ILLINOIS BASIN PROVINCE (064)

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With a section on the New Albany Shale Gas unconventional play by Joseph R. Hatch, and a section on coalbed gas by Dudley D. Rice, Thomas M. Finn, and Joseph R. Hatch

INTRODUCTION

The Illinois Basin Province divides itself geologically into two parts: 1) The Illinois Basin proper in the midcontinent of the United States, primarily in Illinois, Indiana, and Kentucky, but including small areas in Tennessee and Missouri; and 2) the northern part of the Mississippi embayment at the southern end of the Illinois Basin in Arkansas, Kentucky, Missouri, Tennessee, and Mississippi. The Illinois Basin proper and the Northern Mississippi Embayment will be treated separately here.

The Illinois Basin is an interior cratonic basin that has resulted from numerous subsidence events and marginal uplifts. The Northern Mississippi Embayment is an area of subsidence centered on the Late Proterozoic Reelfoot Rift and is related to subsidence of the Gulf Coast following Mesozoic rifting of the southern margin of the continent.

The Illinois Basin is flanked by a series of arches and domes that were active at various times during the basin's history. Several large oil-producing structures are present within the basin, including the La Salle, Clay City, and Salem-Louden Anticlines and the DuQuoin Monocline. These structures generally trend northwest or northeast. The southern end of the basin is cut by a series of east trending faults, including the Cottage Grove and Rough Creek-Shawneetown Fault Systems. The Cottage Grove Fault System generally marks the southern extent of hydrocarbon production in Illinois. The Wabash Valley Fault System, a series of faults that extend north-northeast from near the Rough Creek-Shawneetown Fault System in southeastern Illinois, southwestern Indiana and western Kentucky, is productive of hydrocarbons. The Rough Creek Graben, an early Paleozoic rift graben that forms an east-trending extension of the Reelfoot (New Madrid) Rift System beneath the Mississippi Embayment, occupies the southern part of the basin in Kentucky and southeastern Illinois (see, for example, Potter and Drahovzal, 1994). The Rough Creek Fault System, which forms the northern edge of the Rough Creek Graben, is apparently related to several named fault and fold systems, including the Ste. Genevieve Fault System, that form the southwestern margin of the Illinois Basin. The Pennyrile Fault Zone and related faults in western Kentucky mark the approximate southern boundary of the Rough Creek Graben. The western part of the basin in Illinois has been named the Western Shelf and is bordered on the northwest by the Sangamon Arch and on the southeast by the Fairfield Basin, the deepest part of the Illinois Basin outside of the Rough Creek Graben.

The Northern Mississippi Embayment is centered on the Late Proterozoic Reelfoot Rift and is underlain by the late Paleozoic to early Mesozoic Pascola arch. It is bordered on the east by the Black Warrior Basin and on the west by the Ozark Dome, the Arkoma Basin, and the Ouachita Mountains.

The Illinois basin and the Northern Mississippi Embayment contain primarily Cambrian- through Pennsylvanian-age rocks. The oldest sedimentary rocks within the basin are within the Reelfoot-Rough Creek Graben System and may be as old as Early Cambrian or late Precambrian. Initial Cambrian deposition was apparently almost continuous with deposition of the overlying Sauk Sequence. Deposition of the Sauk Sequence began primarily as siliciclastic deposition and ended with primarily carbonate rock deposition. The Sauk Sequence includes the Mt. Simon and Eau Claire Formations which are considered potential reservoir and source rocks, respectively, for gas within the deeper parts of the Illinois Basin proper. and equivalent and older rocks could be reservoirs within the Rough Creek and Reelfoot Grabens The Sauk Sequence is separated from the overlying Middle and Upper Ordovician Tippecanoe Sequence by a major unconformity. The Tippecanoe Sequence is primarily a carbonate-rock depositional sequence but includes the Upper Ordovician (Cincinnatian) Maquoketa Group, which served as a petroleum source for at least a small percentage of oil within the basin. The Maquoketa Group is underlain by a relatively minor unconformity that is probably related to a porosity zone below the top of the underlying Trenton Dolomite. The Maquoketa is overlain by a regional unconformity (the sub-Tippecanoe II unconformity) that separates the Maquoketa from the overlying Silurian and Lower Devonian Hunton Group, which has produced significant quantities of hydrocarbons from the Illinois Basin.

The Middle Devonian through Mississippian Kaskaskia Sequence overlies the Tippecanoe sequence with major unconformity. In Illinois and western Indiana, the base of the Kaskaskia Sequence locally includes the Dutch Creek Sandstone, which has produced the single most productive oil well in the basin. The overlying basal carbonate units of the Kaskaskia (part of the Knobs Megagroup) grade eastward into and are overlain by the New Albany Shale, which is the major petroleum source rock within the basin. The Knobs Megagroup is overlain, successively, by the Mammoth Cave and Pennsylvanian Pope Megagroups, which, together with the overlying Absaroka Sequence, make up the major hydrocarbon producing units within the basin.

The Northern Mississippi Embayment is covered by Cretaceous sedimentary rocks that were deposited after rifting of the southern margin of the continent and subsidence of the Pascola Arch.

Because the Illinois Basin is not a topographic feature, it has been defined in a variety of ways. Buschbach and Kolata (1990) defined the basin following the -500 foot contour on the top of the Ottawa Supergroup through southern Illinois, Kentucky, and Indiana and the erosional edge of Pennsylvanian strata in northern and western Illinois. The basin, thus defined, is slightly elongate northwest-southeast, is about 385 mi long and 233 mi wide, and has an area of approximately 60,000 sq mi. It contains about 100,000 mi^3 of Cambrian- through Pennsylvanian-age sedimentary rocks. In the deepest part of the basin, the Rough Creek Graben, depths to basement exceed 30,000 ft.

The Northern Mississippi Embayment covers an area of more the 26,000 sq mi and is defined by the area of Cretaceous sedimentary cover over downwarped pre-Mesozoic basement rocks. Its pre-Cretaceous stratigraphy is similar to that of the Illinois Basin except that, over large parts of the Embayment, Permian through Jurassic erosion of the Pascola Arch has removed large parts of the sedimentary section and has exposed Cambrian-age rocks in the center of the arch. The Pascola Arch is cut by a number of large faults. The Embayment is underlain by the Reelfoot Rift, a series of alternating graben and half-grabens that originated as an aulocogen in pre-early Late Cambrian, and possibly as early as Late Proterozoic time.

Oil was first discovered in the Illinois Basin in Pennsylvanian rocks at Litchfield, Illinois, in 1866. The basin was not, however, a major producer of oil until several large, shallow fields were developed along the La Salle Anticlinal Belt, beginning about 1905. An early peak in hydrocarbon production occurred prior to 1910 as the result of surface mapping of anticlinal structures. A second peak in production occurred in the late 1930's and early 1940's as a result of the development of seismic exploration techniques. A third peak in production, although not in discovery, occurred in the mid-1950's with the general application of fracing and water-flood secondary recovery techniques. A small rise in production occurred in the early 1980's as a result of intensified exploration spurred by high oil prices. The last field of greater than 1 MMBO barrels of oil to be discovered in the Illinois Basin was the North King field, Jefferson County, Illinois discovered in 1981. The last field of greater than 5 MMBO barrels of oil to be discovered in the basin was the Plummerfield, Greene County, Indiana, discovered in 1969. The deepest parts of the basin, however, have not been extensively explored: the majority of exploration has been at depths less than 3,000 ft.

Plays within the Illinois Basin proper are preceded by the term Illinois Basin; plays within the Northern Mississippi Embayment are preceded by the term Northern Mississippi Embayment. In the eight Illinois Basin plays, six are conventional and two are unconventional plays, one continuous type play described by Joseph R. Hatch and one coalbed gas play described by Dudley D. Rice, Thomas M. Finn, and Joseph R. Hatch. An expanded chapter on coalbed gas plays, with references, "Geologic framework and description of coalbed gas plays" by Dudley D. Rice may be found elsewhere in this CD-ROM. Three conventional plays are defined in the Northern Mississippi Embayment. However, the Hunton, Silurian Reefs, Middle and Upper Ordovician Carbonates, and the Pre-Middle Ordovician equivalents within the Embayment area are discussed with the appropriate Illinois Basin plays. All data on field sizes, reservoir thickness and quality are taken from the U.S. Geological Survey Nehring database. The plays described for this province are:

CONVENTIONAL PLAYS

6401	Illinois Basin-Post-New Albany
6402	Illinois Basin-Hunton
6403	Illinois Basin-Silurian Reef
6404	Illinois Basin-Middle and Upper Ordovician Carbonate
6405	Illinois Basin-Rough Creek Graben
6409	Illinois Basin-Pre-Middle Ordovician
6410	Northern Mississippi Embayment–Reelfoot Rift
6411	Mississippi Embayment–Post-Mid-Cambrian
6412	Northern Mississippi Embayment–Late Paleozoic

UNCONVENTIONAL PLAYS

6407	*Illinois Basin–New Albany Shale Gas*
6450	*Illinois Basin–Central Basin Coalbed Gas*

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CONVENTIONAL PLAYS

6401. ILLINOIS BASIN–POST-NEW ALBANY PLAY

The Post-New Albany Play includes all Mississippian and Pennsylvanian reservoirs within the Illinois Basin and produces oil and minor amounts of gas and associated wet gas. The play covers an area of more than 34,000 sq mi and involves oil accumulations principally in large structural traps, stratigraphic traps, and structural combination traps. Almost all of the fields in this play were discovered by prospecting for structural traps, including those classified as stratigraphic or as combined structural and stratigraphic traps.

