over the aulacogen in the southern part of the basin. This subsidence produced a thicker and more complete sedimentary record in the southern part of the basin. It was not until the end of the Paleozoic or early Mesozoic, during uplift of the Pascola Arch, that the southern end of the basin was structurally closed, producing the present configuration. During much of the Paleozoic, the basin was part of a widespread cratonic seaway that flooded the basin-bounding arches as well.

STRATIGRAPHY

Precambrian

Precambrian rocks in Illinois are dominantly granitic and rhyolitic (Bradbury and Atherton 1965) and have been radiometrically dated at 1420 to 1500 Ma (Bickford et al. 1986). The four wells that penetrated basement in the cross section, the Cisne (A), Goodwin (G), Mathesius (I), and UPH-3 (L) drill holes, encountered red granite. Local relief at the top of Precambrian crystalline rocks is known to be more than 1,000 feet (M.L. Sargent, Illinois State Geological Survey, personal communication 1993). Precambrian knoblike features have been illustrated on several other cross sections in this series, including those for the 9 o'clock (Whitaker and Treworgy 1990), 3 o'clock (Treworgy and Whitaker 1990a), and 6 o'clock (Whitaker et al. 1992) positions, but none are evident on this cross section.

Sauk Sequence

Mt. Simon Sandstone (Upper Cambrian) A major rise in eustatic sea level flooded all but the highest hills on the Precambrian erosional surface and led to deposition of the basal Late Cambrian Mt. Simon Sandstone throughout the basin. The Mt. Simon is a fine to coarse grained, white to pink, subarkose to quartz arenite. It thickens northward from about 350 feet in the Cisne (A) drill hole in Wayne County, at the south end of the cross section, to more than 2,000 feet in La Salle County (in the Goodwin [G] and Mathesius [I] drill holes), which is just west of its point of maximum thickness in the basin. From La Salle County, the sandstone thins northward to about 900 feet in the UPH-3 (L) drill hole in Stephenson County at the north end of the cross section.

Distribution of the Mt. Simon is atypical for the Illinois Basin because it is thickest in northern Illinois, whereas most other Paleozoic units thicken southward.

Eau Claire Formation (Upper Cambrian) Relative sea level remained high through the remainder of the Cambrian and into the Ordovician, in part because of a relatively rapid rate of tectonic subsidence of the basin (Treworgy et al. 1991, Kolata and Nelson 1991b). Regionally, the Eau Claire Formation represents a transition from siliciclastic deposition of the Mt. Simon to carbonate deposition. The Eau Claire, as defined in Wisconsin and used in northern Illinois, is a fine to medium grained, gray, dolomitic sandstone interbedded with shaley siltstone and silty, sandy, glauconitic dolomite (Buschbach 1975). Carbonates become increasingly prominent in the Eau Claire southward (Harrison [D] and Cisne [A] drill holes) into the Illinois Basin (Buschbach 1975). The unit is laterally equivalent to the Bonneterre Formation in southeastern Missouri. The lower part of the Eau Claire in the southern part of the basin is mixed siliciclastics and carbonates (Harrison [D] and Cisne [A] drill holes). In Indiana and Kentucky, this lower siliciclastic carbonate unit constitutes the entire Eau Claire (Droste and Patton 1985). The upper, carbonate-rich portion of the Illinois Eau Claire is included in the lower part of the Knox Group.

The Eau Claire carbonates are separated from overlying carbonates of the Knox Group by the Davis; this shaley carbonate member of the Franconia Formation in southern Illinois is present from the Cisne (A) drill hole to the Peru (H) drill hole in La Salle County. The Davis loses its siliciclastic component eastward beyond south-central Illinois. Loss of this shaley unit makes it difficult to pick the top of the Eau Claire.

