STATEMAP
Johnson County-BG

Bedrock Geology of Johnson County, Illinois

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Location and History

Situated in far southern Illinois, Johnson County was carved out of Randolph County in 1812, six years before Illinois gained statehood. The county was "named for Col. Richard M. Johnson (1780-1850), a hero of the War of 1812 and rumored to have killed the Shawnee leader Tecumseh at the Battle of the Thames in Ontario in 1813." (Callary 2009, p. 178). Originally, Johnson County extended south to the Ohio River. It was reduced to its present boundaries in three increments, the final in 1843. Total area is 349 square miles (900 km^2). Estimated population in 2019 was 12,417, a slight decline from 12,582 in 2010 (census.gov/data.html). Vienna (pronounced *vy*-en-*uh*) is the only city, having an estimated population of 1,544 as of 2019 (census.gov/data.html). Source of the name is uncertain. It may refer to the city in Austria or may have been a woman's name (Callary 2009). Vienna was established as the county seat in 1818 after Elvira served that role for a few years. One of the oldest in the state, the courthouse in Vienna dates to 1868. Incorporated villages in Johnson County are Belknap, Buncombe, Cypress, Goreville, New Burnside, and Simpson (fig. 1).

Geologic Setting

As Horberg (1950) depicts, Johnson County is situated in the Shawnee Hills section of the Interior Low Plateaus province and borders the northern edge of the Gulf Coastal Plain province (fig. 2). The county holds the unique distinction of containing both the northernmost original extent of the Gulf of Mexico and the southernmost limit of Pleistocene continental glaciation. The former is marked by the northern edge of the Cache Valley due south of Vienna, whereas the latter reaches about 1.3 miles (2 km) into Johnson County in the vicinity of Lake of Egypt (Willman and Frye 1980, Grimley et al. 2020). The Shawnee Hills are composed of sandstone, limestone, and shale of Carboniferous (Mississippian and Pennsylvanian) age. Reflecting the overall slight northward dip of these strata, the hills comprise a series of south-facing escarpments and north-facing cuestas. Quaternary sand and gravel of the Cache Valley compose the northernmost deposits in the Mississippi Embayment section of the Gulf Coastal Plain. As will be detailed in a later section of this report, the Cache Valley represents part of the former course of the Ohio River. South of the Cache Valley in Massac and Pulaski counties are weakly indurated clay, silt, and sand of late Cretaceous and early Cenozoic ages. These sediments were deposited here when the area was an arm of the Gulf of Mexico.

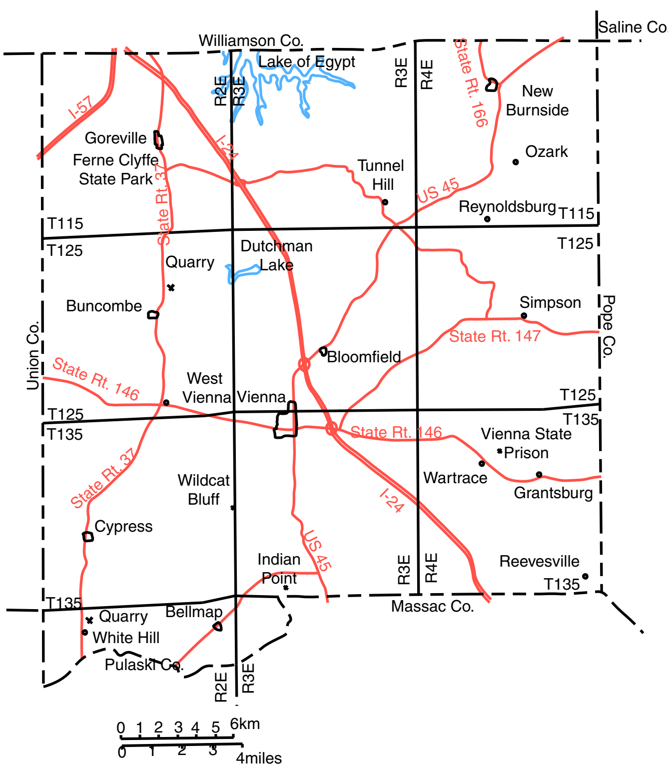


Figure 1 Map of Johnson County, showing communities, highways, streams, and other features.

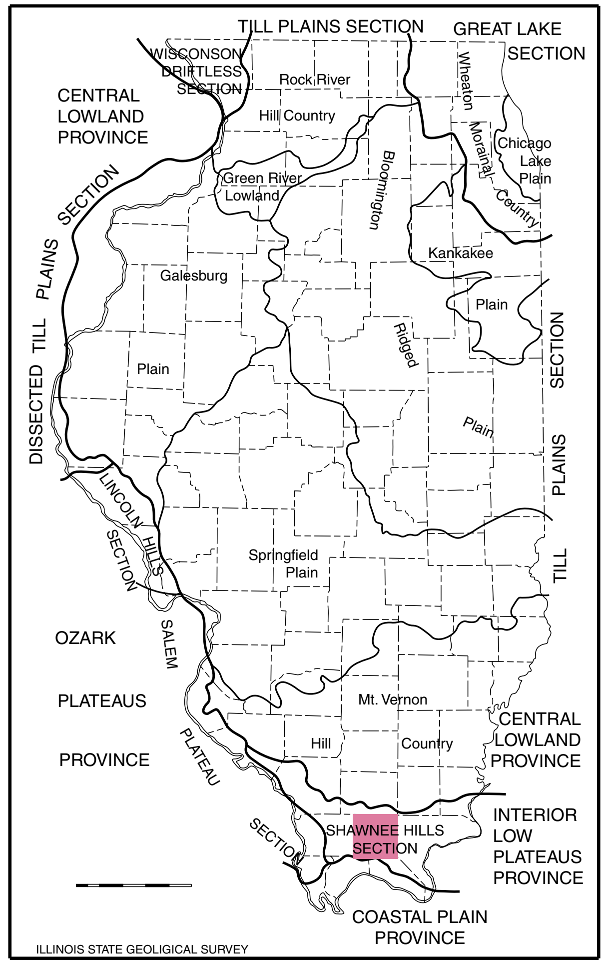


Figure 2 Map from Horberg (1950, p. 21) showing location of Johnson County in relation to physiographic provinces of Illinois.

Structurally, Johnson County lies along the southern margin of the Illinois Basin, which covers most of southern and central Illinois, southwestern Indiana, and parts of western

Kentucky. The Illinois Basin is an interior cratonic basin that developed incrementally from the Cambrian through the Carboniferous Period. The sediments that filled the basin accumulated in shallow to moderately deep marine and associated near-shore and coastal-plain settings.

Previous Investigations

The first author to describe the geology of Johnson County was Henry Engelmann (1866). The geologic map of J.M. Lamar (1925) includes part of northwestern Johnson County. Stuart Weller et al. (1939) mapped and described formations of Mississippian age in Johnson County. J.M. Weller (1940) discussed the stratigraphic, structural geology, and petroleum possibilities of Johnson and several neighboring counties.

Geologic maps that cover individual 7.5-minute quadrangles (scale 1:24,000) are the basis for the compilation map that accompanies this report. These maps together cover all of Johnson County (fig. 3). Additional field work was carried out to resolve some discrepancies that turned up in the earlier maps.

An array of published and unpublished maps, reports, and graduate theses (especially from Southern Illinois University at Carbondale) treat various aspects of the geology of Johnson County. All of those that are cited herein will be found in the References at the end of this report.

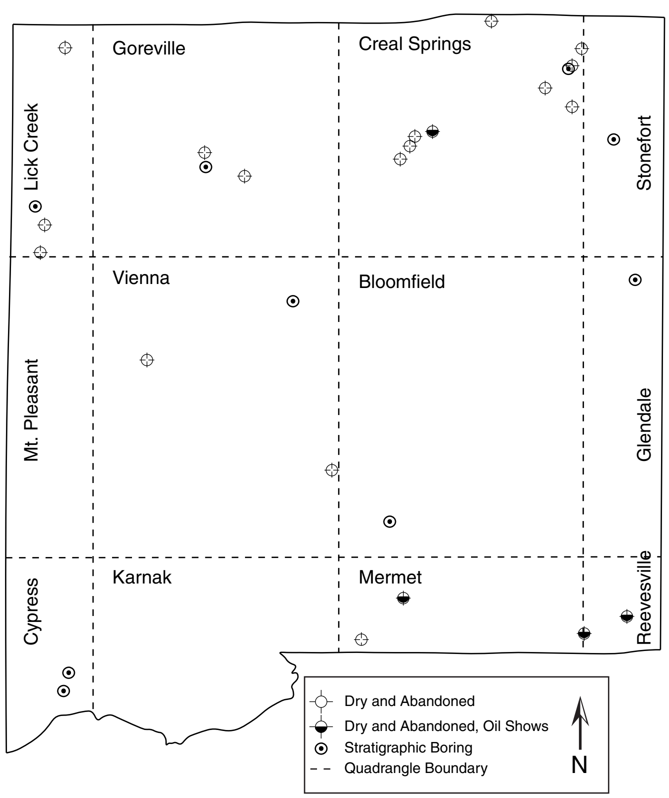


Figure 3 Map showing geologic quadrangles and significant drill holes in Johnson County.