The play extends throughout the area where Mississippian and Pennsylvanian rocks are present above the Devonian New Albany Shale but is generally considered most favorable where Pennsylvanian shales have prevented ground-water flushing of hydrocarbons from underlying Mississippian carbonate rocks. The play is bounded on the south in Illinois by the Rough Creek Fault Zone and the mineralized area of southern Illinois and Kentucky. In Kentucky, production in the play is found south of the Rough Creek Fault Zone. The north, east, and west boundaries are less definitive because of extensive vertical and horizontal migration of oil from source rocks in the New Albany Shale.

The Post-New Albany Play is bounded below by the New Albany Shale and above by the surface outcrops. The play is coextensive with the pattern of Mississippian and Pennsylvanian outcrops but has been limited on the east to exclude areas of deep erosion into the Mississippian through Pennsylvanian section.

Reservoirs: The play includes sandstone and carbonate-rock reservoirs of Mississippian and Pennsylvanian age. Sandstone reservoirs are concentrated in the Mississippian Chesterian Series and Lower Pennsylvanian part of the section. Limestone reservoirs are mainly in the lower part of the Mississippian in the Valmeyeran Series (Ullin ("Warsaw"), Salem, St. Louis, Ste. Genevieve). Mississippian reservoirs include: Borden* (includes Carper, Cole, and Sonora), Warsaw (Harrodsburg, Ullin), Salem, St. Louis (includes Martinsville and Westfield), Ste. Genevieve (includes McClosky (Oblong), Spar Mountain (Rosiclare), and Ohara), Aux Vases* (includes Aux Vases lime), Renault*, Yankeetown* (Benoist), Bethel* (Paint Creek Sand), Ridenhower* (Sample), Cypress* (includes Weiler, Kirkwood, Carlyle, Bellair 900, and Lindley), Beach Creek* (Barlow, basal Golconda), Fraileys* (includes Big Clifty, and Jackson), Haney (Golconda lime), Hardinsburg*, Glen Dean, Tar Springs*, Waltersburg*, Palestine*, Clore*, and Degonia*. Pennsylvanian reservoirs include Caseyville* (includes Biehl, Buchanan, Jordan, Pottsville, and Ridgley), Abbott* (includes Bellair 800, Butschi, Casey, Mansfield, Dagley, Partlow, and 3rd and 4th Siggins), Spoon* (includes Bellair 500, Bridgeport, Browning, Claypool, Lower Dudley, Isabel, Kickapoo, Petro, Robinson, Lower Siggins, and Wilson), Carbondale* (includes

Anvil Rock, Cuba, Upper Dudley, Dykstra, Jake Creek, Jamestown, Pleasantview, upper Siggins, and Wilson), Modesto* (includes Trivoli). (Note: asterisks (*) denotes sandstone reservoirs).

Sandstone reservoirs are moderately thin and have oil columns averaging about 22 ft. Limestone reservoirs are also generally thin, and have an average oil column of 11 ft. The thickest reservoir recorded for fields greater than 1 MMBO is 161 ft for the Chesterian reservoirs of the New Harmony Consolidated field in White County, Illinois. Properties of the reservoirs within the play vary greatly. Sandstones generally have excellent reservoir properties; reservoir limestones of the Ste. Genevieve, St. Louis, and Salem limestones are oolitic and grainstones and have fair to excellent reservoir characteristics.

Source rocks: The hydrocarbons within this play were sourced predominantly from the Upper Devonian-Lower Mississippian New Albany Shale. Minor amounts of petroleum may have been derived from limestones within the Mississippian section and shales within the Pennsylvanian section. The amounts generated by self-sourced reservoirs are anticipated, however, to be virtually undetectable because of the overriding geochemical signature of the New Albany Shale.

In the southern Illinois Basin, the New Albany Shale consists of laminated brownish-black shale characterized by high concentrations of organic material, trace elements, and pyrite, and lesser amounts of sandstone, siltstone, limestone, dolomite, and phosphate. The New Albany Group also contains greenish-gray shale of the Hannibal Formation in west-central Illinois, along the western flank of the basin (Hasenmueller, 1993).

The New Albany Shale is more than 460 ft thick in the southern part of the Illinois Basin in southeastern Illinois and adjacent Kentucky. In this area of thick New Albany, the dominant lithology is brownish-black shale. The shale thins toward the basin margins except in west-central Illinois, where bioturbated, greenish-gray shale more than 300 ft thick is present. The two areas of thick New Albany Shale are separated by a northeastward-trending area of thinner shale in Illinois. This band of thinner shale extends eastward into west-central Indiana (Hasenmueller, 1993). The black shales are the most important hydrocarbon source rocks within the New Albany, and my own research suggests that many of the gray and greenish-gray shales of the Saverton and Hannibal Shales that are frequently included in the New Albany Group in the northwestern part of the basin are genetically unrelated to and are younger than the brownish-black shales.

The New Albany Shale contains type II (sapropelic-marine) organic matter (J.R. Hatch, U. S. Geological Survey, written commun., 1994). Vitrinite reflectance (percent R_o) within the New Albany ranges from less than 0.50 in the western parts of the basin and within the eastern Rough Creek Graben area to greater than 1.2 in southwestern Illinois (Cluff and Byrnes, 1990). The greatest concentrations of organic carbon are in the upper part of the New Albany in southeastern Indiana and west-central Kentucky. In these areas, organic-carbon content is commonly 12–13 weight percent and can be more than 15 percent. Limited data from the deeper part of the basin indicate that this interval contains 8–11 percent organic carbon. The organic-carbon content of greenish-gray shale is low, commonly 1–2 weight percent (Hasenmueller, 1993; J.R. Hatch, U.S. Geological Survey, written commun., 1994). The organic matter of the New Albany should produce both oil and gas (Illinois Basin Consortium, 1994).

Onset of hydrocarbon generation in the New Albany Shale began about 300 Ma and rapidly expanded to encompass the central part of the basin by 250 Ma. From 250 Ma to present, the thermal zone of oil generation has expanded outward to cover most of the basin, excluding only the extreme northwestern margin. Peak oil generation in the New Albany Shale occurred only in the Fluorspar District-Hicks Dome area and the northern part of the Mississippian Embayment, at approximately 210-260 Ma. The New Albany Shale in this area passed through the thermal zone of oil generation and entered the zone of wet gas generation by 150 Ma (Cluff and Byrnes, 1991; J.R. Hatch, written commun., 1994).

Traps: Traps within the play include stratigraphic traps, domes, anticlines, and fault traps. Combination stratigraphic-structural traps are the predominant reservoirs, and range from almost pure structural traps, such as in the Salem Consolidated field, to almost pure stratigraphic traps in the Eldorado Consolidated field. Stratigraphic traps generally have at least a minor structural element involved with the trapping. Stratigraphic-fault traps are associated with the Wabash Valley Fault System, the Mt. Carmel Fault, and the Rough Creek-Shawneetown Fault System (Seyler and Cluff, 1990). Diagenesis may have locally enhanced porosity, especially within the carbonate-rock reservoirs of the play.

Traps formed prior to the time of major petroleum generation and migration, mainly during the Pennsylvanian and Permian Periods as part of the Alleghenian orogeny. Movement on several of the larger structures, such as the La Salle Anticlinal Belt and the Salem and Louden Anticlines, began as early as Late Mississippian time (Kolata and Nelson, 1990). Fields range in size from a few thousand barrels to more than 400 MMBO. Seals for traps are generally shale or dense limestone (Seyler and Cluff, 1990). Drilling depths range from less than 500 ft to more than 4,000 ft. Fields are widely distributed throughout the play area but are concentrated on large, generally north-trending structures within the south-central part of the basin.

Exploration status: The Post-New Albany Play is a very mature play. This play accounts for more than 95 percent of the hydrocarbon production with the basin. More than 190 oil accumulations greater than 1 MMBO have been discovered within the play, but only three gas fields greater than 6 BCF have been discovered: (1) Russellville, Lawrence County, Illinois, discovered in 1937, (8.65 BCF): (2) Midland, Muhlenberg County Kentucky, discovered in 1962 (154 BCF, Brandon Nuttall, Kentucky State Geological Survey, written comm., 1994); and (3) Luzern, Muhlenberg County, Kentucky, discovered in 1957 (7 BCF, Brandon Nuttall, Kentucky State Geological Survey, written comm., 1994). The Post-New Albany Play is primarily an oil play and has an associated-dissolved gas to oil ratio of about 750 CFG/bbl, based on historical records. The API gravity of oil within this play ranges from 22¡ to 42¡, and averages 38¡; the oil contains about 0.3 percent sulfur.

Two fields within the play, Salem Consolidated, Marion County, Illinois, and Louden, Effingham County, Illinois, have known accumulation sizes of greater than 500 MMBO; Clay City Consolidated, Wayne County, Illinois, and Lawrence field, Lawrence County, Illinois, have known accumulation sizes of greater than 400 MMBO.

Resource potential: This play is in an extremely mature stage of development, however, it is estimated that there are more fields of greater than 1 MMBO left in this play. The limiting factor for the potential of this play is the large number of tests made into these rocks. All of the major structures within the basin have been drilled, and the likelihood of finding more major structures is extremely remote. Subtle stratigraphic traps offer the best possibility for discovery of accumulations greater than 1 MMBO. A current target for field extension within operating fields is facies changes within the Ullin ("Warsaw")-Salem (Mississippian) interval (Lasemi, 1994). This interval might also provide opportunities for new discoveries. Two sizable area, one in western Kentucky (in Breckenridge, Grayson, Butler, Ohio, and Muhlenberg Counties) and a second in southeastern Indiana (Wanderburgh and Warrick Counties), have not been explored because of coal mining and may contain fields greater than 1 MMBO.

Because there have only been three gas fields of greater than 6 BCF discovered in the basin, the play has been analyzed exclusively as an oil play. The area is Kentucky that has not be extensively explored due to coal mining is the area in the basin most likely to contain additional gas fields greater than 6 BCF.