Ironton and Galesville Sandstones (Upper Cambrian) Overlying the Eau Claire in northern Illinois are the Ironton and Galesville Sandstones. The Galesville is a white, generally pure, fine grained, friable, nondolomitic quartz arenite. The overlying Ironton is similar, but it is coarser grained and somewhat dolomitic in places. The contact between the two is gradational and has not been drawn on the cross section. These sandstones, derived from a source north of Illinois, thin distally southward. Just south of the Harrison (D) drill hole in Moultrie County, these sandstones grade into carbonates that are assigned to the Eau Claire Formation.

Franconia Formation, Potosi Dolomite, and Eminence Formation (Upper Cambrian) The Franconia Formation is a dominantly siliciclastic unit consisting of glauconitic, silty, argillaceous, fine grained, dolomitic sandstone in northernmost Illinois and Wisconsin. The lower part of the Franconia becomes increasingly shaley southward, where it is called the Davis Member. The upper part grades to a silty, sandy dolomite southward into the basin (Goodwin [G] drill hole). In southern and central Illinois, the Franconia is included in the carbonate Knox Group.

The Potosi and Eminence, also parts of the Knox Group, are predominantly carbonate rocks throughout the state, except for the northwestern tip of Illinois where the Jordan Sandstone is in facies relationship with the Eminence (UPH-3 [L] drill hole). In the southern part of the basin, the dolomites of the lower Knox Group generally cannot be differentiated in samples or on wireline logs (Cisne [A] drill hole). In the northern part of the basin, however, the pure carbonates of the Potosi and the somewhat sandy carbonates of the Eminence are clearly distinguishable in drill cuttings, cores, and outcrops.

Oneota Dolomite, New Richmond Sandstone, and Shakopee Dolomite (Lower Ordovician) The Oneota and Shakopee Dolomites, which form the upper part of the Knox Group, underlie all of Illinois, except for the northernmost portions of the state where they were eroded before deposition of the St. Peter Sandstone. Toward the south along the cross section, these units thicken substantially, reflecting the increased rate of subsidence southward.

Separating the Oneota and Shakopee in northern and west-central Illinois is the New Richmond Sandstone (northward from around the Ryan [E] drill hole), which represents an influx of siliciclastic sediments into the basin from the north. These siliciclastics thicken, then thin and disappear southward with increasing distance from the source area.

The Oneota typically is a coarse grained, light gray dolomite throughout the state, distinguishable in samples from the slightly sandy Eminence Dolomite below and the argillaceous, sandy and shaley Shakopee Dolomite above. On wireline logs, the Oneota is not easily distinguishable from the underlying Eminence Dolomite (Cisne [A] drill hole). Its purity, however, lithologically distinguishes it from the overlying shaley Shakopee Dolomite and produces lower gamma-ray and spontaneous-potential log signatures than the Shakopee (best seen in the Cisne [A], Thompson-Wetherell [C], and Harrison [D] drill holes).

Toward the end of deposition of the Lower Ordovician Shakopee carbonates, a widespread drop in sea level apparently led to subaerial exposure and erosion of the basin margins while deposition continued in the southernmost part of the basin (Shaw and Schreiber 1991). This exposure altered by karstification some of the upper portions of the Shakopee and locally enhanced its porosity, as can be seen in several drill holes elsewhere in the state. The resulting unconformity, and its correlative surface at the top of the Knox Group, defines the boundary between the Sauk Sequence and the overlying Tippecanoe Sequence.

Tippecanoe Sequence

Everton Dolomite, St. Peter Sandstone, Dutchtown Formation, and Joachim Dolomite (Middle and Upper Ordovician) Overlying the sub-Tippecanoe unconformity is the lower part of the Tippecanoe I Sequence—a basal transgressive sequence containing mixed carbonate and siliciclastic facies that make up the Everton Dolomite and the St. Peter, Dutchtown, and Joachim Formations of the Ancell Group. The dominantly carbonate units, the Everton, Dutchtown, and Joachim, are mostly present in the southern part of the basin (south of the Ryan [E] and Thompson-Wetherell [C] drill holes). This depocenter was situated over the Reelfoot Rift where tectonic subsidence was most rapid (Treworgy et al. 1991, Kolata and Nelson 1991b).