Stratigraphy

All bedrock that crops out in Johnson County belongs to the Carboniferous System. The oldest formation exposed at the surface is the Ste. Genevieve Limestone, which resides at the base of the Chesterian Series in the Mississippian Subsystem. Older rocks are known from oil and gas test borings, of which 21 are on record in Johnson County (table 1, fig. 3). Nine of these holes reached formations older than the Ste. Genevieve, but only one hole provides information on rocks older than Devonian age. Continuously cored test holes drilled by the ISGS are listed in table 2.

Rock units older than the Lower Devonian Clear Creek Formation in Johnson County are known from a single oil-test hole, the Texas Pacific No. 1 Farley test, which was drilled about 6 miles (10 km) south of Vienna (table 1, fig. 3). The Farley hole reached a total depth of 14,284 feet, making it among the deepest holes ever drilled in the Illinois Basin. A full suite of geophysical logs and several sample studies made by company and ISGS geologists provide a thorough and reasonably accurate record of the strata penetrated. Table 3 lists the formations encountered from the Clear Creek downward, as interpreted from the logs.

County and API Numbers

The ISGS assigns a county number to every drillhole in its database. Originally, county numbers were serial, beginning with the number 1. Sometime in the early 1970s the ISGS switched to five-digit numbers beginning at 20,000 for the convenience of computer operators. The American Petroleum Institute (API) assigns a unique 12-digit number to each petroleum test hole drilled in the United States. The first two digits signify the state: 12 for Illinois. The next three digits designate the county: 087 for Johnson. The next five digits are a serial number, which in Illinois is the county number. The final two zeros are for deepening the well 01 or an off-set to the well. Thus, the Owens #1 McCall test hole, Johnson County number 218, translates to API number 120-87-00218-00. For the convenience of computer operators, the API number is usually rendered without commas or hyphens: 120870021800.

Cambrian System

The oldest formation in the Farley well is the Mt. Simon Sandstone, which is correlative with the LaMotte Sandstone in southeastern Missouri. Approximately 1,400 feet (430 m) thick, the Mt. Simon is composed of sandstone that is white to gray, pink, and marron, and fine to very coarse-grained, with occasional quartz granules and small pebbles. Unfortunately, the sample log does not specify mineralogy of the sand, except that a little glauconite is present and some of the sandstone is "quartzitic." Thin black shale laminae or interbeds contain linguloid brachiopods. The upper contact is gradational.

County No.	Operator	Farm or Lease	No.	Sec/Twp	Year	Depth (ft.)	Fm. At Bottom	Logs	Oil Shows
20370	Monjeb Minerals	Throgmorton	1	5-11S-2E	1983	2,015	Ste. Genevieve	D, IE, SS (2)	no
59	Eber McEndree	Parrish	1	24-11S-2E	1955	2,232	Ste. Genevieve(?)	E	no
77	Walter Adams	Walker	1	31-11S-2E	1957	926	Cypress	E	no
104	Mitchell & Stanonis	Simmons	1	23-11S-3E	1965	1,676	Cypress	D, E, GR, N	no
20341	Ronald Mitchell	Biver	1	24-11S-3E	1980	2,400	St. Louis	D, IE	Aux Vases, Spar Mt.
23	Benedum & Trees	Cavitt	1	24-11S-3E	1941	4,250	Clear Creek	E, SS (2)	Bethel
24	Hardin & Harlow	McCuan	1	26-11S-3E	1941	708	unknown	none	no
25	Tunnel Hill Oil	Boner	1	30-11S-3E	1939	4,165	Clear Creek	SS	no
26	Whitnel & Cunning-ham		1	3-11S-4E	1941	1,508	Cypress?	driller's	no
75	Fletcher Farrar	Horn	1	5-11S-4E	1956	2,450	Ste. Genevieve	E, SS	Aux Vases
74	Shure Oil Co.	Evans	1	10-11S-4E	1955	2,231	St. Louis	E, SS	Aux Vases
1	W.W. Reeves	Gibson	1	15-11S-4E	1909	1,560	Golconda	driller's	no
28	C. Wrightsman	Jackson-Whitnal	1	17-11S-4E	1917	2,002	Ste. Genevieve(?)	driller's	no
78	Clyde Adams	Barringer	1	6-12S-2E	1958	601	Hardinsburg	driller's	no
29	Zeppa & Coates	Albright	1	22-12S-2E	1939	1,748	St. Louis	E, SS (2)	no
218	Curtis Owen	McCall	1	4-13S-3E	1969	335	Cypress	SS	no
20305	Texas Pacific	Farris	1	26-13S-3E	1976	2,395	Springville	IE, SS	no
20285	Texas Pacific	Farley	1	34-13S-3E	1975	14,284	Mt. Simon	D, GR, IE, N, SN, SS	no
55	Theodore Glass	Cummins	1	25-13S-4E	1952	1,010	St. Louis	SS	no
20282	Comanche Oil	Branham	1-C	31-13S-4E	1975	3,175	Clear Creek	GR, N, SS	no
57	H.T. McGee	Taylor	1	34-13S-4E	1942	705	Paoli	SS	no

Table 1 Oil and Gas Test Holes in Johnson County. Log types are D = density, E = electric, GR = gamma-ray, N = neutron, Sn = sonic, SS = sample study. All holes were dry and abandoned.

County No.	Name or Number	Section/Township	Year Drilled	Depth (ft.)	Formations
20413	G-2	25-11S-2E	1988	234	Tradewater, Caseyville
20427	L-2	31-11S-2E	1988	264	Caseyville to Degonia
20720	Bloodworth	10-11S-4E	2004	381	Tradewater, Caseyville
20444	LT-1	23-11S-4E	1990	381	Tradewater, Caseyville
20721	J. & B. Jones	17-12S-3E	2004	591	Caseyville to Palestine
20443	GD-1	12-12S-4E	1987	243	Caseyville, Kinkaid
20761	White Hill Quarry	5-14S-2E	2010	135	Bethel to Ste. Genevieve

Table 2 ISGS Stratigraphic Test Holes in Johnson County

System	Formation	Top Depth (ft.)	Thickness (ft.)	Lithology
Devonian	Clear Creek	2,530	570	Fine-grained light gray limestone with abundant chert
	Backbone Ls.	3,100	20	White coarsely crystalline limestone
	Grassy Knob	3,120	200	Similar to Clear Creek
Dev. and Sil.	Bailey Limestone	3,320	351	Fine-grained dolomitic limestone with abundant chert
Silurian	Moccasin Springs	3,671	181	Red to green argillaceous limestone and shale
	St. Clair Limestone	3,852	101	White limestone with pink spots
	Sexton Creek Ls.	3,953	54	Light gray cherty limestone
Ordovician	Maquoketa	4,007	237	Gray to black silty shale, phoisphatic near base
	Kimmswick Ls.	4,244	92	Light gray, coarse crinoidal limestone
	Plattin Limestone	4,336	584	Micritic gray to brown mottled limestone
	Joachim	4,920	300	Dolomitic limestone, micritic, black shale partings
	Dutchtown	5,220	293	Light to dark gray, sandy dolomite
	St. Peter Ss.	5,513	75	White, fine grained, pure quartz sandstone
	Everton Dolomite	5,588	312	Sandy dolomite, dense to sucrosic
	"Shakopee"	5,900	2,560	Dolomite and limestone,minor anhydrite and chert
	Roubidoux	8,460	590	White sandy dolomite and dolomitic sandstone, rounded grains
	Gasconade Dol.	9,150	410	Miostly buff to light gray dolomite without sand; chert common
Cambrian	Eminence Dol.	9,560	870	Buff to light gray, sandy dolomite with minor chert
	Potosi Dol.	10,430	1,030	Dolomite, partly oolitic and pelletal; chert common
	"Franconia"	11,460	440	White to gray dolomite with minor anhydrite and green shale
	Bonneterre Ls.	11,900	980	Pelletal and oolitic limestone; lower half contains much sand-stone
	Mt. Simon	12,880	1,404	White to maroon, fine to very coarse sandstone with thin shale layers
	Total depth	14,284		

Table 3 Formations Interpreted from Logs of the Texas Pacific No. 1 Farley Petroleum Test Hole

Overlying the Mt. Simon is limestone that the logs identify as Eau Claire Formation, but is better identified with the Bonneterre Limestone, as found in southeastern Missouri. This is light to dark gray and brownish gray, fine to coarsely oolitic and pelletal, and commonly contains glauconite. Sandstone layers occur in the lower half, increasing toward the base. The upper contact is abrupt to dolomite called "Franconia", which is likely the Davis and Derby-Doerun Formations of southeastern Missouri. This rock is white to light gray, finely to coarsely granular and crystalline, and partly oolitic and pelletal. Minor anhydrite and green shale are present.