6402. ILLINOIS BASIN–HUNTON PLAY

The Hunton Play covers an area of more than 29,000 sq mi and is defined to include Silurian- and Devonian-age reservoirs below the New Albany Shale and exclude Silurian reef reservoirs. The play is present throughout the basin area but is most favorable to the south of the Sangamon Arch where the source potential of the New Albany Shale is greatest. In Illinois the play is bounded on the south by the Rough Creek Fault Zone and the faulted mineralized area; in Kentucky however, the area south of the Rough Creek Fault Zone and east of the mineralized area is both a productive and prospective part of the play.

Rocks of the Hunton Group are present around the rim of the Pascola Arch within the Northern Mississippi Embayment. In this area, however, post-Pennsylvanian uplift has probably flushed any hydrocarbon accumulations that might have been present within the interval. The Illinois Basin–Hunton Play is bounded above by the New Albany Shale and below by the sub-Tippecanoe II (Late Ordovician) unconformity.

Reservoirs: Reservoir rocks include the Backbone, Grassy Knob, Clear Creek, Dutch Creek, North Vernon, Grand Tower (Geneva), Lingle (Hibbard, Hoing), Jeffersonville, and Hardin Member of the New Albany Shale. The reservoirs are primarily dolomite, limestone, and sandstone and are highly variable in thickness, ranging from a few feet to as thick as 40 ft in the Salem Consolidated field. Permeability and porosity also are highly variable. A few excellent sandstone reservoirs are in the Dutch Creek Member of the Middle Devonian Grand Tower Limestone.

Source rocks: Source rocks are principally organic-rich shales in the overlying Devonian-Mississippian New Albany Shale, discussed in the section on Illinois Basin–Post-New Albany Play (6401). Some oil could also be locally derived from shaley carbonate source rocks within the play and from the underlying Upper Ordovician Maquoketa Shale. Occurrences of New Albany-type oil, particularly in the Dutch Creek Member a few hundred ft below the local base of the New Albany Shale, suggest some downward migration of New Albany-generated oil. Lateral updip migration of oil is indicated by the presence of New Albany-type oil in the play outside of the area in which the New Albany Shale is know to be mature. The Hunton Play is primarily an oil play and has an expected ratio of associated-dissolved gas to oil of 750 CFG/bbl, based on estimates from the Post-New Albany play.

Primary migration of hydrocarbons was in the Paleozoic and Mesozoic, although the New Albany Shale is still in the thermal zone of oil generation. Most of the structural traps and all of the stratigraphic traps were in place prior to initiation of hydrocarbon generation. Lateral migration pathways are difficult to identify, and in some areas movement of oil may have had to occur through fractures in low-permeability carbonate rocks.

Traps: The Illinois Basin–Hunton Play involves oil accumulation primarily in combination stratigraphic and structural traps and lesser numbers of anticlinal, dome, fault, truncation, and unconformity traps. Traps range from almost pure structural traps, such as the Centralia field, Clinton County, Illinois, to unconformity traps at the Mt. Auburn Consolidated field, Christian County, Illinois. Discovered fields within the Hunton Play are small in size, generally less than 5 MMBO and range from 400 ft to about 5,500 ft in depth and have a median depth of about 2,500 ft. Structural traps formed mainly during the Pennsylvanian and Permian, although movement on several of the larger structures may have begun as early as the Late Mississippian. Unconformity-related traps developed during the Early Devonian or pre- or post-Middle Devonian erosional episodes.

The New Albany Shale is commonly the seal for traps in the Illinois Basin–Hunton Play, such as in the Greensburg field, Green and Taylor Counties, Kentucky, in the Hunton equivalent play in the adjacent Cincinnati Arch province. Shale and nonporous carbonate rocks locally form seals, but frequently these carbonate seals are dependent on the presence of the New Albany above to maintain their integrity.

The major Hunton reservoirs are primarily associated with large structures within the basin including those (1) along the edge of the Sangamon Arch in Brown and McDonough Counties, Illinois; (2) along the Du Quoin Monocline and Salem-Louden anticlinal trends in Franklin, Washington, Clinton and Bond Counties, Illinois; and (3) along the trend of the La Salle Anticline Belt in Clark and Coles Counties, Illinois. Fields also are in Christian and Macon Counties, Illinois, along the northwest flank of the Fairfield Basin, not associated with regional structural features. Hunton reservoirs also are scattered along the southeastern margin of the basin in Kentucky, as are traps associated with the pre-Middle Devonian unconformity.

Exploration status: The Illinois Basin–Hunton Play is well explored in its northern half and along its margins. Moderate to low amounts of exploration drilling have been done in the Fairfield Basin. Approximately 150–200 million barrels (4 percent) of the recoverable oil discovered in the Illinois Basin has been found in the play. Based on analogy with the Illinois Basin–Post-New Albany Play (6401), the GOR is about 750 CFG/bbl. The API gravity of oil within this play ranges from 28¡ to 48¡, and averages 37¡; the oil is estimated to contain about 0.3 percent sulfur.

The largest hydrocarbon accumulation within the Hunton Group is at the Louden field, Effingham County, Illinois, discovered in 1939, which has a size of about 12 MMBO. Centralia field, Clinton County, Illinois, discovered in 1937, has an accumulation size of about 10 MMBO and is the second largest Hunton reservoir within the Illinois Basin. Significant accumulations also occur at Mt. Auburn field, Christian County, Illinois, discovered in 1943, and Woburn Consolidated field, Bond County, Illinois, discovered in 1949.

Resource potential: Some potential remains for discovery of reservoirs formed by fill of paleovalleys cut into the top of the Maquoketa Shale, such as the Buckhorn Consolidated field in Adams and Brown Counties, Illinois. Dolomitized Silurian and Devonian strata along the flanks of the basin may also contain undiscovered reservoirs. The potential for undiscovered resources is limited by the lack of good-quality reservoirs and adequate seals in the prospective section below the base of the New Albany Group.

6403. ILLINOIS BASIN–SILURIAN REEF PLAY

The Silurian Reef Play is a stratigraphic structural play that covers an area of more than 35,000 sq mi and includes oil accumulations in pinnacle reef carbonate reservoirs or in younger reservoirs that are draped over reefs, both with a common oil source in the New Albany Shale. The play includes the area of pinnacle and interstratal reef limestone occurrences that are overlain by the New Albany Shale.

The primary control on the extent of the play is the extent of Middle Devonian and Silurian strata beneath the sub-Kaskaskia (Middle Devonian) unconformity. The boundaries of the play are further restricted by the paleogeography that controlled reef deposition. This description follows Whitaker (1988) in defining the limits of the play boundary throughout most of Illinois. The southern limit of the play is defined where the thickness of rock between the New Albany source rocks and the Silurian reef was greater than about 500 ft, which appears, empirically, to be approximately the depth to which the New Albany was capable of charging the reef reservoirs (R.F. Mast, U.S. Geological Survey, oral commun., 1993).

Rocks of this age are also present in the Northern Mississippi Embayment but were not assessed because they were involved in uplift around the Pascola Arch in post-Pennsylvanian time and have been subject to extensive flushing by ground water throughout most of the Embayment area.

Reservoirs: Reef limestone reservoirs are of Silurian age, and in many instances the overlying Devonian and Mississippian limestones also form part of the total reservoir sequence. The areal extent and thickness of the oil-bearing reservoirs vary widely. Thickness of 13 reservoirs ranges from 8 to 74 ft and averages about 28.5 ft. Reservoir quality ranges from fair to excellent. Porosity of nine reefs ranges from 10 to 20 percent and averages 14.6 percent, and permeability ranges from 9 to 400 mD and averages 113.2 mD.

Source rocks: Most, if not all, of the pinnacle reef accumulations in the play contain New Albany-type oil (see discussion of the Illinois Basin–Post-New Albany Play 6401).

Primary migration of hydrocarbons occurred during the Paleozoic and Mesozoic, although the New Albany Shale is still in the thermal zone of oil generation. Most of the structural traps and all of the stratigraphic traps were in place prior to the hydrocarbon generation. Lateral migration pathways are difficult to identify, and in some areas movement of oil may have occurred through fractures in low-permeability carbonate rocks.

Traps: The pinnacle reefs and drapes over them are the principal traps of the play. The Silurian reefs of the Illinois Basin originated as isolated biohermal structures during Niagaran time and continued to develop into Cayugan time. The reefs are constructed primarily of algae, coral, and stromatoporoids localized principally on a platform flanking a deeper water basin in the southern part of the Illinois Basin and the northern part of the Mississippi Embayment (Whitaker, 1988). The productive reefs are mostly on the basin shelves. The interval between the source shales and the underlying reservoirs is very thin, which allows for downward migration of hydrocarbons. In many cases, the New Albany Shale is part of the draped sequence and forms at least a part of the trap.

Exploration status: Fields are small, generally less than 5 MMBO. The largest accumulation in the play is the Marine field, which has an estimated known size of more than 12 MMBO. The Boulder field, Clinton County, Illinois, discovered in 1941, has an accumulation size of 6.4 MMBO. Depth to production is fairly shallow, ranging from about 1,000 to 2,500 ft. In many instances the New Albany forms both the source rock and the seal for the pinnacle reefs. In other cases, the seal is nonporous limestone overlying the reefs.

Overlying strata are usually draped over reef buildups, and seismic reflections from the overlying Devonian limestones easily define these features. Interstratal reefs cannot be detected so easily and, therefore, are more likely targets for future exploration.

Approximately 2 percent (roughly 130 MMBO) of the recoverable oil discovered in the Illinois Basin has been found in Silurian reefs of this play, or in drape structures over these features in both southwestern and eastern Illinois and in intrastratal(?) reefs on the northern shelf of the basin. The Hunton is primarily an oil play and has an ratio of associated-dissolved gas to oil of about 750 CFG/bbl, based on comparison with the post-New Albany play. The API gravity of oil within this play ranges from 22¡ to 42¡ and averages 38¡; the oil contains about 0.3 percent sulfur.

