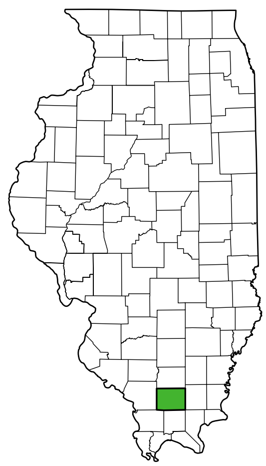
STATEMAP
Williamson County-BG

Bedrock Geology of Williamson County, Illinois

W. John Nelson

2020



ILLINOIS
Illinois State Geological Survey
PRAIRIE RESEARCH INSTITUTE

615 East Peabody Drive
Champaign, Illinois 61820-6918
(217) 244-2414
http://www.isgs.illinois.edu

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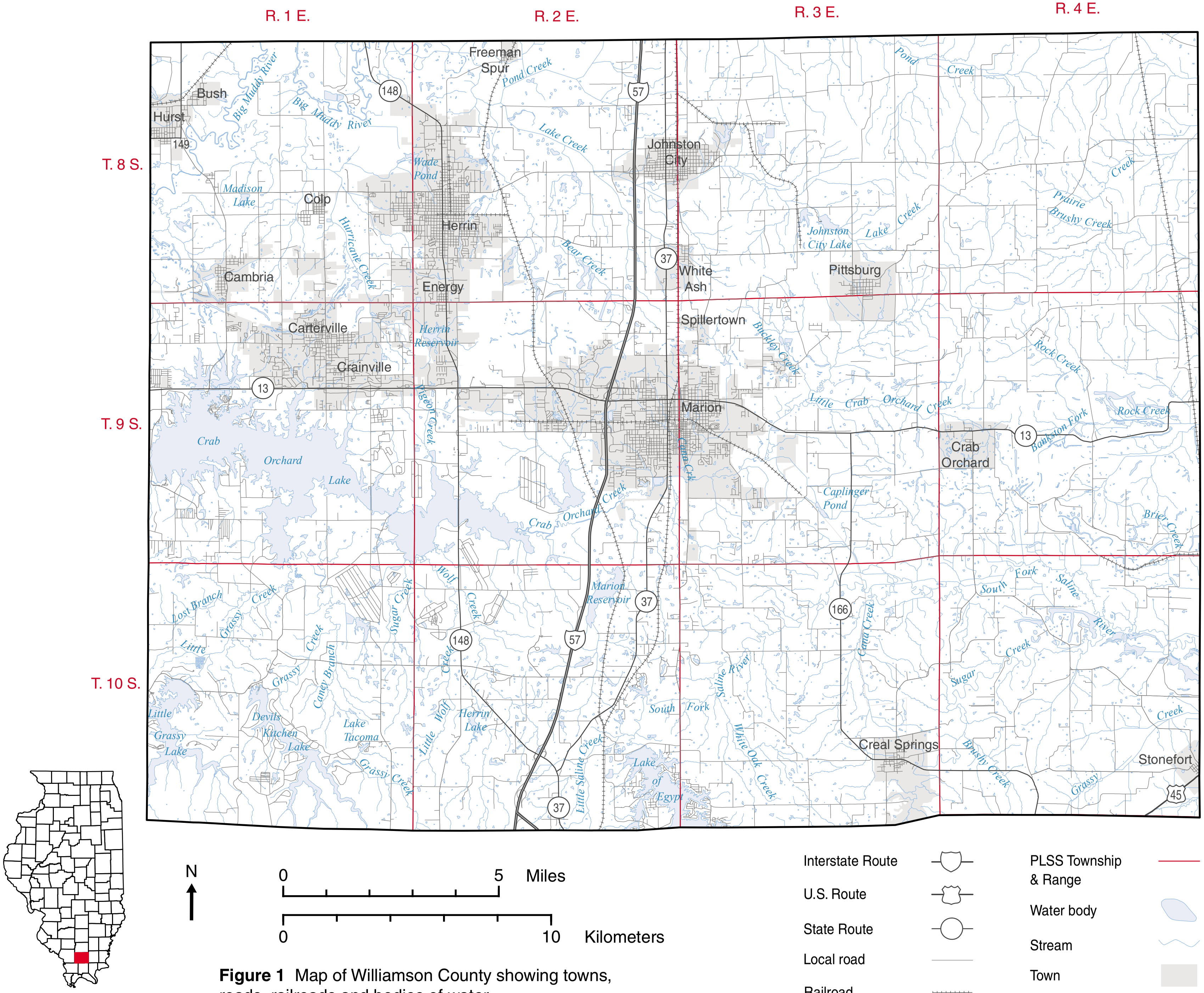


Figure 1 Map of Williamson County showing towns, roads, railroads and bodies of water.

Introduction

Geographic and Geologic Setting

One of 102 counties in Illinois, Williamson County is located in the southern part of the state (Fig. 1). Land area of the county is 444 square miles (1,150 km^2) and population as of 2019 was 66,597(https://www.census.gov/quickfacts/williamsoncountyillinois). The county seat and largest city is Marion, population 17,413 (https://en.wikipedia.org/wiki/Williamson_County%2C_Illinois, https://cityofmarionil.gov/grow/). Williamson County was carved out of Franklin County in 1839 and its name was transferred from a county in Tennessee just southwest of Nashville. Until recently, coal mining was the dominant industry in the county. This activity continues today, but a more diverse economy based on mixed light industry and agriculture has taken hold. Marion is a regional center for retail and wholesale business and for medical services.

Williamson County straddles the border between the Mt. Vernon Hill Country of the Central Lowland Province on the north and the Shawnee Hills Section of the Interior Low Plateaus Province on the south (Horberg 1950). Essentially, the physiographic boundary is the border between glaciated terrain on the north and unglaciated bedrock hills on the south. The southernmost advance of continental glaciers in the Northern Hemisphere took place near Lake of Egypt in Williamson County. Mt. Vernon Hill Country is characterized by broad lowlands underlain by relatively thick glacial and glacial-fluvial and lacustrine sediments that partly mask the pre-glacial topography. Rounded hills are largely cored by bedrock that is mantled with loess and thin, patchy drift. In the Shawnee Hills, resistant sandstone layers of Pennsylvanian age (and Mississippian age south of Williamson County) are inclined gently northward, forming a series of south-facing escarpments near the south border of the county.

Geologically, Williamson County lies along the southern margin of the Illinois Basin (or Eastern Interior Basin), which encompasses much of Illinois together with southwestern Indiana, part of western Kentucky, and small areas of Missouri and Tennessee (depending upon precise definition). The Illinois Basin is an interior cratonic basin that underwent active subsidence and sedimentation from Cambrian through Pennsylvanian time (Leighton et al. 1991; Kolata and Nimz 2010). Regional dip throughout the county is northward, exemplified by the north-facing cuestas of the Shawnee Hills. Trending east-west across the northern part of the county is the Cottage Grove Fault System, a zone of strike-slip faulting that probably was active primarily during Late Pennsylvanian and Permian time (Nelson and Krausse 1981)

Previous geologic mapping

Several detailed geologic maps that cover part or all of Williamson County were published during the first quarter of the 20th century. These include Cady (1910), who mapped geology and mineral resources of an area including the Johnston City and Pittsburg 7.5-minute quadrangles. Savage (1910) and Shaw and Savage (1912) mapped the Herrin 15-minute quadrangle, which includes the De Soto and Herrin 7.5-minute quadrangles. Cady (1916) mapped and described coal resources. Lamar (1925) mapped the Carbondale 15-minute quadrangle, which includes southwestern Williamson County and parts of neighboring Jackson and Union Counties. His accompanying report describes in detail bedrock and surficial deposits, structural features, and mineral deposits. All of the above maps were produced at scales of 1:62,500 or smaller.

The "modern" era of geologic mapping in southern Illinois, at 1:24,000 scale, began during the 1980s and continues today with financial support from the U.S. Geological Survey. Five maps published during the early 1990s (Trask and Jacobson 1990; Nelson and Lumm 1990; Jacobson 1991; Jacobson and Weibel 1993; Weibel and Nelson 1993) take in a narrow strip along the southern border of Williamson County (Fig. 2). The major effort specifically targeted at Williamson County entailed data collection during 2001 to 2003, with the bedrock geologic maps published several years later (Nelson 2007b, 2007c, 2007d, 2007e, 2007f, and 2007g). Also during this effort the surficial geology of much of the county was mapped, publication being further delayed (Follmer and Nelson 2010a, 2010b, 2010c, 2010d, 2010e, 2010f). The six "core" quadrangles covered during this project lie entirely or largely in Williamson County, but strips along the eastern and western edges of the county were left unmapped. These bedrock maps were completed independently later, again with financial support from the U.S. Geological Survey (Nelson 2007a, 2013a, 2019; Nelson and Denny 2015).

Knitting these 15 quadrangle maps into a coherent whole took place in late 2019 and early 2020. Dee Lund and Emily Bunse electronically combined existing maps into a single sheet covering the entire county, revealing glaring and not so obvious mismatches and discrepancies among the 15 maps. Most of these entailed simple oversight or errors on the part of previous authors and cartographers, but larger problems needed to be corrected by working up new data, chiefly from borehole records. Largest among these changes, the Shelburn and Patoka Formations, previously undivided, have been differentiated across the Herrin, Johnston City, and Pittsburg Quadrangles. Also, the Bond Formation has been remapped extensively in the Pittsburg Quadrangle. Some earlier edge-matching problems in the southern part of the county had been addressed by outcrop study circa 2001 to 2003, but these problems all reside within the Tradewater Formation, which is not subdivided on the present product.

Method of study

Three primary sources of geologic data are available for Williamson County: outcrops, coal mines, and well records.

Outcrops Bedrock outcrops are numerous in southern Williamson County. This area lies largely south of the limit of glacial drift and includes resistant sandstone units, which commonly form cliffs and ledges. Non-resistant rocks such

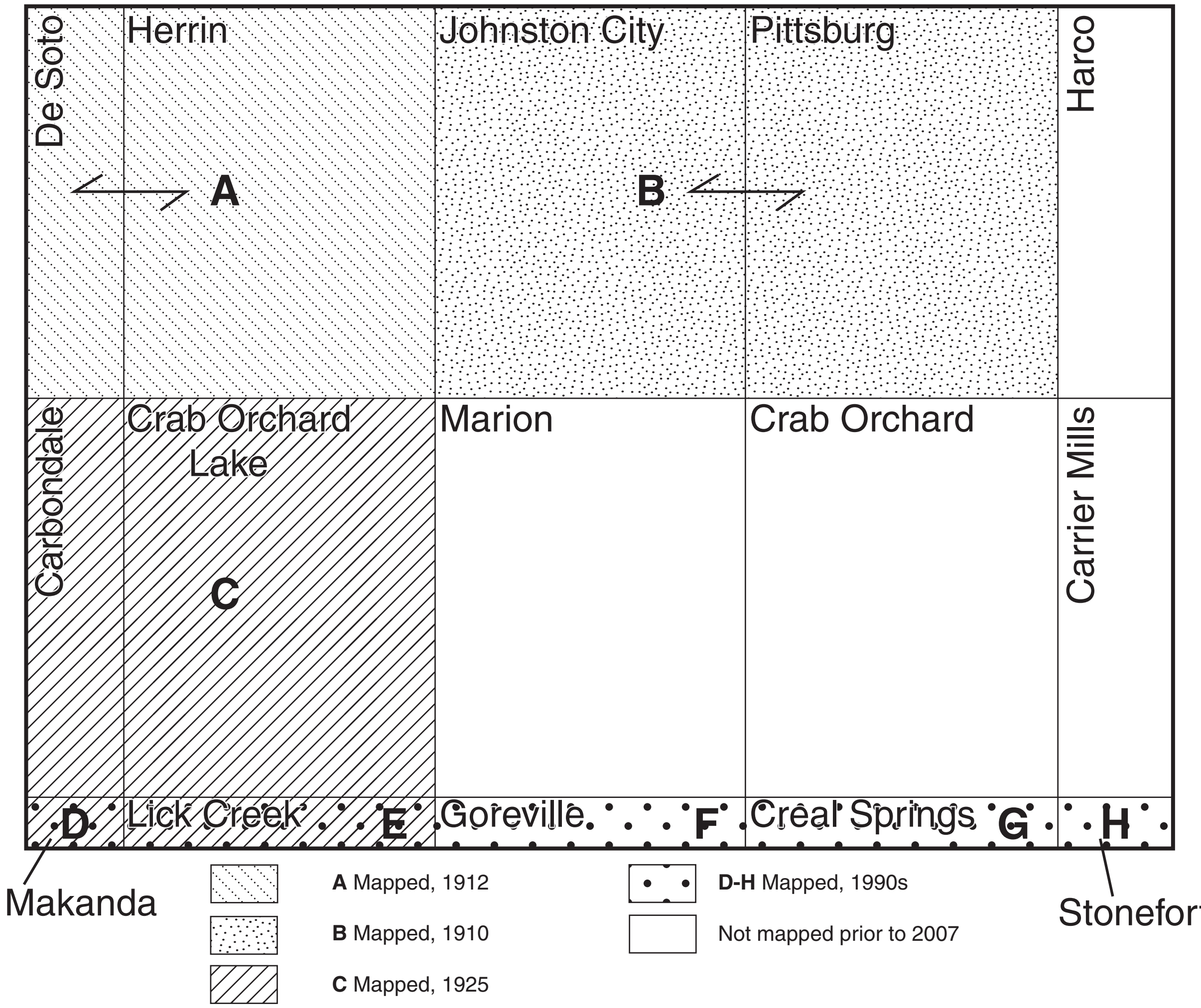


Figure 2 Diagram showing geologic mapping in Williamson County prior to 2007. A. Shaw and Savage (1912), B. Savage (1910), C. Lamar (1925), D. Jacobson and Weibel (1993), E. Weibel and Nelson (1993), F. Jacobson (1991), G. Trask and Jacobson (1990), and H. Nelson and Lumm (1990).

as shale, coal, and limestone crop out in steep ravines and gullies. I traversed southern Williamson County thoroughly, walking out mappable units and contacts. My work load was lightened by the fact that I and other ISGS geologists had already mapped all of southernmost Williamson County at scale 1:24,000. Thus a stratigraphic framework was already in place, awaiting extension into new areas.

Northern Williamson County is mantled by thick Quaternary deposits. Only small, scattered rock outcrops occur north of Crab Orchard Lake and the South Fork of the Saline River. Limited time and the need to get permission from hundreds of private landowners precluded visiting all areas where outcrops might occur. Field notes of previous ISGS geologists, archived at the ISGS, describe scores of outcrops that we were unable to visit or that no longer exist because of erosion, sedimentation, slumping, and man's activities. In particular, grading and paving county roads eliminated many rock exposures that were formerly visible in rutted, unimproved roads.

Coal Mines Active surface and underground coal mines provide magnificent exposures of selected rock strata. When underground mines are abandoned they are sealed; surface mines are reclaimed in accordance with law, leaving no rock exposed. Rock is still visible on the highwalls of a few strip mines that pre-date reclamation law, but such exposures are difficult of access and seldom yield useful information. Fortunately, observations made by ISGS geologists in active mines are archived and provide a wealth of information, especially on faults. Room-and-pillar underground mines expose faults both in map and cross-sectional view for thousands of feet along strike. Faults were mapped extensively at the Orient No. 4 and Zeigler No. 4 underground mines (Nelson and Krausse 1981).

Borehole Data Logs and samples from drill holes are the leading source of geologic information in Williamson County. For many areas of the county such records are the only source of data. Wells vary greatly in the quantity and quality of information recorded. Figure 3 is a map showing boreholes of special significance in Williamson County, including deep test holes and selected borings that were continuously cored.

Logs made by water-well drillers are typically cursory; many are worthless. Most are of little value beyond indicating depth to bedrock, and even that information may not be reli-

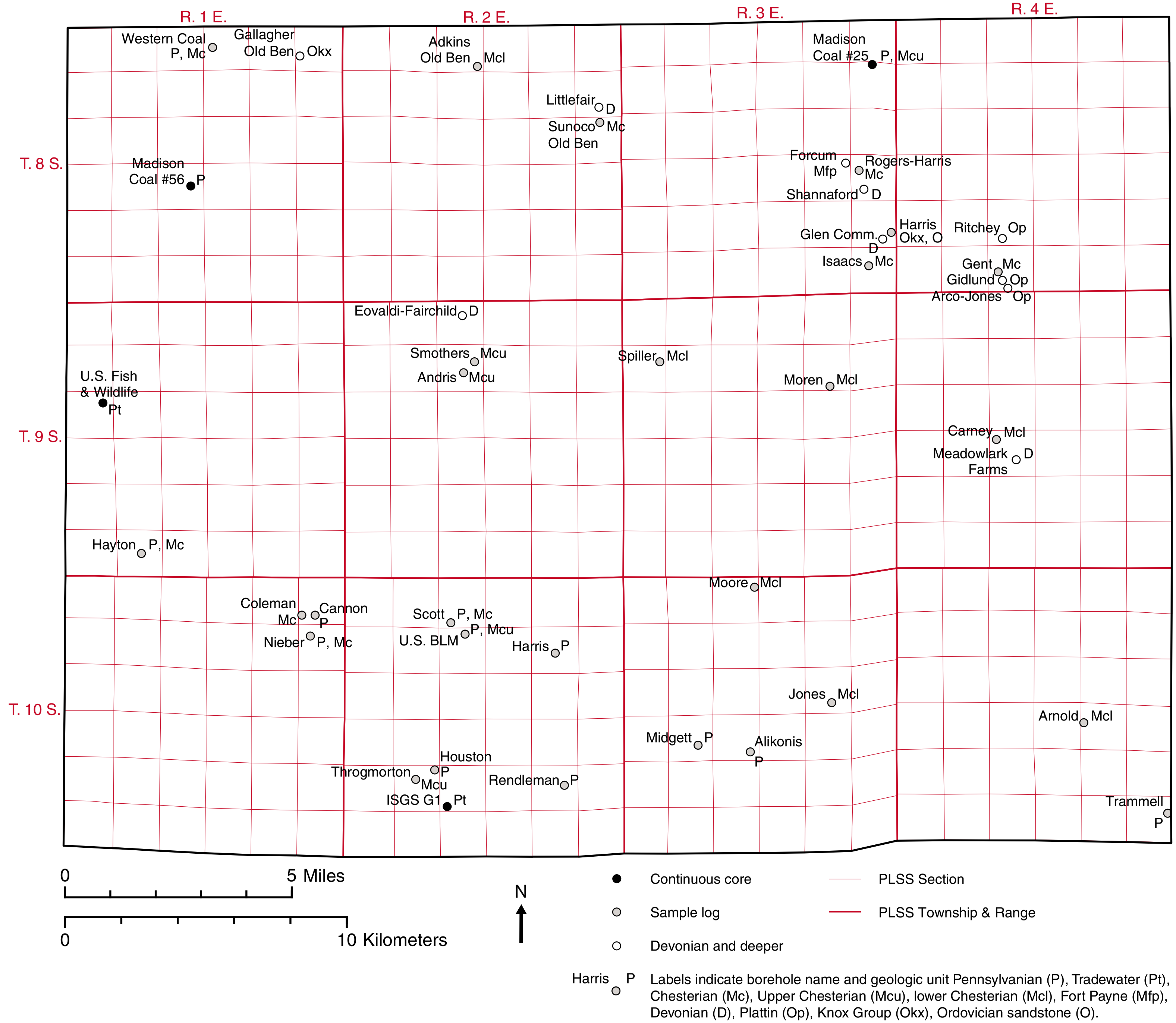


Figure 3 Map showing boreholes of special note in Williamson County.

able. Less than 10% of water wells have samples (cuttings) on file and were logged by previous geologists or logged specifically during the quadrangle mapping phase of the project.

The Illinois Department of Transportation (IDOT) logs bridge borings and other engineering test holes along highway rights-of-way. Although geared toward engineering rather than geologic properties, these logs provide plentiful data on Quaternary strata and reliable depth to bedrock. Nearly all IDOT holes terminate at bedrock, and samples are rarely made available to the ISGS. Considerable effort was expended deciphering IDOT's arcane manner of designating highways and structures and thereby determining their accurate locations.

Logs of hundreds of coal-test borings are on file at the ISGS. Most have only drillers' logs, of highly variable quality. Some coal-test borings were continuously cored, and samples described by geologists. Although ISGS geologists logged many coal-company cores, few actual samples came into ISGS possession. A noteworthy exception is the Madison Coal Company's Hole 25 in sec. 12, T 8 S, R 3 E, which was drilled in 1923. This hole was cored continuously from bedrock surface to a depth of 2,136 feet (651 m) in the Mississippian Waltersburg Formation. Few other coal test borings in the county were drilled below the Springfield Coal. Petroleum test holes provide data on deeper strata. The large majority have wireline geophysical logs that are of great value for stratigraphic work. Electric logs (spontaneous potential and resistivity) are by far the most common. Some holes also have gamma-ray, density, neutron, sonic, and other wireline logs. Samples (cuttings) from roughly half the oil and gas test holes in the county are on file at the ISGS; however, most sample sets have never been examined by a geologist. A few oil wells were cored, mostly short runs (10 to 30 feet) through reservoir rocks. Some core descriptions made by geologists are on file.

Three dedicated test holes, continuously cored through bedrock strata, were drilled for this study (Table 1). These are supplemented by several holes cored previously for other projects a short distance outside Williamson County.

Stratigraphy

Precambrian Rocks

"Basement" rocks of Williamson County are essentially unknown, as no wells have reached them. The nearest Precambrian penetrations are in Hamilton and Perry Counties, about 15 miles (24 km) northeast and 20 miles (32 km) northwest, respectively. These and other deep wells in the region encountered granite and rhyolite, similar to outcropping Precambrian in the St. Francois Mountains of southeastern Missouri. Collectively, these rocks are assigned to the "eastern granite-rhyolite province" of roughly 1.42 to 1.50 billion years old (Buschbach and Kolata 1991; Duchek et al. 2004, Freiburg et al. 2020). Depth to Precambrian basement in Williamson County increases from less than 12,000 feet (3,700 m) at the northwest corner to more than 15,000 feet (4,600 m) at the southeast corner (Sargent 1991).

Cambrian System

Cambrian rocks also have not been reached by the drill in Williamson County. Regionally, they comprise the Mt. Simon Sandstone at the base overlain by the Knox Group, a thick succession dominated by dolomite and extending into Lower Ordovician (Fig. 4). Sargent (1991) estimated the Mt. Simon to be about 1,000 feet (300 m) thick in central Williamson County, becoming thicker to the southeast. Sargent's isopach map of the Knox shows the group increasing from 4,600 feet (1,400 m) at the northwest corner to 6,200 feet (1,900 m) at the southeast corner. Of this amount, at least 2,000 feet (600 m) is probably Ordovician, leaving some 2,500 to 4,000 feet (760 to 1,200 m) in the Cambrian portion of the Knox.

Seismic reflection profiles in Williamson County provide limited additional information. The top of Precambrian rocks is not clearly resolved, a common situation in southern Illinois where Mt. Simon Sandstone and granite or rhyolite have similar seismic properties. The deepest strong seismic reflector is commonly called "base of Knox Group", but it is not truly such. This reflector represents the sharp velocity change at the contact between shale and siltstone of the Davis Formation and overlying dolomite (Duchek et al. 2004).

Ordovician System

Shakopee Dolomite The oldest stratum reached by the drill in Williamson County is the Shakopee Dolomite. The Gallagher Oil #1 Old Ben Coal test in sec. 1, T 8 S, R 1 E drilled about 200 feet (60 m) into the Shakopee, whereas the C.E. Brehm #1 Harris test in sec. 25, T 8 S, R 3 E drilled 112 feet (34.1 m) into the unit. Samples from both wells are dolomite that is light gray to light brownish-gray and microgranular to finely granular. Dolomite near the top is partly sandy and cherty; these impurities disappear downward. These well samples agree with the Shakopee Dolomite as described by Willman et al. (1975), Sargent (1991), and Kolata (2010).

"Unnamed unit" An "unnamed dolomite unit" 296 feet (90.2 m) thick overlying the Shakopee Dolomite was logged by Z. Lasemi of the ISGS based on cuttings from the Brehm #1 Harris test hole. The lower half is composed of dolomite similar to Shakopee but somewhat darker and containing more sand, clay, and silt impurities. Chert comprises 20 to 30% of the samples. The upper half of the unnamed unit grades to dark gray and dark brown, sandy dolomite that is interbedded with dolomitic sandstone similar to that of the overlying Everton Formation.

The "unnamed unit" described by Lasemi is shown on several regional cross sections in southern Illinois (Sargent et al. 1992; Treworgy et al. 1992; Whitaker et al. 1992). These authors observed that the "unnamed argillaceous dolomite overlying the Shakopee" is confined to the southern, deepest

Table 1 List of Selected Deep Holes in Williamson County.

County No.	Operator	Number	Farm or Lease	Spot Location	Section	Depth (ft.)	Type of Logs	Formation at Bottom
T8S, R1E								
33290	Gallagher	1	Old Ben Coal	SW NW SW	1	7,404	D, GR, IE, N, S, SS	Shakopee Dolomite
23990	Paragon Oil	1 11	Illinois Minerals	SE NE NW	11	4,404	D, GR, IE, N, S, SS	Grand Tower(?)
T8S, R2E								
24160	Stewart Producers	4 1	Stewart-Hamilton	SE SW SE	4	4,595	D, GR, IE, N	Clear Creek
2512	C.E. Brehm	3-B	Littlefair	NE SE SW	12	4,669	D, E, IE, SS	Clear Creek
24157	Paragon Oil	2 12	Illinois Minerals	ctr NE SW	12	4,650	D, GR, IE. N	Clear Creek
24156	Paragon Oil	1 12	Illinois Minerals	SW NW SE	12	4,602	D, GR, IE, N	Clear Creek
23999	DeMier Oil	1	Roach	SW SW SE	12	4,450	D, GR, IE, N	Clear Creek
T8S, R3E								
24159	Stewart Producers	8 1	Illinois Minerals	SW NW SE	8	4,650	D, GR, IE, N	Clear Creek
24145	Paragon Oil	1	Illinois Minerals	NW NW NW	17	6,725	D, GR, IE, N, S, SS	Plattin
23516	Eugene Morrris	1-C	Forcum	SE NE NE	23	4,043	D, GR, IE, N	Fort Payne
2544	C.E. Brehm	1	Shannaford	SW NE SW	24	4,784	GR, IE, N	Clear Creek
2531	C.E. Brehm	1	Harris	SE NE SE	25	8,500	E, SS	Shakopee (deepest in county)
2477	C.E. Brehm	1	Glen Comm.	NW SE SE	25	4,730	E, SS	Clear Creek
T8S, R4E								
24136	Gesell's Pump	1 GA	Illinois Minerals	SW NW NW	6	4,075	D, GR, IE, N	Ullin
23381	Atlantic Richfield	1	Ritchey	NW SE SW	28	6,901	D, GR, IE, N, S, SS	Plattin
23495	Gallagher	1	Gidlund	NW SE SW	33	6,600	D, GR, IE, N, SS	Plattin
23383	Atlantic Richfield	1	Perry	SE SE SW	33	7,100	IE, S	Plattin
T9S, R2E								
23523	Vaughn	1	Eovaldi-Fairchild	NW SW NE	4	4,414	D, GR, IE, N, SS	Clear Creek
T9S, R4E								
23421	Ashland	1	Meadowlark Farms	NW NW SE	21	4,650	D, GR, IE, S, SS	Clear Creek

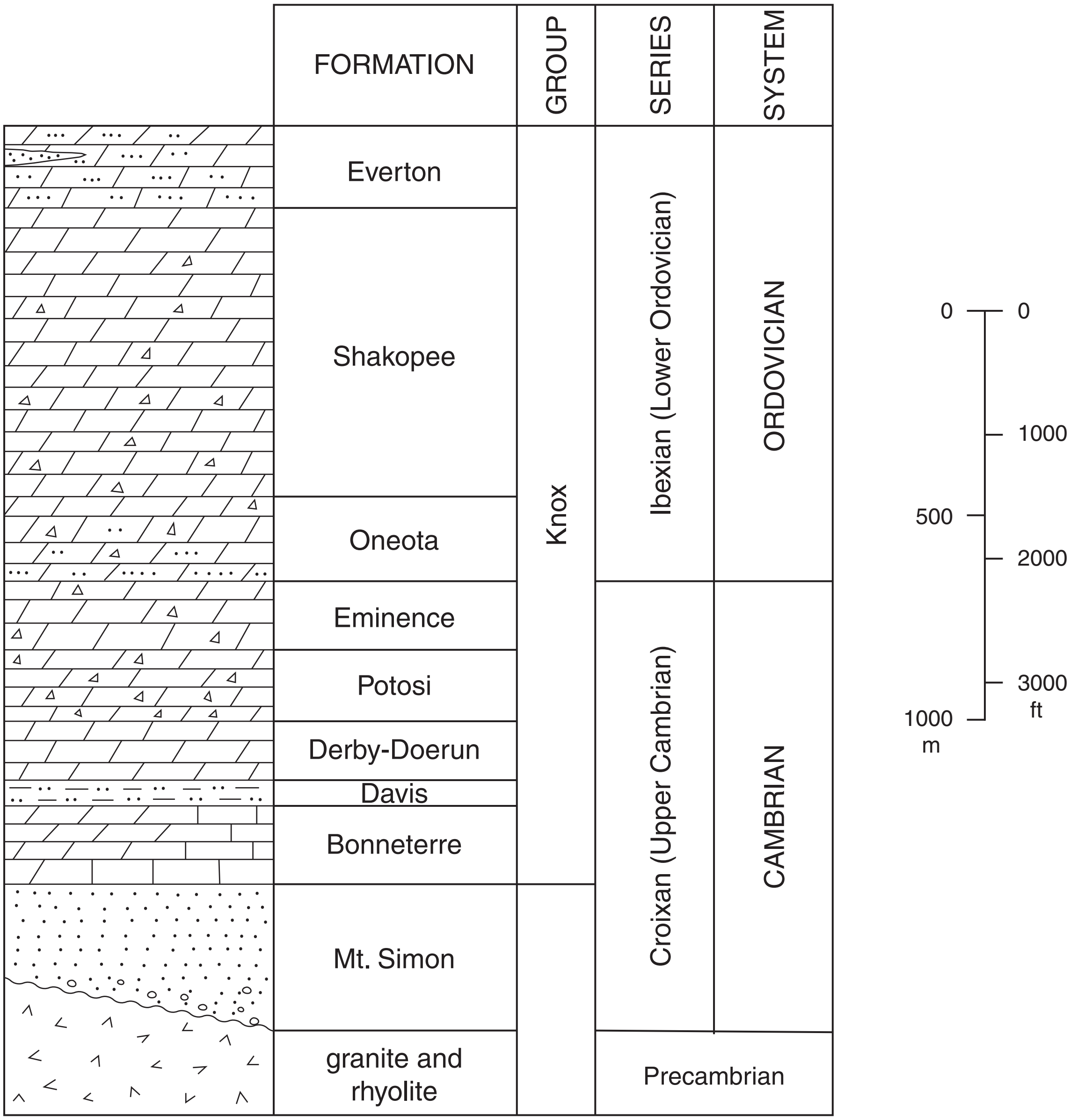


Figure 4 Stratigraphic column showing Cambrian and Lower Ordovician rocks in southern Illinois. The deepest borehole in Williamson County extended about 200 ft (60 m) into the Shakopee Dolomite.

part of the Illinois Basin. Although cross sections suggest correlation with the Smithville Dolomite in Missouri, neither the Smithville nor any other Lower Ordovician unit in Missouri resembles the unnamed unit (Thompson 1991).

In cuttings from the Gallagher #1 Old Ben hole, I observed dolomitic sandstone and very sandy dolomite 7,050 to 7,200 feet (2,150 to 2,190 m) depth directly overlying the Shakopee Dolomite. These samples appear to be typical Everton, as described by Willman et al. (1975), Kolata and Noger (1991), and Thompson (1991). On the latest statewide bedrock geologic map of Illinois, D.R. Kolata (2005) included the "unnamed unit" with the Everton Formation.

Everton Formation The Everton is an interval of sandy dolomite and dolomitic sandstone underlying the St. Peter Sandstone and overlying sand-free dolomite (Willman et al. 1975; Thompson 1991; Kolata and Noger 1991). Strata meeting this description are 264 feet (80.5 m) thick in the Harris well and 350(?) feet (107(?) m) thick in the Old Ben well. Thickness in the latter is questionable because samples from the lower St. Peter and upper Everton are missing.

In both wells, sandstone of the Everton is light gray to brownish-gray and composed of fine to medium-grained, well rounded quartz sand. Dolomite is medium brownish-gray and microgranular to finely granular, containing varying amounts of rounded quartz sand. A little dark gray to greenish-gray shale was logged in the Harris well.

St. Peter Sandstone The St. Peter Sandstone (Fig. 5) is a highly distinctive Ordovician unit found throughout the upper Mississippi Valley. The Old Ben and Harris wells penetrated typical St. Peter composed of pure quartz sand that is white to light gray and fine to medium-grained. Sand grains are subrounded to well rounded; many are frosted. Most sandstone is

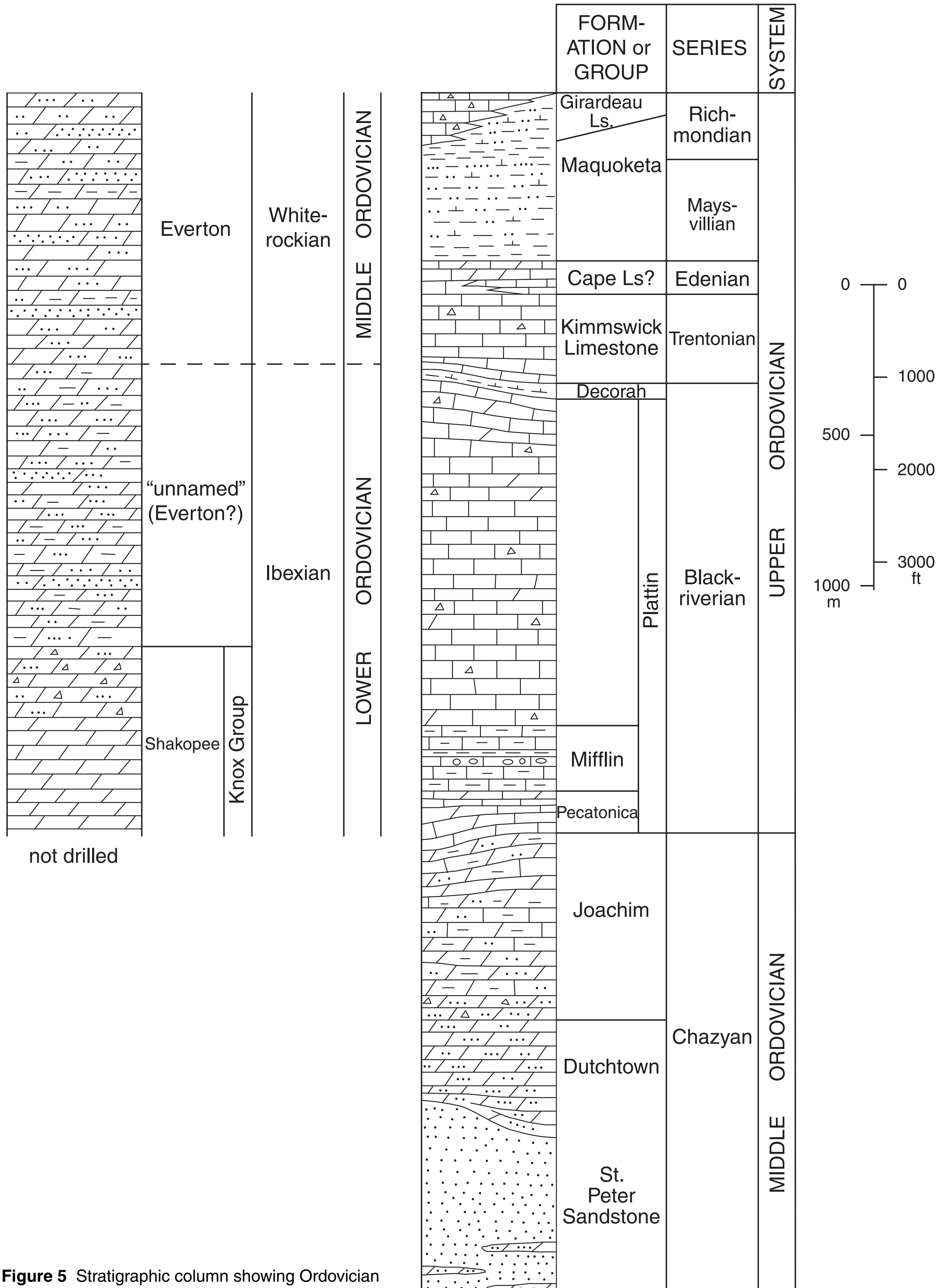


Figure 5 Stratigraphic column showing Ordovician rocks penetrated by the drill in Williamson County.

weakly cemented and is sampled as loose sand. The lower St. Peter has dolomitic cement and may grade to sandy dolomite. The St. Peter is about 250 feet (76 m) thick in the Harris well and appears to be about 200 feet (61 m) thick in the Old Ben well, although the lower contact was not sampled in the latter.