Next upward is dolomite identified as the Potosi Formation, although the drusy quartz that is characteristic of this formation was not mentioned. Colors range from light to dark gray and grayish brown. Chert is common and anhydrite rare. Contacts to adjacent units are indistinct. The Eminence Dolomite, overlying the Potosi, differs from the latter mainly in containing plentiful sandstone and sandy dolomite and little chert.

Ordovician System

Ordovician rocks crop out on the eastern flank of the Ozark Dome in southeastern Illinois and in Illinois along the Mississippi River and are known in the subsurface of Johnson County from logs of the Farley test hole (table 3). Limestone and dolomite predominate, but the St. Peter Sandstone in the middle part and the Maquoketa Shale at the top are important siliciclastic units.

Ostensibly representing the lowest part of the Ordovician in the Farley well is dolomite about 410 feet (125 m) thick that contains plentiful chert and little or no sand. The lower part has oolitic texture. The logs identify this unit as the Oneota Dolomite, as found in Wisconsin, but the Missouri name Gasconade Formation might be more appropriate. Given the subtle lithologic distinction and absence of identifiable fossils in the well cuttings, location of the Cambrian-Ordovician contact is problematic.

Logged as the Roubidoux Formation is an interval of sandy dolomite and dolomitic sandstone approximately 590 feet (180 m) thick. Sandstone is white, fine to coarse-grained quartz with rounded, frosted grains. Dolomite is light to dark gray and brown and commonly cherty.

The Shakopee Formation in the Farley well is a succession of dolomite and limestone approximately 2,560 feet (780 m) thick. Texture varies from sublithographic to pelletal and oolitic. Minor sandstone, anhydrite, and chert were logged. These rocks probably correspond to the Jefferson City (oldest), Cotter, and Powell dolomites of southeastern Missouri, but cannot be distinguished using the available records.

The Everton Dolomite, above the "Shakopee", is recognized by plentiful occurrence of fine to coarse, floating quartz sand grains. Most of the dolomite is light to medium brown and very fine to fine-grained with dense to sucrosic texture. A little gray shale is present, and no chert. Thickness is about 312 feet (95 m).

The St. Peter Sandstone, 75 feet (23 m) thick, is unmistakable as white, fine to coarse, pure quartz sandstone that has well rounded, frosted grains. A little dark gray, sandy dolomite was logged in the lower part.

Continuing upward, the Dutchtown Formation logged as light to dark gray, sandy dolomite that contains fossil fragments (unidentified) and is 293 feet (89 m) thick. The Joachim Formation, above the Dutchtown, is 300 feet (91 m) of limestone that is light to dark gray and brownish gray, sublithographic to very finely granular, and dolomitic. Black shale partings are numerous. The Plattin Limestone is similar in lithology to the Joachim, but more brownish in color and mostly sublithographic, although pelletal and bioclastic layers are present. Ostracods were noted in well cuttings. Thickness of the Plattin is 584 feet (178 m).

The Kimmswick or "Trenton" Limestone is a distinctive unit of white to light gray, finely to coarsely crystalline limestone that is slightly dolomitic and cherty. Although the Farley sample log does not mention fossils, the Kimmswick typically is crinoidal grainstone. Thickness in the Farley well 92 feet (28 m).

At the top of the Ordovician is the Maquoketa Shale, which is logged as shale that is medium to dark gray, locally almost black; slightly to moderately fissile, and partly silty. Phosphatic pellets occur near the base. Thickness is 237 feet (72 m).

Silurian System

Sample logs are available for only the lowermost part of the Silurian in the Farley well. At the base is light to medium gray limestone that contains plentiful chert and is about 55 feet (17 m) thick. This unit is probably the Sexton Creek Limestone. The St. Clair Limestone is reported to be 101 feet (31 m) thick, and white to buff limestone that has "red to flesh speckles" at the base of this interval is characteristic for the St. Clair. Above the St. Clair, the Moccasin Springs Formation generally consists of alternating beds of reddish brown, maroon, and greenish gray calcareous mudstone and argillaceous to silty limestone. Thickness is reported to be 181 feet (55 m).

The Bailey Limestone, which overlies the Moccasin Springs, is only partly Silurian in the basal 20 feet (6 m) and the remainder is Devonian. This is based on the Klonk carbon isotopic excursion found in the McFarland well just southwest of the study area in the Thebes Quadrangle (Grosch et al. 2021). No sample logs are available, but the Bailey in southern Illinois is drab gray dolomitic limestone and dolomite that is very finely granular and contains abundant layers and lenses of chert. This formation is well exposed in the west-facing bluffs of the Larue-Pine Hills in northwestern Union County. The Bailey is 351 feet (107 m) in the Farley well.

Devonian System

The Texas Pacific No. 1 Farley test hole completely penetrated the Devonian System. Three other holes in Johnson County partially penetrated the Devonian. These are the Benedum & Trees No. 1 Cavitt, the Tunnel Hill Oil No. 1 Boner, and the Comanche Oil No. 1-C Branham (table 1). All of these holes have sample studies; the Cavitt and Branham holes also have geophysical logs.

Tamms Group. The name Tamms Group was introduced by Rogers (1972) to comprise the Bailey Limestone (oldest), Grassy Knob Chert, Backbone Limestone, and Clear Creek Formation in southern Illinois. This name was used on the Mill Creek and McClure geologic quadrangle maps (Devera et al. 1994) and also on the Paducah 1° X 2° Quadrangle (Nelson 1995). The Tamms Group is a useful group, combining four similar formations of cherty or siliceous limestone either as light colored, nodular chert, bedded chert or siliceous lime mudstones. These formations can be difficult to differentiate both in the outcrop belt and the subsurface, but are readily distinguishable from the Bainbridge Group below and the Muscatatuck Group above.
Sample studies are not available for the Grassy Knob, Backbone, and lower part of the Clear Creek Formation. On outcrops in Union County, the Grassy Knob is composed of bedded chert and microgranular silica. Well records also indicate the Grassy Knob is mostly chert, although light gray, micritic to finely granular limestone and dolomite occur in the upper part. Extensive silicification of Devonian and Mississippian strata in Union County has been attributed to hydrothermal alteration derived from deep-seated igneous intrusions (Berg and Masters 1994, Nelson et al. 1995). No evidence for such alteration has been reported in Johnson County, so the Grassy Knob Formation here is likely to be cherty limestone and dolomite, similar to the Bailey and Clear Creek formations.

Reported to be 20 feet (6 m) thick in the Farley well, the Backbone Limestone typically is white, relatively pure, crinoidal limestone that contains little or no chert. The overlying Clear Creek Formation is said to be 570 feet (174 m) in this hole, but no sample descriptions are on file. The Boner and Branham test holes drilled into the upper Clear Creek and samples have been logged. The log by J.N. Payne from the Boner hole records 39 feet of limestone that is light gray to brownish gray, very fine to fine-grained, dolomitic, siliceous, and cherty. Euhedral quartz crystals are present, and the lower part of the drilled limestone is finely sandy. The Branham test penetrated 95 feet (27 m) into the Clear Creek, yielding cuttings of limestone that is medium to light brownish gray, microgranular, dolomitic, and silty to finely sandy. Chert is plentiful and some of it is vitreous, but most of the chert has tripolitic texture. These sample descriptions agree closely with the appearance of the Clear Creek Formation on outcrops in Union County where the rock has not been heavily silicified (Nelson et al. 1995).