Of the 13 fields assigned to this play, 2 fields are larger than 10 MMBO known oil resources. These are the Marine field, Madison County, Illinois (18.6 MMBO) and the Mt. Auburn Consolidated field (11.2 MMBO).

Resource potential: The Silurian Reef Play is in a very mature stage of exploration. Most of the productive areas have been extensively drilled, and unproductive areas have been extensively explored using seismic methods. Potential is low for discovery of new reef reservoirs. The Fairfield Basin is not considered favorable for two reasons: (1) occurrences of similar reservoir rocks are considered unlikely, and (2) the vertical distance between the New Albany Shale source rocks and potential reservoirs is too great to allow for downward migration of oil from the New Albany. The Northern Mississippi Embayment is not considered favorable because of post-Pennsylvanian uplift of the Pascola Arch and because the vertical distance between the New Albany source rock and the potential reservoirs is too great. In addition, water depths throughout most of this area were too great for reef-facies development.

Resource estimates for this play are based on estimates from known discovery rates. The last field of the minimum size discovered in this play was the Nashville field, Washington County, Illinois, discovered in 1974 (4.5 MMBO).

6404. ILLINOIS BASIN–MIDDLE AND UPPER ORDOVICIAN CARBONATE PLAY

This play includes all reservoirs of Middle and Upper Ordovician age (lower Tippecanoe Sequence). Known production in both the western shelf area and the La Salle Anticline area is in limestone-matrix porosity present as localized carbonate grainstone shoals where intergranular porosity has been preserved (Keith, 1988). The production may be enhanced by the presence of fractures associated with the structure. Production in the La Salle Anticline area comes from fractured limestone with no matrix porosity. The play contains both carbonate and clastic rocks, but only the carbonate rocks are productive.

The play is primarily structural, involving anticlines; minor stratigraphic traps involving facies changes also are present.

The play is bounded below by the sub-Tippecanoe unconformity and above by the sub-Tippecanoe II unconformity. The rocks of the play are present throughout the Illinois Basin and Northern Mississippi Embayment except in the center of the Pascola Arch within the Embayment, where Permian-Jurassic erosion has removed strata down to the Cambrian. The subcrop of the Middle and Upper Ordovician beneath the Cretaceous sedimentary cover of the Embayment also has low potential.

Reservoirs: All production from this play has been from fossiliferous limestones of the Champlainian-Cincinnatian Galena Group ("Trenton"). Reservoir thickness ranges from 12 ft in the Woburn Consolidated field, Bond County, Illinois, to 140 ft in the Clark County division, Clark County, Illinois. There has been minor gas production tests from the Trenton along the eastern edge of the Embayment in Calloway County, Kentucky, but there are no fields that are of the minimum size for assessment. Gas has also been recovered from a drillstem test of the Thebes Sandstone Member of the Maquoketa in Crittenden County, Kentucky, which is located roughly 20 mile northeast of the Mississippi Embayment. Most Trenton reservoirs are characterized by primary, intergranular porosity (grainstone/rudstone) enhanced by fractures (Duquoin Monocline) ranging to entirely fractured reservoirs with minimal porosity (LaSalle Anticline).

Most zones of secondary porosity developed several tens of ft below the top of the Galena within a porosity fairway trending southwest-northeast through the central part of the basin that may be related to paleogroundwater flow patterns developed during the formation of the sub-Tippecanoe (latest Ordovician) unconformity. Porosity zones within the interval have been seen in Green County, Indian, however there is no known production from this zone. Another zone of porous dolomite is located in Jackson County, Illinois, in the vicinity of the Cottage Grove fault system. Other secondary porosity reservoirs are possible as discontinuous dolomite horizons within limestone located in the southern and central parts of the Illinois Basin and as regional dolostones in the northern parts of the basin. Reservoir quality is quite variable with porosity ranging from 6 to 12 percent and permeability from 2 to 320 mD although these values may grossly underestimate the reservoir properties within zones of secondary porosity. Other possible reservoirs, other than the Trenton reservoirs within the play are suggested by: (1) production tests of oil recovered from fractured High Bridge carbonates along the Rough Creek fault zone in Webster County, Kentucky; (2) drill-stem tests of oil and gas from the Fort Atkinson Limestone (Maquoketa) of the western shelf in western and northwestern Illinois; and (3) oil saturated cores taken from the Thebes Sandstone (Maquoketa) in southwestern Illinois.

Source rocks: Ordovician Glenwood shaley carbonate rocks are the primary source for the Ordovician oils on the western shelf area of the Illinois Basin, as indicated by source-reservoir fluid correlations and source rock evaluation (J.R. Hatch, personal communication, 1993). Maquoketa shales are the primary source rock for the Ordovician oil in the La Salle Anticlinal Belt, as indicated by source-reservoir fluid correlation (J.R. Hatch, personal commun., 1993). The Glenwood is absent at many locations but is as thick as 75 ft in some places. Shales of the Maquoketa are as thick as 300 ft or more in the Kentucky and Indiana parts of the Illinois Basin and are generally between 150 and 200 ft thick throughout Illinois. Both the Glenwood and the Maquoketa contain type I and II organic matter. Dark argillaceous limestone and dolomite of the Dutchtown are also a potential source. The Dutchtown Limestone is about 150 ft thick in the Cape Giradeau, Missouri area, and as thick as 200 ft in southeastern Illinois.

Vitrinite reflectance has been estimated at 0.7 percent R_o for the La Salle Anticline Belt. The thermal maturity of the Glenwood shaley carbonates of the western shelf area is unknown; however, Cluff and Byrnes (1990) have estimated the present-day thermal maturity of the base of the Maquoketa Group on the western shelf to be between 0.5 and 0.7 percent R_o, based on Lopatin analysis.

Organic carbon content of five Paleozoic stratigraphic intervals or rock types shows a median organic carbon content for 32 Champlainian shale and limestone samples of 7.9 percent (range 0.5–43.3 percent); highest organic carbon contents are for samples from the Glenwood Formation and Guttenberg Member of the Decorah Formation collected from southeastern Iowa. Median organic carbon for 17 samples from the Maquoketa Group is 1.5 percent (range 0.5– 9.5 percent); highest contents are also in samples from southeastern Iowa where the rocks are thermally immature (Hatch and others, 1990). The thickness of the organic-rich intervals, however, was not reported. The organic-matter types and thermal maturity of samples from the basin suggest that this play should produce both oil and gas; historical production, however, suggests that this is primarily an oil play.

Ordovician oil in the La Salle Anticline was generated during the Early Pennsylvanian to Early Jurassic and migrated into traps during the Early Pennsylvanian through Cretaceous; Ordovician oil in the western shelf was generated and migration took place during the middle Paleozoic.

A major problem for pre-Maquoketa rocks is that, if hydrocarbon source beds were present, most hydrocarbon generation in pre-Maquoketa Group rocks would have occurred during the Paleozoic before most structural development in the basin, which occurred after 245 Ma (Cluff and Byrnes, 1990). Oil generation in the Knox Dolomite Megagroup would have begun by 460-470 Ma, and by 400 Ma the Knox, throughout most of the basin, would have passed through the oil-generation phase and entered the gas-generation phase. Gas generation would have been widespread by 240 Ma. Because no significant structures were present during this time period, any oil or gas generated that migrated out of the source beds and into regional carrier beds (such as the St. Peter Sandstone) would have migrated toward the major arches surrounding the Illinois Basin (Cluff and Byrnes, 1991).

Traps: Traps include structural and minor stratigraphic traps; fields may be greater than 10 MMBO. Structural traps are basement-involved, including compressive block uplift and drape folding. Most structures are post-Mississippian, but pre-Mississippian structures might also provide traps. Shales of the Maquoketa provide a regional seal for the play. In some locations, such as the Waterloo field, Monroe County, Illinois (a field of less than the minimum size for assessment), where the Kimmswick ("Trenton") reservoir is overlain by the Fernvale Limestone, the Maquoketa, above the Fernvale, has helped to maintain the integrity of the seal. Argillaceous members of the Denleith may also form seals, especially in conjunction with the Maquoketa. Local anhydrite seals may be present in the Joachim. Productive reservoirs are generally restricted to the Du Quoin Monocline area in the western third of the Illinois Basin and to the La Salle anticlinal belt.

Exploration status: The Illinois Basin–Middle and Upper Ordovician Carbonate Play has produced oil and minor amounts of gas from depths ranging from 400 to almost 5,000 ft. Depth to objective in the Illinois Basin outside of the known productive areas and within the Mississippi Embayment may be as much as 6,000 ft. The Casey pool of the Clark County Division field was discovered in 1904, but it is unknown when the first Trenton production in Clark and Cumberland Counties was developed. The Dupo field was discovered in 1928. Within the western shelf area there are nine known accumulations: Centralia, Dupo (4 MMBO), Fairman, Irvington (6.4 MMBO), Patoka, Salem Consolidated, St. Jacob (11.4 MMBO), Woburn Consolidated, and Florissant (Missouri) (1.8 MMBO). The only known accumulation greater than 1 MMBO along the La Salle Anticline is the Clark County division. The Salem Consolidated field is the largest field on the western shelf (395 MMBO).

Resource potential: The potential for finding new areas of limestone-matrix porosity within the Illinois Basin Province is limited. Reservoirs might be present in areas of local dolomitization on paleohighs flanking the basin, local fractured reservoirs related to structural features with good seals might also have some potential, and there are potential stratigraphic traps within the Joachim Formation. Localized sandstone and dolomite within the Dutchtown Formation might form stratigraphic traps. The St. Peter Sandstone and Everton Formation might contain traps, but the blanket nature of the St. Peter makes this unlikely. The potential for the play within the Embayment, however, is lower than that for the play within the Illinois Basin proper because of removal of Middle and Upper Ordovician rocks from the crest of the Pascola Arch and post-Pennsylvanian uplift and ground-water flushing of reservoirs around the rim of the Pascola Arch.