Dutchtown Formation The Dutchtown appears to be 90 feet (27 m) thick in the Old Ben well, but it is 354 feet (108 m) thick in the Harris well, 14 miles (23 km) southeast. In both wells the unit is sandy dolomite that is medium to dark gray and brown and generally microgranular. This includes interbeds of white, fine to medium-grained sandstone composed of rounded quartz grains cemented by dolomite. A small amount of anhydrite was logged in the upper part of the Dutchtown in the Harris well.

Joachim Formation The Joachim Formation is approximately 190 feet (58 m) thick in both the Harris and Old Ben holes and consists of partly argillaceous, dolomitic limestone and dolomite that are mottled in light to dark gray and brownish-gray, generally becoming darker downward. These rocks are microgranular to finely granular and classified as lime mudstone to pelloidal wackestone. No fossils were observed. Minor lithologies include greenish-gray to dark gray shale, dark gray calcareous siltstone, and anhydrite. The Joachim becomes sandy and cherty toward the base, apparently grading into the Dutchtown.

Plattin Limestone Although most publications on Illinois geology refer to these rocks as the Platteville Group, the name Plattin Limestone is more appropriate for Williamson County. Thompson (1991) observed that the Platteville (named for Platteville, Wisconsin) is a unit of dolomite and dolomitic limestone, whereas the Plattin (named for a creek south of St. Louis, Missouri) is dominantly limestone containing little dolomite. Because well samples from the relevant interval in Williamson County closely resemble typical Plattin Limestone rather than Platteville dolomite, the name Plattin is used here.

Two wells in Williamson County penetrated the entire Plattin; three others bottomed within it (Table 2). Plattin samples consist of limestone that is mottled in light to medium gray and brownish-gray. Texture varies from sublithographic to very finely granular lime mudstone, with very small amounts of fine- to medium-grained wackestone, packstone and grainstone. Some limestone is dolomitic, but true dolomite is absent. Rare echinoderm and brachiopod fragments occur. Chert is sparse. The Plattin is 470 feet (143 m) thick in the Old Ben well and 530 feet (162 m) thick in the Harris well.

The Plattin can be subdivided in the Harris and Old Ben wells, as in many deep wells in southern Illinois, The Pecatonica Member at the base is 65 to 70 feet (20 to 21 m) of pure carbonate rock, yielding uniformly low gamma-ray readings. The overlying Mifflin Member is argillaceous to silty limestone that produces a ragged signature on gamma-ray logs. Light gray to brown oolitic and peloidal packstone and grainstone logged at the top of the Mifflin in the Harris well may represent the Brickeys Member (Thompson 1991). Above the Brickeys is pure carbonate rock, similar to the Pecatonica. The Deicke K-bentonite Bed, 20 to 25 feet (6 to 8 m) below the top of the Plattin, is a regionally widespread volcanic-ash layer that is prominent on gamma-ray logs.

Decorah Formation The Decorah is less than 10 feet (3 m) thick in Williamson County and is identified as a thin shaly interval overlying the Plattin. A characteristic "spike" on the gamma ray-density log from the Old Ben well probably represents the Millbrig K-Bentonite Bed, another volcanic

Table 2 Wells in Williamson County that penetrate faults in Mississippian strata.

County No.	Operator	Number	Farm/lease	Spot Loc.	Section	Township	Range	Depth (ft)	Throw (ft)	Fault Dip	Formations
1934	Rehn & Calvert	1-A	Humphreys	SE-SE-NE	4	8S	2E	2,120	200	65 S	Hardinsburg, Golconda, Cypress
2231	J.E. Fulford	1	Madison Coal	SE-SE-SE	14	8S	3E	2,200	75	62 SW	Golconda
2515	C.E. Brehm	1	Morris	SE-NE-NW	24	8S	3E	1,650	95	60 SW	Kinkaid, Degonia
2099	Rehn & Calvert	1	Hearn et al.	NE-NW-SE	24	8S	3E	2,600	110	62 SW	Cypress to Bethel
2476	C.E. Brehm	1	Edwards	NE-SE-NW	1	9S	4E	2,515	180	86 S	Cypress to Bethel

ash bed (Kolata 2010). Because the Decorah is so thin, well cuttings provide little information. Regionally, this unit is argillaceous limestone with interbeds of calcareous shale, containing abundant and diverse marine fossils.

Kimmswick (Trenton) Limestone The Kimmswick (Trenton of petroleum geologists) is white, coarsely crystalline limestone that is correlative to darker dolomite and dolomitic limestone of the Galena Group in northern Illinois. In Williamson County the Kimmswick is 110 to 150 feet (34 to 46 m) thick. Samples consist of nearly white to medium brownish-gray, medium to very coarsely crystalline crinoidal grainstone. The upper 20 to 30 feet (6 to 9 m) is darker, dolomitic limestone that is microgranular to medium granular. This may represent the Cape Limestone, a formation distinct from the Kimmswick (Thompson 1991; Nelson et al. 1995).

Maquoketa Formation The Upper Ordovician Maquoketa Formation is 127 to 161 feet (38.7 to 49.1 m) of siltstone and silty shale that are medium to dark olive and brownish gray, weakly laminated, and somewhat calcareous or dolomitic. At the base is about 5 feet (1.5 m) of dark gray, non-silty, thinly fissile shale that contains tiny black, well rounded pellets of phosphorite. Above this is are two upward-coarsening intervals, the lower being 100 to 130 feet (30 to 40 m) thick and the upper 25 to 35 feet (8 to 11 m) thick.

Limestone 35 to 53 feet (11 to 16 m) thick overlies Maquoketa shale and siltstone in northeastern Williamson County. This rock is medium brownish-gray and sublithographic, containing a few echinoderm fragments and less that 10% chert. Distinct from the overlying, much chertier Sexton Creek Limestone (Silurian), the older limestone is a good match for the Girardeau Limestone (Ordovician) in its type area (Nelson et al. 1995; Thompson 1991).

Silurian System

Sexton Creek Limestone The Sexton Creek Limestone (Fig. 6) is composed of medium to light gray lime mudstone and crinoidal wackestone along with 10% to 30% chert that is brownish gray and opaque to slightly translucent. It appears to be 70 to 90 feet (21 to 27 m) thick; but distinguishing Sexton Creek from Girardeau(?) using wireline logs alone is difficult. Sexton Creek and Girardeau together are 110 to 138 feet (34 to 42 m thick) according to available logs.

St. Clair Limestone This chert-free limestone is light gray to buff, mottled and spotted with orange and pink material that appear to be clay. The rock is sublithographic to finely crystalline and lacks recognizable fossil fragments. Thickness varies from approximately 40 to 65 feet (12 to 20 m). Gamma-ray logs suggest the upper St. Clair is more argillaceous than the lower part. These logs also show a thin but sharply defined shale at the base: probably the Seventy-Six Shale Member, which in southeastern Missouri is a green to brick-red unit loaded with glauconite and hematite (Thompson 1993).

Moccasin Springs Formation Samples from Williamson County wells are silty and argillaceous, dolomitic limestone having microgranular to very finely granular texture. Chert is sparse and scattered echinoderm fragments are the only fossils. Some rock is reddish to purplish-gray and brick-red; other rock is light to medium-dark gray and greenish gray. Reddish and gray varieties alternate in irregular fashion. Moccasin Springs of Williamson County appears to be in transition between the strongly red, highly argillaceous limestone of southernmost Illinois and the gray, slightly argillaceous rock of central Illinois. Thickness ranges from 160 to 215 feet (49 to 66 m). The highly variable clay content produces a ragged profile on all types of wireline logs, in contrast with the more uniform or "massive" log patterns of the relatively pure carbonate rocks above and below.

Devonian System

New Harmony Group The New Harmony Group (Fig. 6) comprises four formations: Bailey Limestone (partly Silurian age) at the base, Grassy Knob Chert, Backbone Limestone, and Clear Creek Formation. All four were identified in two wells having good sample sets, the Gallagher #1 Old Ben and Brehm #1 Harris. Distinguishing these formations using wireline logs alone is problematic. Total thickness of the group in the five wells that completely penetrate it is 1,020 to 1,290 feet (311 to 393 m).

The Bailey Limestone, 430 to 620(?) feet (130 to 190(?) m) thick, is light gray to medium-dark brownish gray limestone that is partly dolomitic and microgranular to very finely granular. No fossils were observed. Chert comprises 10 to 20% of the samples; it is slightly translucent and has a bluish cast. In the Harris well, white to light gray, coarse crinoidal grainstone (similar to Backbone) was logged in the upper-middle Bailey.

Grassy Knob Chert is bedded chert and very cherty limestone and dolomite. Carbonate rock resembles that of the Bailey but contains sand-size grains of dark green glauconite, particularly near the base. Chert is light gray to smoky bluish gray and opaque to slightly translucent. Chert and carbonate rock are intricately intergrown, suggesting the latter was silicified after deposition. In the Old Ben and Harris wells, chert content varies from 1/3 to 2/3 of the rock volume. Thickness of the Grassy Knob is about 150 to 200 feet (45 to 60 m).

The Backbone Limestone is white to light gray, medium to coarse-grained crinoidal grainstone having crystalline texture. It contains a little opaque, white to light gray chert and scattered glauconite grains. Based on samples, the Backbone is about 145 feet (44 m) thick in the Old Ben well and 175 feet (53 m) thick in the Harris well, but within these intervals, finely textured carbonate rock like that of the overlying Clear Creek alternates with crinoidal grainstone. Whether the fine-grained rock represents a facies changes or recrystallized grainstone is unclear.

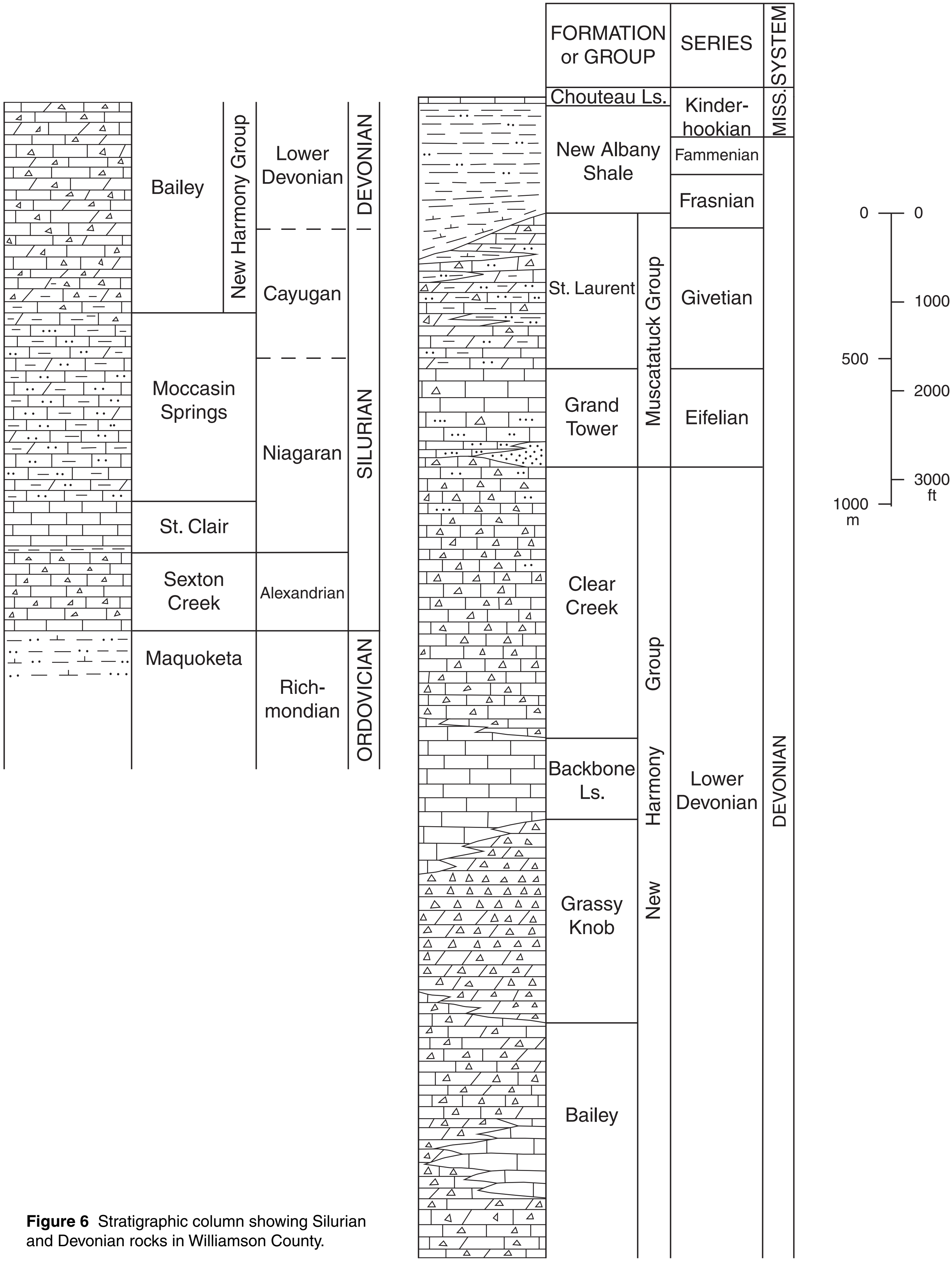


Figure 6 Stratigraphic column showing Silurian and Devonian rocks in Williamson County.

The Clear Creek Formation is a unit of cherty limestone that resembles the Bailey. It contains a few brachiopod fragments and has quartz silt and very fine sand scattered in the upper part. The upper contact is sharp in samples but difficult to identify on wireline logs. Thickness of the Clear Creek is approximately 300 feet (90 m).

Grand Tower Limestone The Grand Tower in Williamson County is about 80 to 140 feet (24 to 43 m) thick, the lower contact being indefinite in wells that lack samples. White to light gray, medium to coarse crinoidal grainstone is characteristic. Lesser amounts of packstone, wackestone, and lime mudstone are present; chert is a minor constituent. The Dutch Creek Sandstone Member at the base ranges from a few feet to about 30 feet (9 m) thick. This unit varies from slightly sandy limestone to quartz sandstone having calcite cement. Sand grains are fine, well sorted, and well rounded.

Two dry oil-test holes, the Ashland #1 Meadowlark Farms (sec. 21, T9S, R4E) and the Vaughn #5 Eovaldi-Fairchild (sec. 4, T9S, R2E) reached Middle Devonian strata but stopped short of the Dutch Creek, their presumed objective. Well-site geologists may have misidentified St. Laurent or upper Grand Tower carbonates as Clear Creek.

St. Laurent Formation Previously called Alto and Lingle Formations, the St. Laurent differs from the Grand Tower in being darker colored and dominantly micritic limestone and dolomite. Some wackestone and packstone are present, but most of the rock is lime mudstone. Fossil fragments are mostly echinoderms and bryozoans. Plenty of chert occurs in the St. Laurent. Some beds are very silty and argillaceous; silty dolomite may grade to dolomitic siltstone and silty shale, especially at the base. The impure character of the St. Laurent compared to the Grand Tower is evident on most wireline logs. Thickness is in the range from 120 to 170 feet (36 to 52 m).

New Albany Shale This well-known "black" shale is 65 to 237 feet (20 to 72 m) thick in Williamson County wells, increasing toward the southeast in line with regional trends. Most of the shale is dark brownish-gray to nearly black, silty, slightly to moderately fissile, pyritic, and non-calcareous. Very high gamma-ray readings are diagnostic. On electric logs, the New Albany responds much like impure carbonate rock. Where the New Albany is thick, the lower part is generally a little lighter in color, partly dolomitic, and exhibits lower gamma-ray readings. Both contacts are sharp.

Mississippian System

Chouteau Limestone The Kinderhookian Chouteau Limestone (Fig. 7) is a thin (3 to 10 feet, 1 to 3 m) but widespread and easily identified on wireline logs and in samples, which reveal limestone that is light brown, slightly dolomitic and argillaceous, and sublithographic to indistinctly granular.

Springville Shale This dark brownish-gray silty shale and siltstone is hard, slightly calcareous, and weakly fissile. Samples and wireline logs record an upward-coarsening sequence, finely silty shale at the base grading to siltstone at the top. Thickness increases from 27 feet (8.2 m) on the southeast to 94 feet (29 m) on the northwest. The Springville is a thin, fine-grained lateral facies of the Borden Siltstone (Lineback 1966).

Borden Siltstone The only well in Williamson County that encountered Borden Siltstone is the Gallagher #1 Old Ben Coal in sec. 1, T8S, R1E. Here the Borden is 217 feet (66.1 m) thick, and is basically an thicker version of the Springville. Dark gray, calcareous, moderately laminated, silty shale in the lower part gradually changes upward to lighter colored, massive to weakly laminated siltstone. Both contacts are sharp. As mapped by Lineback (1966), this area is at the southern tip of a large Borden delta that advanced into Illinois from the northeast.

Fort Payne Formation The Fort Payne is absent in the Old Ben well cited above; elsewhere in the county this unit ranges from about 150 to 390(?) feet (45 to 120(?) m) thick. Typical Fort Payne is dark gray to brownish-gray, microgranular to very finely granular dolomite and dolomitic limestone. This rock can be very argillaceous and silty and partly silicified, containing plentiful chert that is dark bluish gray and bluish brown. Sponge spicules and a few echinoderm fragments are the only fossils. Pyrite and glauconite are concentrated at the base, which is sharply defined in samples and wireline logs. The upper contact is gradational and difficult to pick from wireline logs alone.

Ullin Limestone Well-site geologists and oil scouts call this unit the Warsaw. Well samples consist of light gray to light brown packstone and grainstone. Bioclasts are mostly echinoderms; fenestrate bryozoans and brachiopods also are present. Some grains are rounded and coated, although true oolites are absent. Much of the limestone is dolomitic and obscurely granular, fossil grains are difficult to identify even in wet samples. Toward the bottom the rock gradually becomes darker and finer as chert appears along with a trace of glauconite. The chert is bluish-gray to brown and has the same bioclastic texture as the limestone.

Uniformly low gamma-ray readings, indicative of clean carbonate rock, identify the Ullin. The contact to the Salem is generally distinct. The Ullin is approximately 340 to 680 feet thick in Williamson County.

Ullin Limestone in Williamson County differs from that of the type area in Union County, where the Ullin is distinctly speckled and consists of coarse echinoderm fragments in a matrix of fenestrate bryozoan fronds. In Williamson County, much of the Ullin appears to have been dolomitized and recrystallized.

Salem Limestone The Salem Limestone (Fig. 7) ranges from about 225 to 390 feet (69 to 120 m) thick in Williamson County. It is distinctly granular, bioclastic limestone,

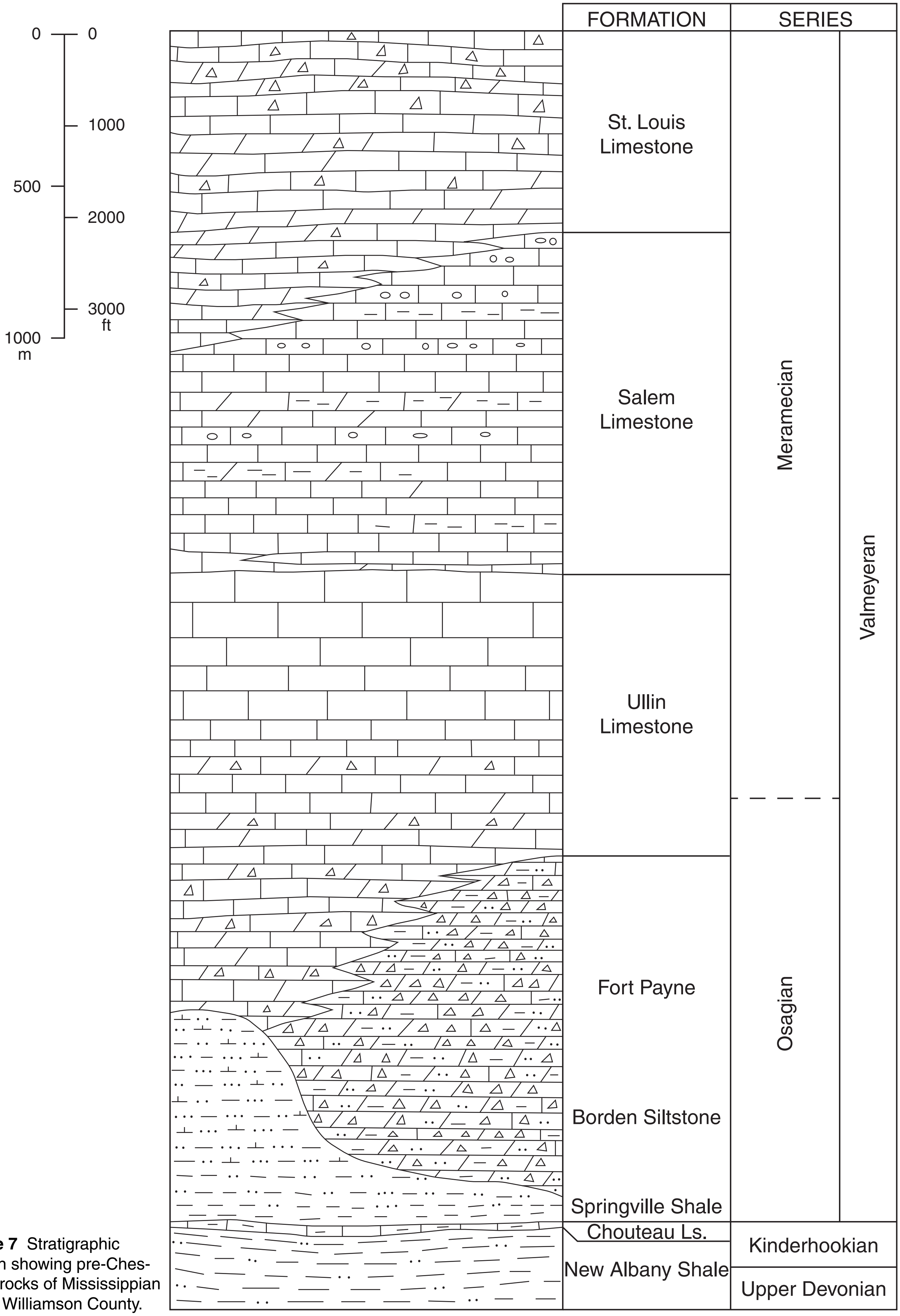


Figure 7 Stratigraphic column showing pre-Chesterian rocks of Mississippian age in Williamson County.

ranging from lime mudstone to grainstone. Colors range from light gray to dark brownish-gray; the more micritic and argillaceous varieties being darker. Fossil grains include echinoderms (most abundant), bryozoans, brachiopods, and foraminifera. Endothyrid foraminifera, widely reported to be diagnostic of the Salem, are rare in cuttings from Williamson County. Fossil grains commonly are rounded and coated; true oolites are present but darker and smaller than those of the younger Ste. Genevieve Limestone. Many samples from the Salem are obscurely granular limestone that have undergone recrystallization. The Salem contains a little dolomite and dolomitic limestone, chert is a minor constituent.

The lower contact is distinct in most wells where uniformly low gamma-ray readings of the Ullin become more variable in the Salem. The upper contact to the St. Louis is subtle at best. The St. Louis is generally dense limestone and dolomite that lacks porosity, whereas the Salem contains alternating intervals of pure, slightly porous limestone and argillaceous, impermeable carbonate rock.

St. Louis Limestone The St. Louis may vary from 205 to 350 feet (62 to 110 m) thick, both contacts are difficult to locate precisely. Applying my own lithologic criteria, sample tops for St. Louis and Salem consistently fall 100 feet (30 m) or more below those of well-site geologists and oil scouts. My criteria for the St. Louis are: dominantly micritic limestone and dolomite, sublithographic to very finely granular, in variable shades of light to medium gray and brownish gray. Pelletal and skeletal wackestone and packstone occur in the St. Louis and may contain rounded, coated fossil grains, but grainstone and true oolites are rare. Light bluish-gray to brown, translucent chert is abundant in the upper part of the formation but sparse in the middle and lower part.

Distinguishing the St. Louis from its bounding formations on wireline logs is difficult. I placed the upper contact at the base of the lowest porous grainstone of the Ste. Genevieve Limestone, as indicated by high S.P., very low gamma-ray, and relatively low density readings.

Ste. Genevieve Limestone A primary target of petroleum exploration, the Ste. Genevieve Limestone (Fig. 8) is typically light-colored, oolitic and skeletal grainstone that contains subordinate amounts of darker-colored micritic limestone (packstone, wackestone, and lime mudstone) along with microgranular dolomite, sandstone, siltstone and shale. Oolites are larger, more abundant, and more conspicuous in the Ste. Genevieve than in any other formation of the region. Oolitic grainstone having intergranular porosity is a highly-sought petroleum reservoir not only in Williamson County but throughout the Illinois Basin.

Fossils identified in well samples include echinoderms, bryozoans, brachiopods, molluscs, and foraminifera. All except the last-named are generally fragmentary. Dolomite in the Ste. Genevieve is light to medium gray and brown, microgranular, and in some cases slightly vuggy. Sandstone is light gray and greenish gray, very fine to fine-grained, calcareous, and glauconitic. It commonly contains oolites and calcareous fossil fragments and it grades to sandy limestone. Siltstone and shale are generally dark gray and dark greenish-gray and well laminated.

Three members can be identified. The lower and middle Ste. Genevieve comprise the **Fredonia Limestone Member**, which is overlain by the **Spar Mountain Sandstone Member**, 8 to 40 feet (2.4 to 12 m) thick and the **Karnak Limestone Member**, 30 to 70 feet (9 to 21 m) thick. The Fredonia and Karnak Members are virtually identical in lithology: limestone as described above with at most thin lenses and interbeds of clastic rocks. The Spar Mountain is mostly sandstone, grading in part to sandy limestone and siltstone and containing a little dark gray, greenish gray, and reddish-brown shale, mainly at the top and base. Glauconite is conspicuous, more so than in other Mississippian sandstones. In northwestern and north-central Williamson County a second sandstone 5 to 20 feet (1½ to 6 m) thick occurs 20 to 30 feet (6 to 9 m) below the Spar Mountain.

The upper contact to sandstone of the Aux Vases Formation is distinct in samples and on most wireline logs; my picks generally agree with those of wellsite geologists and scouts. Because of differences in placing the lower contact, I interpret the Ste. Genevieve as being 300 to 370 feet (90 to 113 m) thick, whereas most wellsite geologists called it 200 to 250 feet (61 to 76 m) thick.

Aux Vases Formation Principal oil-producing formation in Williamson County, the Aux Vases is mostly sandstone, but also includes limestone, siltstone, shale, and mudstone. Sandstone varies from nearly white to greenish gray and is very fine to fine-grained, typically calcareous, and commonly contains oolites and fossil fragments. Glauconite is present, but less abundant than in the Spar Mountain. Sandstone grades laterally to limestone that is silty to sandy and is mostly oolitic and skeletal packstone and grainstone. Shale and mudstone occur mostly at the top and base; shale at the base generally is green, whereas shale and mudstone at the top are variegated in gray, green, and red. Thickness is generally in the range from 30 to 50 feet (9 to 15 m).

In core samples from the Energy oil field the Aux Vases sandstone averages 85% quartz, 5% feldspar, and 10% accessory minerals, clay matrix, and calcite cement (Huff ,1993). This falls into the range of subarkose and feldspathic arenite and contrasts with nearly all younger Mississippian sandstones, which are quartz arenite (more than 95% quartz grains). Cores reveal tidal rhythmites, bidirectional crossbedding, and the marine trace fossils *Asterosoma* and *Conostichus*. Huff interpreted oil-productive sandstone bodies as tidal sand bars and ridges, and I concur. The lenticular sandstone bodies pinch and swell; no scouring or valley incision is evident. Both contacts generally are sharp but conformable.

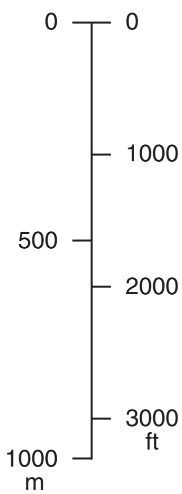
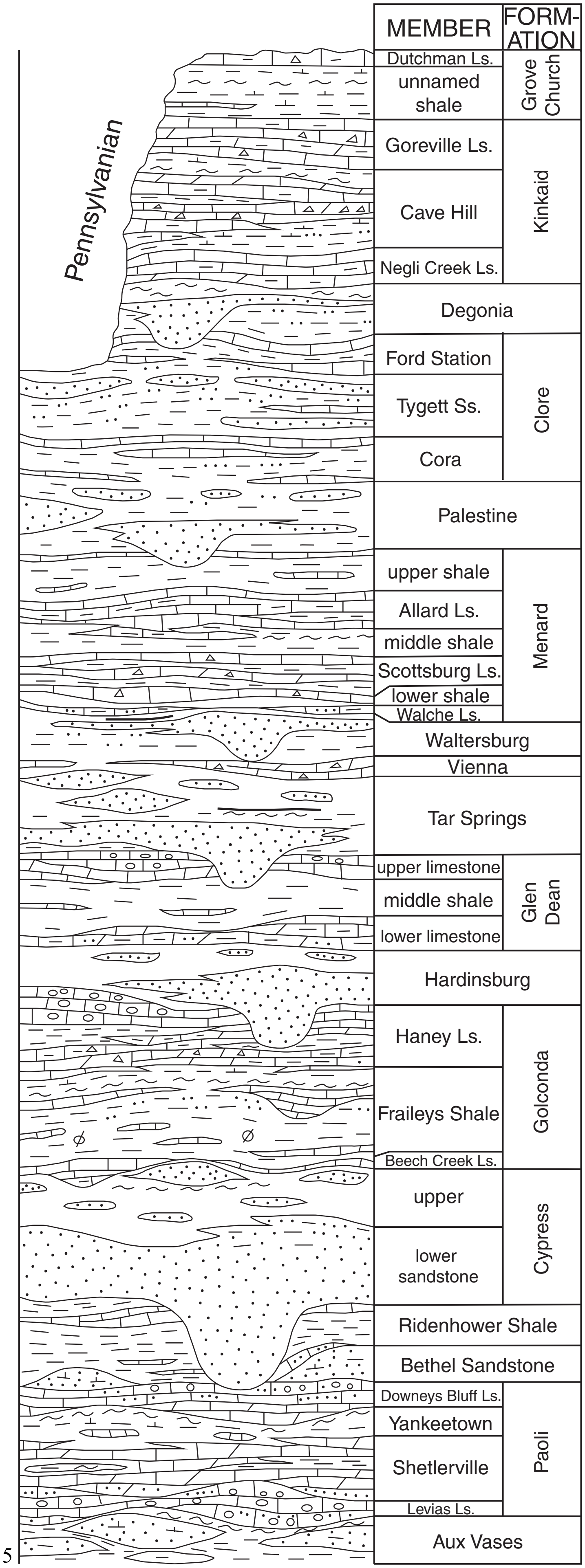
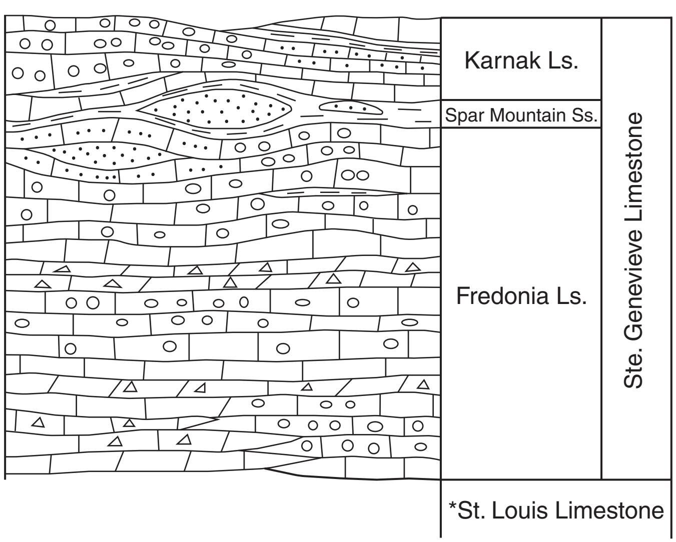


Figure 8 Stratigraphic column showing Chesterian (Upper Mississippian) rocks in Williamson County.

* The St. Louis Limestone belongs to the Valmeyeran (or Meramecian) Series.





Paoli Limestone The Paoli Limestone is the interval of mostly limestone that lies above the Aux Vases Formation and below the Bethel Sandstone or Ridenhower Shale (Nelson et al. 2002). Thickness of the Paoli varies from 72 to 147 feet (22 to 45 m), generally increasing southward. Where good samples and wireline logs are available, four members can be identified.

The **Levias Limestone Member** at the base is about 5 to 30 feet (1½ to 9 m) thick and composed of white to brown, coarse, sandy skeletal and oolitic grainstone. Red and pink hematitic oolites are characteristic.