Grand Tower Limestone. The Grand Tower generally is distinguished from the underlying Clear Creek and overlying St. Laurent Formation (Lingle Limestone) in being lighter colored, coarser grained, more fossiliferous, and sandy, especially near the base. Sample logs from the Boner and Branham test holes conform these distinctions and indicate the Grand Tower to be about 45 to 65 feet (14 to 20 m) thick. In my study of samples from the Branham hole, I described the Grand Tower as being largely skeletal grainstone, but partially recrystallized. Micritic limestone and chert were minor constituents. A target in petroleum exploration, the Dutch Creek Sandstone Member resides at the base of the Grand Tower and is about 10 to 20 feet (3 to 6 m) thick in the two test holes. The sandstone is composed of fine to coarse quartz grains that are well rounded and frosted, like those of the St. Peter Sandstone. A gradation between limestone having floating sand grains and sandstone having calcite cement was observed. The contact between the Grand Tower and St. Laurent limestones is indistinct and likely is gradational.

St. Laurent Formation (Lingle Limestone). The Lingle Limestone of Illinois is correlative with the St. Laurent Formation of southeastern Missouri and both names appear in geologic literature and in well records. St. Laurent has been mainly used on the geologic maps of southern Illinois because it is similar lithologically to the upper Middle Devonian rocks of Missouri. The name Lingle Limestone is retained in central Illinois in areas around the southern part of the Sangamon Arch. Here it is a useful term for the petroleum industry. The sample log from the Boner test hole indicates about 70 feet (21 m) of limestone that is white to light brown, fine-textured, silty, and very cherty. Samples from the Branham test indicate that the St. Laurent Formation is absent or replaced by the Blocher Shale (basal part of the New Albany Shale Group), which is equivalent to the upper Middle Devonian St. Laurent. Thus, in places the New Albany Shale lies directly on the Grand Tower Limestone. Also, very fine quartz sand occurs at the base of the New Albany in samples from this well. These observations suggest that the base of the New Albany is an unconformity.

New Albany Shale. Thickness of this unit ranges from 183 to 225 feet (56 to 69 m) among the four holes that penetrated it. Colors logged in well samples are mostly dark gray, dark brownish gray, and black; but portions are greenish gray. The shale varies from silt-free to highly silty, approaching siltstone. Pyrite is finely disseminated. In two out of three sample studies, the basal part of the New Albany was very calcareous. Very fine sandstone was logged at the base in the Branham well. The New Albany produces moderately to very high readings on gamma-ray logs. The upper contact, to the thin Chouteau Limestone, is abrupt.

Carboniferous System - Mississippian Subsystem
Mississippian rocks are well represented in Johnson County. The Kinderhookian, Osagean, and Meramecian Series occur in the subsurface only, where they are known from four complete well penetrations and a fifth that is nearly complete. Aside from the Springville Shale near the base, these rocks are almost entirely limestone and dolomite. The Chesterian Series, Upper Mississippian, crops out in Johnson County and is further known from the records of 24 boreholes, including 4 that were cored (Tables 1 and 2). Chesterian rocks consist of alternating units of limestone, sandstone, and shale.

Chouteau Limestone. This thin but distinctive unit (fig. 4) registers on the logs of four wells in Johnson County. Thickness ranges from 6 to 9 feet (1.8 to 2.7 m); sample studies record limestone that is light gray, "sublithographic" or "finely sucrosic", and glauconitic. These characteristics are typical for the Chouteau in far southern Illinois.

Springville Shale. Correlative with the lower part of the Borden Formation, the Springville is a unit of shale and siltstone that generally coarsens upward. Logs of four wells in Johnson County indicate the Springville is 53 to 135 feet (16 to 43 m) thick. In samples, the shale and siltstone are greenish gray, brownish gray, and grayish black, slightly calcareous, pyritic, and glauconitic.

Fort Payne Formation. Based on my own sample log from the Branham test, the Fort Payne is approximately 550 feet (168 m) thick and consists mostly of dark gray, dolomitic, microgranular limestone that contains 10% to 20% bluish to brownish-gray, opaque to translucent chert (fig. 4). Also present is 10% to 20% of limestone that is light gray and microgranular to obscurely bioclastic. Small amounts of dark gray to brownish gray, silty shale are present, especially in the lower 60 feet (18 m). The contact with the underlying Springville Shale may be gradational.

The sample log of the Boner oil-test hole, made by J.N. Payne, G.W. Prescott, and F.E. Tippie of the ISGS, suggests that the Fort Payne is approximately 360 feet (110 m) thick. Samples are described as limestone and dolomite that are light to dark brown, darker and increasingly cherty and siliceous downward, and grading to calcareous or dolomitic siltstone and silty shale in about the lower 50 feet (15 m).

Ullin Limestone. Named for a locality in Pulaski County, the Ullin Limestone ("Warsaw" in western Kentucky) has a characteristic texture of brownish echinoderm fragments in a matrix of dull-white fenestrate bryozoan fragments.

In samples that I logged from the Branham oil test, the Ullin is approximately 300 feet (90 m) thick and contains a mixture of two types of limestone. One type is light gray, fine to coarse skeletal grainstone that appears to be partially recrystallized. Recognizable bioclasts are uncommon; they include brachiopods, bryozoans, and echinoderms. The other type of limestone is medium to dark gray, finer grained packstone, wackestone, and lime mudstone, some of which is dolomitic. The darker variety increases in abundance downward and chert becomes increasingly prevalent, as the Ullin grades into the underlying Fort Payne.

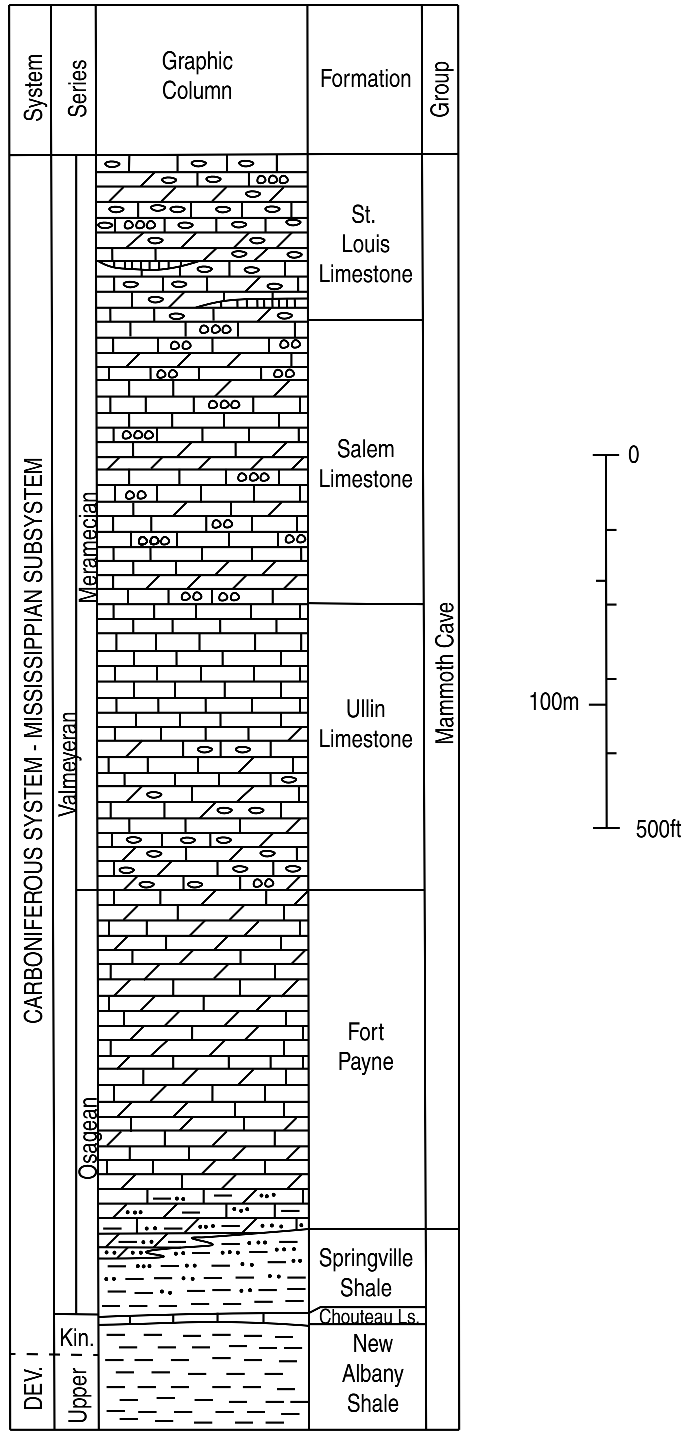


Figure 4 Column showing Lower and Middle Mississippian rocks in Johnson County. Kin = Kinderhookian Series. Osagean-Meramecian boundary after Kammer et al., 1991.