Dolomite in the Everton represents a transition from sabkha and restricted marine conditions that occurred during deposition of its lower part, to peritidal and subtidal marine conditions that existed by the time of upper Everton deposition (Shaw and Schreiber 1991). To the north in Illinois, an irregular karstic surface developed on the exposed Sauk carbonates. During deposition of the upper part of the Everton, siliciclastic input gradually increased as exposed Cambrian siliciclastics on the Canadian Shield and Wisconsin Arch were reworked and transported into the basin.

The St. Peter Sandstone is present throughout most of the Illinois portion of the basin, except where it is eroded along part of the La Salle Anticlinorium (Mathesius [I] drill hole) and Sandwich Fault Zone in northern Illinois (Willman and Buschbach 1975, p. 62). The St. Peter is a pure, mature quartz arenite with well rounded, frosted grains. Derived primarily from older Ordovician and Cambrian sandstones exposed to the north (Dott et al. 1986), the St. Peter in Illinois represents a relatively rapid marine transgression over the post-Sauk erosional surface and consists of reworked shoreline and offshore bar sands (Shaw and Schreiber 1991). The St. Peter varies greatly in thickness due to the irregularity of the erosional surface it overlies.

At the north end of this cross section (north of the Keckler [K] drill hole) is a particularly intriguing area. Here the St. Peter is more than 300 feet thick and rests on the Cambrian Eminence Formation where all the Lower Ordovician rocks had been eroded. This area of thick St. Peter extends from west to east across most of northern Illinois in a band about 15 to 25 miles wide (Willman and Buschbach 1975, p. 62). Although extensive dissolution of underlying carbonate rocks through underground channels may have caused this broad valleylike feature, it is more likely that a system of deep stream valleys cut into the Sauk carbonates (Buschbach 1961).

A decrease in the supply of siliciclastics, possibly due to a relative rise in sea level, led to deposition of subtidal to peritidal carbonates, represented by the Dutchtown and overlying Joachim in the southern part of the basin. The Dutchtown, in part a relatively organic-rich, dark gray, argillaceous limestone and dolomite that emits a fetid odor when broken, is restricted to the southern part of the basin (south of the Thompson-Wetherell [C] drill hole). The Joachim has a varied lithology, but is dominantly light gray, argillaceous, silty or sandy dolomite with beds of limestone and sandstone and some anhydrite layers. The Dutchtown (south of the Thompson-Wetherell [C] drill hole) and the overlying Joachim, which extends as far as north-central Illinois (south of the Ryan [E] drill hole), are interpreted to be in facies relationship with the upper part of the St. Peter. A disconformity marks the top of the Joachim and St. Peter (Shaw and Schreiber 1991).

Platteville (Black River), Galena (Trenton), and Maquoketa Groups (Upper Ordovician)
The upper part of the Tippecanoe I Sequence consists of the carbonates of the Platteville and Galena Groups and the siliciclastics and carbonates of the Maquoketa Group. The Platteville and Galena were deposited during widespread inundation of the craton, a time of high carbonate production, relatively stable sea level, and slow rate of tectonic subsidence in the basin (Treworgy et al. 1991, Kolata and Nelson 1991b). These carbonates are mostly dolomitic in northern Illinois, where they were subjected to diagenetic alteration, whereas south of McLean County, they are dominantly limestone.

The Platteville (Black River) is a blanket carbonate unit of slightly argillaceous lime mudstone and wackestone (Kolata and Noger 1991) that thickens southward in the Illinois Basin. In the northern part of Illinois, fossil content indicates deposition in peritidal to subtidal open-marine environments, whereas in the southern part of the basin, sedimentary features indicate deposition in tidal flats and shallow lagoons.

In the northern part of the basin, the Galena (Trenton) consists of lime mudstone and wackestone and reflects deposition in quiet water on a stable shelf below wave base (Kolata and Noger 1991). In the southern part of the basin, however, the Galena, or Kimmswick Limestone of Missouri (Thompson 1991), consists largely of massive beds of broken and abraded crinoidal-bryozoan grainstone, indicating deposition in highly agitated water. Unlike most other Paleozoic units, the Galena thins southward, suggesting a reduction in the rate of tectonic subsidence at the southern end of the basin during that time.