The **Shetlerville Member** consists mostly of limestone with interbeds of shale. Most of the limestone is "drab" gray and brown grainstone to packstone, wackestone, and lime mudstone. Oolitic limestone is present, but not abundant. Shale, poorly represented in well cuttings, is dark gray, thinly fissile, calcareous, and fossiliferous (bryozoans being common). Several sample logs show sandy limestone or calcareous sandstone in the lower part; one log reports a basal conglomerate of micrite pebbles in a sandy matrix. This material probably represents the **Popcorn Sandstone Bed**, a regionally widespread but thin and patchy deposit that marks a regional unconformity separating the Levias from the Shetlerville (Swann 1963; Nelson et al. 2002). The Shetlerville is generally 20 to 40 feet (6 to 12 m) thick in Williamson County.

The **Yankeetown Member** is a variable interval of clastic rocks and limestone. Variegated red, green, gray, and purple mudstone to fissile shale is common, especially at the top. Siltstone to fine sandstone is present in some wells, particularly in the southeastern part of the county. Colors range from light gray to olive and greenish to reddish gray. Clastic rocks are calcareous and contains numerous marine fossil fragments, grading to sandy limestone. Thickness of the Yankeetown is 10 to 30 feet (3 to 10 m) thick in most wells, but picking its boundaries can be difficult because of intertonguing and gradational contacts.

The **Downeys Bluff Limestone Member** is largely white to light gray or light olive-colored, coarse crinoidal grainstone containing small oolites and scattered quartz sand grains. The most distinctive feature, not always present, is silicified echinoderm fragments in pink, red, and orange. The Downeys Bluff also contains microgranular dolomite and limestone along with shale that is dark gray and greenish gray and "splintery". Thickness varies from about 15 to 35 feet (5 to 11 m). The upper contact typically is sharp and probably disconformable.

Bethel Sandstone Petroleum geologists who work in Williamson County frequently call this unit the "Benoist sand", but that name properly refers to the older Yankeetown Sandstone, which is poorly developed here. The Bethel occurs as a series of isolated lenses less than 30 feet (9 m) thick in the western part of the county but reaching 85 feet (26 m) on the southeast. Lenses have flat bottoms and convex tops so that thickness of the overlying Ridenhower Shale varies in reciprocal fashion. Sandstone of the Bethel is light to medium gray, very fine to fine (occasionally medium) grained, and strongly calcareous. Echinoderm and other fossil fragments along with oolites commonly are present. Sandstone grades vertically and laterally to sandy limestone; electrical resistivity resembles that of limestone. Geometry and lithology of the Bethel indicate it is a marine sand, most likely formed (like the Aux Vases) as tidal sand bars or ridges (Nelson et al. 2002).

Ridenhower Shale Informally called "Paint Creek", the Ridenhower comprises a lower shale 50 to 70 feet (15 to 21 m) thick, a medial limestone as thick as 20 feet (6 m) but normally 3 to 8 feet (1 to 2½ m) thick; and an upper shale as thick as 20 feet (6 m). The lower shale is dark gray with a greenish to olive cast and a little dark red mottling (in the upper part). The thinly fissile, calcareous clay-shale contains few fossils. A uniform very low resistivity-log profile is characteristic. Isolated limestone beds occur within the lower Ridenhower shale. These are typically less than 5 feet (1½ m) thick, but one well in sec. 26, T8S, R4E contained a limestone lens 35 feet (11 m) thick. The geometry of this limestone body suggests an infilled channel.

The upper, persistent limestone bed of the Ridenhower varies from light gray to medium brown, coarse, crinoidal packstone to grainstone. This limestone is thickest on the southeast where it is overlain 15 to 20 feet (4½ to 6 m) of dark gray shale that is fossiliferous and contains laminae or interbeds of light gray sandstone. Whether the upper shale belongs to the Ridenhower or the overlying Cypress Formation is uncertain.

The Ridenhower generally thins as the underlying Bethel Sandstone thickens. Also, the Ridenhower thins where it has been incised by paleovalleys filled with sandstone of the younger Cypress Formation. In a few places such channels entirely cut out the Ridenhower and reach the top of the Paoli Limestone.

Cypress Formation The Cypress in generally divisible into a lower, thick valley-filling sandstone and an upper interval of interbedded siltstone, shale, mudstone, and lenticular sandstone. Such a two-fold division is prevalent in much of southern Illinois (Cole and Nelson 1995). In Williamson County, the Cypress ranges from about 80 to 200 feet (24 to 60 m) thick, the upper division being 50 to 80 feet (15 to 24 m) thick and the lower sandstone 20 to nearly 150 feet (6 to 45 m) in thickness.

The lower sandstone is white to light gray, very fine to medium-grained quartz arenite that is generally clean and well-sorted and has silica or calcite cement. Its log profile is either uniform and "massive" or fining-upward, becoming shaly near the top. The lower contact is strongly erosional, locally taking out the entire Ridenhower and cutting into the Bethel and Paoli Formations.

The upper Cypress contains shale, siltstone, and sandstone in highly variable proportions. Shale and siltstone are generally medium to dark gray, greenish gray, and olive gray. These lithologies intergrade and probably are interlaminated. Sandstone is also greenish to olive-gray, very fine to fine-grained, argillaceous, and calcareous. Most of it is tightly cemented. Red and green mottled mudstone is fairly common near the top of the Cypress. Coal was logged near the top of the Cypress in one well.

Golconda Formation The Golconda is a unit of limestone and shale that ranges from 115 to 210 feet (35 to 64 m) thick, being thickest in the southwest part of the county. It comprises three members that can be recognized through much of the Illinois Basin.

The **Beech Creek Limestone Member** at the base is uniformly called "Barlow[1]" by petroleum geologists. The Beech Creek is lenticular in Williamson County and in places it is absent or very thin. Generally less than 15 feet (4½ m) thick, the limestone attains a maximum of 27 feet (8.3 m) in what may represent an infilled channel. Gray to brown packstone, wackestone, and lime mudstone rich in echinoderm and bryozoan fragments are typical. The lower part can be sandy, grading to sandstone of the uppermost Cypress. The Beech Creek is missing in many wells where a sandstone lens is developed at the top of the Cypress, a relationship suggesting that such lenses formed highs on the sea floor.

The **Fraileys Shale Member** varies from 55 to 125 feet (17 to 38 m) thick, but 80 to 90 feet (24 to 27 m) is more typical. The Fraileys is largely dark gray to dark greenish and olive gray, thinly fissile, calcareous clay shale.

Bryozoans and other fossils are common, as are siderite nodules. On electric logs this shale exhibits a uniform, very low "flat" resistivity profile, similar to that of the older Ridenhower Shale.

Limestone beds and lenses occur within the Fraileys. In most of the county a limestone bed 5 to 10 feet thick is 10 to 15 feet below the top. This is light gray or brown to green and orange crinoidal grainstone and packstone having scattered pink and red grains. Some sample logs show several such beds intercalated with shale. The limestone locally and abruptly thickens to as much as 30 feet (9 m), apparently filling channels scoured into the shale. At the top of the Fraileys Member is claystone or silty mudstone variegated in red, green, and gray. Angular, blocky or hackly fracture and slickensides are common. Extensive through large areas of the Illinois Basin, this red and green unit is an excellent marker bed and is interpreted as a paleosol (Treworgy 1988; Nelson et al. 2002).

The **Haney Limestone Member** at the top of the Golconda ranges from about 20 to 100 feet (6 to 30 m) thick. This member is mostly limestone, but contains considerable shale. Limestone beds are moderately continuous; some are traceable for several miles. The rock is mottled in various shades of gray and brown. Crinoid-bryozoan packstone and grainstone is most prevalent, but the Haney contains diverse types of carbonate rock. Oolitic grainstone commonly is found near the top; scattered oolites and rounded, coated fossil grains are found throughout. Microgranular dolomite is a minor rock type. Shale of the Haney is dark gray to greenish gray, fissile, and calcareous. Marine fossils are abundant, especially bryozoans and echinoderms. The upper contact is generally sharp and in many wells is erosional.

Hardinsburg Formation The Hardinsburg is a variable succession of shale, siltstone, and sandstone that varies from about 30 to 145 feet (9 to 44 m) thick. Fine-grained rocks are medium to dark gray, well laminated, finely micaceous, and noncalcareous. Rooted, slickensided mudstone is present near the top. Sandstone is white to light gray, very fine to fine-grained quartz arenite with some medium sand in the lower Hardinsburg. Grains are angular to subrounded and cemented by silica or calcite. The Hardinsburg is entirely shale in some wells, entirely sandstone in others. Generally, where the formation is thin it is mostly shale. Where thicker the usual succession is a lower sandstone and an upper shale and siltstone containing lenses of sandstone. The lower sandstone is clean and relatively coarse, become finer-grained and more shaly upward and commonly filling valleys incised into the Haney Limestone. Lenticular sandstone of the upper Hardinsburg is finer grained and likely represents tidal sand bars or ridges (Nelson et al. 2002).

Glen Dean Limestone The Glen Dean comprises interbedded limestone and shale 55 to 85 feet (17 to 26 m) thick where fully preserved and thinning to as little as 20 feet (6 m) where it has been incised by valleys filled with the overlying Tar Springs Formation. In most of Williamson County the Glen Dean consists of two limestone members separated by shale. The **lower limestone** ranges up to 30 feet (9 m) thick and is mostly dark gray to brownish-gray, argillaceous to silty, dolomitic lime mudstone and wackestone. In some wells, this limestone is lighter colored and coarsely crinoidal near the top. Reflecting its clay and silt content, the lower limestone exhibits lower electrical resistivity than the upper Glen Dean. The **middle shale**, 14 to 40 feet (4.3 to 12 m) thick, is mostly dark gray, thinly fissile, soft, and calcareous clay shale to finely silty shale. Fossils, especially bryozoans, are abundant. Thin interbeds and lenses of limestone locally are present. The **upper limestone** is about 10 to 30 feet (3 to 9 m) thick and is composed largely light-colored medium to coarse-grained skeletal packstone and grainstone, containing oolites or rounded and coated fossil grains. Bioclasts are mostly echinoderm fragments. Lesser amounts of microgranular dolomite or dolomitic limestone occur in this unit. The limestone is sandy near the top in a few wells, suggesting

[1]This name is derived from a 1923 oil lease east of Owensboro, Kentucky and pre-dates formal naming of the Beech Creek Limestone in Indiana.

gradation to the Tar Springs. In other wells, as mentioned, the upper contact is erosional.

Tar Springs Formation The Tar Springs ranges from 63 to 150 feet (19 to 46 m) thick, but 90 to 100 feet (27 to 30 m) is usual. Thickest Tar Springs is found in the eastern part of the county, where the unit fills incised valleys or channels. This formation can be all shale or all sandstone, but more commonly contains a lower thick sandstone and an upper shaly interval with small lenses of sandstone. A few sample logs indicate thin coal and rooted mudstone near the middle. The lower sandstone is clean quartz arenite that becomes finer grained and shaly upward. Its lower contact is erosional, sandstone filling channels eroded into the Glen Dean. Where the lower sandstone is absent, the contact to the Glen Dean is conformable. The contact to the overlying Vienna limestone is sharp or rapidly gradational.

Vienna Limestone The Vienna Limestone is 0 to 15 feet (4½ m) thick in northern Williamson County and 5 to 20 feet (1½ to 6 m) thick in the southern part of the county. Well samples show mostly dark brownish-gray, argillaceous or siliceous, cherty, dolomitic lime mudstone and wackestone. Crinoidal packstone or grainstone containing scattered oolites occur near the top in some wells. The Vienna is generally a single limestone bed, but in places it splits into two limestone layers separated by shale.

Waltersburg Formation The Waltersburg is 35 to 70 feet (11 to 21 m) thick in Williamson County and shows no clearly defined thickness trends. In a large majority of wells this unit is dominantly shale that coarsens upward to thin siltstone or very fine sandstone near the top. Shale is dark gray or olive-gray to nearly black, thinly fissile, and noncalcareous. The lower part is a clay shale that produces a uniform “flat” profile on resistivity logs. Locally, thin limestone interbeds occur near the base of the Waltersburg. Toward the top the shale becomes silty, grading into dark olive-gray siltstone and tightly cemented sandstone. Thin coal was reported near the top of the Waltersburg in several wells.

Lenses of sandstone as thick as 50 feet (15 m) occur in less than 10% of wells. Such sandstone is white to light gray, very fine to medium quartz arenite, much like thick Tar Springs, Hardinsburg, and Cypress sandstone. Regional subsurface mapping of Waltersburg sand bodies shows elongate, linear or arcuate to gently meandering belts that trend southwest (Potter 1963). Where one of these sand bodies crops out in eastern Johnson County, it exhibits strongly unidirectional, southwest-dipping crossbedding and an erosional lower contact (Potter 1963; Nelson 1993a). These features suggest that Waltersburg sand bodies are fluvial or estuarine deposits filling incised valleys.

Menard Limestone The Menard is a highly uniform and consistent formation in the study area. Its thickness ranges from 105 to 142 feet (32 to 43 m), becoming slightly greater southward. Limestone and shale beds are widely continuous; many are traceable throughout the county. Six subdivisions are consistently present.

The **Walche Limestone Member** at the base is a single bed of impure limestone or dolomite 2 to 7 feet (0.6 to 2.1 m) thick. Well samples show dark gray or brownish gray, micritic dolomite or dolomitic limestone that is very argillaceous and silty. This impure rock exhibits lower electrical resistivity than most other carbonate beds of the Menard. On some logs, the Walche may be confused with tightly cemented sandstone at the top of the Waltersburg.

An **unnamed shale** 4 to 10 feet (1.2 to 3 m) thick separates the Walche and Scottsburg Members. This shale is dark gray, thinly fissile, and calcareous in cores and outcrops from adjoining counties.

The **Scottsburg Limestone Member** is 25 to 45 feet thick (7½ to 14 m), becoming slightly thicker toward the south. In most of the county this member comprises three limestone beds, each 5 to 10 feet (1½ to 3 m) thick, separated by similar thicknesses of shale. Limestone is mostly medium to dark brownish-gray, cherty lime mudstone and skeletal wackestone, with lesser amounts of packstone. Sublithographic limestone or dolomite commonly occurs near the top. Shale in the Scottsburg is thinly fissile, soft, calcareous clay-shale that is mostly dark gray with some greenish and olive mottling.

An **unnamed middle shale**, 10 to 27 feet (3 to 8.2 m) thick, consists mostly of dark gray shale similar to that of the Scottsburg. Some of the shale is silty. Near the top is massive claystone that is green or greenish gray with red and purple mottling. Angular blocky structure and slickensides suggest that this is a paleosol. Cores elsewhere in southern Illinois, particularly in the Fluorspar District, show this claystone is widely distributed.

The **Allard Limestone Member** is 22 to 42 feet (6.7 to 13 m) of limestone with thin shale interbeds. As in the Scottsburg, most of the limestone is drab-colored lime mudstone and skeletal or pelletal wackestone; but packstone and crinoidal grainstone also are present. Greenish gray, silty, microgranular dolomite was logged in the lower Allard in several wells. Shale resembles that found elsewhere in the Menard. The position and thickness of shale interbeds is more variable in the Allard than in the Scottsburg. Limestone beds of the lower Allard come and go, intertonguing with the middle shale.

At the top of the Menard is an **upper shale** that contains a couple of thin but highly persistent limestone beds. The member is 15 to 40 feet (4½ to 12 m) thick, being thickest on the southeast and thinnest where the overlying Palestine fills channels. The dark gray, thinly fissile, calcareous shale contains abundant bryozoans, brachiopods, and echinoderm fragments. Limestone is brownish-gray, argillaceous skeletal wackestone and packstone. A limestone bed 2 to 3 feet (60 to 90 cm) thick occurs near the top in almost every well in the county. The contact to the Palestine is sharp and erosional, with about 20 feet (6 m) of relief.

Palestine Formation This unit of sandstone, siltstone, and shale ranges from 40 to 100 feet (12 to 30 m) thick, with 60 to 70 feet (18 to 21 m) being typical. Like the Tar Springs, Hardinsburg, and Cypress, the Palestine commonly has a lower sandstone and an upper shaly unit with sandstone lenses. The lower sandstone is fine to medium-grained quartz arenite that tends to become finer grained and more shaly upward. Lenses of clean sandstone as thick as 45 feet (14 m) occur in the middle part of the Palestine. These are not incised into underlying strata and likely represent marine sand bars.

Carbonaceous, dark gray massive mudstone, possibly a paleosol, was logged in several wells near the middle of the Palestine. Also found locally near the middle of the Palestine is a limestone bed less than 5 feet (1½ m) thick. This dark, argillaceous lime mudstone or wackestone resembles limestone of the overlying Clore Formation. The upper Palestine is largely medium to dark gray, silty shale and siltstone, with lenses of very fine sandstone. The first limestone bed overlying these rocks marks the top of the Palestine. This limestone, however, commonly is so thin it does not register on electric logs.

Clore Formation Ranging from 75 to 145 feet (23 to 44 m) thick and thinning westward, the Clore Formation consists of shale, siltstone, sandstone, and limestone. Three named members are readily distinguishable. The **Cora Member** in the lower Clore comprises 25 to 65 feet (8 to 20 m) of shale and minor siltstone having thin interbeds of limestone. Shale is dark gray with an olive cast, thinly fissile, soft, and calcareous. Some is silty and grades to calcareous, argillaceous siltstone and very fine sandstone having scattered glauconite grains. Limestone of the Cora is dark brownish gray, silty and argillaceous lime mudstone and skeletal wackestone. Beds 2 to 5 feet (60 to 150 cm) thick near top and base of the member are widely traceable. Both shale and limestone contain echinoderm fragments, bryozoans, and brachiopods, especially productids.

The **Tygett Sandstone Member** is 15 to 45 feet (4½ to 14 m) thick in most of Williamson County, but this unit is absent around Johnston City and thickens to 70 feet (21 m) in the southeastern part of the county. In most wells the Tygett is a single sequence that coarsens upward from silty shale or siltstone at the base to sandstone at the top. Such a sequence probably represents a small, prograding delta. Elsewhere the Tygrett is composed of sandstone that is clean, white to light gray, fine to medium-grained, well sorted quartz arenite. A lack of downcutting at the base and the observation that the Ford Station Member thins where it overlies thick sandstone implies that the lenses are marine sand bars or tidal sand ridges similar to those of the Bethel Sandstone. Also, in the southern part of the county the Tygett comprises two sandstone bodies that coarsen upward and are separated by thin limestone and shale. Two to three distinct Tygett sandstone bodies have been mapped along the outcrop south of Williamson County (Devera 1991; Nelson 1993a; Nelson and Weibel 1996).

The **Ford Station Member** at the top of the Clore Formation is 20 to 50 feet (6 to 15 m) thick and consists of approximately equal parts of limestone and shale. Most limestone beds range from a few feet to about 15 feet (~1 to 4½ m) thick, but near Johnston City a limestone in the Ford Station is as thick as 28 feet (8.5 m). Sample logs record mostly yellowish to brownish gray, dolomitic, argillaceous and silty lime mudstone containing a few shell and echinoderm fragments. Green, marly limestone is a minor but conspicuous component. Shale of the Ford Station is dark gray to greenish gray and calcareous. The upper contact is conformable and gradational in most places, but locally it is erosional.

Degonia Formation The Degonia ranges from 30 to 100 feet (9 to 30 m) thick, being 40 to 60 feet (12 to 18 m) thick in most wells. An upward-fining sequence, grading from sandstone at the base to claystone at the top, is usual. Sandstone tends to be medium-dark gray or olive gray, carbonaceous, very fine to fine-grained, and argillaceous. Less common are lenses of clean white quartz arenite that are incised slightly into the Clore Formation. Both types of sandstone grade upward to siltstone and silty shale. Variegated maroon, purple, green, olive, and gray, massive to blocky mudstone 10 to 25 feet thick is at the top of the Degonia in most of the county. This mudstone, widespread throughout southern Illinois, probably is a paleosol. The upper contact to limestone of the Kinkaid is sharp, planar, and conformable.

Kinkaid Formation The Kinkaid is the youngest widely distributed Mississippian unit in the Illinois Basin. Three highly distinctive members have been recognized throughout the Illinois Basin.

The **Negli Creek Limestone Member** at the base is 25 to 33 feet (7½ to 10 m) thick throughout Williamson County. The Negli Creek is entirely limestone that is dominantly medium to dark brownish-gray, slightly argillaceous, dolomitic, and cherty lime mudstone and skeletal wackestone. Light gray, crinoidal packstone and grainstone, containing scattered oolites, occurs near the top in some wells. On electric logs, the Negli Creek has uniformly high resistivity. This is one of the best Mississippian marker units; its base was used as datum for the structure contours on the map that accompanies this report.

Overlying the Negli Creek is the **Cave Hill Member**, which itself is readily divided into a lower shale, a middle limestone-and-shale, and an upper shale-and-mudstone. Total thickness of the Cave Hill is 80 to 100 feet (24 to 30 m); the lower shale thickens from as little as 7 feet (2.1 m) on the west to 40 feet (12 m) on the east. The lower Cave Hill is composed of weakly fissile shale and siltstone that is dark greenish to olive-gray and calcareous, and contains bryozoans and echinoderm fragments. Samples and wireline logs consistently show an upward-coarsening profile. Limestone interbeds occur near the top, grading to and intertonguing with the middle limestone-and-shale. The lower shale seems to thicken eastward at the expense of the middle limestone-and-shale. The middle Cave Hill limestone-and-shale varies from 30 to 55 feet (9 to 17 m) thick, becoming thicker toward the northwest where the lower shale is thinner. This interval is mostly limestone with lesser dolomite and interbeds of greenish-gray and dark gray shale. Limestone is light to dark gray and brown lime mudstone and skeletal wackestone; packstone and grainstone occur in the middle to lower portion. Sublithographic limestone with dark, vitreous chert is characteristic. Light-gray lithographic dolomite that contains green clay inclusions is at the top. The only fossils identified in well cuttings are echinoderm fragments. The upper Cave Hill shale-and-mudstone is 15 to 20 feet (4 ½ to 6 m) thick in most places but reaches 27 feet (8.3 m) in northwestern Williamson County. Massive and blocky to weakly fissile mudstone is mottled in red, green, gray, olive, and purple. This rock varies from claystone to siltstone and commonly is calcareous. The variegated mudstone has been traced from southwestern Indiana through western Kentucky as well as Illinois (Willman et al. 1975; Shaver et al. 1986; Droste and Keller 1995; Trace and Amos 1984) and almost certainly represents a paleosol. Overlying the mudstone is fissile shale that is dark gray, greenish gray to nearly black, calcareous, silty, and contains thin interbeds of micritic limestone. Both contacts are sharp and apparently conformable.

The **Goreville Limestone Member** at the top of the Kinkaid ranges from 35 to 40 feet (11 to 12 m) thick on the southeast to 45 to 50 feet (14 to 15 m) elsewhere in the county. This member consists of dark gray and brownish-gray lime mudstone and wackestone along with light gray, coarse crinoidal packstone and grainstone. The more micritic rocks are somewhat argillaceous, dolomitic, and cherty. In most cases the grainstone is near the top, but some sample logs show it near the base. The Goreville exhibits a high resistivity log profile like that of the Negli Creek.

Grove Church Shale Swann (1963) originally described the Grove Church Shale as the youngest Mississippian formation in the Illinois Basin, overlying the Kinkaid Limestone. Nelson et al. (1991) revised the Grove Church to a member of the Kinkaid; some (but not all) subsequent authors followed this classification. In the present report the Grove Church is revised back to a separate formation chiefly because it is predominantly shale, whereas the Kinkaid is largely limestone with subordinate shale. Also the Grove Church Shale has a fauna markedly different from that of the Kinkaid Limestone. The trilobite, *Paladin grovechurchensis*, the crinoid, *Pterotocrinus pegasus* and the conodont, *Adetognathus unicornis* are characteristic of the Grove Church and do not occur in the Kinkaid Limestone (Joseph A. Devera, ISGS, written communication, 2020). As recognized here, the Grove Church is divided into two members: an unnamed lower shale member and the Dutchman Limestone Member at the top. Although the name Dutchman Member was used in an earlier publication (Nelson et al. 2004), the type section and other relevant attributes are fully detailed here for the first time.

The Grove Church occurs sporadically because of erosion at the base of the Pennsylvanian Caseyville Formation. Across most of Williamson County and elsewhere in southern Illinois the Grove Church is absent and Pennsylvanian strata rest unconformably on the Kinkaid Limestone or older Mississippian units. Where fully preserved, the **unnamed lower shale member** is 50 to 57 feet thick (15 to 17 m) thick and consists mostly of platy and fissile shale that is mottled in greenish, olive, and dark gray along with dark red or maroon. Shale is calcareous and contains bryozoans, brachiopods, echinoderm fragments, and conodonts. Dark gray, silty shale containing plant fragments is in the lower Grove Church. Variegated mudstone is logged in the upper part of the lower member in several wells. This rock is mottled in brick-red, maroon, olive and greenish gray. Massive to blocky structure, waxy texture, and slickensides are prevalent. Thin interbeds of limestone, including brown crinoidal grainstone, also occur in the lower member of the Grove Church.

The name **Dutchman Limestone Member** (of Kinkaid Formation) first appeared on a geologic map by Nelson et al. (2004). The name refers to Dutchman Lake, an artificial body of water situated about 16 miles (26 km) due south of Marion in Johnson County, Illinois. The type section is along the hillside immediately south of the dam in the SE¼ NE¼ SE¼, sec. 7, T12S, R3E, Johnson County, Vienna 7.5' quadrangle (Appendix). In this outcrop, the Dutchman Member is 10 feet (3 m) thick and is overlain almost directly by Pennsylvanian sandstone and underlain by poorly exposed shale of the lower Grove Church approximately 70 feet (21 m) thick. As a principal reference section, core from the ISGS #1 Jones stratigraphic test hole, drilled 5,000 feet (1,500 m) southeast of the type section, is hereby specified (Appendix). The only known outcrops of the Dutchman Limestone member are in the immediate vicinity of Dutchman Lake, where the unit has a maximum thickness of about 15 feet (4½ m) and consists of limestone with minor shale interbeds. The Dutchman conformably overlies the unnamed lower shale member of the Grove Church Shale and is unconformably overlain by the Caseyville Formation (Pennsylvanian). Sample cuttings and electric logs of several oil-test holes in southeastern Williamson County indicate presence of the Dutchman Member. Samples are composed of medium to dark gray and brownish-gray (occasionally light gray) crinoidal wackestone that is dolomitic, argillaceous, and cherty. Lesser amounts of lime mudstone and crinoidal packstone also are logged. The unit shows the very high resistivity readings that are typical for limestone. Thickness of the Dutchman Member in these test holes is 5 to 15 feet (1½ to 4½ m).

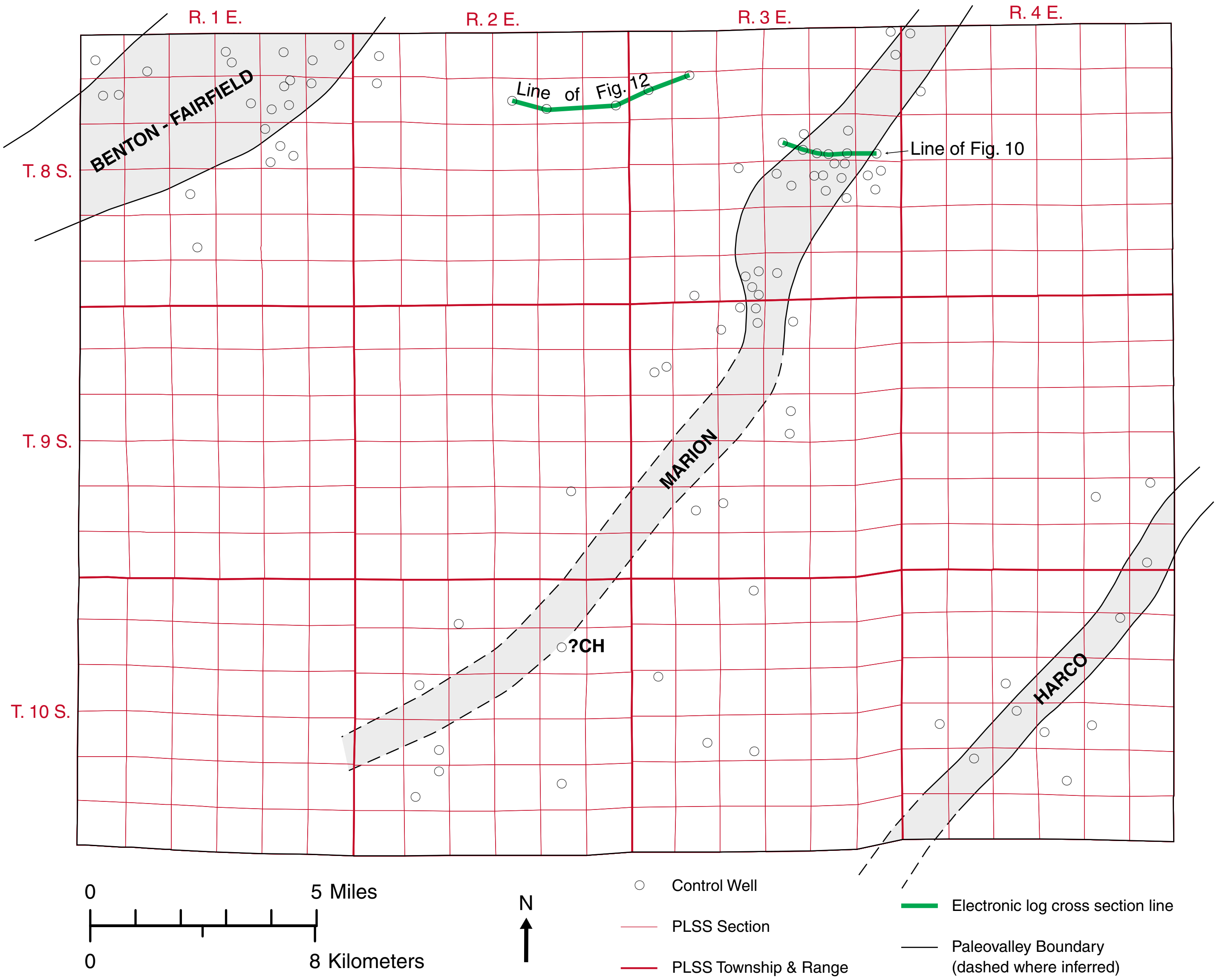


Figure 9 Map showing sub-Pennsylvanian paleovalleys in Williamson County. Boundaries are dashed where approximately located or inferred. Small open circles represent control wells.

Pennsylvanian System

Sub-Pennsylvanian unconformity

The Mississippian-Pennsylvanian contact in Williamson County is unconformable, as it is throughout the Illinois Basin. Basal Pennsylvanian rocks rest on strata ranging from the Ford Station Member of the Clore (oldest) to the Dutchman Limestone Member of the Grove Church Formation. Total relief on the unconformity is approximately 300 feet (90 m).

Bristol and Howard (1971 and 1974) mapped the sub-Pennsylvanian surface throughout the Illinois Basin and defined a series of paleovalleys that generally trend southwest. Three of these cross Williamson County; our mapping verifies theirs in a general way (Figure 9):

1. The Harco valley, which crosses the southeastern corner of the county, is less than 1 mile (1½ km) wide and approximately 200 feet (60 m) deep. The Negli Creek Limestone forms the valley floor while Grove Church, including the Dutchman Member, are at the tops of the valley walls.

2. The Marion valley (Fig. 10**)** in the north-central part of the county is 1 to 2 miles (1½ to 3 km) wide and 200 to 250 feet (60 to 75 m) deep. The valley floor is on upper Clore and Degonia; the Goreville Limestone is on the rim.

3. The broad, complex Benton-Fairfield valley crosses northwestern Williamson County. More than 5 miles (8 km) wide and as deep as 250 feet (75 m), the valley is floored with Ford Station Member and its walls capped by Goreville Limestone. Logs of several wells close to the margins of these valleys show upper Chesterian strata out of normal order. These wells probably penetrated ancient landslide or slump blocks, such as those described by Bristol and Howard (1974).

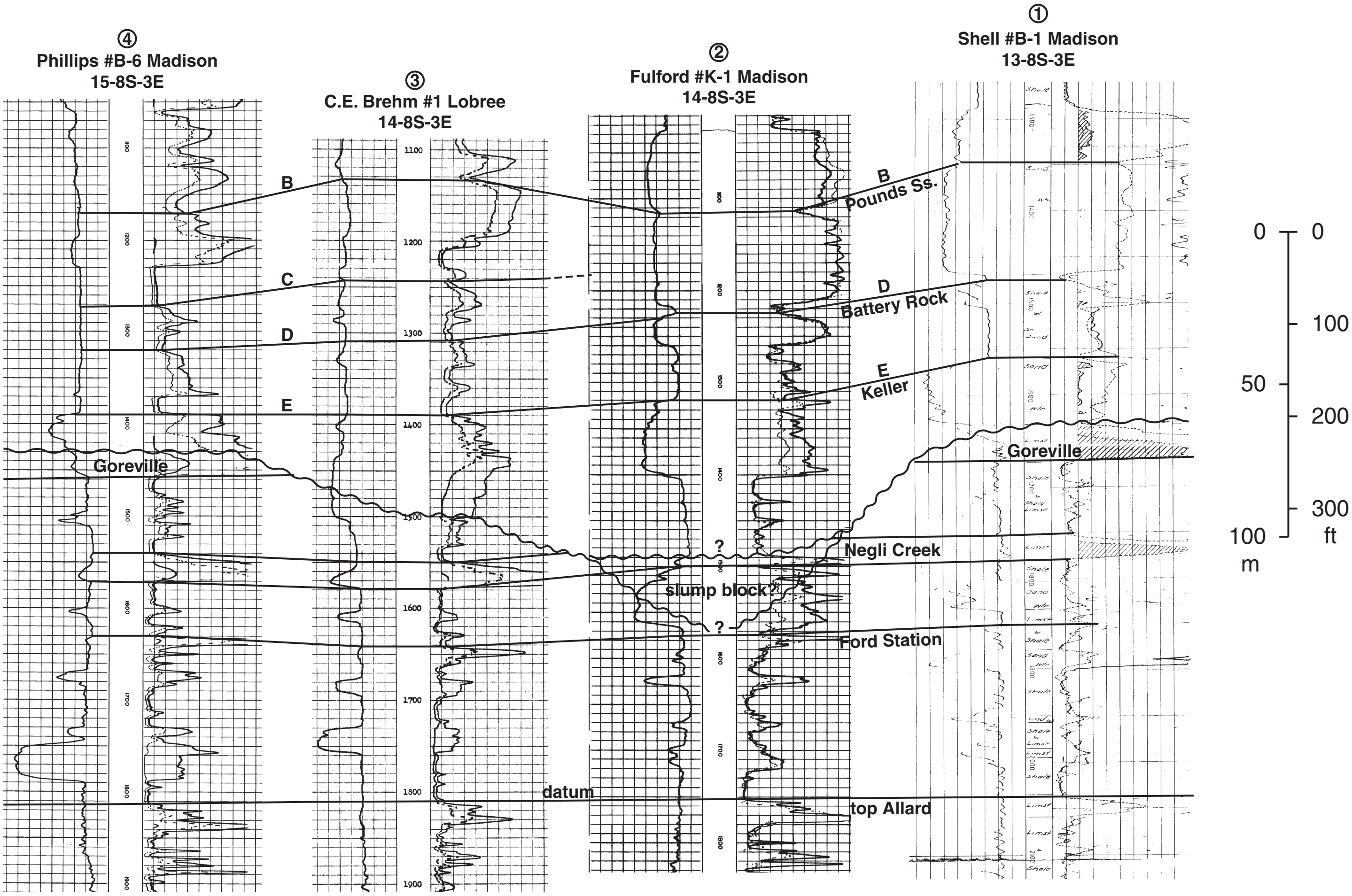


Figure 10 Electric log cross section of Marion paleovalley. Width of section is about 2 miles (3 km) (see Figure 9 for location). Top of Allard Member of Menard Limestone is datum. Note how depositional sequences above "E" maintain more or less constant thickness across the valley, whereas "E" thickens markedly. Log 2 shows multiple "stacked" massive, valley-fill sequences within the Caseyville. Also in the same well, the interval from 1400 to 1575 feet is a complete mismatch for nearby wells, and may represent a Chesterian slump block.