A sample log from the Boner oil-test hole suggests the Ullin is about 465 feet (142 m) thick, although both contacts are indefinite. Samples are described as light gray (upper) to dark brown (lower) limestone that is slightly to moderately cherty. Crinoids are mentioned but not the bryozoans that are conspicuous in the typical Ullin.

Salem Limestone. Concerning the Salem Limestone in southwestern Illinois, Nelson (1995b, p. 17) wrote, "The lower part contains alternating intervals of light gray skeletal and oolitic grainstones and packstones, and darker gray, cherty, and dolomitic wackestones and lime mudstones. The upper part is composed mostly of medium dark gray, fine to medium grained, thick bedded skeletal packstone that contains scattered oolites…The Salem-St. Louis contact is gradational; it is mapped at the highest occurrence of skeletal packstones below cherty lime mudstones of the St. Louis. Thickness of the Salem in southwestern Illinois is about 300 to 450 feet [90 to 137 m]."

The Salem and St. Louis cannot be clearly differentiated in samples from the Branham oil test, although anhydrite at 300 to 320 feet (90 to 96 m) from the top of the 785-foot (239-m) interval clearly belongs to the St. Louis. Samples from the lower, presumably Salem part of the interval were mostly light to medium gray and brownish-gray limestone of variable texture, but largely microgranular to obscurely granular. No oolites were observed and recognizable bioclasts were few. Chert was sparse.

The sample log of the Boner oil-test hole indicates a typical Salem succession about 334 feet (102 m) thick. The limestone is light to dark gray and brown, commonly oolitic and fossiliferous, and contains endothyrid foraminifera that are characteristic of the Salem in southern Illinois. Some layers are slightly to moderately cherty.

St. Louis Limestone. The St. Louis Limestone crops out close to the southwestern corner of Johnson County on the Cypress quadrangle (Devera and Nelson 2009) and has been encountered in 9 wells within the county. The uppermost part of the St. Louis also has been uncovered in the Cypress Quarry of Shawnee Stone Company, located south of Cypress in Johnson County. Outcrops near Cypress show dominantly medium gray, dense lime mudstone that breaks with conchoidal fracture and contains abundant nodules of dark gray to black, vitreous chert. Thinner intervals of fossiliferous wackestone and packstone and a little oolitic grainstone also were observed. Fossils include crinoid fragments, bryozoans, the blastoid *Pentremites,* the solitary coral *Zaphrentis sp.,* and the colonial coral *Acrocyathus proliferus.*
Sample logs indicate a similar suite of lithologies. The log from the Boner test hole, logged by ISGS geologists, indicates the St. Louis to be 214 feet (65 m) thick. Dolomitic limestone, portions of which are oolitic, and finely sucrosic dolomite are prevalent. Both rock types contain chert. A small amount of gypsum was noted near the base of the St. Louis. Elwood Atherton's study of samples from the Shure Oil #1 Evans hole records 230 feet (70 m) plus (bottom not reached) of St. Louis, largely limestone that is "sublithographic" to "obscurely granular". Some of the limestone is dolomitic; nearly all of it is cherty. No fossils were identified. Euhedral quartz grains are present in a few beds.

Ste. Genevieve Limestone. The oldest bedrock at the surface in Johnson County belongs to the Ste. Genevieve Limestone. Outcrops occur along the north side of the Cache River valley on the Cypress and Karnak quadrangles (Devera and Nelson 2009, Nelson and Hintz 2007). Complete exposures exist in the Cypress Quarry, operated by Shawnee Stone, LLC about 3 miles (5 km) south of Cypress. In the quarry the Ste. Genevieve is reported to be 135 feet (41 m) thick, overlying about 10 feet (3 m) of the St. Louis Limestone at the bottom of the pit (Honeywell 2012). However, drilling records in Johnson County indicate the formation is 195 to 230 feet (59 to 70 m) thick possibly reaching 400 feet (122 m) thick in the Boner test hole.

Accompanied by minor dolomite, sandstone, and shale, limestone is the dominant lithology of the Ste. Genevieve. The most abundant and characteristic type of limestone is white to light gray, medium to coarse-grained oolitic and skeletal grainstone and packstone. This rock commonly exhibits large-scale crossbedding, and, as seen in quarries, convex-upward geometry that probably represents coalesced offshore bars and shoals. Separating the oolitic layers are intervals of darker gray and brownish gray, finer grained packstone, wackestone, and lime mudstone. These rocks contain vitreous, bluish-gray chert bands and nodules similar to that found in the St. Louis. Light gray, microgranular dolomite also is present. Sandstone in the Ste. Genevieve is light gray to greenish gray, very fine to medium-grained, glauconitic, and calcareous. Oolites and fossil fragments commonly are present; fossiliferous sandstone grades to sandy limestone. Shale and siltstone are mostly gray to greenish gray and occur in lenses less than about 3 feet (0.9 m) thick. Fossils in the Ste. Genevieve include *Platycrinites* and other crinoids, *Orthotetes* and other brachiopods, and gastropods. Although characteristic of younger formations, the crinoid *Talarocrinus* has been found in the upper part of as low as the Joppa Member of the Ste. Genevieve Limestone in the road cut on U.S. Route 51 in Union County (Cole 1990).

Three members of the Ste. Genevieve can be identified in many well records and quarry exposures in southern Illinois. The <u>Fredonia Limestone Member</u> encompasses the lower and middle part of the formation and is predominantly carbonate rocks, as described above. Well samples indicate thin intervals of fine quartz sandstone, euhedral crystals of quartz, and green to gray shale in the Fredonia. The <u>Spar Mountain Sandstone Member</u> is discontinuous, ranging up to about 25 feet (7.6 m) thick in Johnson County. Overlying the Spar Mountain is the <u>Karnak Limestone Member</u>, which is about 40 to 60 feet (12 to 18 m) thick and similar in lithology to the Fredonia Member. Where the Spar Mountain is absent, the Fredonia and Karnak members cannot be differentiated. Based on outcrops south of Cypress, Swann (1963) named a fourth member, the Joppa Member, at the top of the Ste. Genevieve. The type locality consisted of incomplete outcrops along U.S. Route 51 south of Cypress. Because the Joppa was poorly defined and inconsistently used, Nelson et al. (2002) dropped this unit from formal usage.

The contact with the overlying Aux Vases may be sharp (a minor disconformity) or gradational from sandy limestone below to calcareous sandstone above.

Aux Vases Formation. The Aux Vases has been mapped at the surface in the Cypress and Karnak quadrangles and is known from well records elsewhere in Johnson County. Among six wells having good records, the Aux Vases varies from 17 to 44 feet (5.2 to 13 m) thick. Outcrop data indicate a similar thickness range, except the formation may be as thick as 90 feet (27 m) on the hill just west of Joppa Junction on the Cypress quadrangle (Devera and Nelson 2009). Most outcrops of this unit are small and unimpressive. The best exposures were at the Shawnee Stone quarry south of Cypress.

In Johnson County the Aux Vases is composed of sandstone that intergrades laterally and vertically with sandy limestone. Sandstone varies light gray to brown, greenish gray, and reddish gray and is mostly very fine to fine-grained, although a little medium sand is present. Glauconite, oolites, and marine fossil fragments commonly are present. As shown by a core description, the sandstone also contains laminae and thin interbeds of red and green shale. Observed in outcrops and the quarry were planar and ripple lamination, small-scale crossbedding, and polygonal mud cracks. Shale in the Aux Vases is greenish to olive-gray, platy and fissile. The upper contact typically is gradational to limestone above.