The upper part of the Galena is the lowest stratigraphic unit that has produced commercial hydrocarbons in Illinois. The top of the Galena is marked by a prominent hardground that represents a depositional hiatus, during which relative sea level rose significantly.

Deposition resumed as fine siliciclastics were transported into the basin from the Taconic Orogen, which lay along the eastern margin of North America. Sea floor conditions were periodically anoxic, enabling local preservation of organic material in the black to gray shale of the Maquoketa Group. Throughout most of Illinois, the Maquoketa consists of three units: a lower shale, an overlying more calcareous unit, and another overlying shale. These shales have apparently generated hydrocarbons (Hatch et al. 1991) and are the source for at least some of the oil found in Galena and Silurian reservoirs in the basin. A drop in relative sea level at the end of the Ordovician exposed the Maquoketa to erosion along the flanks of the basin prior to deposition of Silurian strata. Relief of up to 150 feet is present on this erosional surface in northern Illinois (Kolata and Graese 1983). In western Illinois, erosional valleys in the top of the Maquoketa are present but subtle. In the deeper part of the basin, the top of the Maquoketa may be conformable with the overlying Silurian rocks.

Silurian System and Lower Devonian Series Silurian and Lower Devonian rocks are dominantly carbonates that constitute the Tippecanoe II Sequence. These strata become progressively more dolomitic northward from the deeper part of the basin. During much of the Silurian and Early

Devonian, gradual basin subsidence continued and allowed deposition of a thick section of carbonates that became progressively more argillaceous and cherty upward. Presence of deeper water facies in Late Silurian and Early Devonian rocks indicates that the rate of tectonic subsidence may have increased during this time.

In western Illinois, basal Silurian carbonates, which filled subtle valleys that were eroded in the top of the Maquoketa, were dolomitized and formed hydrocarbon reservoirs (Crockett et al. 1988). These reservoirs are restricted to the paleovalleys on the Maquoketa surface and may be more extensive than presently documented.

Reefs began to form in the upper part of the St. Clair Formation (Lower Silurian) and continued during deposition of the Moccasin Springs and Bailey Formations. Isolated pinnacle reefs developed in a shallow carbonate ramp environment (Whitaker 1988) and may be up to 1,000 feet thick near the center of the basin. Many of these Silurian reefs formed important hydrocarbon reservoirs (Ryan [E] drill hole). Pure reef and carbonate bank facies grade laterally into cherty, argillaceous, finely crystalline carbonates interbedded with thin shale. Dolomitic carbonate banks and patch reefs, which occur in the subsurface between the cities of Springfield (Sangamon County) and Decatur (Macon County), formed along the flanks of the Sangamon Arch, which was a subtle, east-northeast trending positive feature during this time. The cross section intersects the east end of the arch from the Harrison (D) to north of the Taylor (F) drill holes.

The Bailey Limestone, thought to be Late Silurian to Early Devonian in age (R.D. Norby, Illinois State Geological Survey, personal communication 1993), is dominantly a silty, argillaceous, cherty, thin bedded lime mudstone characteristic of deposition in a low energy, relatively deep water environment. The unit is present only in the deeper parts of the basin where pre-Middle Devonian erosion did not remove it. Facies relations indicate that a rise in relative sea level probably began during deposition of the Bailey (possibly due to a slight increase in the rate of subsidence) and eventually drowned the reefs (Banaee 1981). Relative sea level apparently continued to rise during the Early Devonian.