6405. ILLINOIS BASIN ROUGH CREEK GRABEN PLAY (HYPOTHETICAL)

6410. NORTHERN MISSISSIPPI EMBAYMENT REELFOOT RIFT PLAY (HYPOTHETICAL)

These Early Paleozoic rift-graben plays cover areas of about 5,500 sq mi and 26,000 sq mi, respectively, and are hypothetical plays involving principally fault and fault-related structural traps in clastic reservoirs. The plays are limited to the areas of the Rough Creek Graben and Reelfoot Rift. The plays are bounded below by the Precambrian basement and above by the base of the Knox Group.

Reservoirs: The principal reservoir of the Rough Creek Graben play is the Cambrian Mt. Simon equivalent and older rift-fill sediments. In the Reelfoot Rift, the Cambrian Lamotte Sandstone (equivalent to the Mt. Simon) and older rocks are considered to be the principal reservoirs and older sandstones are also potential reservoirs. In both settings, older Cambrian rift-fill sediments are prospective reservoir rocks. Rift-fill sediments are locally thicker than 18,000 ft (Kolata, 1990) between Precambrian basement rocks and the base of the Knox Group . The rift-fill sediments, where penetrated in major fields in the basin, have displayed generally poor reservoir properties; however, early accumulation of hydrocarbons may have helped to preserve adequate reservoir properties. Rapid sedimentation within both the Rough Creek and Reelfoot systems may have allowed for the juxtaposition of reservoir facies and source rock facies over very short distances. Rapid facies changes may also have provided Cambrian-age carbonate reservoirs within the upper portions of the rift-fill sequences.

Source rocks: Shales in the Cambrian Eau Claire within the Rough Creek Graben and its general equivalents, including the Bonneterre in the northern part of the Mississippi Embayment, are the principal source for hydrocarbons in the play. It has been speculated that the little known section in the deepest part of the basin might also contain organic-rich faces in early graben sediments that could have been a source for hydrocarbons. Within the area of the Rough Creek Graben, more than 1,000 ft of dark gray to black shale of the Eau Claire Formation are in the Exxon No. 1 Duncan well, Webster County, Kentucky. More than 5,000 ft of shale are in the Eau Claire in the Texas Gas Transmission Shain No. 1 well, Grayson County, Kentucky. The shales thin to the north of the Rough Creek Fault System, and only 500 ft of Eau Claire shale is in the Indiana Farm Bureau No. 1 Brown well, Lawrence County, Indiana (Hester, 1988a; see also Harris, 1994). Similar thicknesses of Cambrian shale have been identified within the Reelfoot Rift area, although no data are available on organic matter content, type, or thermal maturity.

The types of organic matter in the Eau Claire have not been reported. Lopatin analysis (Cluff and Byrnes, 1990) suggests that present day thermal maturity within the deepest parts of the Rough Creek graben ranges from less than 2 to greater than 6 percent R_o. Values for the Reelfoot Rift are expected to be greater than 4 percent R_o. Based on the few analyses available for the Knox Group, weight percent organic carbon in this unit ranges from 0.1 to 0.3 percent. Available geochemical data indicate that the organic content of the Eau Claire and Bonneterre is quite low. Thermal maturity data from the Ouachita Mountains, just west of the Reelfoot Rift, suggest that the source rocks of that area are overly mature

(Houseknecht and Matthew, 1985). Both bitumin stain and a gas show have been reported from the Eau Claire in the Conoco Turner well in Kentucky (J.A. Drahovzal, Kentucky State Geological Survey, written commun., 1994).

Cluff and Byrnes (1990) suggested that oil generation began before 450 Ma (Early Ordovician) from the Eau Claire in the Reelfoot-Rough Creek Graben Complex and that peak oil generation began before 450 Ma in the southern part of the Reelfoot Rift, before 400 Ma (Late Silurian) within the deepest part of the Illinois Basin, and before 300 Ma (Pennsylvanian) for almost all of the Rough Creek Graben. These ages are younger than the formation of the traps associated with the graben systems but prior to the time of formation of most of the hydrocarbon-producing structures within the Illinois Basin.

The St. Peter Sandstone could have provided a migration pathway for hydrocarbons northward and upsection into younger Ordovician carbonate reservoirs. The Reelfoot Rift may have served as a pathway for fluid migration during the Pennsylvanian and Permian tectonic deformation of the Ouachita region, and reservoirs within the play could have been charged at this time, although this is mostly speculation. From Late Permian through the Jurassic, however, the Pascola Arch would have served as a barrier for fluid migration from the Reelfoot Rift into the Rough Creek Graben.

Hydrocarbons might also have been generated during the Late Mesozoic rifting of the Ouachita margin when the clastic sediments of the Reelfoot Rift could have served as a conduit for fluid migration. The Pascola Arch would still have provided as a barrier for petroleum migration into the Rough Creek Graben area.

Traps: Most of the traps within this play would be fault traps associated with development of the grabens and with development of the Pascola Arch. Many bounding faults and fault-related structures in the Reelfoot Rift and Rough Creek Graben are large. Potential trap sizes in the overlying carbonate rocks, however, are expected to be smaller. R.T. Ryder has estimated trap sizes for the petroleum assessment of the Rome Trough based on Cretaceous analogs in South America (Celso Ponete, Dos Reis Fonseca, and Carozzi, 1980); these estimates, however were considered conservative for trap sizes within the Reelfoot-Rough Creek Rift Complex. Traps would have originated during the late stages of the formation of the Reelfoot Rift and Rough Creek Graben. Later-formed traps were developed by reverse faulting accompanied by strike-slip and wrench faulting along the northern margin of the Rough Creek Graben in Late Pennsylvanian or Permian time (Hester, 1988b). The largest structure associated with the Reelfoot Rift would be marginal to the rift basin. Other potential traps would include some early formed structures associated with the rifting including Cambrian horsts and onlap pinchouts onto basement(J.A. Drahovzal, Kentucky Geological Survey, written, comm., 1994). Drilling depths to the majority of targets would exceed 20,000 ft within the Reelfoot Rift. The median depth for targets within the Rough Creek Graben was estimated to be 12,000 ft.

In the Rough Creek Graben, shales in the Eau Claire should provide an adequate regional seal for the underlying sandstone reservoirs. Only local seals are anticipated to be present in the carbonate reservoirs overlying the Eau Claire, and the upper Ordovician Maquoketa Shale would also form a regional seal. In the Northern Mississippi Embayment, however, the Maquoketa is absent and hydrocarbons generated from pre-Maquoketa source rocks can leak upward into the overlying Cretaceous sediments.

Exploration status: Both the Reelfoot Rift and Rough Creek Graben have been the targets of extensive seismic exploration. A few tens of holes have tested the larger structures. The depth to reservoirs (frequently > 20,000 ft) and the thermal maturity of the rocks in this play suggest that this is principally a gas play. Because of the high anticipated thermal maturity of the area, it is suggested that N_2 and CO_2 may exceed 10 percent by volume.

Resource potential: No commercial hydrocarbons have been found in either the St. Peter Sandstone or older rocks of the Illinois Basin Province, and only a few oil shows have been reported in this section. Both the Rough Creek Graben and Reelfoot Rift areas of the plays are not well explored, however, basement rocks have been drilled on most of the major structures north of the Rough Creek Fault Zone, but with only minor evidence of hydrocarbons (see, for example, Harris, 1994). The future potential for gas is considered to be minimal. Resource potential of this play is limited by several factors: (1) a lack of demonstrated source rocks; (2) poor reservoir quality; and (3) possible loss of trap integrity because of tectonic activity within the rift.

The risks probably are higher for the Northern Mississippi Embayment–Reelfoot Rift Play than for the Illinois Basin–Rough Creek Graben Play because of the potential for late diagenetic alteration of the reservoir rocks within the Reelfoot Rift associated with tectonism in the Ouachita Mountains. The Rough Creek Graben Play was assigned a probability of occurrence of 0.24 because of the poor quality of demonstrated source rocks and the risk of poor seal integrity and possible loss of hydrocarbon from potential traps associated with post-migration tectonism within the graben. The Reelfoot Rift Play was assigned a probability of occurrence of 0.1, risked most heavily on charge because of the predicted high thermal maturities of potential source rocks within the play. Additional risks were placed on quality of reservoir rocks and seal integrity for retention of hydrocarbons because the attributes of these quantities are mostly unknown. Discussion of coalbed gas plays, with references, may be found in the chapter by Rice, "Geologic framework and description of coalbed gas plays" elsewhere in this CD-ROM.

6409. ILLINOIS BASIN–PRE-MIDDLE ORDOVICIAN PLAY (HYPOTHETICAL)

This is a mixed structural and stratigraphic, hypothetical play consisting of the Upper and Middle Cambrian and Lower Ordovician rocks within the Illinois Basin. This play does not include the pre-Knox clastic rocks with the Reelfoot Rift and Rough Creek Grabens. The upper surface of the play is the sub-

Tippecanoe (latest Early Ordovician), which has been onlapped by the sandstone of the Everton Formation and the St. Peter Sandstone.

Reservoirs: Reservoir rock is indicated by the presence of secondary crystal growth on rock chips in drill cuttings, zones of oolitic chert and silicified oolites in a carbonate matrix, and sandstone stringers. Porosities probably range from almost 11 percent along the northwestern flank of the basin to less than 1 percent in the deepest parts of the basin (Cluff and Byrnes, 1990). The Knox is commonly a zone of loss of circulation during drilling. Anhydrite in drill cuttings suggests that the rock may contain beds of anhydrite that might have restricted upward migration of petroleum. Insoluble residue studies indicate that clays formed from potassium feldspar, which is present in the Knox, could restrict lateral and vertical migration. Also, interfingering of reservoir and nonreservoir beds could provide a barrier to fluid migration (Stevenson, 1982).