Paoli Limestone. Overlying the Aux Vases is a succession of limestone and mostly fine-grained clastics that Swann (1963) classified into three formations. These were the Renault Limestone at the base, the Yankeetown Formation in the middle, and the Downeys Bluff Limestone at the top. The Renault was further divided into the lower Levias Limestone and upper Shetlerville Limestone members. Given the limited exposures generally available, these units proved to be too thin for practical mapping in Johnson County and elsewhere at the scale of 1:24,000 and smaller. Thus, Nelson et al. (2002) extended the Paoli Limestone from southern Indiana into Illinois, retaining the constituent Levias, Shetlerville, Yankeetown, and Downeys Bluff units as members. On older publications, including Nelson (1996) and Devera and Nelson (1997), the Paoli interval was mapped as "Downeys Bluff and Renault Limestones, undifferentiated".

The Paoli Limestone extends east to west across southern Johnson County, along the north side of the broad Cache River valley. It mainly occupies the lower slopes of bluffs capped by the more resistant Bethel and Cypress sandstones. Limestone of the Paoli forms ledges mainly on south-facing slopes, but no long, continuous artificial or natural exposures are available and no cores of the unit have been drilled in Johnson County. Thus, the section is a composite of outcrop and subsurface information, informed by data from neighboring counties, where cores and quarry walls reveal the entire formation. Thickness in Johnson County ranges from about 80 to 145 feet (24 to 44 m) thick and the four members can be identified with good confidence.

The ***Levias Limestone Member*** is 7 to 40 feet (2.1 to 12 m) thick and consists of limestone that varies from light to medium brown to purplish, reddish and orange-gray. Much of the limestone is oolitic, red-centered oolites being characteristic. Some of the limestone contains quartz sand. Large crinoid fragments, including *Platycrinites penicillus*, occur in this unit. *Talarocrinus* is uncommon in the Levias; however, this fossil has been found as low as the uppermost part of the Ste. Genevieve Limestone (Cole 1990).

The ***Shetlerville Limestone Member*** ranges from 20 to 60 feet (6.1 to 18 m) thick and is mostly medium to dark gray and brown limestone. Texture varies from lime mudstone to wackestone, packstone, and crinoidal and oolitic grainstone. Fossils in the Shetlerville, shared with the Yankeetown, include bryozoans, spiriferid brachiopods, *Pentremites*, and the crinoid *Talarocrinus.* Samples from the Cavitt well showed about 4 feet (1.2 m) of sandstone at the base of the Shetlerville. This thin, discontinuous, but widely distributed sandstone unit is the Popcorn Sandstone Bed of Swann (1963).

The ***Yankeetown Member*** is 10 to 52 feet (3 to 16 m) of interbedded non-fissile claystone, shale, siltstone, and limestone. Clastic rocks are variegated in green, gray, red, and purple. Limestone is mostly gray to brown and varies from dense, sublithographic texture to coarsely bioclastic and oolitic packstone and grainstone. Microgranular dolomite also is present.

The ***Downeys Bluff Limestone Member*** at the top of the Paoli is 20 to 40 feet (6.1 to 12 m) thick and is white, light gray, light brown, and pink in color. This limestone is largely oolitic grainstone that commonly contains fine quartz sand. Pink crinoid grains are characteristic of this unit. Also present are interbeds of gray to green, fossiliferous shale. In the Karnak quadrangle (Nelson and Hintz 2007), the Downeys Bluff comprises two limestone beds separated by dark gray to greenish gray, fissile shale 10 to 15 feet (3.0 to 4.5 m) thick.

The contact between the Paoli Limestone and overlying Bethel Sandstone is sharp and appears to represent a minor disconformity.

Bethel Sandstone. The Bethel Sandstone thickens eastward across Johnson County, from near zero at the western edge and at least 65 feet (20 m) near the eastern border. The sandstone is white to light gray, well sorted, very fine to fine quartz arenite that has subrounded to angular grains. Calcite cement, oolites, and marine bioclasts commonly are present. Sedimentary features include planar, ripple, and cross lamination and trough and herringbone crossbedding. Although the lower contact is erosive, no indications of downcutting were observed. The sandstone appears to have a flat base and a convex-upward top. Geometry and composition of the Bethel strongly suggests a series of offshore marine sand bars.

Ridenhower Formation or Shale. Composed of shale with limestone interbeds, the Ridenhower varies from about 45 to 105 feet (14 to 32 m) in Johnson County. Thickness changes reflect both the hummocky lower contact with the Bethel and the erosive upper contact with the Cypress Formation. The type locality is at Indian Point in the Mermet quadrangle, but here and elsewhere, the Ridenhower is a slope-former and good surface exposures are few. Well records indicate and upper unit of interbedded limestone and shale and a lower, thicker (40 to 64 feet; 12 to 20 m) unit of entirely shale. The lower shale is dark gray, olive gray, and greenish gray and is primarily a thinly fissile clay-shale that is calcareous and contains marine bioclasts such as brachiopods, bryozoans, and crinoids. Siderite bands and nodules commonly are present. The lower shale produces uniform, very low profiles on resistivity logs. The upper Ridenhower contains similar shale that alternates with one or more limestone layers that range up to 25 feet (7.6 m) thick. Limestone is brownish to olive-gray wackestone and packstone that contains oolites, fossil fragments, and in some cases quartz sand grains. Large, unbroken fossils are plentiful, including productid and spiriferid brachiopods, *Archimedes* and other fenestrate bryozoans, *Pentremites* and other blastoids, *Pterotocrinus* and other crinoids, and rugose corals.

Interpretation of the relationship between the Bethel Sandstone and Ridenhower Shale has changed since the 1990s, when the Mermet (Devera and Nelson 1997) and Reevesville (Nelson 1996) quadrangles were mapped and Cole and Nelson (1995) investigated these units. In those publications we interpreted the Bethel to thicken rapidly in eastern Johnson County, intertonguing with the lower and middle parts of the Ridenhower (fig. 5). Later research by Nelson et al. (2002) and mapping the Brownfield quadrangle (east of Reevesville) by Nelson and Denny (2008) changed that model. We now believe that not the Bethel but a younger unit, the Sample Sandstone (earlier named in Indiana), intertongues with the Ridenhower in Pope and eastern Johnson counties. As the Sample Sandstone thickens, it fills paleovalleys that cut into, or through the Bethel (fig. 6**)**. The Sample Sandstone is distinct from the Bethel in being coarser grained and in lacking marine fossils and other marine indicators that characterize the Bethel. However, in some areas of southeastern Illinois and southwestern Indiana, the entire Cypress-to-Bethel interval becomes dominantly sandstone and the constituent formations cannot be differentiated readily. Following the work of Sullivan (1972), the name "West Baden Sandstone" may be used in such areas to denote the succession of "stacked" channel-form sandstone bodies.

Cypress Formation. The Cypress Formation was named in 1863, and the type area is along Cypress Creek in eastern Union County on the Mt. Pleasant quadrangle. There is no specific type section, but sandstone forms impressive bluffs in this area and throughout the outcrop belt in Johnson County. Because it is a prolific oil producer, the Cypress has been the subject of dozens of publications. Most relevant here is Cole and Nelson (1995), which focuses on the Cypress Formation in outcrops and features several exposures in Johnson County.

Outcrops and borehole records demonstrate that the Cypress comprises an upper unit of shale, siltstone, and thin-bedded sandstone that generally erodes to slopes and a lower unit of thick-bedded to massive sandstone that forms cliffs and ledges. Total thickness of the formation ranges from 60 to 190 feet (18 to 58 m) and the usual range is about 100 to 150 feet (30 to 45 m). No regional thickness change across Johnson County is apparent. The lower sandstone is commonly 50 to 100 feet (15 to 30 m) thick and the upper unit tends to be slightly thinner.

The lower Cypress is sandstone that is white to light gray, very fine to medium-grained, partly calcareous quartz arenite. The sandstone has a sugary texture and exhibits quartz overgrowths. Occasional laminae and interbeds of shale and siltstone occur. Large scale wedge- and tabular-planar crossbedding is prevalent and indicates paleocurrents toward the northwest, west, southwest, and south. Bidirectional crossbedding in the Mermet quadrangle suggests tidal activity. The upper parts of cliff exposures commonly are more massive and display extensive soft-sediment deformation such as overturned crossbedding, contorted lamination, and sets of "healed" fractures. Rapid de-watering of sand or earthquake activity during deposition are possible explanations. Casts of *Lepidodendron* and other plants are found occasionally. Rare marine bioclasts (crinoid fragments, brachiopods) have been observed in outcrops and in thin sections.