The Lower Devonian strata, like the underlying Bailey, are present only in the part of the basin south of the Thompson-Wetherell (C) drill hole, having been removed from the area to the north by pre-Middle Devonian erosion. These strata differ lithologically from the Bailey in that they generally contain more beds of chert. The lowest unit, the Grassy Knob Chert, is generally nonfossiliferous; on the outcrop, it is composed of bedded, vesicular to novaculitic chert, and in the subsurface it is composed of interbedded chert and dolomite (Rogers 1972). Overlying the Grassy Knob is the Backbone Limestone, which is a discontinuous, light gray, crinoidal grainstone. The Backbone rims the deeper part of the basin and thins or disappears basinward (Collinson and Atherton 1975). The Clear Creek Chert, at the top of the Lower Devonian succession, consists of moderately fossiliferous, slightly argillaceous and silty, light colored, siliceous lime mudstone and abundant interbedded layers of chert.

The end of the Early Devonian was marked by a widespread drop in sea level that exposed the margins of the basin to erosion, while deposition appears to have continued in the south-central part of the basin (Norby 1991). The resulting erosional unconformity or its correlative surface marks the Tippecanoe-Kaskaskia Sequence boundary. The strata immediately below this unconformity were dolomitized, which locally enhanced porosity and formed isolated hydrocarbon-bearing reservoirs.

Kaskaskia Sequence

Middle and Upper Devonian Series Middle Devonian transgressive carbonates deposited on the sub-Kaskaskia erosional surface progressively overlap older rocks northward as shown between the Cisne (A) and Thompson-Wetherell (C) drill holes. Middle Devonian strata consist of dolomite, fossiliferous limestone, and, locally, sandstone; these facies indicate relatively shallow marine conditions. Hydrocarbon-bearing reservoirs have been located in the sandstone and dolomite beds.

New Albany Group (Upper Devonian-Kinderhookian) As relative sea level continued to rise and a relatively deep basin evolved in the Illinois Basin in Late Devonian time (Cluff et al. 1981), black, gray, and green shales of the Upper Devonian and Kinderhookian (early Mississippian) New Albany Group were deposited in the southern two-thirds of the basin. The relatively deep water conditions and the influx of the siliciclastics of the New Albany halted carbonate production. A small increase in the rate of tectonic subsidence—and, therefore, an increase in accommodation space—is shown by backstripping methods to have occurred during deposition of the mid-Mississippian Valmeyeran Series (Treworgy et al. 1991, Kolata and Nelson 1991b). This increased rate of tectonic subsidence may actually have occurred as early as late Middle Devonian or Late Devonian, but backstripping did not indicate this subsidence because of the thin Upper Devonian sedimentary record. This increased subsidence rate could account for the Late Devonian deepened basin during New Albany deposition.

The shales of the New Albany achieve a maximum thickness of about 400 feet in the extreme southern part of the basin. Organic carbon content is high (median value of 3.7%; range of 0.2% to 9.3%) in some of the shale beds, and the unit is the main source of hydrocarbons in the basin (Hatch et al. 1991). Fractures in the shales have produced some natural gas in western Kentucky and southern Indiana (Seyler and Cluff 1991, p. 363, Hasenmueller and Comer 1994). The upper part of the New Albany is Kinderhookian (Mississippian) in age.

Mississippian System During early Valmeyeran time, following deposition of the New Albany and the thin Chouteau Limestone, the lower part of the Burlington-Keokuk Limestone bank developed in western Illinois and westward as far as Kansas (Lane 1978). The northeast extent of the bank is present between the Harrison (D) and Taylor (F) drill holes. At this time, minimal sedimentation occurred in the Illinois Basin east of the bank. Subsequently, influx of siliciclastics formed a submarine fan, the Borden Siltstone, that entered the basin from the east-northeast. The submarine fan was confined on the west by the Burlington-Keokuk Limestone bank (Lineback 1966), which continued to develop during early Borden deposition. With continued rise of relative sea level, the Borden siliciclastics overtopped the Burlington-Keokuk Limestone bank; these are called the Warsaw Shale (shown between the Harrison [D] and Taylor [F] drill holes). As the supply of siliciclastic sediment waned, carbonate deposition resumed in the basin, forming the Fort Payne and Ullin Formations. These units, partially in facies relationship with one another (Lineback and Cluff 1985, Lasemi et al. 1994), bound the siliciclastic Borden fan on the south and east, as shown between the Cisne (A) and Thompson-Wetherell (C) drill holes. Lasemi (1994) interpreted the Ullin to include coalesced Waulsortian-type mud mounds in its lower part and bryozoan patch reefs and storm generated sandwaves in its upper part. The mound facies is equivalent in part to the siliceous, dark brown Fort Payne carbonates, a relatively deep water facies that is a potential source for hydrocarbons. The coarser grained and lighter colored packstones and grainstones of the mound-flanking facies and of the overlying sandwave and bryozoan patch reef facies in the upper part of the Ullin are potential reservoir rocks (Lasemi 1994), a few of which are presently producing hydrocarbons in the basin (e.g., in Franklin, Hamilton, Wayne, and White Counties, Illinois). The age relationships of these units are currently being worked out on the basis of conodont biostratigraphy.