Source rocks: This play depends on Middle Cambrian and Lower Ordovician source rocks, primarily shales of the Eau Claire Formation and carbonates of the Knox Group. Thicknesses of potential source rocks in the Eau Claire and Knox are unknown, as is the type of organic matter, although type II or III organic matter is likely.

Thermal maturity of the Knox Group ranges from less than 0.60 percent R_o in northwestern Illinois to greater than 5 percent R_o in southeastern Illinois. The shale of the Eau Claire would be of the higher thermal maturity. Because of the thermal maturity of the play, it is expected to be primarily a gas play. Peak oil generation for the Knox in the deepest part of the basin began before 450 Ma (Cluff and Byrnes, 1990).

The highest reported organic carbon content for the Knox is 0.85 weight percent (Stevenson, 1982). In the deeper part of the basin, in Hamilton County, Illinois, shale of the Eau Claire Formation contains as much as 1.5 percent organic carbon. Rocks of similar age in Lake County, Tennessee (Bonneterre Formation) contain 0.4–0.5 percent organic carbon (Stevenson, 1971).

Oil generation in the Knox Group would have begun by 460-470 Ma and by 400 Ma, the Knox, throughout most of the Illinois Basin proper, would have passed through the oil-generation phase and entered the gas-generation phase. Gas generation would have been widespread by 240 Ma. Because no significant structures were present during this time period, any oil or gas generated and able to migrate out of the source beds and into regional carrier beds (such as the St. Peter Sandstone) would have been lost toward the major arches surrounding the Illinois Basin (J.R. Hatch, U.S. Geological Survey, written commun., 1994).

Traps: Structural, stratigraphic, and combination traps are possible within the play. Structural and combination traps would depend on large-scale structures developed during the late Paleozoic or on earlier, buried structures. Stratigraphic traps are most likely in the lower Eau Claire Formation. Sizes of traps within this play were not estimated. Seals would be local shale or non-porous carbonate rocks. Depths to traps could be from a few hundred feet to greater than 15,000 ft.

Exploration status: This play has been tested in all major fields of the basin area. Some hydrocarbons were recovered from a test of the Shakopee in the Unocal 1 Cisne well near the center of the basin. All major structures within the Illinois Basin have been drilled to basement, with the exception of structures within the Rough Creek Graben that are demonstrated on seismic studies.

Resource potential: No commercial hydrocarbons have been found in either the St. Peter Sandstone or older rocks of the Illinois Basin, and only a few oil shows have been reported. Dolomites of the Knox Group, including the Shakopee and Oneota Formations (Ordovician) and the Eminence, Potosi, Franconian and upper Eau Claire (Cambrian) beneath the sub-Tippecanoe (uppermost Lower Ordovician) unconformity, have limited potential as targets. Stratigraphic traps are possible within the interlayered dolomite, shale, and sandstone of the Eau Claire.

The most limiting factor for this play is the risk of charge. Shales of the Knox Group have low potential as source rocks, and the Eau Claire probably has even lower potential. A second limiting factor is the quality of reservoir rocks within the play: these rocks are almost uniformly tight, and either late fracture porosity or early entrapment of hydrocarbons to preserve porosity is required to develop or maintain adequate reservoir rocks. The 0.85-percent total organic carbon value from the Knox represents the highest measured value; however, more realistic values are probably on the order of 0.1 percent. The presence of anhydrite and red shale suggests an arid depositional environment and a very low potential as a source rock (similar to the underlying Mt. Simon). Furthermore, the time of peak oil migration of the Knox in the southern end of the Illinois Basin was 400 Ma (Cluff and Byrnes, 1990). All of the above limiting factors suggest relatively low petroleum potential for the Knox Group. Because of the risks on charge and reservoir rocks, this play was not assessed.

6411. NORTHERN MISSISSIPPI EMBAYMENT–POST-MID CAMBRIAN PLAY (HYPOTHETICAL)

This play is a hypothetical play that includes Late Cambrian- through Pennsylvanian-age rock within the northern part of the Mississippi Embayment. The play is analogous to the Lower Paleozoic through Mississippian Eastern Arkoma Gas Play (6208) and Morrowan Clastic Wedge Gas Play (6209) of the Arkoma Basin and partly analogous to the Cambrian and Ordovician Carbonate Play (6501) of the Black Warrior Basin. The play is for gas and local oil trapped in basement-controlled fault blocks, ramp anticlines associated with frontal thrust faults of the Ouachita Fold Belt, and facies changes.

The play is bounded below by pre-Late Cambrian rift-filling sediments of the Reelfoot Rift and above by Cretaceous sedimentary fill of the northern part of the Mississippi Embayment. The play is bounded on the south by the Ouachita thrust front and on the north by the northernmost extension of faulting associated with Ouachita thrusting. The position of the northern boundary is somewhat speculative, based on limited subsurface studies and extension from the Black Warrior Basin to the east and the Arkoma Basin to the west.

Reservoirs: Reservoir properties of this play are unknown but probably vary widely. The properties of the various reservoir horizons could be expected to be analogous to those of the same stratigraphic units in the Illinois Basin proper.

Source rocks: Source rocks for this play could include the Cambrian rift-filling shales proposed as source rocks for the Northern Mississippi Embayment–Reelfoot Rift Play (6410), Ordovician carbonates similar to those proposed for the Illinois Basin–Middle and Upper Ordovician Carbonate Play (6404), Woodford Shale equivalents, and equivalents of the Pride (Floyd) Shale, proposed as a source rock for the Late Paleozoic play within the Northern Mississippi Embayment. Other Mississippian–Pennsylvanian age rocks that could have been source rocks for hydrocarbons within this play, including the Stanley Shale and Atoka Formation, are discussed in the Northern Mississippi Embayment–Late Paleozoic Play (6412). The Cambrian- and Ordovician-age source rocks could be as mature as CAI= 2.5–3 (gas generating zone), as suggested by nearby drilling. Houseknecht and Matthews (1985) measured thermal maturities in Carboniferous strata from the eastern Ouachita Mountains and obtained vitrinite reflectance values from 2.0 to 5.0 percent R_o. These high thermal maturities are the result of a thermal event associated with Mesozoic rifting and intrusive activity within the Mississippi Embayment (Houseknecht and Matthew, 1985). Isolated areas of lower maturity may be present within the embayment. The high thermal maturity of this play suggests that it is primarily a gas play.

Timing is not favorable. Source rocks in the adjacent Black Warrior Basin began to generate hydrocarbons in the Late Pennsylvanian and Early Permian. Uplift of the Pascola Arch, however, began in Late Permian time and continued into the Jurassic. The embayment did not begin to subside until near the end of the Cretaceous. Any hydrocarbons that moved into post-Ordovician reservoirs prior to uplift of the arch probably were flushed from the system before subsidence of the Embayment.

Traps: Trap types are primarily fault blocks related to thrust faulting of the Ouachita Mountains. Fault traps are also possible, and stratigraphic traps are likely. Depths to objective are generally from 4,000 to greater than 10,000 ft. The block faulting related to the frontal thrusting trends southeast, parallel with the Ouachita Mountains to the west.

Exploration status: A few dozen wells have penetrated the Cretaceous sedimentary cover within the northern part of the Mississippi Embayment. Large parts of the area have been explored seismically, the Reelfoot Rift being the main exploration target. Schwalb (1982) mapped the subcrop of Paleozoic rocks beneath the Cretaceous cover at the crest of the Pascola Arch. The Cretaceous cover has been investigated as a municipal water supply. Only a single producing gas well is known in the Maquoketa; the remainder of the Paleozoic section has been nonproductive. If this play were to prove productive, it would be primarily a gas play.

Resource potential: Resources in this play were not assessed separately, but were included in play 6501 in the Black Warrior Basin. The adequacy of charge in this portion of the play, however, may be questionable because of the timing of uplift of the Pascola Arch. The Pascola Arch was a positive feature from near the end of the Permian through most of the Jurassic, a time of major petroleum generation within the Illinois Basin. The flanks of the Pascola Arch were sites for groundwater recharge, which would have flushed any hydrocarbons that moved into traps during oil generation. The southern end of the embayment was subject to high heat flow during the Mesozoic along the Ouachita margin, and source rocks at the southern end of the embayment are probably all overmature (Houseknecht and Matthew, 1985). There is a potential for unconformity traps associated with burial of the Pascola Arch, but the Cretaceous sedimentary cover required to form the seal for these traps is not a good regional seal and local seals would be required.

6412. NORTHERN MISSISSIPPI EMBAYMENT–LATE PALEOZOIC PLAY (HYPOTHETICAL)

This is a hypothetical play that includes all post-Middle Cambrian rocks beneath the Cretaceous sedimentary cover within the Northern Mississippi Embayment. This play is analogous to the Illinois Basin–Pre-Middle Ordovician Play (6409), Illinois Basin–Middle and Upper Ordovician Carbonate Play (6404), Illinois Basin–Silurian Reef Play (6403), Illinois Basin–Hunton Play (6402), and Illinois Basin–Post-New Albany Play (6401). The rocks of this play are present radially around the Pascola Arch beneath the Cretaceous sedimentary cover. The play differs from the analogous plays within the Illinois Basin in that the New Albany Shale, the principal source rock for the Silurian Reef, Hunton, and Post-New Albany Plays, is missing in most of the embayment area. Excluded from this play is the Northern Mississippi Embayment–Post-Mid-Cambrian Play (6411) at the southern end of the province, which is considered separately. There has been no commercial production of hydrocarbons from rocks of this age within the Embayment.