The upper Cypress is a variable succession of shale, siltstone, and lenticular bodies of very fine to fine-grained sandstone. Thin layers of coal and carbonaceous shale occur locally. Shale and siltstone are medium to dark gray and commonly interlaminated. Sandstone is mostly thin-bedded and shows planar and ripple lamination, including ladderback ripples. Some of the sandstone is bioturbated, the ichnofossil *Psamichnites (Olivilites) plumeri* being common. Casts and molds of brachiopods and crinoid fragments are fairly common. The contact to the basal Golconda Formation may be either sharp or gradational from calcareous sandstone to sandy limestone.

Golconda Formation. The Golconda is a formation of limestone and shale that underlies slopes and valleys beneath the protective sandstone cap of the Hardinsburg Formation. From the west, the outcrop belt enters Johnson County north of Cypress, passes south of Vienna, and exits northeast of New

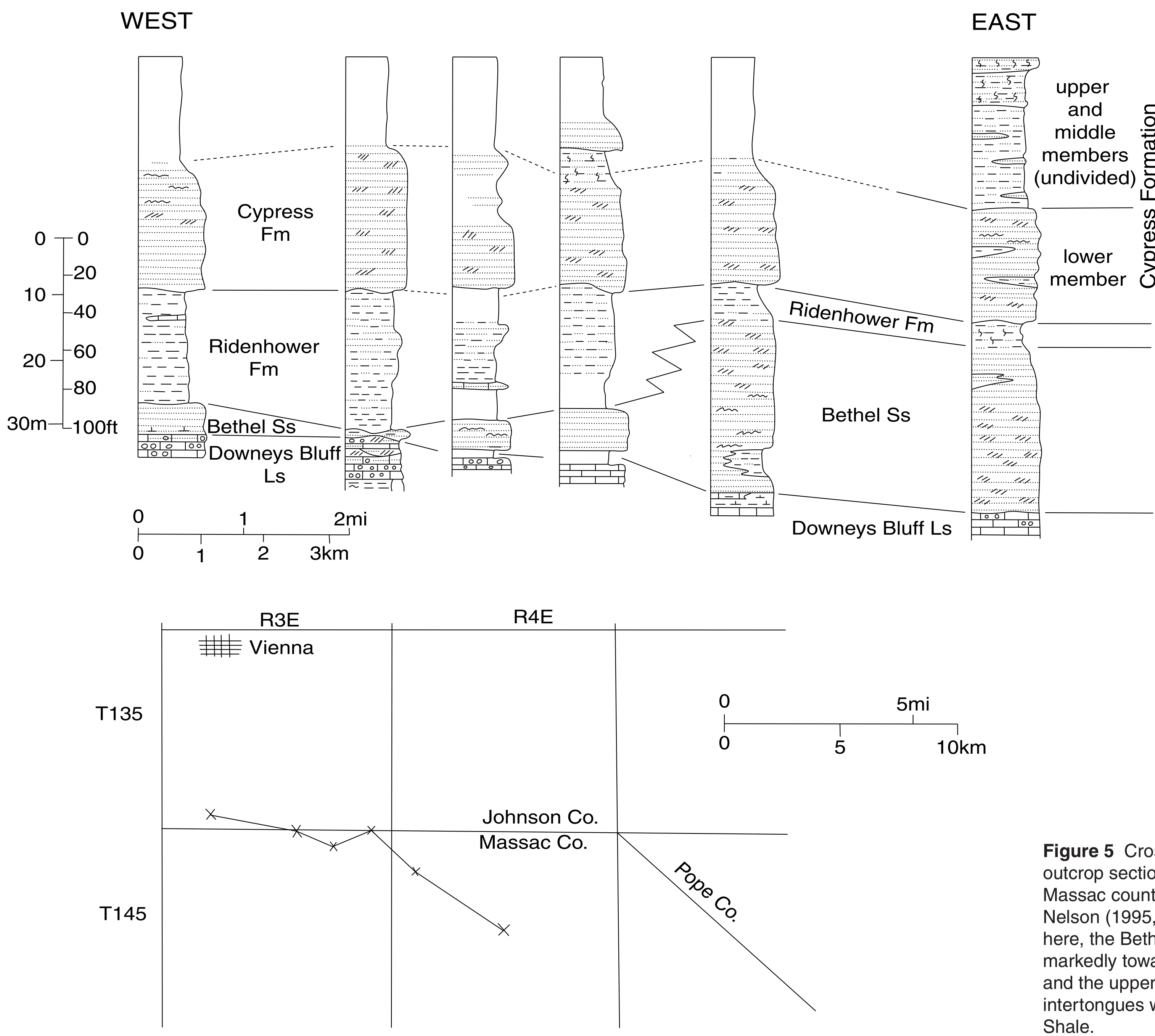


Figure 5 Cross section based on outcrop sections in Johnson and Massac counties, from Cole and Nelson (1995, p. 18). As interpreted here, the Bethel Sandstone thickens markedly toward the southeast and the upper part of the Bethel intertongues with the Ridenhower Shale.

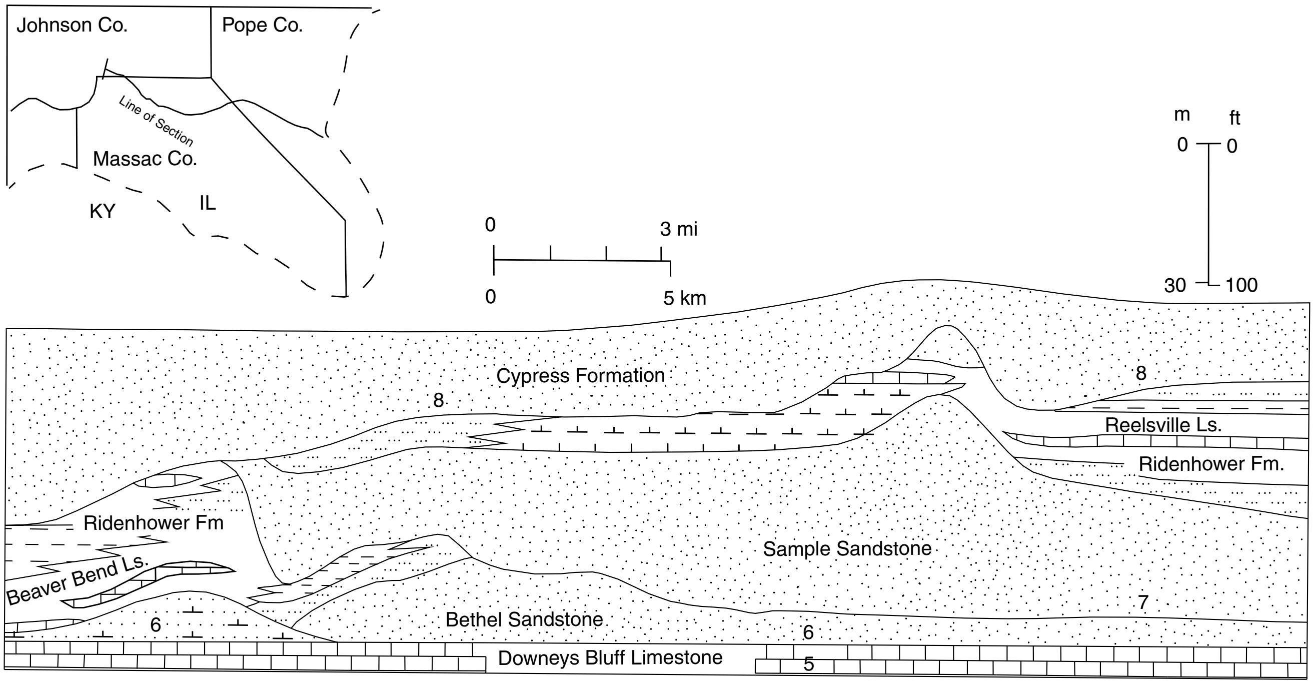


Figure 6 Interpretive cross section from Nelson et al. (2002, p. 33), showing a different interpretation of stratigraphic relationships in the Cypress to Bethel interval. According to this model, which we endorse, the Sample Sandstone and not the Bethel partly intergrades with the Ridenhower Shale, while the lower part of the Sample Sandstone fills paleochannels eroded into the Ridenhower and Bethel.