Caseyville Formation

The Caseyville Formation (Fig. 11) crops out extensively in western Kentucky and the Shawnee Hills of southern Illinois. Marked by high, scenic bluffs, the Caseyville outcrop passes a few miles south of Williamson County. The nearest outcrops are along streams south of Devil's Kitchen Lake less than one mile from the county line (Weibel and Nelson 1993).

Direct knowledge of the Caseyville in Williamson County therefore comes from well records. Wireline logs are useful, but samples (core and/or cuttings) are needed to identify this formation in the subsurface. Its diagnostic lithology, pure quartz sandstone that commonly contains small quartz pebbles, cannot be differentiated from other types of sandstone using geophysical logs alone. With that said, sandstone of the Caseyville tends to exhibit higher porosity and permeability and to yield larger quantities of groundwater than sandstone of the Tradewater. Also, Caseyville sandstone is commonly logged as white or light gray, in contrast to medium gray and brown (iron-rich) colors of the Tradewater.

Thickness The Caseyville ranges from about 175 to 540 feet (53 to 165 m) thick in Williamson County. It is thinnest in the north-central area between the Benton-Fairfield and Marion valleys. The Caseyville also may be less than 200 feet (60 m) thick near the southwest corner of the county (Weibel and Nelson 1993; Jacobson and Weibel 1993). The formation is thickest in paleovalleys, especially the Marion valley, where the thickness of 540 feet (165 m) in the Fulford #K-1 Madison Coal borehole (sec. 14, T8S, R3E) is close to a basin-wide maximum.

The Caseyville is thickest in sub-Pennsylvanian valleys because these valleys were filled sequentially from the bottom upward (Fig. 10). Oldest Caseyville strata are confined to valleys; younger strata overlap divides. On cross sections using either younger Pennsylvanian or Chesterian markers as datum, the top of the Caseyville runs more or less horizontal across valleys and ridges. The same relationship is documented in western Kentucky (Greb et al. 1992).

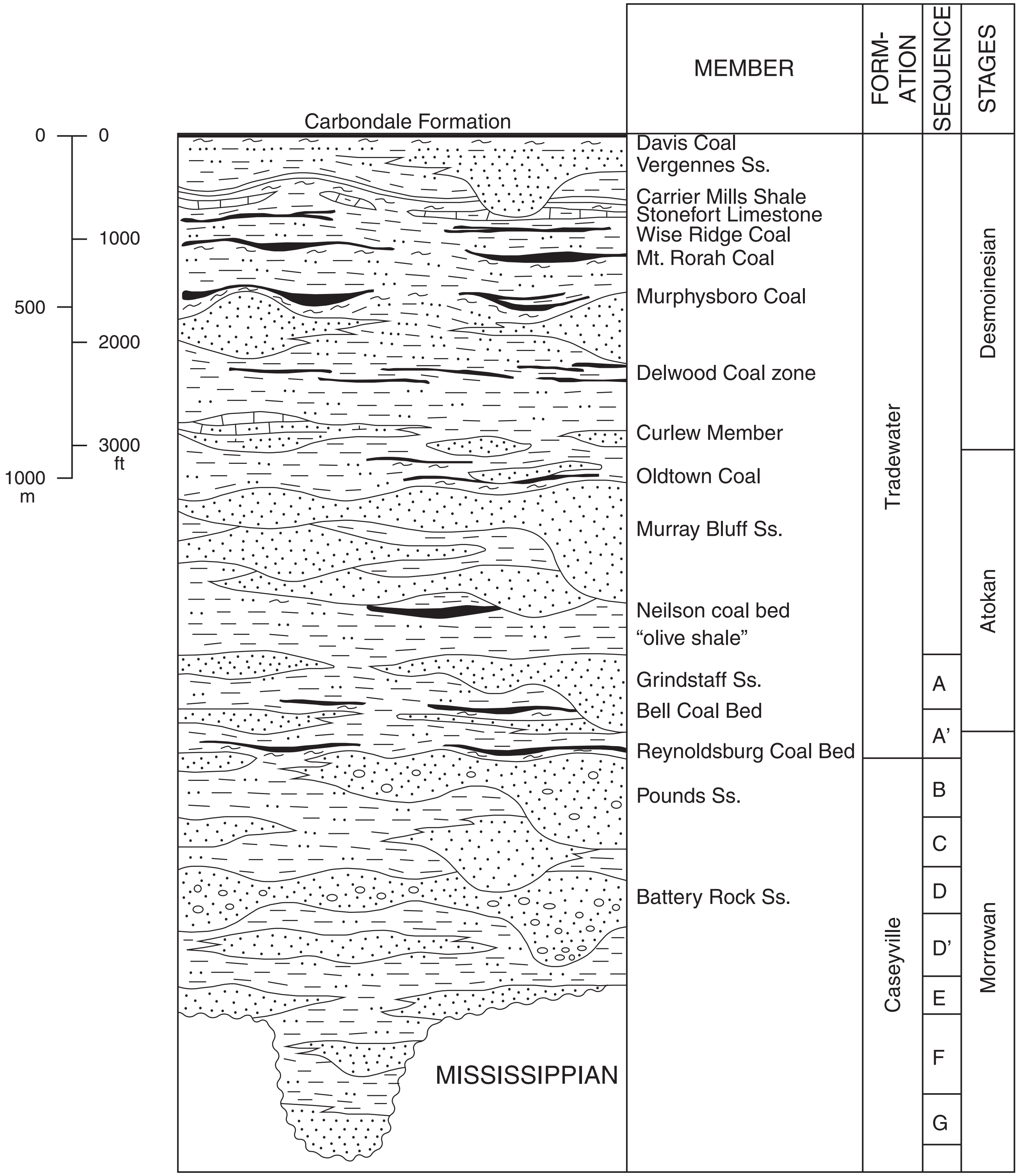


Figure 11 Stratigraphic column showing Tradewater and Caseyville Formations (Pennsylvanian) in Williamson County.

Lithology The Caseyville Formation is composed dominantly of sandstone, siltstone, and shale. Conglomerate, mudstone and coal are minor; limestone is rare, and none has been verified in Williamson County.

Sandstone is characteristically quartz arenite (orthoquartzite), meaning that 95% or more of the sand grains are quartz. Other grains include feldspar, siderite, mica, and dark opaque minerals. Except where stained by iron oxide, Caseyville sandstone is white to light gray. Grain size varies from very fine to coarse, much coarser than any Mississippian sandstone. Sand commonly has a sparkly or sugary appearance because of angular silica overgrowth on the grains. Clay matrix generally is absent; cement is silica, iron oxide, or rarely calcite. Well rounded, clear to white quartz granules and small pebbles (up to 2-3 cm or 1 inch in diameter) are characteristic of the Caseyville but not always present.

In contrast, Pennsylvanian sandstone above the Caseyville is less mature, containing more mica, feldspar, lithic grains, and interstitial clay. Also, quartz granules and pebbles rarely occur above the Caseyville. However, the transition is gradual. Quartz arenite containing scattered quartz granules occurs in the lower Tradewater Formation, as observed by Potter and Siever (1956), Potter and Glass (1958), Kosanke et al. (1960), and many subsequent authors.

Caseyville siltstone is mostly light to medium gray and may be massive to laminated. Shale is dominantly dark gray, well laminated, and slightly to very silty. Fine mica, carbonaceous debris, and siderite nodules are common. Outcrops south of Williamson County and the Madison No. 25 core show interlaminated dark gray shale and light gray siltstone or sandstone. Planar, wavy, and lenticular laminae and various types of infilled burrows and load casts are present. Coal beds of the Caseyville are highly lenticular, typically shaly, and less than 2 feet (60 cm) thick. Massive claystone or siltstone containing slickensides and fossil root casts underlies most coal beds. Well-preserved fossil roots and logs can be seen in sandstone at the top of the Caseyville where Water Valley Road crosses a small stream bed just west of the center of the east line, sec. 8, T 11 S, R 1 E, Union County. Conglomerate consists of clasts of quartz, siderite, shale, coal, and other sedimentary rocks in a sand matrix.

The Caseyville has been divided into four members: Wayside (at base), Battery Rock Sandstone, unnamed shaly member, and Pounds Sandstone Member. Although many geologists have mapped these members along the outcrop, they have had little success tracing them into the subsurface. Well-log analysis indicates the Caseyville contains four to seven depositional sequences (Fig. 12) in Williamson County. Each sequence may consist entirely of sandstone, entirely of shale, or of varying proportions of both. Also, each sequence can take two forms:

1. Shale at the base coarsens upward to siltstone and/or sandstone in the upper part. Both boundaries are sharp. The upper boundary commonly is marked by rooted mudstone (paleosol) and coal. Such sequences imply an upward increase in depositional energy, consistent with a gradual drop of sea level as the shoreline progrades.

2. Sandstone at the base becomes finer-grained upward and may grade to siltstone or shale at the top. Such sequences generally have erosional lower contacts and may be deeply incised into underlying strata. The upper contact may be either sharp or gradational. Rooted mudstone or coal commonly occur at the top. Such sequences represent erosion and infilling of channels or valleys.

Caseyville sequences fit the common definition of stratigraphic sequences (e.g. Mitchum and Van Wagoner 1991): they are packages of rock bounded by unconformities. These boundaries are either surfaces of erosion and valley incision or paleosols that record subaerial exposure, non-deposition, and soil formation. When traced laterally, one type of boundary changes into the other. Similar sequences occur in Chesterian rocks of the Illinois Basin (Nelson et al. 2002).

Caseyville sequence correlation is far from straightforward. Two or more valley-fill sandstone sequences commonly "stack", producing as much as 200 feet (60 m) of continuous sandstone. Also, two or more adjacent sequences may become entirely shale so that their boundaries cannot be identified on logs. In most cases, however, sequences above and below the missing or "hidden" ones can be followed until the latter reappear.

The top of the Caseyville is placed at the highest occurrence of quartz arenite containing quartz granules, a position that commonly corresponds with the top of the Pounds Sandstone Member. Younger sandstones are noticeably "dirtier" and rarely contain sand above medium grain size. The Reynoldsburg Coal above the Pounds helps define the contact. In wells where the Pounds or equivalent sandstone is absent, the formation contact must be interpolated.

Tradewater Formation

The Tradewater Formation (Fig. 11) extends from the top of the Caseyville to the base of the Davis Coal Member (Carbondale Formation) in southern Illinois and western Kentucky (Greb et al. 1992; Tri-State Committee 2001). Lithologically the Tradewater is transitional between older and younger rocks. The lower half is mostly sandstone that contains more mica, feldspar, lithic fragments, and interstitial clay than sandstone of the Caseyville; quartz granules are uncommon. The upper Tradewater contains a larger proportion of shale and siltstone and its sandstones are lithic arenites that contain abundant mica, lithic grains, and interstitial clay. Also, the upper Tradewater contains layers of coal, limestone, and black fissile shale that become increasingly continuous toward the top of the formation. The Davis Coal is nearly continuous throughout the county and is easy to recognize on all types of subsurface logs.

The Tradewater ranges from 335 to about 680 feet (102 to 207 m) thick in Williamson County. Probably reflecting regional basin subsidence rates, the formation is thinnest on the west and thickest in the north-central and southeastern parts of the county. The range of thickness in Williamson County is greater than that reported for all of western Kentucky by Greb et al. (1992).

The lower half of the Tradewater (Murray Bluff Sandstone Member and below) crops out extensively in southern Williamson and in contiguous areas of Jackson, Johnson, and Union counties. Resistant sandstone forms widespread ledges where glacial deposits are thin or absent. The upper Tradewater is less resistant and largely covered by glacial sediment. The best outcrops occur near Sugar Creek, South Fork of the Saline River, and streams south of Crab Orchard Lake.

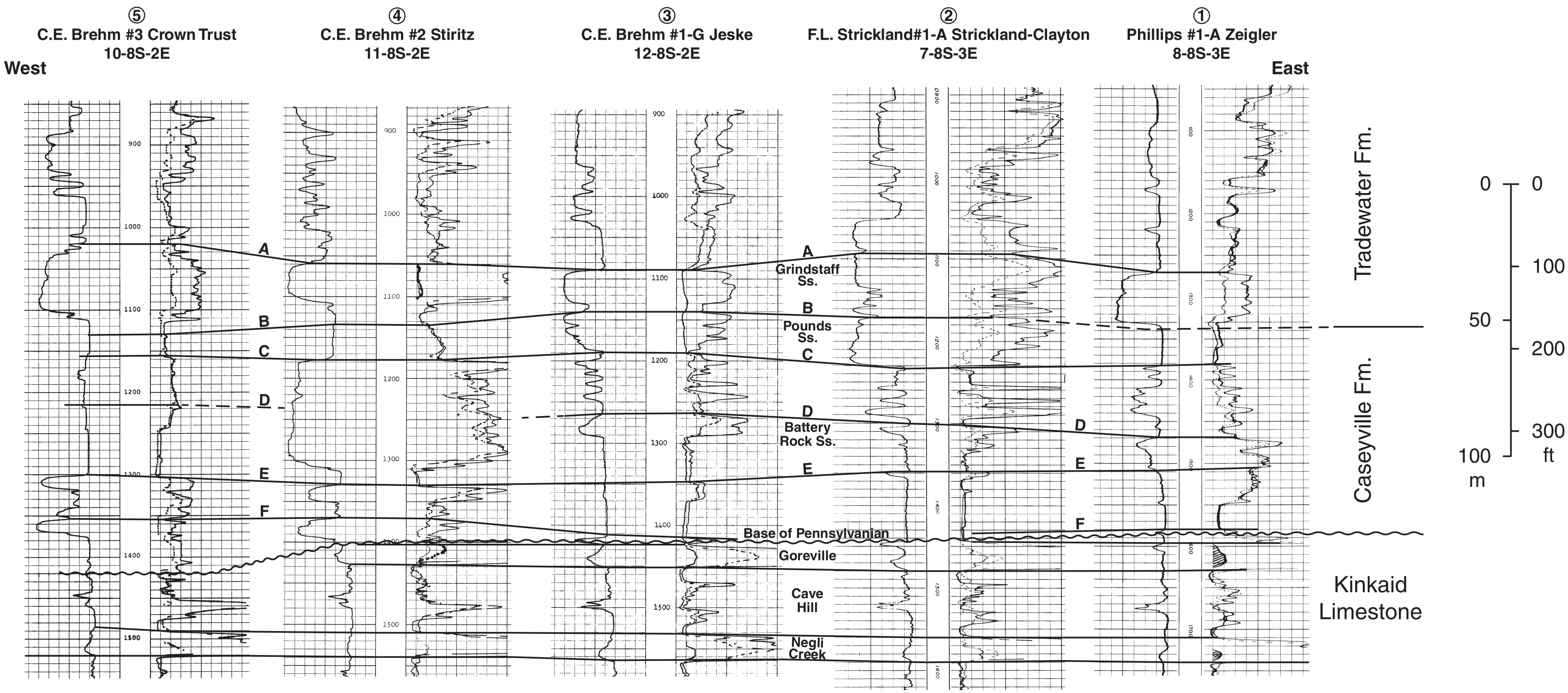


Figure 12 Electric log cross section illustrating depositional sequences of Caseyville and lower Tradewater formations across a distance of about 4 miles (6.4 kilometers). Line of section shown on figure 9. The base of the Mississippian Negli Creek Limestone is datum. Notice how sequence B, the Pounds Sandstone, changes from massive sandstone in well 2 to sandstone that coarsens upward in well 3 to mostly shale in the other three wells. Sequences C and D, which are largely shale and shaly sandstone in most of the wells, "stack up" to a massive sandstone interval 135 feet (41 meters) thick in well 4. This is probably a double valley-fill succession. Sequence F, at the base of Caseyville, is thin or absent in the three right-hand wells but thickens markedly on the left into a sub-Pennsylvanian paleovalley.

The Tradewater contains sequences similar to those of the Caseyville (Fig. 12) but more difficult to identify. Sequences evident in cores lack expression on other types of logs. In many cases, the sequences are thin (less than 30 feet, 9 m) and poorly resolved on electric logs. In other cases multiple valley-fill sandstone units "stack up" and cannot be separated. Nevertheless, tracing sequence boundaries helps to divide the Tradewater into smaller units. Several named members and beds are recognized in Williamson County.

Reynoldsburg Coal Bed The Reynoldsburg Coal is named for a village in northeastern Johnson County where it was formerly mined (Trask and Jacobson 1990). This coal is well exposed in a roadcut along Interstate 24 about three miles south of the Goreville interchange in Johnson County (Palmer and Dutcher 1979; Jacobson 1991). Also it can be located on numerous well logs in south-central and southeastern Williamson County. Here it is either a single bed or two beds of coal, each 1 to 3 feet (30 to 90 cm) thick and separated by as much as 10 feet (3 m) of shale and claystone. Overlying the coal is shale that contains fossil plants, especially the fern-like foliage of *Neuropteris*.

Clastic interval Overlying the Reynoldsburg Coal (or its position) is an interval of shale, siltstone, and sandstone that varies from about 20 to 60 feet (6 to 18 m) thick. This interval commonly coarsens upward; although some logs show either sandstone that becomes finer and shalier upward or an interval that is entirely shale. The sandstone is generally very fine to fine-grained quartz arenite or slightly micaceous sublitharenite.

Bell Coal Bed A coal layer 1 to 2 feet (30 to 60 cm) thick occurs 20 to 60 feet (6 to 18 m) above the Reynoldsburg occurs in numerous boreholes, especially in southern Williamson County. The formerly was mined to the south in Johnson County, where Trask and Jacobson (1990) and Nelson et al. (1991) called it the Tunnel Hill Coal Bed. Correlation of the Tunnel Hill with the Bell coal bed of western Kentucky has been established on the basis of its fossil spores, which are distinct from those of the Reynoldsburg Coal (Peppers 1996).

Grindstaff Sandstone Member Massive to crossbedded, fine-grained, clean quartz sandstone crops out prominently just south of Williamson County and is identified in many well records throughout the county. This sandstone is probably equivalent to the Grindstaff Sandstone Member of Gallatin County (Butts 1925). The Grindstaff is widespread in Pope and Hardin counties (Baxter et al. 1963, 1965, and 1967). West of Gallatin County the Grindstaff becomes discontinuous, but retains its distinctive lithology (Nelson et al. 1991). Palynology of associated coal beds helps identify the Grindstaff in and near Williamson County (Russel A. Peppers, unpublished data).

The Grindstaff forms the high, scenic cliffs in Giant City State Park (southeastern Jackson County) and at Panther Den (SE¼ , sec. 3, T 11 S, R 1 E, Union County) (Fig. 13). At both localities, widely-spaced vertical joints penetrate the entire thickness of the sandstone. Hillside creep has widened the joints, creating the "streets" that give Giant City its name. At Giant City and elsewhere, the Grindstaff is white to light gray, very fine to medium-grained borderline quartz arenite that is case-hardened and has sugary texture. It is thick-bedded to massive and exhibits slumped bedding, along with large-scale planar crossbedding that dips south or southwest. Bluffs and ledges generally have smooth, rounded surfaces except along the joints. Absence of shale interbeds or laminae is noteworthy. Both contacts appear to be sharp. Quartz granules are uncommon.

In the subsurface the Grindstaff is widespread, although not continuous – a "blanket with holes". The sandstone is commonly 20 to 60 feet (6 to 18 m) thick and it ranges up to 100 feet (30 m) thick in northeastern Williamson County. Electric and gamma-ray logs display a "blocky" or "massive" profile that reflects an absence of shale layers. Cores and cuttings are clean quartzose sandstone like that observed on the outcrop. Where the Grindstaff is thick it fills valleys incised into underlying strata.

"Olive shale member" Nelson et al. (1991) gave the informal name "olive shale member" to an interval of extensively bioturbated burrowed shale and siltstone that lies between the Grindstaff and Murray Bluff Sandstone members in parts of Johnson, Saline, and Pope counties (Fig. 13). This unit can be traced into Williamson County, where it is exemplified by outcrops along ravines south of Devil's Kitchen Lake. Dark gray shale, medium gray siltstone, and light gray very fine to fine sandstone are interlaminated and thinly interbedded. Trace fossils (identified by Joseph A. Devera) are common and locally profuse; they include *Lockeia*, *Chondrites*, *Eiona*, and a variety of vertical and horizontal burrows. Stigmarian root casts occur in sandstone near the middle of the olive shale, and a thin coal bed is at the base. Thickness of the olive shale on the outcrop varies from 25 to 80 feet (7½ to 24 m). In the ISGS #1 Fish & Wildlife core east of Carbondale (Plate 1), the olive shale is 65 feet (20 m) thick and contains the trace fossils *Asterosoma*, *Conostichus*, and *Teichichnus*; all of which are indicative of marine environments (Devera 1989). In the ISGS Binkley and S.I.U. cores the olive shale apparently was eroded and replaced by sandstone. The shale can be identified on many electric logs throughout the county.

Subsurface cross sections (W.J. Nelson, unpublished) reveal that the olive shale is widespread in southern Illinois and probably encompasses the Lead Creek Limestone Member of Indiana and Kentucky. The Lead Creek is the only named limestone member in the lower Tradewater, and is the most extensive Atokan marine carbonate unit in the Illinois Basin (Greb et al. 2002).

Neilson coal bed (informal) Coal was extracted during the early 20th century from numerous small slope and drift

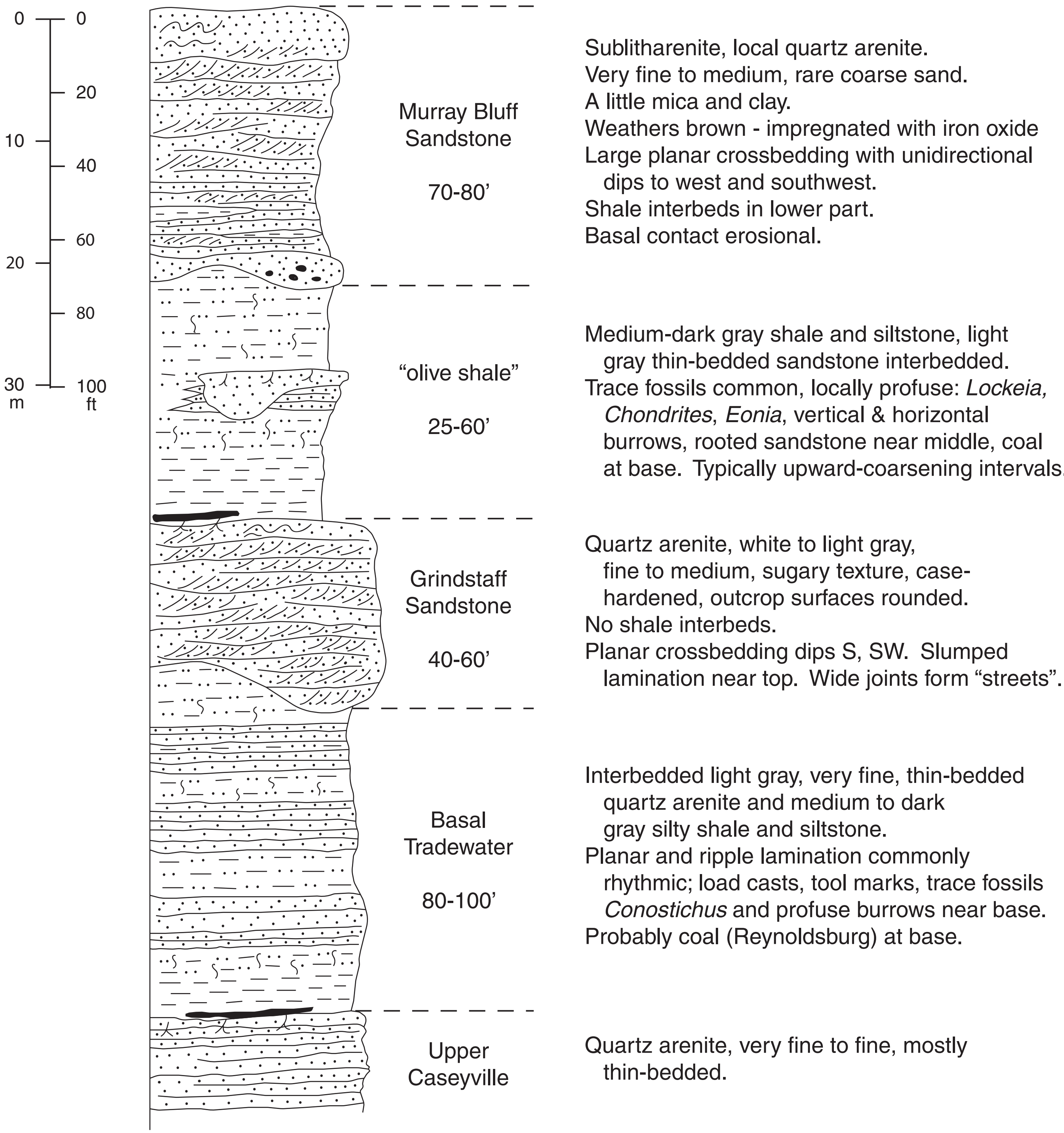


Figure 13 Column showing the lower part of the Tradewater Formation, based on outcrops in the northwestern part of the Lick Creek quadrangle.

mines near the unincorporated village of Neilson, along the South Fork Saline River just north of Lake of Egypt (Secs. 23, 24, and 25, T10S, R2E). Although coal is no longer exposed, many collapsed mine entrances and waste piles are evident. The only written mention of active mining is in field notes by John Hughes from the summer of 1926 (ISGS, open files). Annual Coal Reports published since 1882 by the Illinois Office of Mines and Minerals do not record these mines and no maps of their underground extent are known. The lack of infrastructure such as railroad spurs and tipples, implies that these mines operated on a seasonal basis and removed small quantities of coal for local use.

Field notes and well records indicate that the Neilson coal ranged up to about 4 feet (1.2 m) thick and was confined to a small area. A short distance west of the river the coal is eroded in a pre-glacial valley. Eastward and northward the coal either pinches out or is eroded beneath the Murray Bluff Sandstone. Coal at a similar stratigraphic position appears on the logs of a few holes farther north, between Neilson and Marion. The Neilson coal is overlain by 0 to 2 feet (60 cm) of dark gray to black shale that contains fossil plants and is topped by medium gray shale or mudstone up to about 20 feet (6 m). This in turn is overlain with an erosive contact by the Murray Bluff Sandstone, which forms ledges along both sides of the river.

Based on study of fossil spores, Russel A. Peppers of the ISGS (verbal communication, 2002) concluded that the Neilson coal is correlative to the Tarter Coal of western Illinois. The Tarter, a local coal, is Atokan age and resides below the Rock Island (No. 1) Coal, being approximately equivalent to No. 4a coal in western Kentucky and the Lower Block Coal in Indiana, and slightly younger than the Lead Creek Member (Peppers 1996).

Murray Bluff Sandstone Member Named for a locality in southwestern Saline County (Weller, 1940; Kosanke et al., 1960), the Murray Bluff Sandstone has been mapped widely along the outcrop in southern Illinois (Baxter and Desborough 1965, Baxter et al. 1963, 1967; Nelson et al. 1991, Jacobson 1991, Nelson, unpublished mapping). Despite gaps in map coverage and in the sandstone itself, there is little question about its correlation (Fig. 13). The Murray Bluff is more resistant to erosion than younger sandstones, which are less mature petrographically and tend to be friable. Thus, the Murray Bluff forms prominent cliffs and ledges. It produces much of the north-facing dip slope of the Pennsylvanian escarpment in the Shawnee Hills, which were the final barrier to southward advance of the Illinoian ice sheet. Narrow gorges where streams cut through the Murray Bluff on the north flank of the hills provide ideal places to build dams. Devil's Kitchen Lake, Lake of Egypt, and Herrin Lake all have dams in such places and are good places to see the sandstone. The Murray Bluff also forms bluffs along South Fork Saline River south of Marion and Drury and Indian Creek south of Carbondale (in Jackson County). Thickness ranges up to about 100 feet (30 m), but thickness trends have not been mapped.

Light gray to light brown, very fine to coarse-grained sublitharenite is the usual lithology. Small quartz granules are rare; mica and interstitial clay are inconspicuous. Iron oxide is prevalent; cliff faces exhibit intricate Liesegang banding. Large-scale, unidirectional wedge and planar crossbedding dips mostly south, southwest, and west. Trough, overturned, and slumped crossbedding are less common; some sandstone appears massive from a distance. Other structures include current, interference, and ladderback ripples, small load casts, poorly preserved burrows and feeding traces, and casts of logs or stems. Lenses of thinly bedded or laminated sandstone, siltstone, and silty shale occur within the Murray Bluff. Conglomerate of shale, siltstone, and ironstone pebbles occur in patches near the base. The lower contact typically is erosional. Well samples consist of sandstone similar to that seen on outcrop. On electric logs, the Murray Bluff produces either a "blocky" or upward-fining profile. It commonly has low S.P. and very high resistivity, similar to limestone. These properties reflect a lack of porosity, likely due to iron oxide cement. Log correlation and core study show that two or three sandstone sequences can be "stacked", creating what appears to be a single sandstone on electric logs.

Oldtown Coal Bed The Oldtown Coal Bed is exposed and formerly was mined near the southeastern corner of Williamson County, where it is 1 to 3 feet (30 to 90 cm) thick. The type exposure is in the railroad cut south of Stonefort in sec. 6, T 11 S, R 5 E, Pope County (Nelson and Lumm 1990; Nelson et al. 1991). Palynological analysis (Peppers 1996) suggests correlation with the Rock Island Coal of northwestern Illinois and the Minshall Coal of Indiana (Peppers 1996).

Curlew (Boskydell) Member A unit of marine sandstone and limestone occurs in the middle part of the Tradewater Formation close to the Atokan-Desmoinesian stage boundary. Although this unit is highly lenticular, occurrences are widely distributed across the Illinois Basin, including Williamson County. Distinctive microfossils in this unit enable correlation with the Curlew Limestone Member in western Kentucky, the Perth Limestone Member in west-central Indiana, and the Seville Limestone Member in northwestern Illinois. The name "Curlew" is used here solely because the type Curlew exposure is closest to Williamson County.

The name "Boskydell member" or "Boskydell marine zone" long was applied informally to marine sandstone that crops out about 3 miles (5 km) south of Carbondale in Jackson County (sec. 8, T 10 S, R 1 W). The poorly sorted, iron-rich, calcareous sandstone contains echinoderm fragments, brachiopods, bryozoans, rugose corals, gastropods, pelecypods, and trilobites plus a varietry of ichnofossils that have marine affinities (Devera 1989). This sandstone is widespread in Jackson County, reaching 50 feet thick in the Pomona Quadrangle west of Carbondale (Desborough 1962; Seid et al. 2007). Farther west, marine sandstone and sandy limestone in the Gorham and Oraville Quadrangles (Seid et al. 2009; Nelson et al. 2011) also represents the Boskydell/Curlew Member.
The only definite Curlew outcrop in Williamson County is at the spillway of Little Grassy Lake (sec. 18, T 10 S, R 1 E, Crab Orchard Lake Quadrangle). The hematite-stained sandstone contains an abundant and diverse assemblage of marine ichnofossils dominated by *Zoophycos* sp. and *Aulichnites parkerensis*. Together with rare marine body fossils, these trace fossils suggest deposition in a tidal inlet or delta (Devera, 1989). Possible Curlew outcrops occur along Caney Creek (NE¼ SE¼, sec. 10 and near common corner of secs. 14,15, 22, and 23, T 10 S, R 1 E, Crab Orchard Lake Quadrangle). These outcrops consist of argillaceous sandstone that is thoroughly burrowed and bears numerous specimens of *Eiona* sp., a trace fossil that resembles a string of beads and is also present at Little Grassy Spillway.

Several well logs in southwestern Williamson County report limestone or calcareous sandstone as thick as 22 feet at the expected position of the Curlew. Unfortunately, these wells lack samples. Thin limestone and calcareous, fossiliferous shale in the depth interval from 265 to 270 feet in the ISGS #1 Fish & Wildlife core (sec. 18, T9S, R1E, Carbondale Quadrangle) also may represent the Curlew (Plate 1).

Palynology of associated coal beds by Peppers (1993) and conodonts biostratigraphy (Rexroad et al. 1998; Heckel 2013) indicate that the Boskydell is correlative with the Curlew Limestone of western Kentucky; which further correlates with the Perth Limestone of Indiana and the Seville Limestone of northwestern Illinois. These units together represent a widespread marine incursion close to the Atokan-Desmoinesian boundary.

Delwood Coal Bed or zone Named for an unincorporated village in northern Pope County (Weller 1940; Kosanke et al. 1960; Nelson et al. 1991), the Delwood Coal Bed attains a thickness of nearly 6 feet (1.8 m) in northern Johnson County and has been mined together with the younger New Burnside Coal Bed. In much of Williamson County, however, the Delwood is better designated as a coal zone than as a single bed, because as many as four coal layers that range from less than 1 foot (30 cm) to about 3 feet (90 cm) thick occupy an interval that ranges from a few feet (~1 m) to nearly 50 feet (15 m) thick. Usual thickness of the zone is 10 to 20 feet (3 to 6 m) with shale, siltstone, and mudstone separating the coal layers. The coal zone lies near the top of a shale-dominated interval that is as thick as 100 feet (30 m) in southeastern Williamson County. Traced northwest, this interval thins dramatically and the Delwood zone disappears. The Granger Sandstone seems to cut out and replace the coal zone as the interval between the Granger and Murray Bluff decreases.

Granger Sandstone Member Kosanke et al. (1960) named the Granger Sandstone and described a reference section near Creal Springs (SE¼ SE¼, sec. 25, T10S, R3E, Williamson County, Creal Springs Quadrangle), where the member is 60 to 70 feet (18 to 21 m) thick. The Granger Sandstone extends throughout Williamson County, although it is locally absent. In the eastern part of the county it is as thick as 120 feet (40 m) and fills valleys incised into underlying strata. An upward-fining profile is evident from electric logs. Cores and sample studies show light gray to buff, very fine to coarse-grained lithic arenite that contains abundant mica and carbonaceous debris.

Outcrops are not plentiful because of extensive glacial drift. The best exposures are near the above-cited reference section and along Wolf Creek near the center of sec. 13, T10S, R2E, Crab Orchard Lake Quadrangle). At these localities the sandstone is thin-bedded and shaly in the upper part, becoming thick-bedded to massive in the lower part. The rock is rather soft and friable, weathering to rounded ledges. Large-scale crossbedding, cut-and-fill features, load casts, and slumped bedding are common.