Overlying the Ullin are fairly thick shallow water carbonates of the Salem, St. Louis, and Ste. Genevieve Limestones. The Salem and Ste. Genevieve are significant hydrocarbon-producing units in the basin. Gradational with the Ullin, the Salem marks a transition to deposition within wave base (Cluff and Lineback 1981, Lasemi et al. 1994). The Salem's base is characterized by the first appearance of fine grained, argillaceous, cherty, partly dolomitic, skeletal wackestone to carbonate mudstone. In general, the Salem has oolitic zones, better sorting and rounding of components, and a greater diversity of fossils than does the Ullin.

The overlying St. Louis Limestone is generally gradational with the Salem, as shown between the Sutton (B) and Thompson-Wetherell (C) drill holes. Here, well cuttings indicate that the Salem and St. Louis interfinger. The St. Louis is predominantly cherty lime mudstone that is interlayered with skeletal wackestone and packstone, microsucrosic dolomite, and anhydrite (Cluff and Lineback 1981). The unit represents a shallowing upward from the more-open marine environments of Salem deposition to highly restricted shallow subtidal and intertidal environments, as indicated by abundant exposure features and evaporites around the margins of the basin.

The transition from the St. Louis Limestone to the overlying Ste. Genevieve, a predominantly high-energy, oolitic, skeletal grainstone, was probably due to a slight rise in relative sea level (Cluff and Lineback 1981). The Ste. Genevieve lithology is variable and also includes thin beds of skeletal, pelletal wackestone, lime mudstone, and sucrosic dolomite. Oolitic grainstone beds in the Ste. Genevieve, known as the "McClosky sands" in the oil industry, are the major pay zone in many oil fields in the basin.

The Valmeyeran carbonates are difficult to differentiate on wireline logs (note the Thompson-Wetherell [C] drill hole), and gradational contacts make correlations somewhat difficult in cuttings and cores as well. Subtle changes on the logs, though, can be traced. For example, the lower gamma-ray log response for the Ullin indicates that it is a purer carbonate than the overlying Salem, and both the gamma-ray and spontaneous-potential logs indicate shallowing-upward cycles in the Salem. These interpretations have been supported by study of drill cuttings. Further study of these units is necessary to understand the facies relationships and probable time-transgressive nature of the lithologic contacts (Lineback 1972, Cluff and Lineback 1981).

The upper part of the Mississippian, the Pope Group (Chesterian), consists of alternating thin, interbedded units of shale, sandstone, and limestone, some of which are major hydrocarbon-producing units in the basin. Some units in the Pope, particularly some of the limestones, are relatively widespread in the basin and are useful for structural mapping. Other units are more variable lithologically and include siliciclastic and carbonate facies that intertongue and thereby provide stratigraphic hydrocarbon traps in the Pope Group. Relatively thin units within the Pope are readily distinguishable on wireline logs because of contrasting lithologies.

The Pope Group marks a transition from the dominantly marine environments of the earlier Paleozoic to the dominantly nearshore marine and nonmarine environments of the subsequent Pennsylvanian Period. The Pope was primarily deposited in marine environments that ranged from shallow subtidal to intertidal; some of the rocks were deposited in supratidal and subaerial environments and show evidence of soil development (Treworgy 1988, Ambers and Petzold 1992). The primary source of siliciclastic sediments in the Pope, as in the Pennsylvanian System, was the Canadian Shield to the northeast. Siliciclastics of the Pope Group also entered the basin from the west and possibly from the east.