The play includes the whole area of the Mississippi Embayment north of the Ouachita Fold and Thrust Belt except along the crest of the Pascola Arch, where rocks of this age are missing. The play is bounded below by Lower and Middle Cambrian rocks of the Reelfoot Rift and above by Cretaceous sedimentary cover of the embayment. Petroleum accumulations within the play would be within structural, stratigraphic, and diagenetic traps.

Reservoirs: Reservoirs of this play would include Cambrian through Pennsylvanian carbonate and clastic rocks between the top of the rift-filling sequence of the Reelfoot Rift and the pre-Cretaceous unconformity beneath the Cretaceous sedimentary fill of the embayment. This sequence of rocks extends throughout the embayment area, but the section above the Cambrian has been removed from the area of the central Pascola Arch. The reservoirs would be expected to vary greatly in both porosity and permeability. The reservoir quality is unknown but could be expected to range from good to very poor.

Source rocks: The Upper Mississippian or Lower Pennsylvanian Pride Shale (Black Warrior Basin; roughly equivalent to the Floyd Shale interval of Alabama) is the most likely source rock for the play. The Pride is limited to the southern area of the province adjacent to the Black Warrior Basin to the east and the Arkoma Basin to the west. Older source rocks would include New Albany Shale equivalents around the perimeter of the embayment and equivalents of Champlainian Galena Group carbonate rocks and Platteville Formation shales and Knox Group shales and carbonate rocks of the Illinois Basin. The New Albany Shale has been removed from most of the Embayment area but age-equivalent rocks may be present in the southern part of the area.

The Pride Shale is more than 150 ft thick in the Black Warrior Basin to the east of the Embayment. The total organic carbon content of the Pride in the embayment is unknown but could be as high as several percent. Thicknesses for Cambrian and Ordovician source rocks are expected to be similar to those of the Illinois Basin; see Illinois Basin–Pre-Middle Ordovician Play (6409) and Illinois Basin–Middle and Upper Ordovician Carbonate Play (6404). Mississippian carbonate rocks and Pennsylvanian clastic rocks around the perimeter of the Pascola Arch might also have source-rock potential.

Published organic carbon geochemical data on potential source rocks for the play are from outcrop samples in the Ouachita Mountains to the south of the Northern Mississippi Embayment. Samples include the Atoka Formation (Pennsylvanian, Atokan), which ranges from 0.22 to 1.8 percent TOC and averages 0.78 percent TOC (n=19), and the Caney Shale (Mississippian), which ranges from 4.4 to 5.4 percent TOC and averages 4.8 percent TOC, as reported by Weber (1992). Weber also reported a single sample from the Lower Ordovician Collier Shale that contains 0.29 percent TOC and a single sample from the Upper Ordovician Polk Creek Shale that contains 6.1 percent TOC, both from the Ouachita Mountains. The organic matter is expected to be a mixture of types I, II, and III. The thickness of the organic shales within the formations was not reported.

The Cambrian and Ordovician-age source rocks could be as mature as CAI= 2.5–3 (gas generating zone), as suggested by nearby drilling. Houseknecht and Matthews (1985) measured thermal maturities in Carboniferous strata from the eastern Ouachita Mountains where vitrinite reflectance values range from 2.0 to 5.0 percent R_o. Devonian and Mississippian source rocks may be of lower thermal maturities to the east, under the Cretaceous rocks of the Mississippi Embayment. Analogous plays in adjacent regions have produced both oil and gas.

Timing is not favorable: the timing of oil generation within this play would be similar to that for the Illinois Basin–Post-New Albany Play (6401)within the Illinois Basin, where source rocks began to generate hydrocarbons in the Late Pennsylvanian and Early Permian. Late Permian to Jurassic uplift of the Pascola Arch and Mesozoic subsidence of the embayment suggest that any hydrocarbons that moved into reservoirs prior to uplift of the arch would have been flushed from the system.

Traps: Structural traps could include structures formed as early as Cambrian time and incorporated into the uplift of the Pascola Arch, as well as subsidiary structures developed during uplift of the arch. Diagenetic traps could have developed during uplift of the Pascola arch and would consist primarily of secondary porosity developed by subaerial exposure on the flanks of the arch. Structural traps within the embayment could be quite large, similar in size to the largest structures within the Illinois Basin. Diagenetic traps, on the other hand, would be expected to be smaller but could still be of significant size. Stratigraphic traps are also possible within the play.

Seals are a major problem within the embayment. The New Albany Shale, which forms both source rock and regional seal for the Hunton play within the Illinois Basin, is missing within the Embayment. The Pride Shale equivalent in the embayment could form a broad regional seal for the Mississippian carbonates within the southern part of the embayment. Local shale within the section would have to serve as seals for most reservoirs. There is no known regional seal above the pre-Cretaceous unconformity.

Cretaceous sedimentary cover over the Pascola Arch is 2,000–3,000 ft thick and thins to zero along the eastern, northern, and western margins of the embayment. Depths to objectives in the play are from 4,000 to greater than 10,000 ft.

Exploration status: About a dozen deep holes have been drilled within the embayment and a moderate amount of seismic exploration has occurred. No hydrocarbons have been produced from the embayment, with the possible exception of a recently completed gas well within the Knox along the northeastern most margin of the embayment in Kentucky. Hydrocarbons within the embayment would predominantly be gas, but oil could be present.

There are no accumulations that meet the minimum size requirement for this assessment, and, although it is possible that there are yet undiscovered accumulations within the play, the overall potential is very low.

Factors that limit the potential for petroleum accumulations are the absence of source rocks throughout much of the area and the timing of uplift. Uplift of the Pascola Arch coincided with the time of petroleum generation in the Illinois Basin to the north. Initial uplift of the arch was during the Permian, and the arch remained an uplifted area at least into if not through the Jurassic. The arch began to subside in Cretaceous time, and the Cretaceous sedimentary cover over the arch is mostly flushed by fresh water. It is likely that any hydrocarbons that migrated into the late Paleozoic strata were flushed. The timing of uplift and migration also suggests that the integrity of the reservoirs might have been breached.

UNCONVENTIONAL PLAYS

Continuous-Type Play

by Joseph R. Hatch

6407. NEW ALBANY SHALE GAS PLAY (HYPOTHETICAL)

The Illinois Basin–New Albany Shale Gas Play (6407) in the Illinois Basin is a continuous-type accumulation because (1) the reservoir is low-permeability fractured shale, (2) the shale is the source of the hydrocarbons, (3) formation pressure is abnormally low, (4) there are gas shows or production in most holes drilled, and (5) there is a general lack of structural control. The play is defined by the area of occurrence of organic-matter-rich facies in the New Albany Shale in the southeastern part of the basin where vitrinite reflectance (R_O) values of ^{3} 0.6 (see fig. 6 of Cluff and others, 1981) indicate a potential for generation and accumulation of thermogenic gas in fractured organic-matter-rich shale. The New Albany Shale in west-central Illinois is not included in the play area because the dominant lithology in that area is organic-lean, bioturbated greenish-gray and olive-gray shale.

Stratigraphy: The New Albany Shale, present throughout the Illinois Basin parts of Illinois, Indiana, and western Kentucky, ranges in age from Middle Devonian through Kinderhookian (Early Mississippian) in age, although most of the shale is Late Devonian in age (Cluff and others, 1981). In southeastern Illinois and adjacent western Kentucky, the New Albany Shale is more than 460 ft thick. The shale thins toward the basin margins except in west-central Illinois where thicknesses greater than 300 ft are reported in Henderson and Hancock Counties (Cluff and others, 1981).

Reservoirs: Maximum potential for New Albany Shale gas production in this play is in regions interior to the Moorman Syncline in western Kentucky and in areas in Illinois and Indiana where the lack of surface faulting increases the potential for maintaining a good seal to the gas accumulations (Hamilton-Smith, 1993).

Source rocks: The source of the gas in the fractured New Albany Shale reservoirs is the New Albany Shale itself. For 350 samples of the New Albany Shale, Stevenson and Dickerson (1969) reported a range of organic carbon contents from less than 1 to almost 9 percent. For 371 samples of the New Albany Shale, Frost (1980) reported a range of organic carbon contents from less than 1 to 15.6 percent. Vitrinite reflectance and liptinite fluorescence measurements reveal a regionally consistent pattern of increasing maturation southward toward the area of greatest paleoburial depth and (or) possibly higher heat flow (Barrows and Cluff, 1984, fig. 10 and Comer and others, 1994). Organic maturation levels for the New Albany Shale are highest in southeastern Illinois and adjacent western Kentucky. Here, organic matter maturation is within the uppermost zone of oil generation and approaches the wet-gas- or gas-condensate-generation zone (Barrows and Cluff, 1984).

Exploration status and resource potential: Relatively small amounts of natural gas have been produced from this play along the southeastern border of the basin (Howard, 1991, fig. 21-9). Hamilton-Smith (1993, table 2) listed names of 30 gas fields, number of wells (296 total), average initial open flows, and discovery dates for gas fields in western Kentucky. Of these 30 gas fields, 21 were discovered as a result of high gas prices in the late 1970's. Cumulative production figures for these gas fields are not available, although some information for older fields is available. Further details/discussions of the geology and gas potential of the New Albany Shale are summarized in various chapters in Hasenmeuller and Comer (1994).

CoalBed Gas Play

By Dudley D. Rice, Thomas M. Finn, and Joseph R. Hatch

One coalbed methane play is identified in the Illinois Basin, the Illinois Basin–Central Basin Play (6450).

The geologic aspects of the coalbed gas potential of the Illinois Basin are summarized by Archer and Kirr (1984). Thermal maturity trends and controls in the basin are discussed by Cluff and Byrnes (1991). Harper (1991) described the coalbed gas potential of abandoned underground mines in Indiana. Abandoned mines also have potential for coalbed gas production in Illinois and Kentucky.