Murphysboro Coal Member Mined extensively in Jackson County, the Murphysboro Coal is highly variable and lenticular in Williamson County. It is as thick as 8½ feet (2.6 m) but is absent in large areas, especially toward the east. In places the Murphysboro is split into two benches separated by shale and mudstone as thick as 10 feet (3 m). Jacobson (1983) mapped the coal in Jackson and Perry Counties and related thick coal to a contemporaneous paleochannel that he named the Oraville channel. Unpublished mapping east of Jackson County by W.J. Nelson indicates that thick coal is confined to narrow channel-form deposits that probably represent drowned river valleys or estuaries. Within these deposits the coal is overlain by dark gray to black, marine shale and limestone. Outside of these deposits the coal is thin or absent. The Murphysboro formerly was mined underground and by stripping near the western edge of the county in sec. 31, T9S, R1E in the Carbondale Quadrangle. The coal cannot be mapped east of these mines because of lack of data.

Creal Springs Limestone Member This unit consists of isolated lenses of marine limestone ranging up to about 6 feet (1.8 m) thick. Outcrops are confined to a small area near the type section; only a few well records indicate presence of the limestone. The brownish gray, argillaceous lime mudstone to wackestone is very siliceous and weathers to a porous, cherty residuum. Large productid brachiopods are common. The Creal Springs lies 0 to 10 feet (3 m) above the Murphysboro Coal. Separating coal from limestone is medium to dark gray shale that becomes black and canneloid at the base.

Clastic interval Between the Creal Springs Limestone or Murphysboro Coal and the Mt. Rorah Coal is 20 to 40 feet (6 to 12 m) of dark gray to greenish gray silty shale and siltstone having planar and wavy lamination. At the top is rooted, slickensided claystone or silty mudstone that is greenish to olive gray.

Mt. Rorah Coal Member This unit was defined from a roadcut and gullies at the north edge of Stonefort, SE¼ of sec. 25, T10S, R4E, Williamson County, on the Stonefort Quadrangle (Kosanke et al. 1960). The coal is widespread in Williamson County, attaining a maximum thickness of about 4 feet (1.2 m) and commonly containing a claystone layer a few inches to about 1 foot (~5 to 30 cm) thick. Near Stonefort, the upper coal bench is 1.2 to 1.5 feet (37 to 46 cm) thick and the lower bench is 0.6 to 0.8 feet. (18 to 24 cm) thick. Small-scale strip mining took place during the 1970s near Creal Springs and Stonefort. Older, abandoned drift mines are numerous in the same area.

Clastic interval A clastic interval 10 to 35 feet (3 to 11 m) thick separates the Mt. Rorah and Wise Ridge Coals. In general, this interval is shale and siltstone having rooted mudstone (underclay) at the top. Outcrops near the southeastern corner of the county show two fining-upward sequences. In the upper sequence, rooted claystone grades downward to shale, siltstone, and finally sandstone having a sharp lower contact. The lower sequence has thin black, carbonaceous shale (coal horizon) at the top overlying another rooted mudstone, which grades downward to silty shale or siltstone. The shale is dark gray to black, sideritic, and in places contains fossil plants.

Wise Ridge Coal Bed and Veale Shale Member The Wise Ridge is a thin (0 to 1.5 feet, 46 cm) but widely traceable coal unit. As shown in cores, it varies from bright-banded coal to shaly, dull coal or carbonaceous shale. Directly overlying the coal is the Veale Shale Member (Nelson, in press), which is dark gray to black, thinly fissile shale that commonly yields high radioactivity on gamma-ray logs. The black shale grades upward to claystone that is mottled dark gray and greenish gray, soft, and massive to weakly fissile, having a sharp upper contact with the Stonefort Limestone.

Stonefort Limestone Member The Stonefort is lenticular, yet widely distributed in southern Illinois. Its type section is the same roadcut and gullies in Stonefort that contain the type Wise Ridge and Mt. Rorah. Outcrops also occur in ravines south of the dam of Crab Orchard Lake. The limestone typically is gray to greenish or brownish gray, argillaceous lime mudstone to wackestone that is nodular to massive. It is dolomitic and weathers yellowish orange; brachiopods and echinoderm fragments are plentiful. Many well records, including cores, indicate limestone a few inches (~5-10 cm) to about 5 feet (1½ m) thick.

Carrier Mills Shale Member Nelson et al. (1991) named this unit based on exposures southwest of Carrier Mills in a railroad cut (NW¼ NW¼ NE¼, sec. 30, T10S, R5E, Saline County). The Carrier Mills Shale is highly continuous in outcrops and well records throughout southern Illinois and western Indiana, and this member is present throughout Williamson County except in a few small areas where it was eroded and replaced by younger strata. Normally 2 to 5 feet (60 to 150 cm) thick, the Carrier Mills is jet-black, hard and brittle, thinly fissile, highly carbonaceous, and pyritic. It is "hot", yielding very high radioactivity readings on gamma-ray logs. The Carrier Mills either rests directly on the Stonefort Limestone or is separated by soft, slickensided gray and green claystone that contains lenses of argillaceous sandstone. This is one of few distinctly green horizons in the Pennsylvanian.

Clastic interval The uppermost Tradewater consists of sandstone, siltstone, shale and mudstone occupying an interval 30 to 75 feet (9 to 23 m) thick. In northwestern Williamson County, this interval generally coarsens upward from shale to sandstone, having the underclay of the Davis Coal at the top. In the central and eastern part of the county, sandstone that fines upward from an erosional base makes up much of the interval. Informally designated as the "sub-Davis sandstone" by Nelson et al. (1991) and on many quadrangle maps, this unit is confidently correlated with the Vergennes Sandstone Member, which has its type area in Jackson County (Shaw and Savage 1912; Nelson et al. 2011; Nelson, in press. The Vergennes Sandstone forms prominent bluffs along Sugar Creek in Secs. 17, 18, and 19, T10S, R4E in the Crab Orchard Quadrangle. Similar to the Granger Sandstone, the Vergennes is light to medium gray, fine to coarse-grained lithic arenite containing plenty of mica and fine carbonaceous debris. Planar and wavy lamination, crosslamination and crossbedding, massive bedding, and cut-and-fill structures marked by shale and coal rip-up clasts are common. The lower contact is scoured, but not deeply incised, locally cutting into or through the Carrier Mills Shale.

Carbondale Formation

The name "Carbondale Formation" (Fig. 14) was introduced by Shaw and Savage (1912) to include strata from the "No 2 Coal" (now Murphysboro) through the Herrin (No. 6) Coal in the vicinity of Carbondale, Illinois. Subsequent authors have repeatedly adjusted the boundaries of the Carbondale Formation. Currently, the Carbondale is defined as extending from the base of the Davis Coal to base of the Brereton Limestone throughout the Illinois Basin (Tri-State Committee 2001). On most of the 1:24,000-scale maps in Williamson County the top of the Herrin Coal was used as the top of the Carbondale. The difference in boundary is not great enough to be significant at the scale of mapping presented with this report.

Davis Coal Member The Davis Coal extends throughout Williamson County, and was strip-mined extensively in the southeastern part together with the younger Dekoven Coal. Thickness is generally is the range of 1 to 4 feet (30 to 120 cm), but the coal is locally thinner or absent, and it reaches a maximum of about 6 feet (1.8 m) in the southern part of the Harco Quadrangle. In that same area the Davis locally is split into two or three benches separated by shale and sandstone, which appears to fill a channel that truncates the Carrier Mills Shale (Nelson and Denny 2015). These relationships suggest that the Vergennes Sandstone was deposited partially during the time of Davis peat accumulation. Outside of the "split" area, the Davis is a single seam of bright-banded coal, containing thin laminae of claystone, fusain, and pyrite. Like most Illinois coal, it has a high sulfur content of 3 to 5%.

Will Scarlet Shale Member (new) Directly overlying the Davis Coal Member is a unit of black, hard, thinly fissile shale that generally ranges from about 1 to 4 feet (30 to 120 cm) thick, reaching a maximum of 7 feet (2.1 m). This unit produces sharp inflections with very high readings on gamma-ray logs (Fig. 15) and distinguishes the Davis from the younger Dekoven Coal, which lacks a similar associated shale. The name Will Scarlet Shale Member has been proposed for the black shale (Nelson, in press), in reference to the Will Scarlet surface coal mine in southeastern Williamson and adjacent Saline counties, where this unit and associated strata formerly were well exposed. The type section is in core from the ISGS No. 1 Morris hole in Wil-

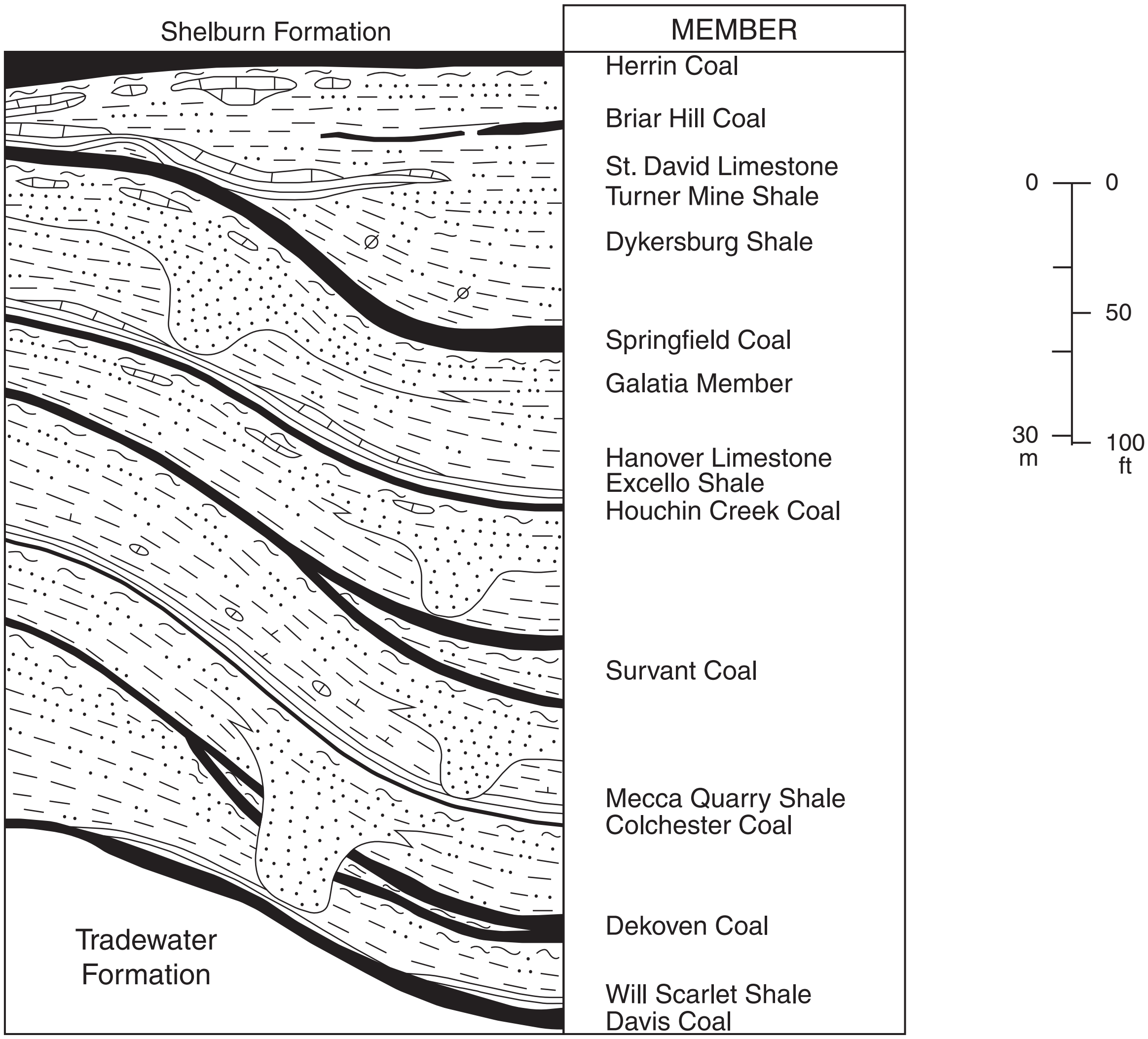


Figure 14 Stratigraphic column showing the Carbondale Formation (Pennsylvanian) in Williamson County.

liamson County in the depth interval from 162.0 to 167.5 feet (Plate 1).

Clastic interval Separating the Will Scarlet Shale from the lower bench of the Dekoven Coal is a succession of shale, mudstone, siltstone, and sandstone that varies from 0 feet to about 35 feet (11 m) in thickness. Overall, this interval thins toward the east; its thickness has been mapped in Saline and Gallatin counties east of the present study area (Jacobson, 1993). In most boreholes the interval coarsens upward and is topped by gray to olive-colored, massive, slickensided mudstone containing abundant fossil roots. Channels filled with sandstone locally truncate the Davis Coal in the Johnston City Quadrangle. Some borehole records in eastern Williamson County indicate that the Dekoven Coal or its underclay rests directly on the Will Scarlet Shale.

Dekoven Coal Member The Dekoven Coal is present throughout the county and was mined together with the Davis in southeastern Williamson and southern Saline County. The Dekoven is either a single bed of coal 1 to 5 feet (1.5 m) thick, or two layers of coal separated by an interval of clastic rocks as thick as 25 feet (8 m). This split has a regional extent (Jacobson, 1993) and thickens toward the north throughout southeastern Illinois. Where the Dekoven is split, its lower bench generally is thinner, about 1.5 feet (45 cm) or less, whereas the upper bench can exceed 3 feet (90 cm). Where the split is thin it is entirely composed of dark-colored, slickensided, rooted mudstone. As the split thickens it changes to an upward coarsening succession in which fissile, silty to silt-free shale grades upward to siltstone and fine-grained sandstone. The basal shale is sparsely fossiliferous, mainly containing pelecypods. Topping the split is rooted underclay, generally thinner than that beneath the lower bench of the Dekoven. The lithologic character and regional extent of the split in the Dekoven indicates that the two benches of coal developed in separate sedimentary cycles. It is likely that the lower and upper benches of the Dekoven correspond with the Greenbush and Abingdon Coal Members, respectively, in western Illinois (Wanless 1957).

Clastic interval Overlying the Dekoven is an interval about 25 to 75 feet (8 to 23 m) thick of shale, siltstone, sandstone, mudstone, and local limestone. In most cases the interval coarsens upward from dark gray shale at the base through silty shale and siltstone to sandstone in the upper part. Thin,

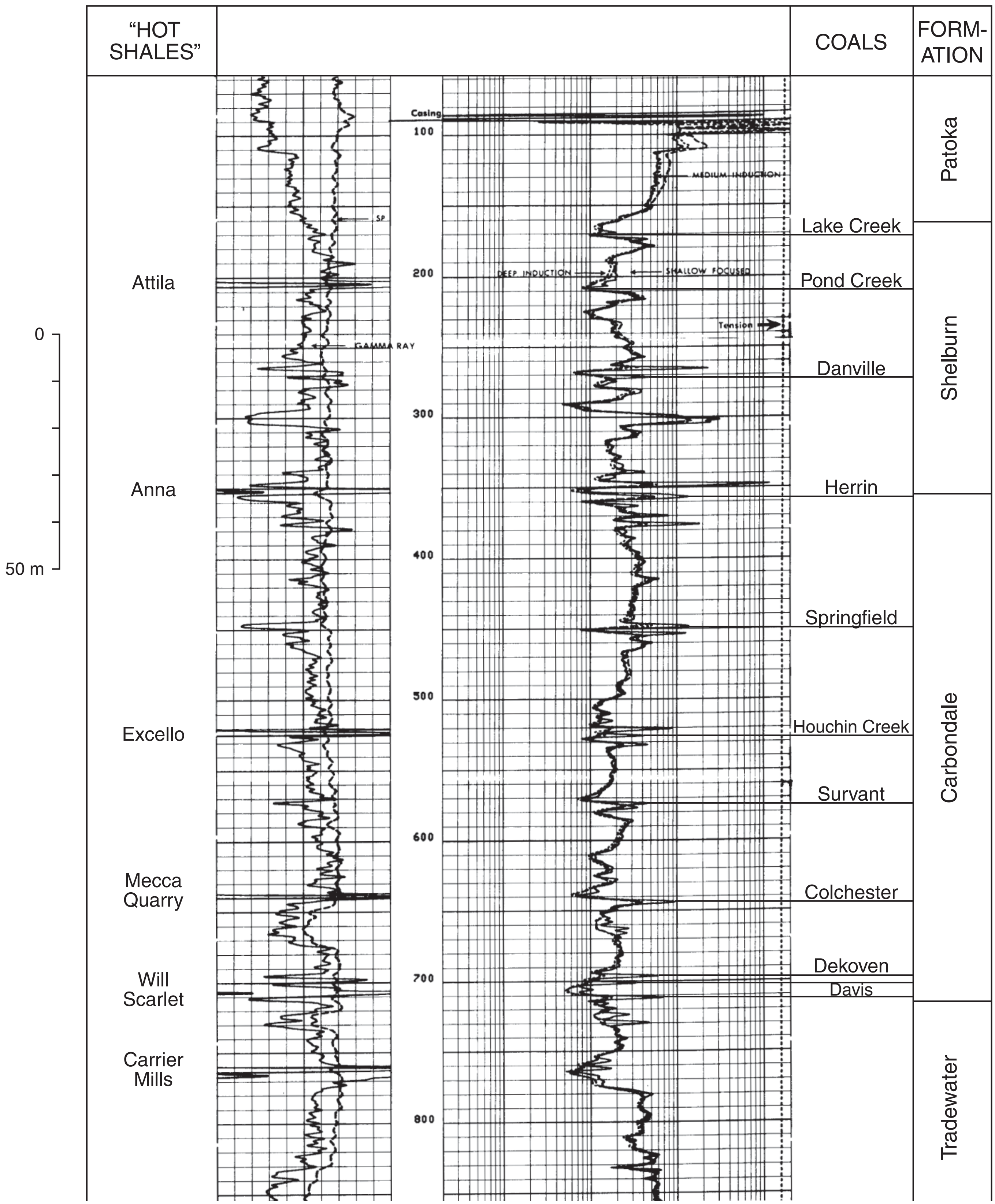


Figure 15 Gamma-ray/induction log showing "hot" black shales and coal beds, Middle Pennsylvanian. Log is from Atlantic Richfield No. 1 Ritchey oil test hole drilled in Sec. 28, T8S, R4E.

lenticular limestone occurs a few feet below the Colchester Coal. Capping the clastic interval is the massive, slickensided, rooted underclay of the Colchester. In some areas the interval includes the **Palzo Sandstone Member**, which fines upward from an erosional contact. Like other sandstones of the Carbondale, the Palzo is a fine- to medium-grained lithic arenite that contains abundant coarse mica and carbonaceous debris and plenty of light gray interstitial clay. Basal conglomerate of rip-up clasts of shale and other sedimentary rocks may be present. In a few wells in the north-central part of the county, the Palzo Sandstone fills channels eroded as deeply as the Wise Ridge Coal, approximately 100 feet (30 m) below the Colchester.

Colchester Coal Member The Colchester, one of the most continuous coal beds in the Illinois Basin, has a maximum thickness of 1.5 feet (45 cm) and is commonly less than 0.5 feet (15 cm) thick in Williamson County, too thin to register on most geophysical logs. The bright-banded, blocky coal is rich in pyrite. It is exposed (although weathered and partially grassed over) in a railroad cut south of Marion near the northeast corner of sec. 27, T9S, R2E. The position of the Colchester is apparent on gamma-ray logs at the base of the highly radioactive Mecca Quarry Shale. The Colchester, Mecca Quarry and lower Purington Shale also create a distinctive inflection on resistivity logs (Fig. 15).

Mecca Quarry Shale Member The Mecca Quarry is black, highly fissile, carbonaceous shale similar to the Carrier Mills and Will Scarlet Shales described previously. The Mecca Quarry is consistently about 2 to 3 feet (60 to 90 cm) thick and produces "hot" gamma-ray log readings and a distinctive sharp leftward (low) inflection on resistivity logs (Fig. 15), making it an excellent unit for subsurface mapping and correlation.

Purington Shale Member Named for a locality east of Galesburg in western Illinois (Wanless 1931 and 1957), the Purington Shale is a regionally extensive fine-grained clastic unit that separates the Mecca Quarry Shale from the Survant Coal. In Williamson County the Purington ranges from 50 to 85 feet (15 to 26 m) thick and generally coarsens upward from dark gray clay-shale in the lower part to silty shale, siltstone, and sandstone in the upper part. Shale near the base is calcareous and contains small limestone concretions along with the pelecypods *Pecten* sp. and *Nucula* sp. In some wells, the Purington interval includes sandstone (Pleasantview Sandstone Member) that fills valleys incised almost to the Colchester Coal.

Survant Coal Member Formerly called the Shawneetown or Lowell (No. 2-A) Coal, the Survant Coal is regionally extensive through most of southern and eastern Illinois, western Indiana, and western Kentucky. Like the Dekoven Coal, the Survant actually comprises two distinct coal layers that are separated by a wedge of clastic strata that typically coarsen upward. The lower and upper benches of the Survant probably correspond, respectively, to the Wheeler and Bevier Coal Beds in the Midcontinent (Western Interior) Basin.

The Survant is a single coal layer a few inches to about 3 feet (~10 to 90 cm) thick in western and south-central Williamson County. Toward the east and north the two coal layers are separated by clastic strata as thick as 20 feet (6 m). The lower coal is a few inches to 1.5 feet (45 cm) thick, whereas the upper coal is 0.8 to 3.0 feet (24 to 90 cm) thick. The two coals are divided by medium to dark gray shale that grades upward to siltstone and is capped by rooted underclay. The repetitive upward-coarsening cycles that bracket and separate the coal benches are distinctive on resistivity and other geophysical logs (Fig. 15).

Clastic interval The interval between the upper Survant and Houchin Creek coals is 25 to 60 feet (8 to 18 m) thick, generally thickening eastward. In most places the succession coarsens upward, grading from shale at the base to sandstone in the upper part, topped by underclay. Basal shale is medium to dark gray and contains small siderite nodules and plant fossils. H.R. Wanless (ISGS field notes, 1933) identified the brachiopods *Productus cora* and *Marginifera muricata* and the pelecypods *Acanthopecten entiolum*, *Aviculopecten* sp., *Phanerotrema* sp., and (?) *Schizodus* sp. in a roadcut (now grassed over) near the bridge across the Saline River, SE 1/4 of sec. 6, T10S, R4E. Sandstone fills channels that cut within about 10 feet of the top of the Survant in northeastern Williamson County. As observed in drill cores, the underclay of the Houchin Creek is gray, massive, slickensided mudstone that contains fossil roots and nodules of sandy, ferruginous limestone.

Houchin Creek Coal Member Previously called Summum (No. 4) Coal, the Houchin Creek is highly persistent and easily identified across most of the Illinois Basin. A sharp double spike on resistivity logs marks the coal and overlying Excello Shale (Fig. 15). The coal is as thin as 0.3 ft (10 cm) on the northwest, elsewhere ranging from about 1 foot to 2.8 feet (30 to 85 cm) and it is banded, pyritic, and lacks persistent clastic partings. The Houchin Creek was strip-mined in the Will Scarlet Mine and smaller mines near the southeastern corner of the county.

Excello Shale Member Named for a locality in eastern Kansas, this black, fissile, phosphatic, highly organic shale ranges across large areas of the Midcontinent and Illinois Basins. In Williamson County the Excello typically is 2 to 5 feet (60 to 150 cm) thick and contains conodonts and fish scales. Like other black fissile shales, the Excello produces "hot" spikes on gamma-ray logs and a distinctive double inflection on resistivity logs (Fig. 15).

Hanover Limestone Member Directly overlying the Excello Shale, the Hanover Limestone is 0.4 to 2.6 feet thick and is dark gray, argillaceous lime mudstone to wackestone. This unit, however, is commonly absent or too thin to register on geophysical logs. As shown by drill cores, the limestone grades laterally to calcareous shale.

Delafield Member The name Delafield Member has been introduced (Nelson, in press) for the upward-coarsening interval that lies between the Hanover Limestone and Springfield Coal in southern Illinois. The name refers to the hamlet of Delafield, northwest of McLeansboro in Hamilton County, where cored coal-test boreholes provide an excellent record. The type section is in continuous core from a coal-exploration borehole 2.5 km southeast of Delafield in Hamilton County.

In Williamson County the Delafield Member is 55 to 75 feet (17 to 23 m) thick. Dark gray shale at the base grades upward to silty shale, siltstone, and very fine to fine-grained shaly sandstone. Topping the interval is the gray, massive, rooted underclay of the Springfield. Nodules or lenses of silty to sandy limestone (non-marine or pedogenic?) are common in the lower part of the underclay. The newly named Galatia Sandstone (see next entry) fills paleovalleys incised into the Delafield Member in eastern Williamson and contiguous areas of neighboring counties.

Galatia Member Coal mine operators in southeastern Illinois were long aware of an area in southeastern Illinois where the Springfield Coal is absent and replaced by or interbedded with shale, siltstone, and sandstone. The first to map the disturbance was Hopkins (1968), who delineated an extensive paleochannel interrupting the coal, and Hopkins et al. (1979) named this feature the Galatia channel. Hopkins further interpreted the Galatia channel as a fluvial channel that existed partly contemporaneous with Springfield peat accumulation. A more comprehensive investigation (Nelson et al., in press) modified Hopkins' model and formally named the deposits of the Galatia channel as the Galatia Member of the Carbondale Formation. Channel and stratigraphic member are named for the town of Galatia in Saline County and the type section is a continuous core drilled near that community.

As interpreted by Nelson et al. (2020), the Galatia Member comprises sediments, mainly sandstone, that fill paleovalleys that were eroded during the late stages of deposition of the Delafield Member, probably while the underclay of the Springfield Coal was developing elsewhere. The Galatia Member also includes mainly fine-grained clastic rocks that are interlayered with the Springfield Coal together with clastic rocks that take the place of the coal along the axis of the channel. Thus, the member includes sediments that were laid down shortly before and also during accumulation of the Springfield peat. Related gray shale and siltstone deposited on top of the Springfield Coal along the margins of the Galatia channel is classified as the Dykersburg Shale Member, as originally defined by Hopkins (1968).

The Galatia channel does not enter Williamson County, but sandstone-filled channels that replace the upper part of the Delafield Member occur in the eastern part of the county and are interpreted to represent the Galatia Member.

Springfield Coal Member Called the Harrisburg Coal in older reports; miners know this as the No. 5 coal (Illinois), coal V (Indiana) and No. 9 coal (western Kentucky). The Springfield ranks second in historic production in Williamson County and contains the largest remaining resources. Thickness is consistently between 3.0 and 5.5 feet (90 to 170 cm), increasing slightly toward the east. The bed contains thin, discontinuous laminae and lenses of claystone and pyrite, along with pyrite and calcite on cleat faces. Mine operators appreciate the Springfield's consistent thickness and lack of splits, rolls, and other geologic disturbances. The Springfield has been strip-mined along the full length of its outcrop and mined underground extensively near Crab Orchard. The coal is readily recognized on all types of borehole logs and its top was used as the datum for structure mapping in the Carrier Mills (Nelson 2007a) and Harco (Nelson and Denny 2015) quadrangle maps.

Dykersburg Shale Member Hopkins (1968) was the first to delineate this unit, and he named it on the basis of strip-mine exposures near Dykersburg (Absher) in sec. 34, T9S, R4E, Crab Orchard Quadrangle. The Dykersburg is gray shale, siltstone, and sandstone that directly overlies the Springfield Coal in the vicinity of the Galatia channel. In northwestern Williamson County the Dykersburg forms isolated lenses up to 16 feet (4.9 m) thick; eastward it becomes a blanket deposit as thick as 80 feet (24 m). Where the Dykersburg is thin and lenticular, it is composed of shale is medium to dark gray, indistinctly bedded, and slightly silty. Siderite nodules, plant fossils (mostly fragmentary) and pelecypods are common. The same type of shale commonly occurs in the lower part of thick Dykersburg in eastern Williamson County. Such shale tends to coarsen upward to siltstone and very fine-grained, shaly sandstone. Underground mines in Saline County have revealed a rich, diverse, and beautifully preserved terrestrial flora, fossil tree stumps rooted in the coal and buried in growth position, and thick sets of rhythmically laminations that display neap-spring tidal cycles. The contact with the Springfield Coal is generally sharp but in places intertongues, with stringers of coal splaying upward into the shale. The upper contact with the Turner Mine Shale is sharp and probably erosive where the Dykersburg is thin, becoming gradational where the shale is thick.

Sedimentary features, flora, and sparse fauna signify that the Energy Shale accumulated in fresh to brackish water. Rapid burial of the peat took place close to the Galatia channel, entombing tree stumps in growth position. The Dykersburg probably was laid down in an estuary that developed when the Galatia channel was drowned during early stages of marine transgression.

Turner Mine Shale Member Nelson (1983a) named this unit based on cores drilled at the Turner No. 1 Mine in sec.

27, T9S, R4E in the Crab Orchard Quadrangle. The Turner Mine is a typical black, thinly fissile, highly organic, "hot" shale similar to Carrier Mills, Mecca Quarry, and Excello Shales. The shale is hard and brittle, finely silty and micaceous, and contains plentiful pyrite along with limestone concretions up to 4 feet in diameter. Thickness is typically about 2 to 4 feet (60 to 120 cm), but attains a maximum of 9 feet (2.7 m). Where the underlying Dykersburg Shale is thicker than about 40 feet (12 m), the Turner Mine is commonly absent. The contact to the overlying St. David Limestone is gradational through a few inches (5-10 cm) of highly burrowed, mottled, non-fissile greenish gray shale or mudstone.

St. David Limestone Member This unit is 0 to 3.5 feet (110 cm) thick, although 1 to 2 feet (30 to 60 cm) is typical and the limestone is generally absent where the Dykersburg Shale is thicker than 40 feet (12 m). The olive to dark gray (nearly black), argillaceous lime mudstone contains crinoid fragments and abundant brachiopods. The upper contact may be either sharp or gradational through a few inches (5-10 cm) of calcareous shale.

Canton Shale Member In eastern Williamson County, the Canton Member includes 10 to 20 feet (3 to 6 m) of gray shale, siltstone, and sandstone separating the St. David Limestone from the Briar Hill Coal. These strata typically coarsen upward, but some well logs indicate an upward-fining sequence. In the north-central and northwestern areas of the county the Briar Hill is absent and the Canton Shale merges with unnamed clastic rocks above the Briar Hill position. The entire interval between Springfield and Herrin Coals thickens eastward across the county from 25 feet to 115 feet. The Dykersburg Shale accounts for most of the eastward thickening, which probably was driven by increased tectonic subsidence on the east.

Briar Hill Coal Member The Briar Hill is present only on the east, where it varies from a carbonaceous streak to bright-banded coal about 2 feet (60 cm) thick. A few well records indicate two or three thin coal layers separated by carbonaceous shale. The Briar Hill generally lacks an underclay, being underlain by gray mudstone, siltstone, or fine sandstone that contains root traces.

Clastic interval Gray clastic rocks as thick as 40 feet (12 m) separate the Briar Hill from the Herrin Coal. These strata typically coarsen upward from shale at the base to sandstone at the top, although some wells show an upward-fining sequence. Pectenoid pelecypods and the brachiopod *Lingula* sp. occur in the shale immediately overlying the Briar Hill.

Unnamed limestone Massive to nodular limestone that may correlate to part of the Higginsville Limestone in Missouri occurs a short distance below the Herrin Coal, especially in western Williamson County. Thickness of the limestone may be as great as 16 feet (4.9 m). The limestone generally is light brownish-gray, dense and micritic, and it contains laminae and thin interbeds of greenish gray shale. Core descriptions from Williamson County record unspecified "marine fossils"; Palmer and Dutcher (1979, p. 111) reported crinoids and brachiopods in this limestone in Perry County. Mine exposures also reveal abrupt lateral change from massive limestone to isolated carbonate nodules in a mudstone matrix. These observations imply that the limestone is a marine deposit that was extensively leached and altered during subaerial exposure and soil formation prior to Herrin peat accumulation.

Underclay of Herrin Coal The olive to brownish gray claystone and siltstone is massive with a blocky fracture. Slickensided fractures and well-preserved, carbonized stigmarian roots are abundant. Limestone or dolomite nodules are common in the lower part, which tends to have higher silt content. Typical thickness is 2 to 5 feet (60 to 150 cm), locally reaching 8 feet (240 cm). Like other Pennsylvanian underclays, that of the Herrin is a paleosol that reflects subaerial exposure prior to peat formation.

Walshville Member (new) A major paleochannel that interrupts the Herrin Coal passes less than 1 mile (1½ km) from the western border of Williamson County (Nelson 2019). Known by mine operators since the early 20th century, this channel was mapped in an unpublished thesis (Johnson 1972) and subsequent publication (Allgaier and Hopkins (1975). Up until now, there has been no convenient name, formal or informal, to designate the strata that occupy the Walshville channel. The name Walshville Member (of Carbondale Formation has been proposed by Nelson (in press). The name Walshville is derived from the unincorporated community of Walshville, south of Litchfield in Montgomery County (roughly midway between Springfield and St. Louis). Because no long-lived surface exposures are known (and certainly none that portray the full thickness and relationship to adjacent rocks), a composite section based on five borehole records in southwestern Franklin County was designated as the type section (Nelson, in press).

In its relationship to the Herrin Coal the Walshville closely parallels the relationship of the Galatia channel to the Springfield Coal. The channel follows a broadly meandering course from the northeastern outcrop of the Herrin Coal, north of Danville, to the southern outcrop 1 mile (1 ½ km) west of Hurst in Williamson County. Within the channel the Herrin is replaced by shale, siltstone, and sandstone containing occasional ragged stringers of coal that probably represent rafted peat. Bordering the no-coal area are belts in which the Herrin contains multiple laminae and interbeds of carbonaceous mudstone and dull, impure coal. The "blue band" claystone layer in the lower part of the Herrin thickens from its normal 1-3 inches (2 to 8 cm) to more than 1 foot (30 cm) approaching the channel from the east, as observed in the Royal Falcon underground mine. Beyond these belts of "split" coal the Herrin becomes a normal bright-banded coal with near-normal ash content and abnormally low sulfur content, a factor which combined with great thickness of the seam near the channel, made this an area of intensive mining. As defined here, the Walshville Member comprises three types of clastic strata:

1. Coarse clastics, chiefly sandstone, that are older than the Herrin Coal and fill a paleovalley that is commonly incised into and through the Springfield Coal.

2. Finer and coarse clastics that occupy the position of the Herrin Coal along the central axis of the Walsville channel, and

3. Claystone and carbonaceous shale that intertongue with the Herrin along the margins of the channel.
Relationship of Walshville Member to the Herrin Coal indicates that the channel was active before accumulation of the Herrin peat began and continued active throughout the formation of the peat.