A eustatic drop in sea level at the end of the Mississippian Period and subsequent erosion formed the major unconformity that marks the Kaskaskia-Absaroka Sequence boundary. In the southernmost part of the basin, this unconformity represents a relatively short hiatus of probably less than two conodont zones (Weibel and Norby 1992).

Absaroka Sequence

Pennsylvanian System The unconformable surface at the top of the Mississippian is characterized by an anastamosing network of channels (note channels near infill drill holes 5 and 45), some of which are as deep as 450 feet (Bristol and Howard 1971). Coarse grained, lower Pennsylvanian sandstones commonly found at the base of these incised channels form important hydrocarbon reservoirs (Howard and Whitaker 1988, 1990).

The remainder of the Pennsylvanian System in Illinois consists of cyclically deposited marine, estuarine, and nonmarine siliciclastic rocks and widespread, thin coals and limestones. Upward within this succession, the amount of sandstone generally decreases while thin limestones become more common, as shown in the southern four drill holes (A–D). These changes indicate a gradual rise in sea level and a corresponding reduction in siliciclastic influx. Numerous hydrocarbon-bearing reservoirs have been found in the lower part of the Pennsylvanian. In the middle of the Pennsylvanian, the Desmoinesian Series includes several widespread minable coal beds.

Post-Pennsylvanian The Pennsylvanian is bounded at the top by a major unconformity that extends to the Quaternary throughout most of the Illinois Basin. However, in a fault block in the Rough Creek-Shawneetown Fault System in western Kentucky, drilling penetrated a succession of Permian marine rocks consisting of nearly 400 feet of shale, siltstone, and limestone (Kehn et al. 1982). The presence of these rocks indicates that marine deposition continued into the Permian in at least the southernmost part of the basin. Data on moisture content relative to depth for Pennsylvanian coals in the basin indicate that a mile or more of rock, which has subsequently been eroded, may have overlain the present Pennsylvanian surface throughout the basin (Damberger 1991). Elsewhere in southernmost Illinois, Cretaceous and Tertiary sandstones, shales, and gravels unconformably overlie strata of various ages. Cretaceous gravels occur locally in westernmost Illinois as well.

By the beginning of the Quaternary, the top of the Pennsylvanian throughout most of the Illinois Basin had been exposed to erosion. During the Quaternary, a mantle of glacial sediments was deposited, concealing most of the Paleozoic bedrock. Where these deposits fill paleovalleys, they are up to 500 feet thick (for example, between the Mathesius [I] and Vedovell [J] drill holes).

STRUCTURE

Fault blocks in the Precambrian crystalline basement have been inferred beneath several areas of known faults and steep folds in the overlying Paleozoic section. Additional fractures and fault blocks are possibly present in the basement rocks beneath other Paleozoic structures.

Much of the major post-rifting structural movement in the Illinois Basin occurred during latest Pennsylvanian and the Early Permian. The entire Paleozoic section has been rather uniformly folded or faulted over the major structural features traversed by this cross section, indicating that major movement followed deposition of the entire stratigraphic section. Movement apparently occurred on some structures at other times as well. The La Salle Anticlinorium, for example, underwent significant uplift during mid-Mississippian (this cross section, Treworgy and Whitaker 1990b, Reed et al. 1991), late Mississippian (Cluff and Lasemi 1980, Treworgy 1988), and early Pennsylvanian, as well as intermittent movement during the remainder of the Pennsylvanian (Kolata and Nelson 1991a). The Plum River Fault Zone became active during the Middle Devonian and was most active from post-Devonian to pre-Pennsylvanian time; post-Pennsylvanian displacements, however, were limited (Bunker et al. 1985).