Middle Pennsylvanian (Desmoinesian) coal seams are important for coal mining in the Illinois Basin, both surface and underground, and have potential for recoverable resources of coalbed gas. Coal beds also occur in the Lower and Upper Pennsylvanian section, but they are generally thin and discontinuous. In Illinois, the coals are generally referred to by geographic names; however, in Kentucky and Indiana they are commonly referred to by number with the oldest coal having the lowest number. More than 75 seams have been identified in the basin and about 20 have been mined. The major seams for both mining and coalbed gas potential, in ascending order, are Colchester No. 2, Houchin Creek No. 4, Springfield No. 5, Herrin No. 6, and Danville No. 7. Coal seams are variable in thickness and continuity and can be as much as 15 ft thick. More than one half of the minable coal (more than 28 in thick) occurs in beds less than 54 in thick. The thinner coals, which are not important for mining, are important for coalbed gas potential because multiple-seam production may be needed for economic development. The greatest net thickness of coal probably occurs in the southeastern part of the basin where the Pennsylvanian section is thickest. In the Illinois part of the basin, one half of the coal resources are at depths less than 650 ft deep. Over the entire basin, all coal seams are less than 3,000 ft deep, and the thick Middle Pennsylvanian coals are less than 1,500 ft deep.

Coal rank in the basin increases to the southeast from high-volatile C to A bituminous rank. Isorank trends commonly cut across structure in the southern part of the basin, and coals of highest rank commonly crop out. The observed coalification pattern can be explained in two ways. First, maximum depth of burial occurred in late Pennsylvanian or Permian time, and as much as 5,000 ft of uplift and erosion has occurred since that time. The second explanation is that short-term elevation of geothermal gradient occurred in the southern part of the basin (Hicks Dome area) during late Pennsylvanian to Triassic time. This thermal event was related to deep-seated igneous intrusions. The southerly increase in rank can best be explained by a combination of both factors. Because of the general low rank, only minor amounts of thermogenic gas were probably generated in the Pennsylvanian coals in late Paleozoic and early Mesozoic time.

Gas samples desorbed from cores and sampled from abandoned mines consist mainly of methane (as much as 90 percent), nitrogen (as much as 58 percent), and CO_2 (as much as 21 percent). The high nitrogen values are interpreted to result, in part, from air contamination. The amount of nitrogen in gases produced from abandoned mines usually decreases with time indicating air contamination. The carbon isotopic composition of the methane fraction of the coalbed gas samples suggests a biogenic origin, and the gases were probably formed relatively recently in association with groundwater flow.

The Illinois Basin is a broad, relatively undeformed structural depression. In addition to several north-south trending folds, the main structural features of the basin are high-angle faults concentrated in the south part of the basin. These faults, such as the Rough Creek-Shawneetown Fault Zone, exhibit significant displacement and lateral extent and trend approximately east-west. In addition, numerous small-scale north-south trending thrust faults with displacements up to 10 ft have been observed only in coal mines. These thrust faults are related to the contemporary stress field in the region.

Systematic studies have not been made of the cleat systems in the basin. In general, cleats are not readily apparent in small-scale studies, and the fractures in the coal have a tendency to be mineralized. However, the density of fracturing is expected to be higher in the southern part of the basin where faulting and folding are concentrated.

Relatively small amounts of water are pumped from most underground mines, suggesting that the coals have low permeability. Many mines, even those below surface drainage, remain dry after abandonment if the roof and floor rocks are relatively impermeable. Analyses of a few samples indicate that the water is relatively fresh.

Gas contents of coals in the Illinois Basin are low, ranging from about 30 to 150 Scf/t without any strong correlation with depth. In fact, some of the highest values are from relatively shallow horizons. The low gas contents can be explained by (1) relatively shallow depths, (2) low coal rank, (3) probable degassing of any earlier generated thermogenic gas, and (4) replacement by relatively recent biogenic gas that occurs in lower concentrations.

On the basis of coal resource estimates and a range of gas content values, the in-place coalbed gas resources for the Springfield No. 5, Herrin No. 6, and Danville No. 7 coal beds are estimated to range from about 5 to 21 TCF. Significant coal resources occur in other beds that are commonly thinner, but deeper with probable higher gas contents. The addition of potential gas resources for these other coal beds would add to these in-place estimates.

Illinois, which contains a large part of the Illinois Basin, is an important state for coal resources, mining, and emissions. Of all the States, it has the largest bituminous coal reserves, largest strippable bituminous coal reserves, and second largest coal reserves in the United States. On the basis of 1991 statistics, Illinois ranked fifth in the country for total coal production and third for coal production from underground mines. More than 70 percent of their coal was produced from underground mines. Several counties in both Illinois and Kentucky are in the top 35 counties in the U.S. in terms of underground mining. At present, very little underground mining is taking place in Indiana. In spite of the relatively low gas contents, Illinois had the fifth largest methane emissions from underground mining in 1988, which could be targeted for possible recovery and utilization.

Only about 25 wells have been drilled for coalbed gas in the Illinois Basin. Most of these wells were drilled to recover gas from shallow (less than 500 ft), abandoned mines, which used the room-and-pillar method. The gas in these mines probably migrates from both the coal and adjacent roof and floor rocks. One well in an abandoned mine had stabilized flow rates of about 100 MCFGPD for about 20 years. With the recent tax credit, some effort has been made to recover gas from virgin coal beds, but no information is available.

The gas in abandoned mines has also created a hazard for drillers who are exploring for oil and gas from deeper reservoirs in the mining districts. During the past 20 years, many drilling rigs have been destroyed by fire after penetrating gas-filled, abandoned mine workings.

Mostly oil is produced from conventional reservoirs in the Illinois Basin. In addition to the oil pipelines, a couple of regional, high-pressure gas pipelines are present in the potential area for coalbed gas. However, more infrastructure is required for future development of coalbed gas.

6450. ILLINOIS BASIN–CENTRAL BASIN PLAY

The Illinois Basin–Central Basin Play (6450) is the one coalbed gas play identified in the Illinois Basin. It corresponds to the area where the Herrin No. 6 coal bed is generally deeper than 200 ft and is covered by Upper Pennsylvanian (Missourian) rocks. Although the coal resources of the basin are large, the undiscovered coalbed gas potential is essentially untested and assessed to be fair to poor. The potential is restricted because of (1) low gas contents, (2) questionably low permeability, and (3) possible undersaturation. The best potential is in the southern part of the basin where the coal beds are of higher rank and deeper. This is the part of the basin where most of the wells have been drilled.

The coalbed gas resource can be developed by two types of wells. First, wells may be drilled into shallow, abandoned underground mines where the gas is migrating from both the coal beds and adjoining rocks. These wells will undoubtedly be characterized by low pressure and the gas will be contaminated by air (nitrogen) during early stages of production. Gas from these wells might be used for local consumption. Second, vertical, hydraulically-fractured wells may be drilled into virgin coal seams. Maximum production will be gained by completion in multiple coal seams.

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SYSTEM	SERIES	SEQUENCE	GROUP	FORMATION, MEMBER: ILLINOIS BASIN	FORMATION, MEMBER: NO. MISSISSIPPIAN EMBAYMENT
Eocene		Zuni			Claiborne Wilcox
Paleocene		Zuni			Midway
CRETACEOUS		Zuni			McNairy Sandstone Coffee Sandstone
		Absaroka		Undifferentiated	
MISSISSIPPIAN	Chesterian	Kaskaskia	Knobs – Mamoth Cave – Pope	Undifferentiated	
MISSISSIPPIAN	Valmeyeran	Kaskaskia	Knobs – Mamoth Cave – Pope	Aux Vases Ste Genevieve St. Louis Salem – Ullin Port Payne Borden	Undifferentiated Ste Genevieve St. Louis Warsaw Port Payne New Providence
MISSISSIPPIAN	Kinderhookian	Kaskaskia	Knobs – Mamoth Cave – Pope	Chouteau	
DEVONIAN	Upper	Kaskaskia	Knobs – Mamoth Cave – Pope	New Albany Group Lingle	New Albany Group Sellersburg
DEVONIAN	Middle	Kaskaskia	Knobs – Mamoth Cave – Pope	Grand Tower Dutch Creek Member	Jeffersonville Limestone Dutch Creek Mbr.
DEVONIAN	Lower	Tippecanoe	Hunton	Clear Creek Backbone Grassy Knob – Flat Gap	Clear Creek Backbone Grassy Knob
SILURIAN	Cayugan	Tippecanoe	Hunton	Bailey	Bailey
SILURIAN	Niagaran	Tippecanoe	Hunton	Moccasin Springs St. Clair Limestone	Brownsport Louisville – Osgood
SILURIAN	Alexandrian	Tippecanoe	Hunton	Sexton Creek Edgewood	Sexton Creek / Brass Field
ORDOVICIAN	Upper	Tippecanoe	Ottawa	Maquoketa Group Galena Group Platville Group	Maquoketa Kimmswick Decorah Plattin
ORDOVICIAN	Upper	Tippecanoe	Ottawa	Pecatonica Joachin	Pecatonica Joachin
ORDOVICIAN	Middle	Tippecanoe	Ottawa	Dutchtown St. Peter Everton	Dutchtown St. Peter Everton
ORDOVICIAN	Lower	Sauk	Knox	Shakopee Dolomite	Smithville – Powell Cotter Jefferson City Roubidoux
ORDOVICIAN	Lower	Sauk	Knox	Gasconade Gunter Member	Gasconade Gunter Sandstone
CAMBRIAN	Upper	Sauk	Knox / Potsdam	Eminence Potosi Franconia Eau Clair Mt. Simon	Eminence Potosi Elvins Bonneterre Lamotte
CAMBRIAN	Middle Lower	Sauk	Potsdam	Unnamed sediments ?	Unnamed sediments ?
PRECAMBRIAN					