Herrin Coal Member Commonly called the No. 6 Coal, the Herrin is the thickest coal seam in Williamson County and accounts for the lion's share of historic production. Average thickness increases from about 5 feet (1.5 m) along the eastern border to 10 feet (3 m) near the northwestern corner. Disregarding local absence due to erosion and faulting, the thickness range is 3.6 to 12.3 feet (1.1 to 3.75 m). Found throughout Williamson County and most of the Illinois Basin is a claystone layer known as the "blue band", 0.1 to 0.3 ft (2 to 8 cm) thick and 1 to 3.3 feet (15 to 100 cm) above the base of the Herrin The "blue band" tends to rise higher in the seam as the coal thickens. Near the western border of the county the "blue band" thickens to approximately 1 foot (30 cm) in proximity to the Walshville channel, suggesting the claystone was derived from the channel. In addition to the "blue band", the Herrin contains several thinner, discontinuous claystone partings. Pyrite occurs as thin laminae and lenses and as cleat facings. Coal balls - football-shaped lenses of brown limestone replacing peat - were encountered at three underground mines near Johnston City. So-called "rolls" are common where the Herrin is overlain by thick Energy Shale Member. These are elongate channel-like deposits of gray shale near the top of the coal, lens-shaped in profile and sinuous in map view (Bauer and DeMaris 1982; Nelson 1983b).

Energy Shale Membe. The Energy Shale directly overlies the Herrin Coal in much of Williamson County and is well known from mapping in underground coal mines. The type section (probably no longer exposed) is at an abandoned strip mine near the village of Energy, south of Herrin (Allgaier and Hopkins 1975). Intimately related to the Walshville channel, the Energy Shale is thickest close to the channel (maximum thickness 97 feet, 32 m) and gradually tapers eastward, being reduced to isolated lenses in eastern Williamson County. Light to medium gray, silty shale that is weakly fissile and indistinctly laminated is the prevalent lithology. Bands and small nodules of reddish to orange-brown siderite are common. Fossils include a variety of land plants together with arthropods, crustaceans, and the branchiopod *Leiaia tricarinata* (Palmer and Dutcher 1979). Siderite nodules from strip mines near Carterville have yielded fossils of soft-bodied organisms that include horseshoe crabs, insects, spiders, and a scorpion (Joseph A. Devera, ISGS, verbal communication, 2020). Where the Energy Shale is thick it coarsens upward, grading to siltstone and fine sandstone in the upper part. The coarser rocks display planar, ripple, cross, and slumped lamination. Neap-spring tidal rhythmites have been observed in mines and drill cores from north of Williamson County.

The contact with the Herrin Coal is sharp and commonly ragged, with stringers of coal splaying into the shale and "rolls" of shale intruding or replacing the upper part of the coal (Nelson 1983b). The overlying black Anna Shale truncates the Energy with a sharply erosional contact at an angle as steep as 20°. As seen in underground mines such as the Orient No. 4 and Zeigler No. 4 mines east of Johnston City, the Energy can thicken from a feather-edge to more than 10 feet (3 m) thick in less than 50 feet (15 m) laterally. Evidently, the lenticular Energy Shale found in eastern Williamson County and elsewhere represents erosion of a formerly continuous deposit.

The flora, fauna, and presence of tide-generated sedimentary structures signify that the Energy Shale accumulated in fresh to brackish water. The probable setting was an estuary that developed when the Walshville channel was drowned during early stages of marine transgression.

Anna Shale Member The Anna Shale is black, "slaty" shale like the older Mecca Quarry and Excello shales. Phosphatic laminae and thin lenses, small pyrite nodules, and carbonate concretions up to several feet (~ 1 m) across are common. The shale is brittle and strongly jointed. In places a thin layer or series of lenses of impure, pyritic, fossiliferous limestone occurs at the base. Fossils include pectenoid pelecypods, the brachiopod *Orbiculoidea*, conodonts, and fish remains. Like other black shales, the Anna produces "hot" inflections on gamma-ray logs and very low readings on density and neutron logs.

Thickness varies from zero to about 7 feet (2.1 m) thick, although 1 to 4 feet (30 to 120 cm) is usual. As mapped in underground mines, the Anna has highly irregular distribution and may occur as lenses entirely surrounded by areas where the Brereton Limestone directly overlies the Herrin Coal. Among Pennsylvanian black shales, such lenticular distribution is unusual. The lower contact is sharp and commonly erosive; the upper contact may be sharp or gradational through an interval of weakly bedded, gray and green mottled, burrowed, calcareous shale. Where the Energy Shale is thicker than about 40 feet (12 m), the Anna is generally absent.

Black shales such as the Anna clearly were deposited slowly in extremely quiet water having little or no oxygen near the bottom of the water column. Heckel (1977) proposed that such shales were deposited in deep water near the highstand of a eustatic cycle, resulting in a stratified water column. Thus, the accumulation of lenses of Anna Shale in a series of isolated "ponds" is improbable. An episode of erosion prior to deposition of the Brereton Limestone appears to be the most likely explanation, although direct evidence (such as truncated lamination is the shale) is rarely observable. The episode of burrowing and sedimentary reworking that immediately preceded limestone deposition may have obscured evidence for erosion.

McLeansboro Group
DeWolf (1910, p. 181) named the McLeansboro formation to encompass all Pennsylvanian strata overlying the Herrin Coal. Subsequent authors elevated the McLeansboro to a group and divided it into formations. Names and boundaries of these formations has changed over time. Current classification is that of the Tri-State Committee (2001), which designated the Shelburn (oldest), Patoka, Bond, and Mattoon formations. The Shelburn and Patoka Formations, derived from Indiana, replaced the Modesto Formation (Kosanke et al. 1960) as previously used in Illinois. The Shelburn, Patoka, and lower part of the Bond Formation occur within the boundaries of Williamson County (Fig. 16).

Shelburn Formation
The Shelburn Formation constitutes strata between the base of the Brereton Limestone Member and the top of the West Franklin Limestone Member or its uppermost constituent, the Exline Limestone Member (Tri-State Committee 2001). During the initial phase of quadrangle mapping in Williamson County the Shelburn and Patoka Formations were not differentiated (Nelson 2007d, 2007e, 2007g) because of difficulty in identifying the Exline Limestone. However, in subsequent mapping of the Harco Quadrangle (Nelson and Denny 2015), the Exline was recognized and the Shelburn Formation differentiated from the Patoka. Re-examination of core records and other high-quality drilling logs enabled tracing the Exline (or its closely approximated position) westward across Williamson County, so the Shelburn and Patoka have been mapped throughout the county for the present project (the map that accompanies this report) and revised editions of the Herrin, Johnston City, and Pittsburg 7.5-minute quadrangles have been prepared.

Brereton Limestone Member The Brereton is medium to dark gray, argillaceous lime mudstone and skeletal wackestone containing echinoderm fragments, pelecypods, brachiopods, fusulinids, and phylloid algae. Bedding is nodular or "bouldery" to massive. Dark gray, ragged shaly partings and laminae separate hummocky limestone layers. In most of the county the Brereton is 2 to 10 feet (0.6 to 3 m) thick; it is locally absent. Near Spillertown the limestone is as thick as 32 feet (9.8 m) and was quarried on a small scale in conjunction with coal mining. Limestone here has silt and clay content as high as 50%, approaching calcareous siltstone. Spillertown is near the eastern edge of thick Energy Shale; silt and clay from the Energy might have been reworked into the Brereton. Where the Energy is thicker than about 40 feet (12 m), the Brereton generally is absent.

Jamestown Coal Member The Jamestown is confined to northeastern Williamson County, where it is less than 1 foot (30 cm) thick and shaly. In this area, the Jamestown overlies as much as 10 feet (3 m) of dark gray to black, calcareous shale containing marine fossils and grading to a thin rooted underclay at the top. Information comes largely from cores because the coal is too thin to register on most logs.

Conant Limestone Member The Conant is limestone or fossiliferous shale less than 1.5 feet (45 cm) thick, overlying the Jamestown Coal in the northeastern part of the county. The Conant generally resembles the Brereton: dark gray, argillaceous lime mudstone and wackestone containing brachiopods and echinoderm fragments; grading to dark gray or black, calcareous shale.

Lawson Shale and Anvil Rock Sandstone Members The Lawson Shale and Anvil Rock Sandstone are facies of one another and could be considered a single unit. Together they thicken from about 30 feet (9 m) on the west to as much as 80 feet (24 m) on the east. Commonly seen is an upward-coarsening succession from shale in the lower part to sandstone in the upper part. The shale is dark gray and silty, containing laminae and lenses of light gray siltstone and sandstone. Sandstone is light gray, very fine to fine-grained lithic arenite that is thinly to thickly bedded. Cores and exposures in surface mines reveal planar and ripple lamination, flaser bedding, and small burrows. Thin, shaly coal ("sub-Bankston coal") or carbonaceous shale that lacks an underclay commonly occurs near the top. Some drilling records indicate the Anvil Rock Sandstone fills channels that cut down to the Bankston Fork Limestone. Sandstone that fills channels that cut through the Herrin Coal near the Jackson-Williamson county border were formerly correlated with the Anvil Rock (Palmer and Dutcher 1979) but now are identified as the younger Gimlet Sandstone (Nelson 2019).

Bankston Fork Limestone Member This member takes its name from a stream east of Crab Orchard; the type section, just over the line in Saline County, has been obliterated by strip mining. Thickness varies from about 2 to 14 feet (0.6 to 4.3 m) with no regional trend obvious. The limestone is light gray to buff, yellowish gray, or cream-colored lime mudstone and wackestone that contains crinoid fragments, brachiopods, and fusulinids. Structure varies from massive to nodular. Local interbeds of greenish gray claystone separate the limestone into two or more benches.

Baker (Allenby) Coal Member and associated strata Separating the Bankston Fork Limestone from the Danville Coal is an interval of strata that thickens from about 10 feet (3 m) on the west to as much as 40 feet (12 m) on the east. Near the base of this interval is a thin, discontinuous coal that Kosanke

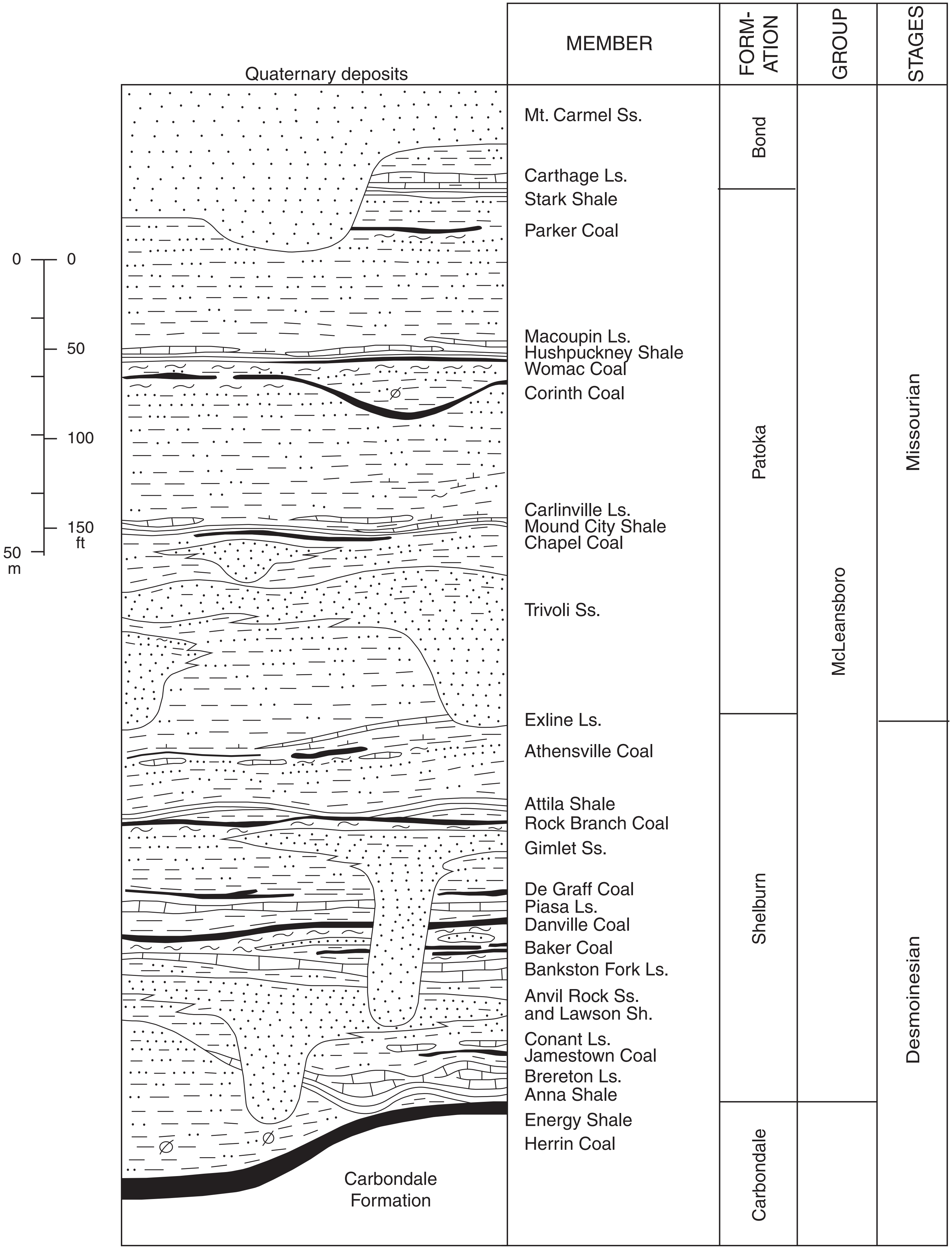


Figure 16 Stratigraphic column showing the McLeansboro Group (Pennsylvanian) in Williamson County.

et al. (1960) named the Allenby Coal Member based on exposures in the NE¼ NW¼ of sec. 24, T9S, R4E in Williamson County on the Carrier Mills Quadrangle. My own investigations demonstrate that the Allenby is correlative with the earlier named Baker (No. 13) coal bed of western Kentucky, which has been mined extensively in Indiana and Kentucky and locally in Gallatin and Saline Counties, Illinois. As recorded in borehole data from Williamson County, the Baker Coal is discontinuous and varies from a carbonaceous streak to bright coal approximately 2 feet (60 cm) thick. Some drilling records and surface mine exposures show one or two additional coal layers a few inches (cm) thick and situated less than 3 feet (1 m) above the main bed. Separating the Baker from the Bankston Fork Limestone is green to gray claystone that contains limestone and is less than 5 feet (1.5 m) thick.

The remainder of this interval is composed of variable and lenticular bodies of mudstone, shale, siltstone, and sandstone. Massive claystone or siltstone bearing roots and other paleosol features generally is found beneath the Danville Coal. Also identified in some drilling records from Williamson County is a valley-filling sandstone for which Nelson (in press) introduced the name **Crown Mine Sandstone Member**. Commonly misidentified as the Anvil Rock Sandstone by earlier authors, the Crown Mine fills meandering channels that are incised through the Herrin Coal in some areas of southern Illinois. In Williamson County channels of Crown Mine Sandstone do not cut deeper than the Brereton Limestone.

Danville (No. 7) Coal Member The Danville is a highly continuous unit that varies from about 0.5 to 4.5 feet (15 to 140 cm) thick, but the usual range is 1 to 2½ feet (30 to 80 cm). The Danville is bright-banded, pyritic coal that lacks persistent clastic layers.

Farmington Shale Member Although historically used only in northwestern Illinois, the name Farmington Shale Member is appropriate for the generally fine-grained clastic interval that lies above the Danville Coal and the Piasa Limestone. The Farmington extends throughout the Illinois Basin and varies from less than 3 feet (1 m) in southwestern Illinois to at least 225 feet (69 m) in White County, southeastern Illinois (Nelson, in press). In Williamson County, the Farmington ranges from about 2 to 15 feet (0.6 to 4.6 m) in thickness. The member includes black, fissile shale directly overlying the Danville and grading upward to mudstone or weakly bedded shale that is mottled gray, green, and olive. Both contacts typically are sharp.

Piasa Limestone Member Lithologically similar to the older Bankston Fork Limestone, the Piasa Limestone ranges from about 1½ to 10 feet (1/2 to 3 m) thick, overall thinning eastward. The rock is generally light gray to buff or greenish gray, dolomitic limestone that weathers yellowish orange. The argillaceous lime mudstone and wackestone contain echinoderm fragments, brachiopods, and fusulinids. This unit is mostly massive to thickly bedded, becoming shalier and more fossiliferous near the base. The Piasa crops out along streams northeast of Paulton in fault slices along the Cottage Grove Fault System.

De Graff Coal Member Although present through most of northern Williamson County, the DeGraff Coal is typically impure coal or coaly shale that varies from a streak to approximately 1 foot (30 cm) in thickness. Rooted, slickensided claystone a few feet (~1 m) thick separates the De Graff from the Piasa Limestone. Some core records indicate thin limestone or calcareous shale, containing marine fossils, directly overlying the De Graff Coal. In the slope of the abandoned Zeigler No. 4 Mine, a channel beneath the De Graff cut out the Piasa Limestone. Filling the channel was sandstone 3 feet (90 cm) thick overlain by siltstone bearing fossil plants (W.J. Nelson, unpublished field notes, ISGS, open files).

Clastic interval Separating the De Graff Coal from the Rock Branch Coal is an upward-coarsening succession of shale, siltstone, and sandstone approximately 20 to 55 feet (6 to 17 m) thick. Dark gray to black, calcareous shale at the base contains scattered marine fossils and grades upward to medium gray, silty shale containing plant fossils. This in turn passes to siltstone or fine-grained, shaly sandstone, topped by greenish to olive-gray mudstone (underclay) having hackly fracture, abundant slickensides, and fossil root casts.

Gimlet Sandstone Member Originally described in Marshall County of north-central Illinois (Wanless 1957), the Gimlet Sandstone Member fills deep paleovalleys that are incised downward from the base of the Rock Branch Coal. The largest Gimlet channel in southern Illinois was exposed in the abandoned Burning Star No. 5 surface mine and in the now-backfilled box cut for the Royal Falcon underground mine, both in Jackson County close to the western border of Williamson County. Palmer and Dutcher (1979) described the sandstone at Burning Star No. 5, but misidentified the unit as Anvil Rock Sandstone. Based on borehole data, the channel is approximately 0.6 mile (1 km) wide and follows a slightly sinuous course running north-south. The channel is cut downward 150 to 200 feet (45 to 60 m), truncating the Herrin Coal and nearly reaching the Springfield (Fig. 17). In mine exposures the sandstone exhibited large-scale trough and planar crossbedding and large scale lateral accretion bedding. Large stringers of coal and casts of plant stems and logs were numerous. The Gimlet also was formerly exposed in open-pit mines near Spillertown, where it was so weakly cemented that it was quarried for sand. Borehole records in eastern Williamson and western Saline counties indicate channels of Gimlet Sandstone that cut as deeply as the Bankston Fork Limestone.

Rock Branch (Pond Creek) Coal Member Kosanke et al. (1960) named the Pond Creek Coal Member (of Modesto Formation) for Pond Creek, which flows through northern Williamson County. As the type section they designated core from Consolidated Coal Company drill hole 91 in SW¼ SW¼ NE¼ NE¼ of sec. 21, T8S, R3E on the West

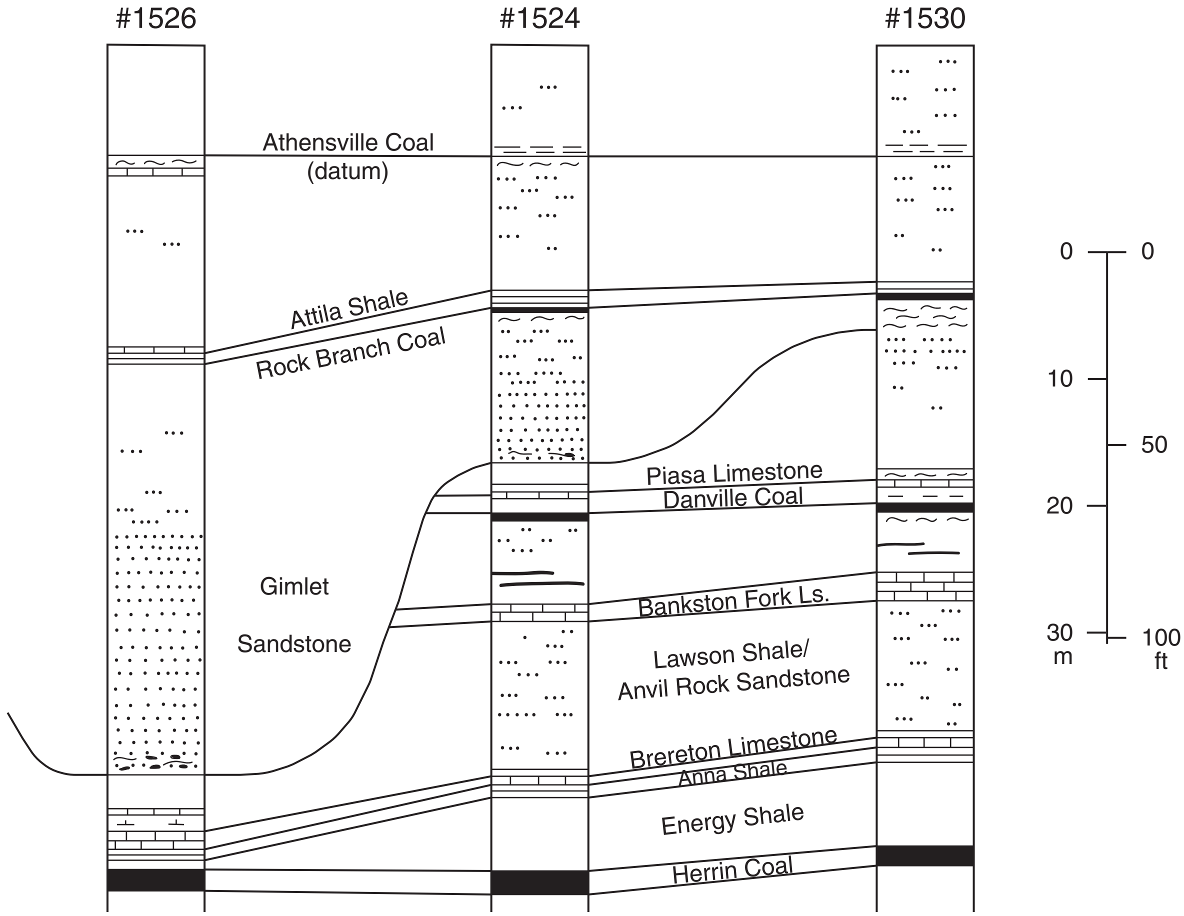


Figure 17 Diagram illustrating paleovalley filled with Gimlet Sandstone Member, based on three cores drilled near Pittsburg in northeastern Williamson County.

Frankfort Quadrangle. In the same publication Kosanke et al. named the Rock Branch Coal Member (of Modesto Formation) with a type section along the stream of that name in Macoupin County, west-central Illinois. Although Peppers (1996) thought the Rock Branch and Pond Creek coals were slightly different ages based on fossil spores, my regional subsurface correlations combined with conodont investigations by Heckel (2013) establishes that Rock Branch and Pond Creek are the same coal. The most compelling point is that the black, fissile, phosphatic Attila Shale Member overlies both coals in their respective type sections. No other such shales occur close to their positions. Because Rock Branch and Pond Creek were named in the same publication, the two names have equal priority and which name to accept becomes somewhat arbitrary. I am choosing Rock Branch Coal Member and abandoning the name Pond Creek, because Pond Creek is a name long used (albeit informally) for an important commercial coal seam in eastern Kentucky. Also, the core that was designated as the Pond Creek type section no longer exists (Nelson, in press).

Thus defined, the Rock Branch is somewhat discontinuous but widely persistent through southern and west-central Illinois. In Williamson County this coal attains a maximum thickness of about 2 feet (60 cm), but is too thin to register on many geophysical logs. As shown by cores, the Rock Branch is bright-banded coal that contains a moderate amount of pyrite and lacks persistent clastic laminae.

Attila Shale Member Overlying the Pond Creek Coal is a regionally persistent black, fissile, phosphatic shale unit that Nelson (2007g) named the Attila Shale Member. The name refers to the community of Attila, where William Nazareth Mitchell settled and opened a post office in 1842. A student of ancient history, Mitchell named his community for “the conquering king of the Huns” (Sneed 1977, p. 241-242). The type section of the Attila Shale is the bed and bank of Rock Creek southwest of Attila in NE¼ SW¼ NW¼ of sec. 9, T9S, R4E on the Pittsburg Quadrangle.

The Attila Shale crops out elsewhere in the Pittsburg Quadrangle and is identified in many cores and well logs throughout northern Williamson County and neighboring areas. Like other black phosphatic shale units, the Attila produces “hot” gamma-ray inflections combined with low readings on density and neutron logs (Fig. 18). The member ranges from about 2 feet (60 cm) to exceptionally 7 feet (2.1 m) thick and rests directly on the Rock Branch Coal at most localities. In a few places, including the type section, shale as thick as 10 feet intervenes between the Rock Branch and the Attila. This shale is medium to dark gray and contains siderite nodules and pectenoid pelecypods. The Attila is the youngest black

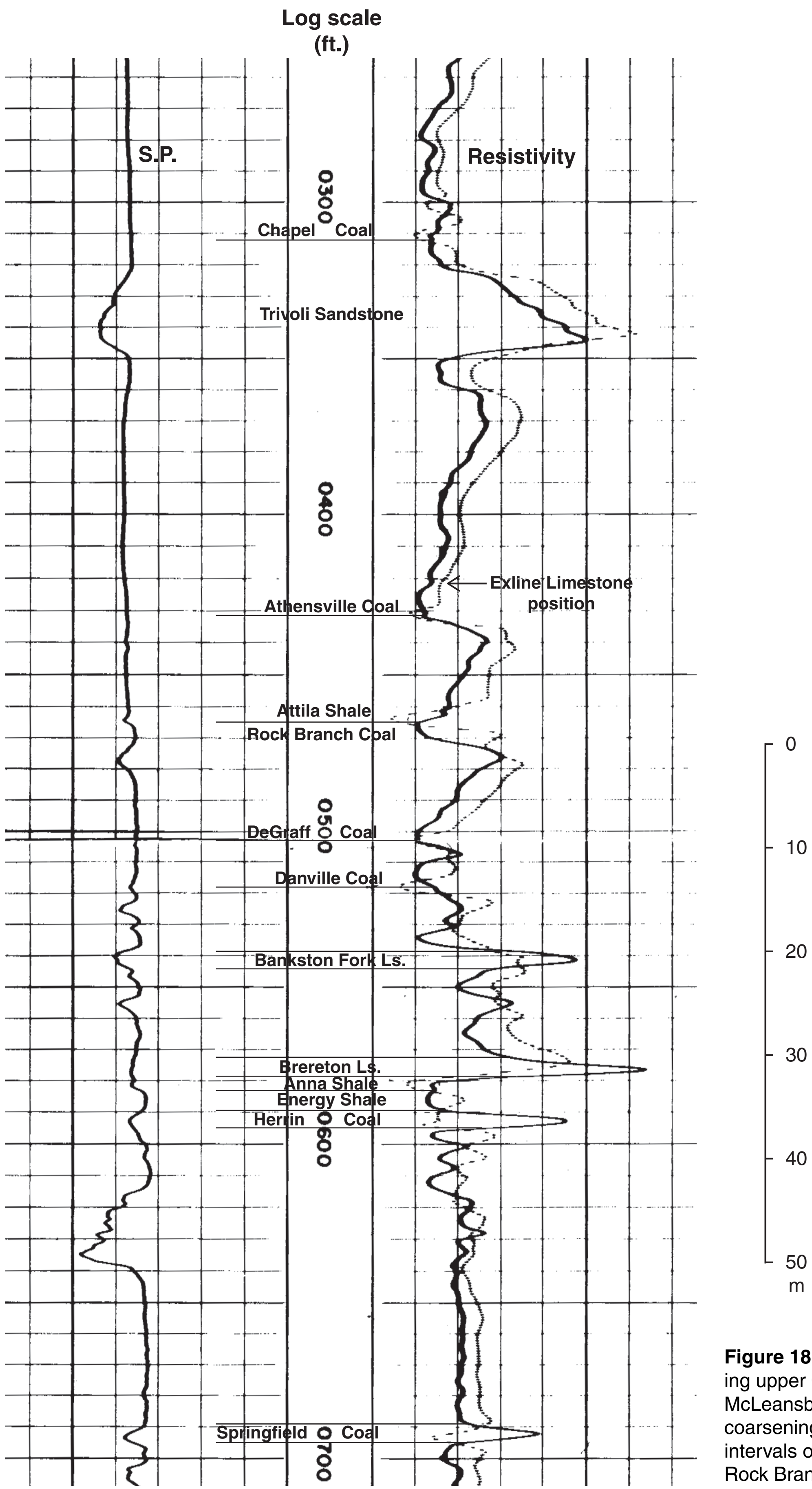


Figure 18 Electric log showing upper Carbondale and lower McLeansboro strata. Note upward-coarsening resistivity profiles for intervals overlying the De Graff, Rock Branch, and Athensville Coals. The log is from C.E. Brehm #1 Barrett et al. oil-test hole drilled in Sec. 1, T8S, R4E.

shale of Desmoinesian age in the Illinois Basin. Based on its conodont flora, the Attila is correlative with the widespread Nuyaka Creek Shale in the Midcontinent (Western Interior) Basin (Heckel 2013).

Clastic interval Between the Attila Shale and the Athensville Coal is a clastic interval that varies from about 25 to 45 feet (8 to 13 m) thick. These rocks consistently coarsen upward, from dark gray shale in the lower part to siltstone and very fine-grained, shaly sandstone in the upper part. Planar, ripple, flaser, and cross-lamination are evident in drill cores. Overlying the sandstone is discontinuous nodular, very argillaceous limestone, topped by greenish gray, massive claystone (underclay) that has hackly fracture, abundant slickensides, and fossil root casts.

Athensville (Lake Creek) Coal Member As was the case with the Rock Branch Coal, Kosanke et al. (1960) gave two different names to what proves to be the same coal bed. The name Lake Creek Coal Member (of Modesto Formation) refers to a stream in Williamson County and the type drill core is the same one used for the Pond Creek Coal. The name Athensville Coal Member (of Modesto Formation) is taken from a village in Greene County and the type locality is along a stream in nearby Macoupin County, west-central Illinois. Regional subsurface correlation and the fact that Athensville and Lake Creek both overlie the Attila Shale and underlie the Exline Limestone establishes that these are the same coal bed. Both names having equal priority, I am accepting Athensville and abandoning Lake Creek chiefly because the core that serves as type section for the latter no longer exists and its log does not record coal at the Lake Creek position (Nelson, in press, Shelburn Formation, Pennsylvanian Subsystem in Illinois).

In Williamson County the Athensville is either dull, shaly coal that varies in thickness from a streak to roughly 1 foot (30 cm) thick, or (more commonly) a few inches (~5-10 cm) of dark gray to black, carbonaceous shale containing fossil plants and coal stringers. Although the coal seldom is thick enough to be detected on wireline logs, its position is marked by a sharp leftward inflection at the top of the underlying upward-coarsening sequence on resistivity logs (Fig. 18). Drillers' logs also commonly record the change from sandy shale or sandstone below the Athensville to sand-free shale above.

Exline Limestone Member Cline (1941) originally named the Exline Limestone for a locality in southern Iowa; this unit has been traced extensively across the Midcontinent (Western Interior) Basin. Following decades of an uncertain and fluctuating stage boundary, Heckel et al. (2002) designated the base of the Exline as the base of the Missourian provincial stage at a locality in northeastern Oklahoma. Wanless (1957) extended use of the name Exline into western Illinois, although Payne (1942) previously introduced the name Scottville Limestone in west-central Illinois for what proved to be the same unit. Identity of the Scottville and Exline of Illinois with the Exline of the Midcontinent has been established through conodont biostratigraphy (Heckel 2013).

The Exline Limestone is barely present in Williamson County, but the limestone (or its position) can be mapped. From 1 foot (30 cm) or thinner near the eastern county line, the Exline gradually thickens to 6 feet (2 m) or more in eastern Saline and Gallatin Counties, and eventually this unit merges with older limestone to become the upper bench of the West Franklin Limestone. From the Harco Quadrangle (Nelson and Denny 2015) westward, the Exline can be identified in cores and on some wireline logs as thin limestone or fossiliferous shale lying 30 feet (m) or less above the Athensville Coal. As the strata are traced westward, the interval between Exline and Athensville diminishes to nearly zero and the position of the Exline can be mapped by identifying the distinctive log inflection of the Athensville. As described from drill cores, the Exline in Williamson County is composed of medium to dark gray calcareous shale or argillaceous limestone that contains brachiopods, gastropods, bivalves (*Myalina*, *Nucula*, and pectenoid types), corals, echinoderm fragments, and ostracods.

Patoka Formation

As accepted by Tri-State Correlation Committee (2001) for usage across the Illinois Basin, the Patoka Formation comprises strata between the top of the Exline or West Franklin[2] Limestone (Shelburn Formation) and the base of the Carthage Limestone Member of the Bond Formation (Fig. 16). As mapped for this project, the Patoka Formation covers large areas of the Harco, Pittsburg, and Johnston City quadrangles in northeastern Williamson County and a narrow strip near the northern edge of the county in the Herrin Quadrangle. Full thickness of the Patoka, 300 to 350 feet (90 to 107 m) is preserved only in the northeastern area where the overlying Bond Formation is present. In most of that area, the Carthage Limestone is absent because the limestone was eroded and replaced by the younger Mt. Carmel Sandstone. The base of the sandstone is mapped as the Patoka-Bond contact where the limestone is missing.

Exline to Chapel interval The interval between the Exline Limestone and the Chapel Coal is 90 to 140 feet (27 to 43 m) thick and includes one named unit, the Trivoli Sandstone Member. This package probably contains three depositional sequences, all of which may either fine or coarsen upward. The lower sequence coarsens upward in most places from dark gray, sideritic shale at the base through silty shale and siltstone to fine-grained, shaly, thin-bedded sandstone at the top. Calcareous shale or impure sandstone is at the base in some wells. Locally, the lower sequence has an erosional lower contact with sandstone grading upward to shale.

[2] The West Franklin Limestone is a composite member that encompasses all strata from the base of the Piasa Limestone through the top of the Exline Limestone. As these strata are traced eastward from Williamson County, the limestone members thicken and the intervening clastic rocks thin until the interval becomes largely or entirely marine limestone that represents three separate cycles of sedimentation.

The Trivoli Sandstone, in the middle sequence, is 20 to 125 feet (6 to 38 m) thick and fills valleys that are locally cut as deeply as the Athensville Coal. The top of the Trivoli resides about 30 feet (9 m) below the Chapel Coal. Outcrops are present on hilltops in the vicinity of Attila and Paulton in the Pittsburg Quadrangle, where glacial drift is thin. Sandstone is light gray to brown, fine to medium-grained lithic arenite that contains plentiful mica and fine carbonaceous debris. In a regional study, Andreson (1961) reported an average of 55% quartz, 4% feldspar, 14% lithic fragments, 18% siderite and calcite cement, and 9% matrix material (mostly clay). Crossbedding is prominent in cores as well as outcrops; it dips mostly south or southeast. Conglomerate commonly marks the lower erosional contact. Good exposures of Trivoli are in the railroad cut near the center of the south line of sec. 36, T8S, R4E on the Harco Quadrangle.