From the Harrison (D) drill hole in Moultrie County northward to the Ryan (E) drill hole in De Witt County, the Middle Devonian section thins. Most of the thinning occurs within four miles of the Harrison drill hole and is due initially to the loss of the Grand Tower Limestone at the base. This thinning is apparently due to a subtle paleostructure, the Sangamon Arch, which was uplifted during the Silurian and Devonian (Whiting and Stevenson 1965). The apparent uniform thickness of the overlying New Albany Group across this feature indicates that the structure had little relief by Late Devonian. It is worth noting, however, that overlying the Sangamon Arch is the Burlington-Keokuk carbonate bank (between the Harrison [D] and Taylor [F] drill holes). Because carbonate banks commonly occur on sea floors with pre-existing topographic relief, there may have been renewed uplift of the Sangamon Arch during the early Valmeyeran.

At the crest of the Sangamon Arch at its northeastern extent in De Witt County (Whiting and Stevenson 1965) is an apparent structural hinge-line just south of the Ryan (E) drill hole. South of this hinge-line, Paleozoic units from the base of the Pennsylvanian to the Precambrian dip slightly more steeply into the basin, whereas north of the hinge-line they almost lie flat. In this hinge-line area, the Ordovician Joachim Dolomite pinches out updip, and the late Valmeyeran carbonates and rocks of the Chesterian Series are truncated below the sub-Absaroka (sub-Pennsylvanian) unconformity. Although most of the movement along the hinge-line apparently occurred during the late Mississippian to early Pennsylvanian, minor movement probably occurred earlier and influenced facies distributions, including the pinchout of the Joachim.

Another structural hinge-line occurs at the Thompson-Wetherell (C) drill hole. South of this drill hole, Paleozoic units dip basinward somewhat more steeply than they do north of the hole. Along with the increase in dip, it is also noteworthy that several facies changes occur, indicating that the hinge-line may have been active at various times during the Paleozoic. Just south of this hinge-line, Late Silurian-Early Devonian Bailey Limestone, an interreef basinal facies, pinches out updip against the thickened carbonate bank facies of the Moccasin Springs Formation. The Bailey facies may include buildups of relatively deeper-water mud mounds (Z. Lasemi, Illinois State Geological Survey, personal communication 1993). Higher in the section, the deeper-water facies of the mid-Mississippian Ullin Limestone thins over a short distance as it onlaps a thickened Borden Siltstone that was deposited along the shallower fringes of the basin. Also, the relatively deep water Fort Payne facies, which is present to the south, is absent in this area. These facies shifts in the Silurian and Mississippian suggest that the hinge-line may have been active during those times, marking a change from deeper-water deposition to the south to shallower-water deposition to the north. The interfingering of the mid-Mississippian Salem and St. Louis facies in this area suggests that this was a transitional area between shallow subtidal (Salem) and intertidal to supratidal (St. Louis) deposition at that time.

Another structural hinge-line occurs at infill drill hole 4. Paleozoic units from the base of the Pennsylvanian to the Precambrian dip relatively more steeply into the basin south of drill hole 4 than they do north of the hole. Along this hinge-line, the Middle Ordovician Dutchtown Limestone pinches out. The Lower Devonian carbonates have also been truncated in this area by post-Tippecanoe erosion. Again, most of the movement along this hinge-line probably occurred during the late Mississippian to early Pennsylvanian.

In general, pre-Pennsylvanian strata in the southern part of the cross section have undergone more tectonic movement than have Pennsylvanian strata. This movement is particularly evident on the south flank of the Wapella East Dome (Ryan [E] drill hole), where the pre-Pennsylvanian strata dip more steeply than do the Pennsylvanian coals, indicating mid-Mississippian to very early Pennsylvanian movement along the La Salle Anticlinorium. Truncation of the mid-Mississippian Valmeyeran units on the south flank of the dome further supports this interpretation.

In summary, most post-rifting deformation in the Illinois Basin occurred during mid-Mississippian to early Pennsylvanian and latest Pennsylvanian to the Early Permian. Times of minor deformation can also be determined from this cross section and have been identified from detailed studies of individual units.

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