The third and youngest sequence overlies the Trivoli Sandstone and averages about 30 feet (9 m) thick. This sequence either fines upward or coarsens upward from shale to sandstone. At the top is rooted claystone, the underclay of the Chapel Coal.

Chapel (No. 8) Coal Member Although widely distributed across the Illinois Basin, the Chapel Coal rarely exceeds 1 foot (30 cm) thick Williamson County. The Chapel varies from bright-banded, pyritic coal to a few inches of carbonaceous shale with coal streaks. On many wireline logs the coal is too thin to be detected, but a resistivity inflection generally marks its position (Fig. 17).

Mound City Shale and Carlinville Limestone Member Two thin marine units overlie the Chapel Coal or occur at the position of the coal. The older unit is shale that is dark gray to black, silty, and thinly fissile. This unit produces a sharp "hot" inflection on gamma-ray logs, but generally is less prominent than the older Attila and younger Hushpuckney Shale. Correlation with the black, phosphatic Mound City Shale of the Midcontinent (Western Interior) Basin has been established through conodont biostratigraphy (Heckel 2013). Overlying the Mound City is either a single bed or two thin beds of limestone that are separated by several feet (~1 m) of calcareous shale. The limestone is medium to dark gray, argillaceous, and fossiliferous; thickness of the limestone and shale interval varies from zero to about 6 feet (1.8 m) thick. Limestone at this position long was called the Cramer Limestone Member (Kosanke et al. 1960), whereas the name Carlinville Limestone Member (Worthen 1873) was attached to a seemingly younger unit confined to part of west-central Illinois. However, conodont analysis by P.H. Heckel (written communication, 2019) established that the Cramer and Carlinville are the same unit. The Carlinville having been named earlier, that name is continued and the name Cramer limestone is hereby abandoned.

Clastic interval Overlying the Carlinville Limestone is 80 to 95 feet (24 to 29 m) of strata that generally coarsen upward from dark gray shale in the lower part, grading through laminated silty shale and siltstone to fine-grained, shaly sandstone at the top. Less commonly, an upward-fining sandstone unit, the Inglefield Sandstone Member, is present in the upper part of the interval. A thin unit of dark gray, argillaceous limestone or calcareous shale occurs 20 to 30 feet (6 to 9 m) above the Carlinville in several drill cores.

Corinth Coal Member (new) Nelson (in press) proposed the name Corinth Coal Member for a coal unit that is developed in northeastern Williamson, northwestern Saline, and southern Hamilton County. The name refers to the unincorporated village of Corinth and the type section is a drill core taken north of Corinth in sec. 18, T7S, R4E, Franklin County. The Corinth Coal is distinct from the Womac Coal Member, the name that was used in the Pittsburg (Nelson, 2007g) and Harco (Nelson and Denny, 2015) quadrangles. Lying directly beneath the Hushpuckney Shale, the Womac Coal is younger than the Corinth although the Womac is absent or very thin within the report area.

The Corinth Coal ranges in thickness from a streak to a maximum of 3.0 feet (90 cm), measured northeast of Corinth in Secs. 14 and 15, T8S, R4E, where the coal was mined from small drifts during the early 20th century and from strip mines between 1976 and 1994. Samples analyzed by the ISGS and analyses reported by mine operators indicated excellent quality: 0.6 to 0.9% sulfur, 7.7 to 9.9% ash, and heating value of 11,800 to 12,050 BTU/lb (2,975 to 3,039 Kcal).

Drilling records and mine exposures indicate that thick Corinth Coal occupies a channel less than 1 mile (1½ km) wide and trending roughly north-south. Thick coal is underlain by sandstone that grades upward to laminated silty shale containing fossil plants, including *Cordaites* stems and *Pecopteris* foliage. The basal few inches of the Corinth Coal consist of hard, mostly dull, shaly, laminated, and pyritic coal. The remainder is bright-banded and has widely-spaced rectangular cleat fractures. Overlying the Corinth is gray, sideritic shale that contains abundant well-preserved plant foliage, including *Neuropteris ovata*, *N. sceuchzeri*, *Cordaites*, *Calamites*, and *Pecopteris* (identified by W.A. DiMichele of the Smithsonian Institution, written communication). Plant-bearing shale grades upward in turn to siltstone, very fine, shaly, thin-bedded sandstone, and rooted, slickensided claystone that contains small limestone nodules. The interval between the Corinth Coal and the base of the Womac Coal (or Hushpuckney Shale, where the Womac is absent) varies from about 20 to 50 feet (6 to 15 m) thick.

Possible origin of the Corinth Coal is explained in stepwise fashion (Fig. 19). During a minor glacial episode when sea level was lowered, a fluvial channel developed and was backfilled with sand, silt, and finally the Corinth peat. As sea level rose during the following interglacial episode, the channel became and estuary where gray mud buried the peat and shielded it from marine water, resulting in the unusually

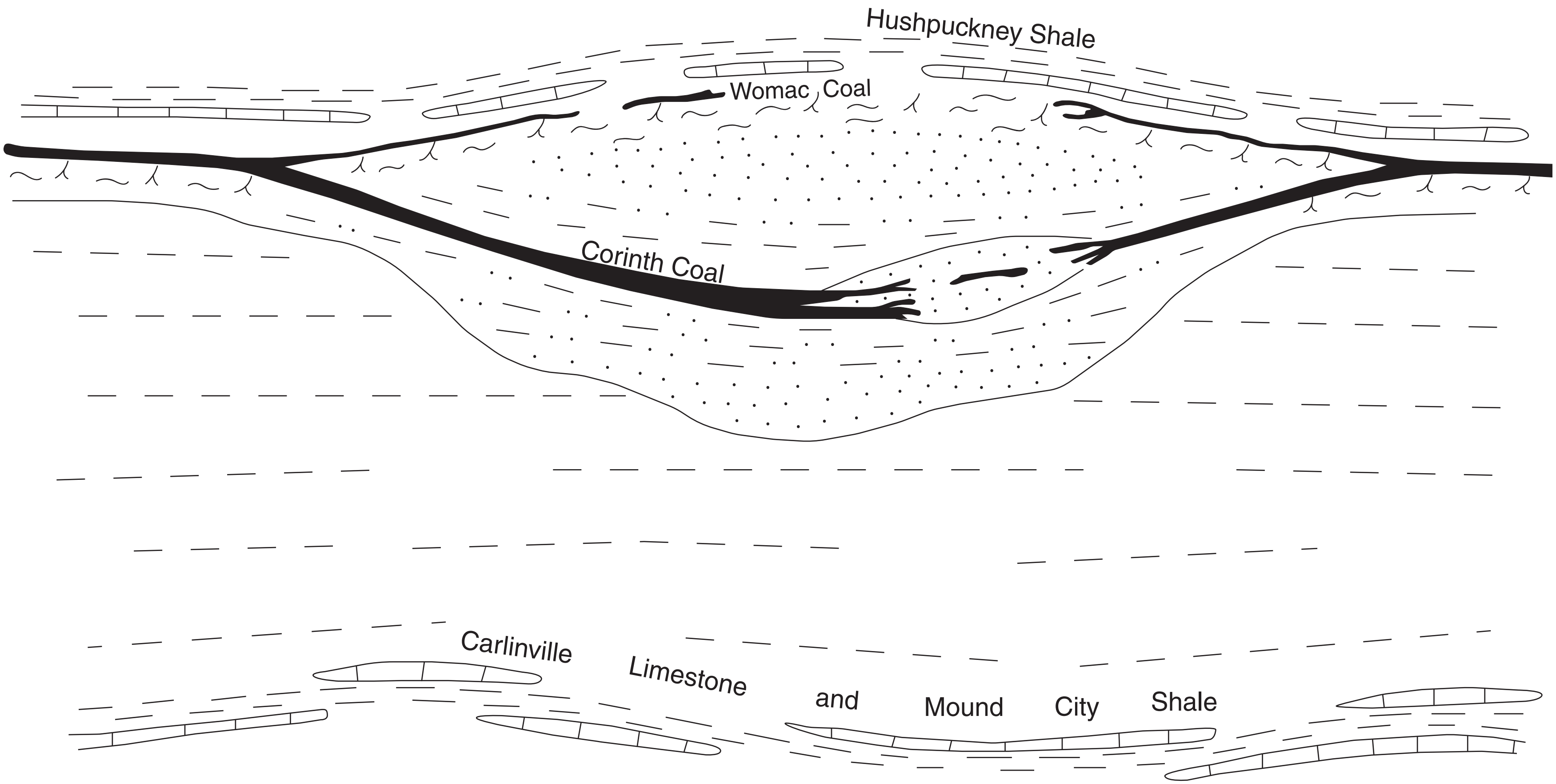


Figure 19 Diagram showing relationship of Corinth Coal Member to enclosing strata. Not to scale.

low sulfur content of the coal. On a smaller scale, this model follows that proposed for the Herrin Coal near the Walshville channel and the Springfield Coal near the Galatia channel (Gluskoter and Simon 1968).

Womac Coal Member Although this unit is widely distributed through the southern part of the Illinois Basin, the Womac Coal Member is very thin or absent in Williamson County, having a maximum thickness of about 1 foot (30 cm) and generally being too thin to register on geophysical logs. Where present, the Womac rests on well developed, rooted underclay and directly underlies the Hushpuckney Shale or the underlying Middle Creek Limestone Member (Nelson and Heckel, in press). As related above, the Womac is distinct from older, more locally developed Corinth Coal Member.

Hushpuckney Shale Member (new in Illinois) As first described by Moore (1936), the Hushpuckney Shale is a widespread black, phosphatic shale unit in the Midcontinent (Western Interior) Basin of Kansas, Missouri, and Iowa. Conodont analysis performed by Heckel (2013) has established direct correlation of the type Hushpuckney with the black, phosphatic shale underlying the Macoupin Limestone Member in Illinois. The Hushpuckney Shale is well developed in Williamson County, where core records show black, highly fissile shale that is slightly silty and partly calcareous, ranging from about 2 to 5 feet (60 to 150 cm) in thickness. Like other black Pennsylvanian shales, the Hushpuckney produces "hot" inflections on gamma-ray lows and low inflections on density and neutron logs. A bed of limestone ranging up to 1.6 feet (49 cm) thick commonly underlies the black shale. The limestone is dark gray, argillaceous lime mudstone to wackestone bearing a fauna of echinoderm fragments, bryozoans, and foraminifera. The name Middle Creek Limestone Member has been extended from the Midcontinent Basin into Illinois for this unit (Nelson and Heckel, in press, Patoka Formation, Pennsylvanian Subsystem in Illinois).

Macoupin Limestone Member Overlying the Hushpuckney Shale, the Macoupin Limestone ranges from a few inches (~5-10 cm) to about 5 feet (1.5 m) thick and includes one or two beds of impure limestone that grade laterally and vertically to calcareous shale. The limestone is argillaceous, nodular to massive lime mudstone and wackestone that contains crinoids, bryozoans, brachiopods, foraminifera, and rugose corals.

Clastic interval An interval approximately 70 to 95 feet (23 to 29 m) separates the Macoupin Limestone from the base of the Stark Shale Member. This succession is dominantly clastic rocks that coarsen from shale at the base to sandstone in the upper part. The basal shale is well laminated, dark gray, sideritic, and contains a brackish to marine fauna of molluscs, ostracods, and small brachiopods. This grades upward to lighter gray silty shale, siltstone, and sandstone. Locally, the upper sandstone fills channels. Some borehole records indicate a thin coal bed 20 to 25 feet (6 to 8 m) below the top of the interval. This may be either the Raben Branch or the younger Parker Coal, both of were first described from outcrops in Posey County, Indiana.

Stark Shale Member (new in Illinois) The uppermost member of the Patoka Formation is black, highly fissile shale approximately 2 to 3 feet thick and directly underlying the Carthage Limestone Member of the Bond Formation. Using conodont biostratigraphy, Heckel and Weibel (1991) determined that the black shale is correlative with the Stark Shale Member of the Midcontinent (Western Interior) Basin. Like other black shale units of Pennsylvanian age, the Stark is characterized by sharp, very high or "hot" inflections on gamma-ray logs corresponding with unusually low inflections on neutron and density logs.

Bond Formation

Kosanke et al. (1960) introduced the Bond Formation based on a composite section of outcrops in Bond County, Illinois, roughly 45 miles (72 km) northeast of St. Louis, Missouri. Definition of the Bond remains as first proposed: strata extending from the base of the widely extensive Carthage Limestone Member (formerly called Shoal Creek) to the top of the Livingston or Millersville Limestone Member (Fig. 16). Only the lower ~80 feet (~25 m) of the Bond is present in Williamson County, confined to the northeastern part of the Pittsburg and northwestern part of the Harco quadrangles. Here, the Bond is largely composed of sandstone that is relatively resistant to erosion and holds up hills and ridges that are thinly mantled by glacial till and loess. The sandstone belongs to the Mt. Carmel Sandstone Member and has an erosive lower contact that commonly truncates the Carthage Limestone. Where the Carthage is absent, the base of the sandstone is mapped as the base of the Bond Formation.

Carthage Limestone Member Information on lithology of the Carthage Limestone is limited because only a single cored test hole penetrated this unit. In that boring, Madison Coal Company's #21 in sec. 5, T8S, R4E, the Carthage is light gray, dense, massive, argillaceous limestone approximately 7 feet (2.1 m) thick. Other subsurface logs indicate that the Carthage has a maximum thickness of about 11 feet (3.3 m). However, most well records in the area indicate that the Carthage was eroded and replaced by the Mt. Carmel Sandstone.

Mt. Carmel Sandstone Member The Mt. Carmel Sandstone is the youngest bedrock stratum in Williamson County, showing a maximum thickness of about 80 feet (24 m) with the upper part eroded. Small outcrops occur along streams, roads, and hillsides but the unit is known mainly from borehole data. near the northeastern corner of the county. In surface exposures the sandstone is light to medium gray, weathering orange; fine to coarse-grained lithic arenite containing abundant mica and carbonaceous debris. Weak cementation produces soft, friable, or "mealy" character. Some outcrops show crossbedding, others show massive sandstone. Core drilling indicates an erosional lower contact marked by conglomerate of shale, limestone, and siderite pebbles.

Permian System

Igneous rocks Many northwest-trending igneous dikes accompany the eastern part of the Cottage Grove Fault System in Saline and Gallatin counties (Clegg and Bradbury 1956; Nelson and Krausse 1981; Nelson and Lumm 1987). They are known from encounters in underground mines, penetrations in cored test holes, and narrow linear magnetic highs (Hildenbrand and Ravat 1997). The "Absher dike" is the only one known in Williamson County. It was formerly visible on the highwall of the Delta strip mine in SE¼, Sec 34, T9S, R4E, Crab Orchard Quadrangle and also was encountered underground in the Hill Coal Co. mine. The Absher dike comprised two parallel intrusions about 50 feet (15 m) apart, running N 40 W, dipping vertically, and ranging from 1½ to 17 feet (1/2 to 5 m) wide. The dike rock was mica peridotite, an ultramafic rock composed chiefly of olivine, pyroxene, biotite, pyrite, and calcite. The Springfield Coal was metamorphosed to natural coke along the dike margins (Clegg 1955). Intrusions in Saline and Gallatin counties have characteristics similar to the Absher dike.

Igneous dikes run parallel and in many cases follow subsidiary faults of the Cottage Grove Fault System. A series of magnetic highs follows the Cottage Grove master fault throughout its length (Duchek et al. 2004). These anomalies may represent intrusions of mafic or ultramafic rock along the fault at depth. Dike rock from Saline and Gallatin counties yielded Permian potassium-argon dates of 235 to 270 Ma (Nelson and Lumm 1985, p. 46). This corresponds to Early Permian, similar to reported ages of ultramafic rocks in the Illinois-Kentucky fluorspar district (Zartman et al. 1967).

Structural Geology

Setting and General Features

Williamson County lies near the southern margin of the Illinois Basin (Fig. 20). As shown by the structure contour lines on the base of the Mississippian Kinkaid Limestone (map that accompanies this report), regional dip in Williamson County is northeast to north-northeast at an average gradient of 1 in 82 or less than 1º of dip. Except close to fault zones, strata dip quite uniformly. The biggest interruption being the belt of anticlines and synclines along the southern side of the Cottage Grove Fault System.

Structural contour maps were prepared for some, but not all of the 1:24,000-scale source maps compiled for this project. Unfortunately, the contouring horizon differs among the quadrangles because availability of data differs from one quadrangle to another. The largest area, including the De Soto, Herrin, Johnston City, Pittsburg, and Crab Orchard quadrangles, was contoured on the top of the Herrin Coal. The top of the Springfield Coal was the contouring horizon in the Carrier Mills and Harco quadrangles, which include a narrow strip at the eastern edge of Williamson County. The Mt. Rorah Coal was contoured in the relevant part of the Creal Springs Quadrangle, the top of the Murray Bluff Sandstone Member (Tradewater Formation) in the Goreville and Stonefort quadrangles. In the Lick Creek and Makanda quadrangles, the base of the Mississippian Kinkaid Limestone was chosen for structural mapping. No structure contours appear on the Carbondale, Crab Orchard Lake, and Marion Quadrangles.

Cottage Grove Fault System

The Cottage Grove Fault System extends about 70 miles (110 km) across southern Illinois, sweeping through northern Williamson County (Fig. 21). The system has been mapped in considerable detail on the basis of outcrops, borehole data, and especially from exposures in underground coal mines. Nelson and Krausse (1981) presented many details on faults observed underground in Williamson County. A few more mine exposures came to light following publication of that report. Further information comes from field notes made by previous ISGS geologists and from publicly available maps of coal mines on which faults are labeled or evident from interruptions in the mining plan. All of these data sources were used in making the primary set of geologic quadrangle maps published in 2007. For the present map (the map that accompanies this report) only a few small adjustments were necessary due to edge-match discrepancies and errors involving control points. The largest source of new data, a map of the currently active Williamson Energy Company's Pond Creek No. 1 Mine, showed no evidence for any faults.

The Cottage Grove Fault System rather complicated geometry (Nelson and Krausse 1981). The master fault is a narrow zone that trends overall west-northwest and exhibits the largest vertical displacements. Branching off both sides of the *master fault* is an array of smaller "subsidiary faults" that mostly trend northwest. Closely associated with the fault system are several anticlines, domes, and dikes of ultramafic igneous rock.

Master fault From Jackson County, the Cottage Grove master fault enters Williamson County near the northwest corner, trending slightly south of east. North of Johnston City, it curves to S 60º E and continues to the east county line, exiting about 5 miles (8 km) due east of Paulton and continuing across Saline County (Fig. 21).

In map view, the master fault is either a single break or a zone of fractures less than 500 feet (150 m) wide. Its trace on the map is slightly sinuous, especially toward the west. East of Johnston City the northeast side is downthrown 75 to 200 feet (23 to 61 m) at the level of the Herrin Coal. West of Johnston City the downthrown side switches back and forth from north to south. In places, the coal is at the same elevation on opposite sides, but mine workings revealed broad zones of intensely sheared rock. Where exposed in mines, master fault surfaces dip from 70 degrees to vertical. In some places the offset is normal (hanging wall downthrown), but in other spots it is reverse (hanging wall upthrown). Five oil-test holes penetrate the master fault in Upper Mississippian rocks (Table 2). In each case the well log shows

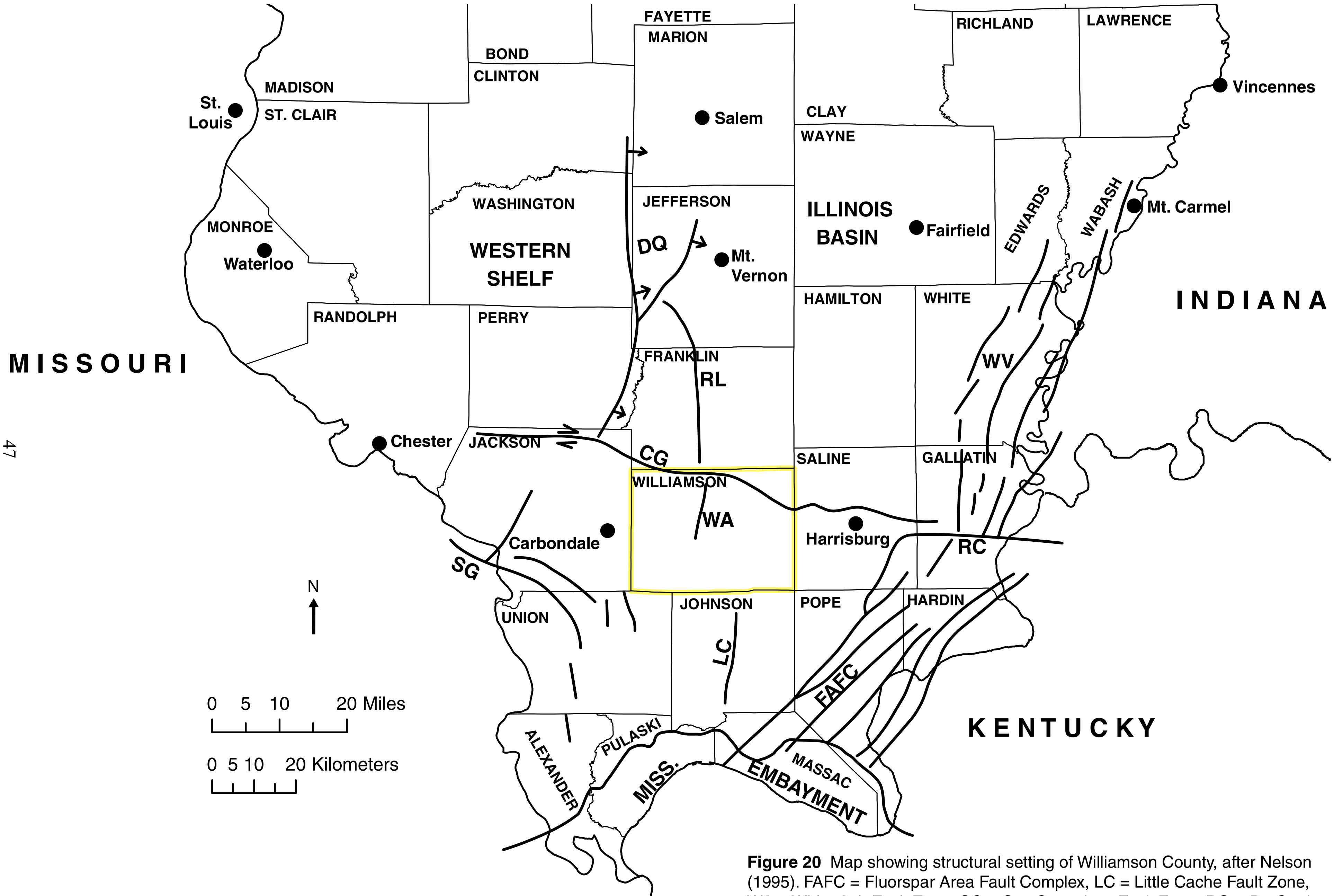


Figure 20 Map showing structural setting of Williamson County, after Nelson (1995). FAFC = Fluorspar Area Fault Complex, LC = Little Cache Fault Zone, WA = White Ash Fault Zone, SG = Ste. Genevieve Fault Zone, DQ = Du Quoin Monocline, RL = Rend Lake Fault Zone, CG = Cottage Grove Fault System, RC = Rough Creek Fault System, and WV = Wabash Valley Fault System.

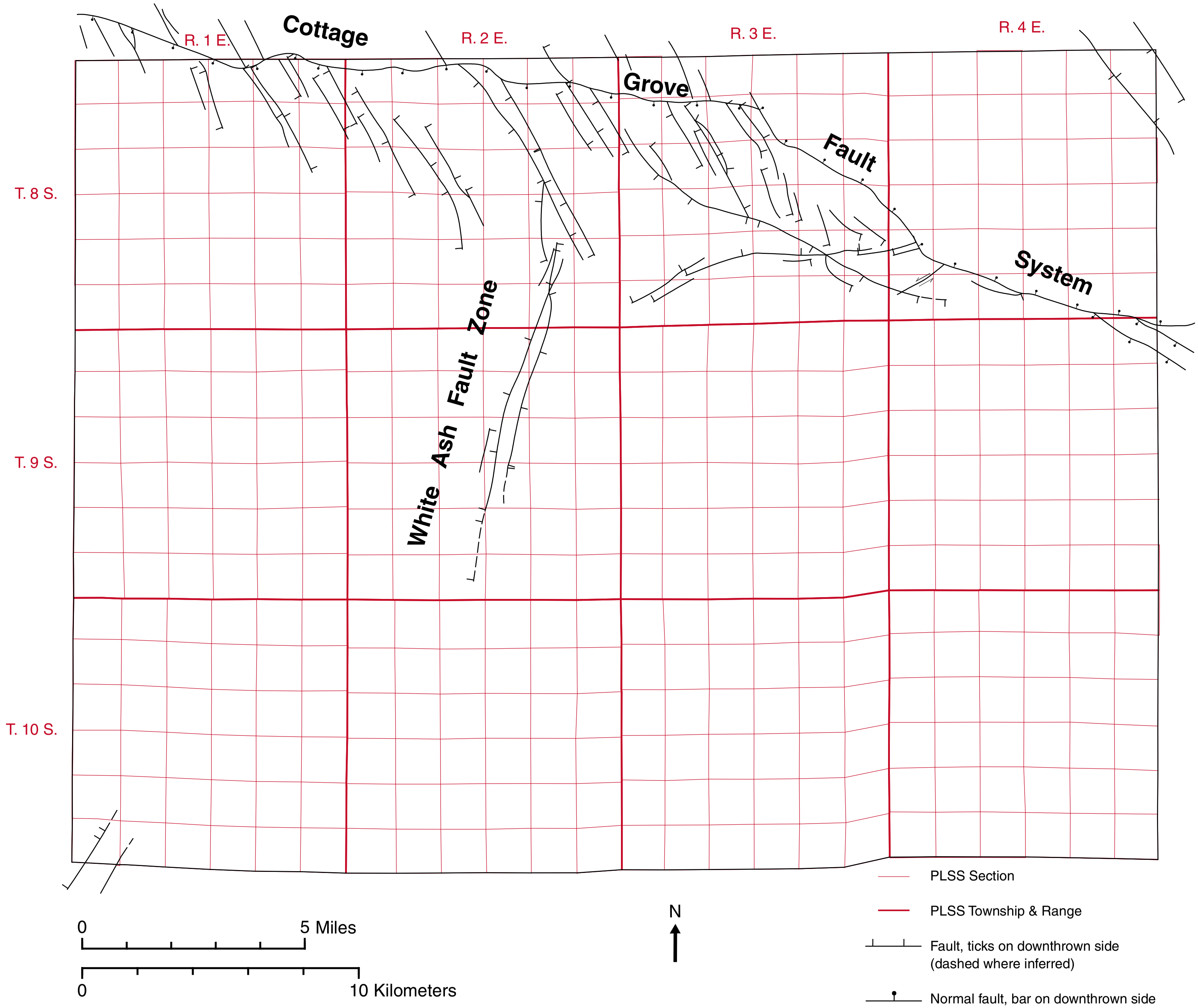


Figure 21 Map showing faults in Williamson County.

repeated section, indicating south-dipping reverse faults that have throws of 75 to 200 feet (23 to 61 m). Dips of these faults, determined by geometric construction between wells and outcrops, range from 62 to 87º. Also, two test holes drilled 660 feet (200 m) apart (county# 1424, Tioga Oil #1 Biehl and #23934, Bufay Oil #3 Old Ben Coal) in NW¼ NW¼ of sec. 8, T 8 S, R 3 E, straddled the master fault without penetrating it. The logs indicated both the Herrin Coal and Kinkaid Limestone are thrown about 120 feet (36 m) down to the north and by geometric construction, the fault dip is no less than 77º. Large segments of the master fault formerly were exposed in the Delta surface mine and Brushy Creek underground mine, both in Saline County, and in the Royal Falcon Mine in Jackson County within 1 mile (1½ km) west of the Williamson County line. In all of these, fault surfaces bore horizontal or gently plunging mullion (large ridges and furrows) and slickensides (fine striations) indicating strike-slip or low-angle oblique-slip displacement.

Seismic reflection profiles in Williamson County show the master fault continues through the base of the Knox Group (Cambrian). The fault trace is nearly vertical in profile but slightly sinuous. Offsets are reverse and may exceed 100 meters (330 feet). Typically a single fault at depth splits into two or more diverging branches in Mississippian rocks. Branches outline upthrown horsts, termed "positive flower structures" (Fig. 22). Seismic lines also show nearly vertical faults at depth that change into folds near the surface (Duchek et al., 2004).

Combining features of strike-slip and high-angle reverse faults, the Cottage Grove master fault is a product of oblique compression. The amount and direction of strike-slip offset have not been determined. For reasons presented below, the movement is believed to have been right-lateral. Where the fault crosses a Pennsylvanian paleochannel in Saline County, the lateral offset is less than 1,000 feet (300 m) (Duchek et al., 2004).

Subsidiary faults Dozens of smaller faults branch off both sides of the master fault (Fig. 21). The large majority strike north-northwest (between N 55 and 70 E) and are straight in map view. They are mapped almost entirely from coal-mine data, because most are too small to be detected by even closely-spaced drilling. Displacements of the Herrin Coal typically range from a fraction of an inch to about 25 feet (8 m). The largest example, southeast of Freeman Spur, has a throw of approximately 60 feet (18 m). As noted earlier, dikes of ultramafic igneous rocks accompany many northwest-trending subsidiary faults east of Williamson County. A single example, the Absher dike, is in Williamson County.

All subsidiary faults exposed in mines dip steeply (60º or more). Most are normal faults but some are reverse and others display clear evidence of oblique or strike-slip movement. Evidence includes horizontal or inclined mullion and slickensides, "scissors faults" (direction of throw changes along strike), "propeller faults" (changes along strike from normal to reverse), and narrow slices of coal or rock displaced a greater distance than the wall rocks. The best example of an oblique-slip fault was observed in the Orient No. 4 Mine. The fault had northeast strike, nearly vertical dip, and displaced the Herrin Coal 10 to 40 feet (3 to 12 m) down to the northwest. The fault surface bore horizontal to gently plunging slickensides and mullion. A lens of Energy Shale in the mine roof was offset with 50 feet (15 m) of left-lateral displacement (Nelson and Krausse 1981).

East of Johnston City and north of Pittsburg is an area where faults have more diverse trends. This area was mapped from exposures in the large Orient No. 4 and Zeigler No. 4 mines (Nelson and Krausse 1981). Most faults lie within a lens-shaped area about 2 miles (3 km) wide and 6 miles (10 km) long, trending northwest (Fig. 21, the map that accompanies this report). East of the Orient No. 4 Mine in T8S, R4E the map of the Pond Creek Mine indicates no subsidiary faults are present north of the master fault. Another lens-shaped fault zone curves west-southwest from Halfway (sec. 30, T 8 S, R 4 E) toward White Ash (north of Marion). Faults within the lens trend NNW, WNW, and west. The fault pattern here suggests that the master fault split into two parallel branches below the level of the Herrin Coal.

Because of their small offsets, subsidiary faults are difficult to detect from borehole data. The only definite example from pre-Pennsylvanian rocks is from the Calvert, Rehn, and Duncan #1 Duty well in sec. 3, T 9 S, R 4 E, where the electric log indicates 20 feet (6 m) of missing section in the Cave Hill Member of the Kinkaid Limestone (Mississippian) at a depth of 1,620 feet (494 m). In several areas where large subsidiary faults were encountered in coal mines, closely spaced oil-test holes yielded no evidence for faults in Mississippian and older strata. This evidence suggests that most subsidiary faults are confined to Pennsylvanian rocks. Analysis of borehole data from the Cat Creek fault zone, a strike-slip structure in central Montana, produced similar findings (Nelson, 1993b). At Cat Creek, a multitude of en echelon normal faults were mapped at the surface and penetrated by drilling in shallow rocks of Cretaceous age but few such faults penetrate deeper strata. Only the master Cat Creek fault continues at depth, demonstrably displacing Precambrian rocks.

Henson et al. (1996) postulated that the Cottage Grove fault system was active during Middle Pennsylvanian and controlled channels filled with Anvil Rock Sandstone. Their evidence came from borehole data and a high-resolution seismic reflection survey in T8S, R5E, Saline County. The seismic line, only 1.9 miles (3 km) long, ran east-west across two northwest-trending subsidiary faults north of the master fault. From published rendition of the seismic profile it is difficult to discern that Anvil Rock Sandstone thickens on the downthrown sides of the two faults, as Henson et al. (1996) assert. Even if it does, the data set is too small to support the conclusions reached.

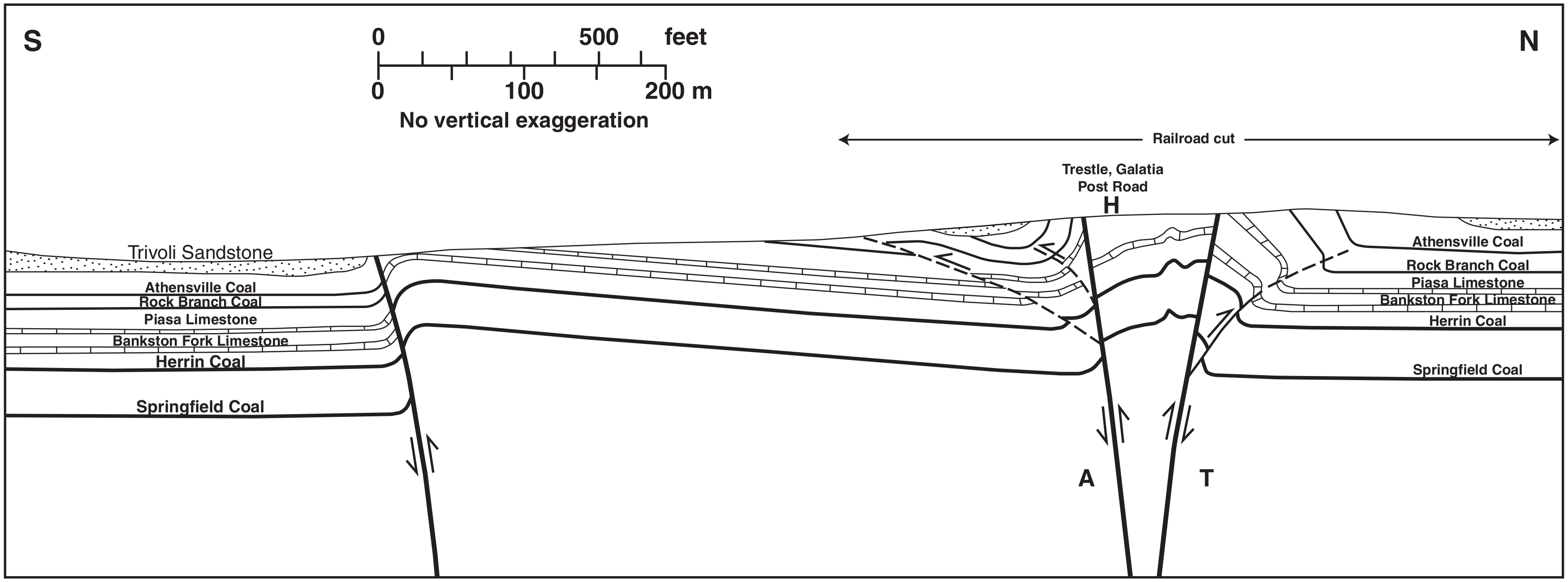


Figure 22 Cross section of Cottage Grove Fault System along Canadian National (formerly Illinois Central) Railroad in Sec. 1, T9S, R4E, Harco quadrangle. Section is based on field notes and diagrams by G.H. Cady, H.R. Wanless, and M.W. Fuller of the ISGS combined with the author's own observations and borehole data outside the line of section. The structure is interpreted as a "positive flower structure" induced by a combination of right-lateral shearing and northwest-directed compression. T = block moved toward observer, A = block moved away from observer.

Folds Elongate anticlines, synclines, and domes flank the southern side of the master fault. These are apparent on the map accompanying this report, contoured on the Herrin Coal on the Johnston City and Pittsburg geologic quadrangle maps (Nelson 2007e and 2007g). As mapped on the Ste. Genevieve Limestone, the structure changes to a single, continuous anticline (Duchek et al. 2004). Nelson and Krausse (1981) gave the name Pittsburg anticline to the largest fold in Williamson County. This and several smaller anticlines and half-anticlines (cut in half by the master fault) are confined to the south side of the master fault. Together, these anticlines reflect the compressive nature of the Cottage Grove fault system.

Discussion The Cottage Grove master fault is strike slip with a strong element of compression expressed by reverse faulting. It penetrates the Paleozoic succession and probably extends through the entire crust, thus serving as a conduit for ultramafic magma. The master fault appears to be a single break at depth, bifurcating toward the surface and outlining positive flower structures. Folds along the southern side of the master fault may express deep-seated branches of the master fault that did not reach the surface (Duchek et al. 2004).

Lateral displacement is undetermined but probably is less than 1,000 feet (300 m) in Pennsylvanian rocks. It is likely that much of the wrenching action at depth was absorbed by folding, minor faulting, and slippage along bedding planes near the surface.

Subsidiary faults are primarily tensional structures, although some underwent oblique or strike slip. They form an *en echelon* pattern characteristic of wrench faulting. Their dominant northwest orientation implies right-lateral movement on the master fault (southern block moving relatively westward). Because dikes are dated as Early Permian, the faults began forming during or before that time. There being no convincing evidence for fault movements during deposition of Pennsylvanian or older sediments, the Cottage Grove probably developed during Late Pennsylvanian and Permian time.

As Heyl et al. (1972) and Duchek et al. (2004) suggested,the Cottage Grove probably follows an Precambrian zone of weakness that was reactivated near the end of the Paleozoic during the Alleghenian orogeny. Northwest-directed compression from the southern Appalachian region shoved the crustal block south of the Cottage Grove westward, producing right-lateral offset.

White Ash Fault Zone
Nelson and Krausse (1981) delineated a north-trending zone of faults near the village of White Ash and named it the White Ash fault zone (Fig. 21). The set of high-angle normal faults runs slightly east of north and passes just west of Marion and Johnston City. The zone is at least 6 miles (10 km) long and 1/4 to ½ mile (~400 to 800 m) wide. At its northern end the White Ash appears to merge with a northwest-trending segment of the Cottage Grove Fault System. The southern end is indefinite because of glacial cover and lack of well control. As observed in surface and underground coal mines, the White ash faults are simple normal faults having little or no associated drag folding. Striations on fault surfaces indicate dip-slip displacement. One small high-angle reverse fault was observed. Throws of individual faults reach a maximum of about 60 feet (18 m). They outline narrow horsts and grabens with overall throw down to the east along most of the length of the zone. Little information is available on structure below Pennsylvanian rocks near the surface. Only one borehole encountered faulting in Mississippian rocks, the New Illinois Mid-Continent #1 Wohlwend oil test in sec. 15, T9S, R2E, which drilled through a normal fault that eliminated 50 to 60 feet (15 to 18 m) of section in the Cypress Formation at a depth of 2,100 feet (640 m).

The White Ash fault zone is nearly in line with the Rend Lake fault zone, which extends northward through Franklin into southern Jefferson County. Both fault zones have closely similar characteristics (Keys and Nelson 1980; Nelson and Krausse 1981). The relationship of these zones to the strike-slip Cottage Grove fault system in unclear, but they clearly reflect an extensional stress regime and most likely are younger than the Cottage Grove.

Other faults
Lamar (1925) mapped a fault at the southwestern corner of Williamson County in sec. 31, T10S, R1E and remarked (p. 136) that the fault was well exposed "where it crosses the main creek", which would be just south of the county line. Mapped is a normal fault that strikes N 30º E, dipping 70º northwest with northwest side downthrown about 25 feet (8 m). Lamar also mentioned slickensided and highly fractured sandstone one-half mile southeast of the above location. This feature is likely a fault, but its throw was not determined. The fault and fracture zone mapped by Lamar appear to be northeast extensions of the Bradshaw Creek Fault mapped by Jacobson and Weibel (1993).

Economic Geology

Coal
History Coal mining was the leading industry in Williamson County from the 1880s into the 1990s. and continues to a limited extent at the time of writing. Cumulative tonnage approaches 470 million short tons (426 million metric tons), nearly 8% of the state's total. Williamson ranks third behind neighboring Franklin and Perry counties in all-time output (Illinois Office of Mines and Minerals 2002).

Worthen (1875) stated that the first coal mine in Williamson County was Spiller's, which opened circa 1850. Presumably using horse-drawn equipment, Spiller strip-mined the Herrin Coal along a small creek near the future site of Spillertown, north of Marion. In 1869, Laban Carter (for whom Carterville is named) opened a mine near that town and subsequently leased his coal to the Carbondale Coal and Coke Co., which began sinking its shaft in November of 1871. This became the first shipping mine in the county. Much of its product went to coke ovens in Grand Tower (Jackson County) where it was used for smelting iron (Worthen 1875). As of 1882, Carbondale Coal & Coke was still the only large mine in the county; others being "small country banks and strippings" (Coal Report, Illinois Dept. of Mines and Minerals 1882).

Coal production blossomed during the 1890s as several large new mines opened. The county's production passed 1 million tons in 1899, and by 1910 Williamson led all Illinois counties in output. Marion, Johnston City, and Herrin became major mining centers. Much of the product was shipped to Chicago, St. Louis, and other northern cities. Railroads were both transporters and big consumers of coal. Production in the county and statewide peaked due to wartime demand in 1916-1918. The largest operators were Peabody Coal Company, which bought its first mine northwest of Marion in 1905; Old Ben Coal Corporation and Zeigler Coal Company, both based in Franklin County; and predecessors to Freeman United Coal Mining Company.

Mechanized strip mining arrived in 1913 when the New Enterprise Mine opened southeast of Herrin. Thick, laterally continuous coal beds and shallow overburden spurred rapid growth. Surface mining peaked from the 1950s through the early 1990s, with AMAX Coal's Delta Mine (62.7 million tons) and Peabody's Will Scarlet Mine (26 m.t.) the leading producers.

After the 1930s, the number of mines and miners decreased due to increased mechanization, leading to greater productivity: fewer workers digging more coal. Consolidation proceeded apace following World War II, although local surface and underground mines remained on the scene through the early 1980s. The largest post-war underground mines were Freeman United's Orient No. 4 (35 m.t.) and Zeigler Coal Company's No. 4 Mine (27 m.t.), both near Pittsburg.

In the 1990s a regional slump hit the Midwest as the market became flooded with cheap, low-sulfur coal from the western U.S. Electric utilities, the principal consumers, found they could purchase Western coal cheaper than Illinois coal and meet emission standards without costly scrubbers. At the same time, several of the county's largest mines reached the end of their reserves. With closure of the Delta Mine in 1997, Williamson County was left with no coal mining for the first time in 150 years until 2005, when Williamson Energy (a subsidiary of Foresight Energy) opened its Pond Creek No. 1 underground mine about 4 miles (6 ½ km) north of Pittsburg. As of 2020 the Pond Creek Mine is still in operation.

Coal Resources The amount of coal remaining in Williamson County is more than five times the quantity already mined. Jacobson and Korose (2003) calculated 2,710 million short tons (2,458 million metric tons) of resources, of which 619 million tons (562 million metric tons) were surface-minable. Included was all coal thicker than 18 inches (46 cm) under less than 150 feet (45 m) of overburden (strippable), plus that thicker than 28 inches (85 cm) and deeper than 150 feet (45 m) and deep-mineable. Out of the total resources, 737 million tons (669 million metric tons) were classified as "recoverable" - potentially mineable under current (circa 2003) economic conditions, assuming 50% recovery underground and 70 to 85% in surface mines (Jacobson and Korose, 2003). Recoverable resources alone equaled 1½ times the volume of coal mined prior to 2003. The tally by seam:

Danville (No. 7)	55	million tons
Herrin (No. 6)	561	" "
Springfield (No. 5)	888	" "
Dekoven	671	" "
Davis	480	" "
Other	52	" "
Total	2,710	" "

These figures listed above were based on a combination of new mapping and older resource estimates, such as those of Cady (1952) and Smith (1957) (C.P. Korose, verbal communication, 2004). Some qualifications are in order. The Danville Coal represents a marginal resource. Although it locally attains 4½ feet (1.4 m), most logs show less than 3 feet (0.9 m). The only known mining was at the Delta Mine, where small amounts of Danville were recovered incidentally while stripping the Herrin Coal. Theoretically, the Danville might be a worthwhile target for small surface mines where cover is thin.

The Herrin Coal is almost entirely mined out or under lease to be mined in Williamson County. The last large block of coal, including most of T8S, R4E north of the Cottage Grove Fault System, is currently being extracted in the Pond Creek underground mine. Small tracts of Herrin Coal remain elsewhere in the county between larger abandoned mines. As late as the 1980s, small excavating companies could economically strip-mine such tracts where they lay at shallow depths. This is no longer the case, and mining such blocks underground would not repay the costs of sinking shafts. Remaining Herrin Coal generally was left in place for good reasons, including faults, steep dips, and incompetent overburden including water-bearing Quaternary sand.

The Springfield Coal remains the largest resource in the county. It is highly consistent in thickness, increasing from 3½ to 4½ feet (1.1 to 1.4 m) on the northwest to 4½ to 5½ feet (14 to 17 m) on the northeast. The Springfield has been surface-mined extensively, but the only significant historic underground mining took place near the eastern edge of the county, mostly in northern T9S, R3E. Hopkins (1968) mapped 557 million tons (505 million metric tons) of Springfield Coal in eastern Williamson County. This includes 274 million tons (249 million metric tons) overlain by gray Dykersburg Shale more than 20 feet (6 m) thick. Thick gray shale and relatively low-sulfur coal are strongly correlated. Sulfur content ranged from 2.3 to 2.9% among 23 coal samples overlain by 20 feet (6 m) or more of Dykersburg in Williamson County. Thick Dykersburg covers about 50 square miles (130 km^2), including all of T 8 S, R 4 E, the eastern edge of T 8 S, R 3 E, and the northern and eastern parts of T 9 S, R 4 E. Most mines in neighboring Saline County experienced good to excellent roof conditions, especially where the black Turner Mine Shale lay directly on the coal. The gray silty shale and siltstone of the Dykersburg Shale Member is moderately competent but can deteriorate when subjected to humidity changes in mine air. Floor heaving and water influx seldom are encountered. Faults can be a problem, although many are accurately located by prior mining of the Herrin. Extensive mining of the Herrin raises concerns about extracting the Springfield beneath abandoned works.

The Houchin Creek Coal was strip-mined in the Will Scarlet Mine and several smaller mines in T 10 S, R 4 E between about 1960 and 1982. Strippable resources have not been evaluated. C.P. Korose (written communication, 2004) tallied about 3.5 million tons (3.2 million metric tons) deep-mineable. In most of Williamson County, the Houchin Creek is about 1.5 to 2.5 feet (45 to 75 cm) thick, which is thinner than any coal currently mined underground in the Illinois Basin. No analyses are available, but the overlying black marine shalke (Excello Shale Member) implies a high sulfur content.

The Survant Coal ranges up to about 3 feet (0.9 m) thick and is potentially strippable in small areas. In the eastern part of the county the Survant splits into two benches, the upper as thick as 2½ feet (75 cm) and the lower less than 1½ feet (45 m). No mining is on record in Williamson County.

The Davis and Dekoven Coals were strip-mined in a large area of southeastern Williamson County, mostly in Peabody's Will Scarlet Mine. They presented an attractive target because of a net coal thickness of 6 to 8 feet (1.8 to 2.4 m) separated by less than 25 feet (75 cm) of interburden. Only a few small underground mines have worked either seam. West of Will Scarlet, little information exists on coal thickness, depth, or quality. For underground mining, the marginal seam thickness renders the Davis and Dekoven subeconomic.

The Mt. Rorah Coal Member (Tradewater Formation) was formerly worked in small strip and underground mines near the southeastern corner of Williamson County. It also was strip-mined together with the underlying, thicker Murphysboro Coal near the Jackson County border. Potential for future development of either seam is slight. Obstacles include variable and uncertain thickness and quality, widespread shale or claystone splits several feet (~1-2 m) thick, and rugged topography in the outcrop area. Moreover, large areas of potential resources underlie the Crab Orchard Lake National Wildlife Refuge. For underground mining, thick coal is present but appears to occur in small pods.

All of the above information may be rendered academic as electric power companies, the predominant customers for Illinois Basin coal, are phasing out their coal-burning power plants and transitioning to cleaner and less capital-intensive sources of energy.

Coalbed Methane

Several wells in northwestern Williamson County extracted gas from abandoned coal mines. No information on gas composition or production rates is available. Data on coalbed methane wells comes from well completion sheets in ISGS files.

Beginning in 1999, several operators attempted producing methane from boreholes drilled into virgin coal seams. One well, completed into the Herrin and Springfield Coals, yielded 35,000 cubic feet of gas per day. Other such holes were plugged after acidizing and perforating casing. Another operator drilled and logged holes as deep as 1,150 feet (350 m) in the northeastern part of the county to test gas output from multiple coal seams. These holes were drilled into, or beyond the expected position of the Murphysboro Coal. Results of testing and production (if any) are not on record. With the natural gas market glutted by production of gas from shale, coalbed methane operations in the Illinois Basin have slid back into dormancy.

Petroleum

One hundred one oil wells and 19 natural gas wells have been drilled in Williamson County. These are distributed among 15 oil and 7 gas fields (Fig. 23, Tables 3 and 4). As of the end of 2004, 62 oil wells in seven fields were still in production, but all gas wells had been capped. The number of producing wells increased by 21 from the previous year as a result of 3 new ones being completed and 18 old ones revived. Cumulative production from all wells is 3,060,100 barrels (approximately 486 million liters) of oil and an estimated 1.5 billion cubic feet (43 million m3) of gas. Unfortunately, no information on Illinois oil and gas fields has been compiled after 2004. Data on oil and gas production comes from well completion sheets in ISGS files.

All oil and gas in the county comes from Chesterian (Upper Mississippian) reservoir rocks at depths of 1,900 to 3,100 feet (580 to 950 m). The Aux Vases Formation accounts for the lion's share of oil production: 69 wells, 70% of the total. Energy Field and three others produce exclusively from Aux Vases. Pay zones are lenses of fine-grained, calcareous sandstone less than 20 feet (6 m) thick, interpreted as tidal sand bars or ridges (Huff 1993). Initial production typically was 50 to 130 barrels per day; one well in Johnston City East reportedly came in at 325 barrels. A rapid decline to "stripper" output of less than 10 barrels per day is the rule.

Aside from Aux Vases, twelve wells scattered among six fields have produced from lenticular, porous, oolitic limestone or calcareous sandstone of the upper Ste. Genevieve.

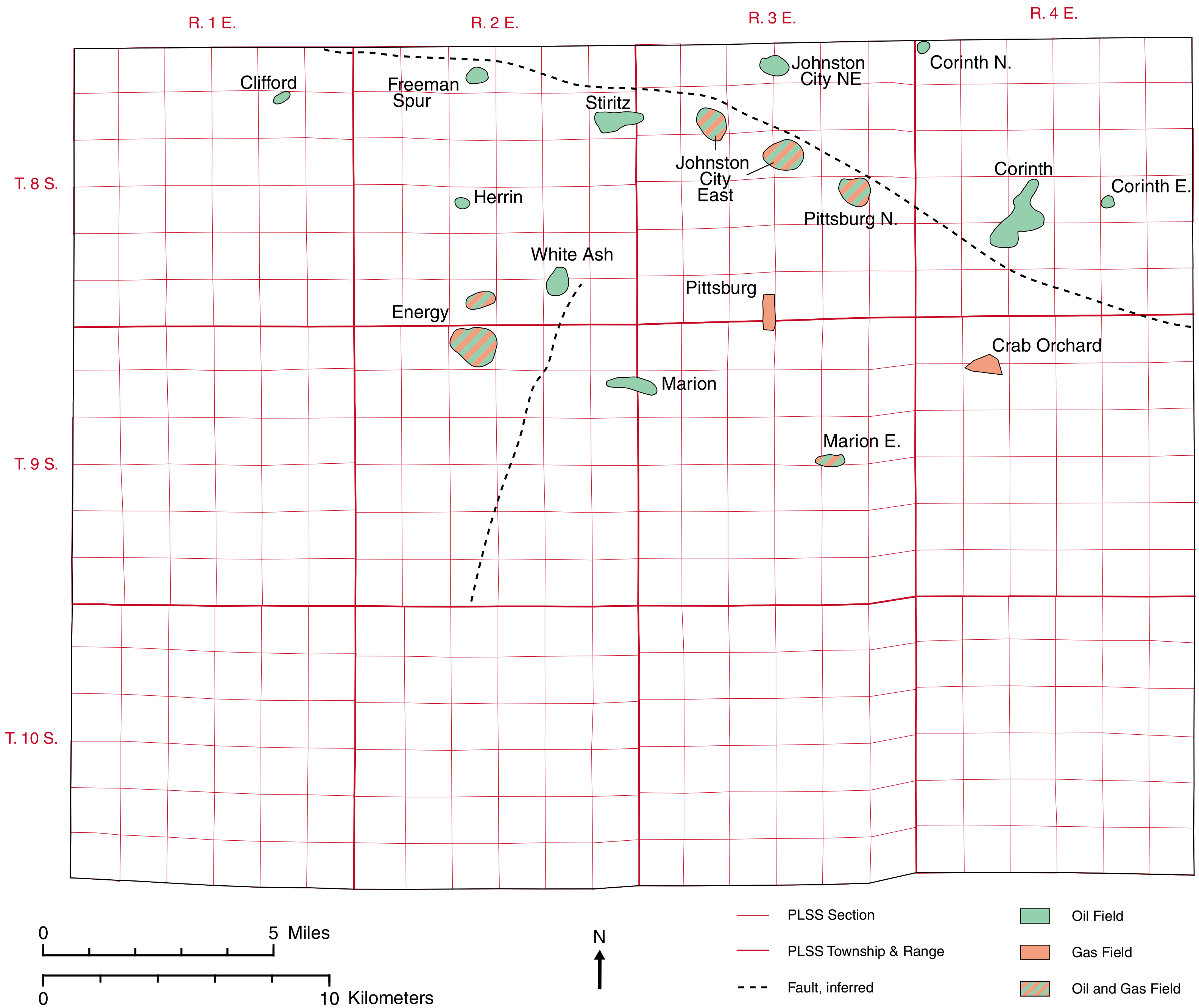


Figure 23 Map showing oil and gas fields in Williamson County.

Table 3 Oil Fields in Williamson County. In Tables 3 and 4, “Total” refers to total number of producing wells ever completed, “2004” is the number producing at the end of 2004, “Cumulative” means cumulative production through 2004 in barrels of oil or million cubic feet of gas. A barrel of oil equates to 42 gallons or approximately 159 liters. Numbers following names of producing formations signify how many wells produce from the unit. These numbers may add to more than the total number of wells in the field where wells produce from more than one formation. Oil and gas production figures for Illinois are seriously out of date; no figures newer than 2004 are available.

Field name	Total	2004	Cumulative	Producing formations
Clifford	2	0	15,000	Aux Vases (1), Ste. Genevieve (1)
Corinth	22	11	622,800	Aux Vases (19), Ste. Genevieve (5)
Corinth East	1	0	10,600	Ste. Genevieve
Corinth North	1	0	3,700	Aux Vases
Corinth South	1	0	11,700	Cypress
Energy	23	20	406,600	Aux Vases (23), Ste. Genevieve (1)
Freeman Spur	3	0	4,000	Aux Vases
Herrin	1	0	2,000	Cypress
Johnston City East	21	14	1,228,600	Cypress (10), Bethel (1), Aux Vases (13), Ste. Genevieve (4)
Johnston City Northeast	4	4	309,000	Aux Vases
Marion	2	0	800	Aux Vases (1), Ste. Genevieve (1)
Marion East	2	1	4,100	Bethel
Pittsburg North	5	4	120,000	Bethel (1), Aux Vases (4)
Stiritz	8	5	286,300	Bethel (2), Aux Vases (6)
White Ash	5	3	36,700	Aux Vases (4), Ste. Genevieve (2)
Crab Orchard	2	0	No data	Hardinsburg
Pittsburg	4	0	No data	Tar Springs
Total	**107**	**62**	**3,060,000**	

Bar-form lenses of calcareous fine to medium-grained Bethel Sandstone produce from 6 wells in 4 fields. In the eastern of two pools of Johnston City East Field, sec. 15, T 8 S, R 3 E, the reservoir is a lens of clean sandstone as thick as 40 feet (12 m) near the top of the Cypress Formation.

Gas comes mostly from Hardinsburg and Tar Springs sandstones, shallower than those that yield oil. One gas well at Marion East produced from the Aux Vases. After exhaustion, four Hardinsburg wells in two fields were converted to gas storage.

Both stratigraphic and structural traps are involved. The Stiritz, Johnston City East, and Pittsburg North fields occupy closed domes along the Cottage Grove master fault. Other fields lack closure, although structure probably influenced oil migration. All reservoir rocks are lenticular, so in a sense, all oil production in the county is stratigraphic.

Table 4 Gas Fields in Williamson County.

Field Name	Total	2003	Cumulative	Producing formations
Corinth South	4	0	147	Hardinsburg
Energy	3	0	no data	Aux Vases
Johnston City East	4	0	998	Tar Springs
Marion East	1	0	no data	Aux Vases
Pittsburg N	2	0	10	Hardinsburg
Stiritz	1	0	68	Tar Springs
Total	**19**	**0**	**1,383+**	

Williamson County oil has API gravity of 36º to 39º at 60º F (15.6º C). Based on geochemistry, Huff (1993) identified oil from the Energy Field as Devonian. Specifically, it is classified as "Group 3 oil" derived from the Upper Devonian New Albany Shale (Hatch et al. 1991).

A key observation is that nearly all oil and gas fields in the county are close to fault zones. The two largest fields, Johnston City East and Corinth; along with Freeman Spur, Stiritz, Pittsburg North, and Johnston City Northeast, all lie within a mile of the Cottage Grove master fault. The other two significant fields, Energy and White Ash, are within one mile of the White Ash Fault Zone. As mentioned above, some fields are in structural traps whereas others, notably Energy, are purely stratigraphic. To some extent the structural factor is self-fulfilling, because oil prospectors seek structural highs. However, extensive "random" drilling away from faults in Williamson County has found no fields larger than four wells.

Fault zones enhance hydrocarbon flow from source rocks and provide pathways from New Albany Shale to Mississippian reservoir rocks. Oil seeps along faults in underground coal mines show that such migration is still taking place. Gas ascends into higher reservoirs than oil.

Groundwater

Williamson County is not well endowed in potable ground water. Creal Springs is the only community that gets its public water supply from wells. Other towns and cities rely on Crab Orchard Lake and other reservoirs. Many rural residences and some commercial users obtain adequate water from drilled wells. Data on water wells comes from well completion sheets in ISGS files.

Creal Springs completed three wells in late 1952 and early 1953. They are 6 to 6½ inches (15 to 16.5 cm) in diameter and 402 to 538 feet (123 to 164 m) deep. They were tested to flow 25 to 40 gallons (95 to 150 liters) per minute and, as of 1960, supplied about 27,000 gallons (100,000 liters) daily (Hanson, 1958, Csallany, 1966). Logs of these wells are sketchy and do not identify water-bearing strata. Considering depth, Creal Springs wells probably produce from sandstone in the lower Tradewater and upper Caseyville Formations.

The federal penitentiary south of Marion is served by eight wells completed in 1990 and 1991. These range from 590 to 700 feet deep and produce 30 to 75 gallons (114 to 284 liters) per minute through 8-inch casing. Logs do not record water-bearing rock units, but all eight wells bottom in the Caseyville Formation. Drillers' logs are moderately detailed and samples from one well were logged for this report. Most domestic wells throughout the county are finished in Pennsylvanian sandstone at depths of 50 to 300 feet (15 to 90 m). The Mt. Carmel, Trivoli, Anvil Rock, Palzo, and Murray Bluff sandstones, among others, serve as aquifers. Most wells yield 5 to 20 gallons (19 to 76 liters) per minute; some produce 30 to 40 gallons (114 to 150 liters) per minute. A few wells 400 to 900 feet (120 to 270 m) deep yield more than 50 gallons (190 liters) per minute from multiple aquifers. Few driller's logs are detailed and accurate enough to identify water-bearing intervals confidently.

Few wells produce from Quaternary sand and gravel. Surprisingly, no wells of record tap sand of the Pearl Formation in the Big Muddy basin. Many coal-test logs here mention "quicksand" that was a serious obstacle in sinking shafts. Aside from the Pearl, lenses of water-bearing sand and gravel probably occur along the bottoms of pre-glacial valleys. Other glacial deposits, including loess, till, and lake deposits, are dominantly silt and clay that do not yield water.

Several wells north of Carterville were completed into abandoned mines that yield 200 to 5,000 gallons (260 to 1,900 liters) per minute. Use of the water is not known; drillers reported it is "not for human consumption". Mine water probably is acidic and mineral-laden.

Lower Tradewater and Caseyville Formation sandstones are the most promising sources of ground water. These sandstones are widespread, generally have good permeability, and can sustain output of 30 gallons (114 liters) per minute or more. Deep wells can tap multiple aquifers.

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Appendix

1. Type section of the Dutchman Limestone Member of the Kinkaid Formation.

Section begins 1,000 feet due south of east end of Dutchman Lake dam, 1500 feet from south line, 500 feet from east line, sec. 7, T12S, R3E, Johnson County, Vienna 7.5' quadrangle. *Top*: concealed by loess, elevation 530 feet.

Caseyville Formation (Pennsylvanian)

8' Sandstone, light gray, very fine to fine quartz arenite, laminated to medium-bedded; planar lamination and small-scale trough cross lamination. Locally conglomerate of shale and ironstone pebbles at base.

Kinkaid Formation, Dutchman Limestone Member

1' Covered

10' Limestone, light to medium gray, crinoidal wackestone and packstone, may include recrystallized grainstone. Bedding undulates gently; beds less than an inch to one foot thick. Rock is argillaceous throughout but lacks distinct shale interbeds. A few bryozoan fragments.

Kinkaid Formation, Grove Church Shale Member

70' Covered; gullies laterally on hillside yield small outcrops of greenish and olive-gray; thinly fissile clay shale, some with dark red mottling; small siderite concretions.

Kinkaid Formation, Goreville Limestone Member

25' Limestone, mostly medium gray; at top is orange-weathering highly fossiliferous wackestone; below is crinoidal grainstone that grades downward to wackestone and lime mudstone. Bedding fairly tabular, a few inches to one foot thick. Brachiopods and Archimedes common. Unit forms a mossy ledge; springs issue from the base. Bottom concealed at flood plain of Dutchman Creek.

2. Reference section of the Dutchman Limestone Member of the Kinkaid Formation. Core of ISGS #1 J. and B. Jones, drilled 500 feet from north line, 1450 feet from east line, sec. 17, T 12 S, R 3 E, Johnson County, Vienna 7.5' quadrangle. Core storage number C-15256; entire core and written log are available for public inspection at ISGS.

Caseyville Formation (Pennsylvanian)

Top Thickness Description

128.0 10.3 ft Sandstone, light gray, fine to medium quartz arenite, coarse sand near base; basal conglomerate of shale, siderite, and sandstone pebbles; sharp contact.

138.3 11.6 Shale, dark gray, silty; light gray siltstone laminae decrease from 30-40% at top to zero at base. Laminae are planar, very fine, and rhythmic; horizontal burrows are common. Lower contact sharp.

149.9 2.5 Conglomerate, gray to dark red, hematitic; composed of quartz granules, clay, shale, ironstone, and chert pebbles in sandstone matrix; several thin beds of shale alternate. Lower contact sharp.

152.4 4.0 Conglomerate, similar to above; including pebbles of crinoidal limestone and lacking shale interbeds. Lower contact sharp.

156.4 2.9 Sandstone, light gray, very fine quartz arenite with 10-20% laminae of dark gray shale; ripple and cross lamination, contorted lamination and ball-and-pillow structure. Lower contact sharp.

159.3 2.4 Conglomerate, like next-to-last unit. Lower contact sharp.

161.7 4.6 Conglomerate, composed of pebbles of gray, argillaceous, crinoidal limestone in a matrix of soft, dark gray clay. The upper part is largely clay with floating pebbles; limestone fragments increase in size and abundance downward. Lower contact is sharp.

Kinkaid Formation, Dutchman Limestone Member

166.3 10.5 Limestone, medium-light gray at top, darker downward; crinoidal wackestone and packstone, wavy to nodular bedding outlined by ragged dark shaly partings. Upper part is dense and micritic, lower part more argillaceous and changing from wackestone to packstone. Lower contact sharp.

176.8 3.7 Shale and limestone, interbedded medium to dark gray, calcareous and fossiliferous shale and gray crinoidal limestone (similar to above). Limestone is roughly half of interval and occurs as nodules, lenses, and thin beds. Echinoderm fragments, fenestrate bryozoans, and chonetid brachiopods are numerous. Lower contact sharp.

Kinkaid Formation, Grove Church Shale Member

180.5 53.7 Shale, claystone, thin limestone, largely dark gray and greenish gray, thinly fissile clay shale; some with reddish mottling; claystone is dark greenish and reddish gray mottled, massive and slickensided, in upper part of unit; limestone beds less than one foot thick occur in lower half of unit.

Kinkaid Formation, Goreville Limestone Member

234.2 47.5 Limestone, mostly medium gray, crinoid-brachiopods wackestone, packstone, and grainstone in a series of upward-fining sequences each 2 to 7 feet thick; argillaceous wackestone at top grading down to pure grainstone with sharp lower contacts.

3. Type Section of the Attila Shale Member

Bed and bank of Rock Creek, 1600 feet from north line and 1200 feet from west line of sec. 9, T 9 S, R 4 E, Pittsburg Quadrangle.

Shelburn Formation

Top: glacial drift, not exposed.

10 ft. Shale, dark gray, slightly silty, well laminated. Sharp contact:

2.7 ft. **Attila Shale Member**, black, hard, thinly fissile, well jointed. Both contacts sharp.

0 to 2 ft. Shale, dark gray, soft, weakly laminated. Forms a small lens.

0.8 ft. **Pond Creek Coal Member**, the uppermost part dull and shaly, the remainder bright-banded.

2 ft. Claystone, medium gray, blocky structure, slickensided, root traces common. Lower contact gradational.

1 ft. Siltstone to very fine sandstone, gray, micaceous, bedding indistinct.

Base concealed under water.

List of Figures

Figure 6. Stratigraphic column showing Silurian and Devonian rocks in Williamson County.

Figure 7. Stratigraphic column showing pre-Chesterian rocks of Mississippian age in Williamson County.

Figure 8. Stratigraphic column showing Chesterian (Upper Mississippian) rocks in Williamson County.

Figure 9. Map showing sub-Pennsylvanian paleovalleys in Williamson County. Boundaries are dashed where approximately located or inferred. Small open circles represent control wells.

Figure 10. Electric log cross section of Marion paleovalley. Width of section is about 2 miles (3 km) (see figure 9 for location). Top of Allard Member of Menard Limestone is datum. Note how depositional sequences above “E” maintain more or less constant thickness across the valley, whereas “E” thickens markedly. Log 2 shows multiple “stacked” massive, valley-fill sequences within the Caseyville. Also in the same well, the interval from 1400 to 1575 feet is a complete mismatch for nearby wells, and may represent a Chesterian slump block.

Figure 11. Stratigraphic column showing Tradewater and Caseyville Formations (Pennsylvanian) in Williamson County.

Figure 12. Electric log cross section illustrating depositional sequences of Caseyville and lower Tradewater formations across a distance of about 4 miles. Line of section shown on figure 9. The base of the Mississippian Negli Creek Limestone is datum. Notice how sequence B, the Pounds Sandstone, changes from massive sandstone in well 2 to sandstone that coarsens upward in well 3 and to mostly shale in the other three wells. Sequences C and D, which are largely shale and shaly sandstone in most of the wells, “stack up” to a massive sandstone interval 135 feet thick in well 4. This is probably a double valley-fill succession. Seqeunce F, at the base of Caseyville, is thin or absent in the three right-hand wells but thickens markedly on the left into a sub-Pennsylvanian paleovalley.

Figure 13. Column showing the lower part of the Tradewater Formation based on outcrops in the northwestern part of the Lick Creek Quadrangle.

Figure 14. Stratigraphic column showing the Carbondale Formation (Pennsylvanian) in Williamson County.

Figure 15. Gamma-ray/induction log showing “hot” black shales and coal beds, Middle Pennsylvanian. Log is from Atlantic Richfield No. 1 Ritchey oil test hole drilled in Sec. 28, T8S, R4E.

Figure 16. Stratigraphic column showing the McLeansboro Formation (Pennsylvanian) in Williamson County.

Figure 17. Electric log showing upper Carbondale and lower McLeansboro strata. Note upward-coarsening resistivity profiles for intervals overlying the De Graff, Rock Branch, and Athensville Coals. The log is from C.E. Brehm #1 Barrett et al. oil-test hole drilled in Sec. 1, T8S, R4E.

Figure 18. Diagram illustrating paleovalley filled with Gimlet Sandstone Member, based on three cores drilled near Pittsburg in northeastern Williamson County.

Figure 19. Diagram showing relationship of Corinth Coal Member to enclosing strata. Not to scale.

Figure 20. Map showing structural setting of Williamson County, after Nelson (1995).

Figure 21. Map showing faults in Williamson County.

Figure 22. Cross section of Cottage Grove Fault System along Canadian National (formerly Illinois Central) Railroad in Sec. 1, T9S, R4E, Harco Quadrangle. Section is based on field notes and diagrams by G.H. Cady, H.R. Wanless, and M.W. Fuller of the ISGS combined with the author’s own observations and borehole data outside the line of section. The structure is interpreted as a “positive flower structure” induced by a combination of right-lateral shearing and northwest-directed compression. T = block moved toward observer, A = block moved away from observer.

Figure 23. Map showing oil and gas fields in Williamson County.

Plates

1. Graphic logs of Fish & Wildlife, Morris, and Binkley cores.

Tables

1. Selected deep test holes in Williamson County.

2. Wells in Williamson County that penetrate faults in Mississippian strata.

3. Oil Fields in Williamson County.

4. Gas Fields in Williamson County.