Columbia. Swamps, sloughs, and Quaternary alluvium mask much of the Golconda outcrop tract. Sample studies and wireline logs from wells supplement the information available from outcrops. Total thickness of the Golconda ranges from about 80 to 190 feet (24 to 58 m), with an average range of roughly 120 to 150 feet (36 to 46 m). No regional thickness trend is apparent. Throughout southern Illinois (and most of the Illinois Basin), three members are distinct.

The ***Beech Creek Limestone Member*** (Barlow of petroleum geologists) ranges from 0 to 12 feet (3.7 m) thick and is seldom seen in outcrops. The limestone is largely dark gray lime mudstone, wackestone, and packstone, although crinoidal grainstone occurs locally at the top. Bedding is generally thin to medium and wavy. Much of the limestone is argillaceous and silty, and the Beech Creek appears to grade to calcareous sandstone in eastern Johnson County.

According to quadrangle map authors, the ***Fraileys Shale Member*** ranges from about 50 to 120 feet (15 to 36 m) thick; however, authors may not have picked the upper contact consistently. The lower Fraileys is dominantly shale that is dark gray to greenish and olive-gray, fissile, silt-free, calcareous, and contains siderite nodules. Like the lower part of the Ridenhower Formation, the lower Fraileys exhibits a uniform very low profile on resistivity logs. Above the lower shale are one or more thin limestone beds that are mostly dark gray wackestone and packstone, weathering yellowish orange in outcrops. Occasionally, the "wing" plate of *Pterotocrinus capitalis* is found in thin-bedded limestone. This species is unique to the Fraileys Shale Member (fig. 7a). Distinctive to the upper Fraileys is red, green, and gray mottled, non-fissile claystone that represents a regionally extensive paleosol. Dark gray, calcareous, fossiliferous shale occurs at the top of the Fraileys in some wells and outcrops. Some Fraileys sections include sandstone that is greenish gray, very fine-grained, calcareous, and burrowed, a short distance beneath the variegated mudstone. This sandstone probably correlates with the Big Clifty Sandstone Member of western Kentucky and southern Indiana. Near the eastern edge of Johnson County, sandstone also has been observed near the base of the Fraileys.

The ***Haney Limestone Member*** has a thickness range from 12 to 90 feet (3.6 to 27 m) in outcrops and 80 to 125 feet (24 to 38 m) in well records, again allowing for inconsistencies in picking its lower contact. Crinoid-bryozoan wackestone and packstone are prevalent, but lime mudstone, microgranular limestone and dolomite, and oolitic and crinoidal grainstone also occur in the Haney. Shale is mostly dark gray to greenish gray, calcareous, and fissile. Fossils are common to abundant and include unbroken crinoid calices, a rarity in Illinois. The crinoids *Phanocrinus formosus, Phanocrinus cylindricus, Phanocrinus bellulus, Zeacrinites wortheni, Taxocrinus sp., and Onychocrinus sp.* all are common. Rarer types are *Ramulocrinus, Fifeocrinus,* and *Pterotocrinus*. Blastoids of genus *Pentremites* and a variety of brachiopods, bryozoans, and rugose corals also are plentiful in the Haney Member.

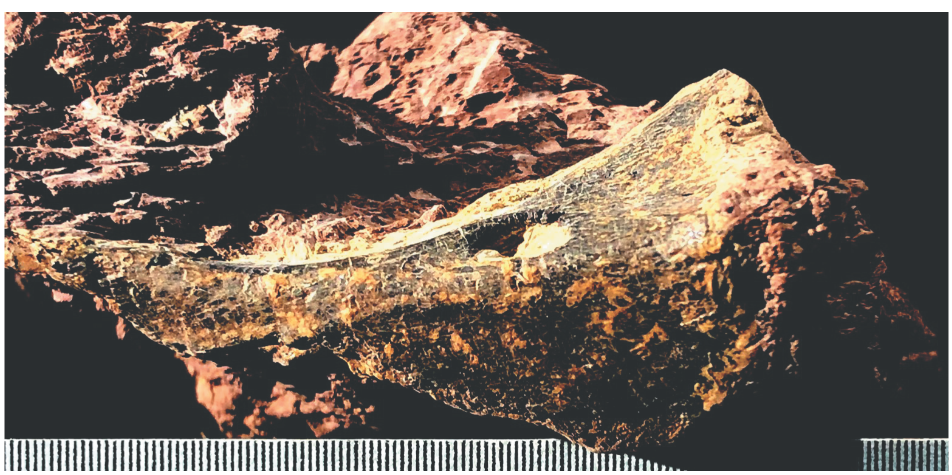
The contact with the overlying Hardinsburg Formation varies from erosive to gradational.

a *Pterotocrinus capatalis* 1X

b *Pterotocrinus menardensis* 1X

c *Pterotocrinus tridecibrachiatus* 1X

d *Pterotocrinus pegasus* 1X



e Vertabrate limb bone of a possible colostied amphibian 2X

Figure 7 (a) Wing plate of the crinoid *Pterotocrinus capatalis*, known only from the Fraileys Shale Member. (b) Wing plate of the crinoid *Pterotocrinus menardensis*, known only from the Menard Limestone. (c) Wing plate of *Pterotocrinus tridecibrachiatus*, known only from the lower Cave Hill Member. (d) *Pterotocrinus pegasus*, known only from the Grove Church Shale. (e) Vertabrate bones in red mudstone near the top of the Cave Hill Member.

Hardinsburg Formation. Like older formations, the Hardinsburg crosses Johnson County on a course that trends slightly south of east. Its lithologic succession is similar to that of the Cypress Formation. The lower sandstone forms a nearly continuous escarpment, especially prominent at Wildcat Bluff, south of Vienna. The upper Hardinsburg is mostly thinly layered, fine-grained clastic rocks, non-resistant to erosion and found on north-facing dip slopes. Thickness of this formation increases from a little over 50 feet (15 m) on the west to as much as 185 feet (56 m) near the southeastern corner of the county.

A basal shale unit as thick as 30 feet (9 m) is confined to the Mermet and Reevesville quadrangles. The shale is dark gray to black, fissile, calcareous, clayey to silty, and contains siderite nodules. The lower sandstone of the Hardinsburg truncates the basal shale with an erosive contact.

Ranging up to 100 feet (30 m), the lower cliff- and ledge-forming sandstone is white to light gray and very fine to medium-grained, generally becoming finer upward. Like other Chesterian sandstones, the lower Hardinsburg is largely quartz arenite. Sand grains typically are well sorted and subrounded to angular. Ripple marks and trough and planar crossbedding are well developed. The Hardinsburg sandstone lacks the massive character and extensive soft-sediment deformation found in the lower Cypress. The upper part of the lower sandstone shows evidence of marine or estuarine conditions, including scattered crinoid fragments and other bioclasts, bidirectional crossbedding, and rhythmic lamination.

The upper part of the Hardinsburg consists of interbedded and interlaminated shale, siltstone, and very fine to fine-grained sandstone. Planar and ripple lamination and small load casts and ball-and-pillow structures are common. Bioturbation is widespread and a variety of trace fossils have been identified, including *Aulichnites, Lockeia, Psammichnites (Olivellites), Nerites (Sclaratuba) missouriensis,* and *Ucherites.* As many as three layers of shaly coal a few inches (~5-10 cm) thick, each overlying rooted claystone, occur in southeastern Johnson County.

In the few places where the contact to the Glen Dean is visible the contact appears to be gradational.

Glen Dean Limestone. Limestone and shale of the Glen Dean are largely non-resistant to erosion and crop out sparingly along ravines and on the lower slopes of cuestas capped by sandstone of the Tar Springs. Sinkholes are numerous along the outcrop. Thickness varies from about 40 to 120 feet (12 to 36 m), showing an overall increase toward the west – opposite the eastward thickening of the Hardinsburg. In most of Johnson County, the Glen Dean has a lower limestone, a middle shale, and an upper limestone.

The lower limestone thickens eastward at the expense of the middle shale, from less than 10 feet (3 m) and locally absent on the west to about 15 to 25 feet (4.6 to 7.6 m) on the east. Texture varies, but reddish to brownish gray, coarse crinoidal packstone and grainstone are conspicuous.

The middle shale is medium to dark gray and greenish to olive-gray, platy or fissile, and clayey to slightly silty. It is partly calcareous and yields bryozoans and other marine fossils. Thickness is generally 20 to 50 feet (6 to 15 m).

Most Glen Dean outcrops show the upper limestone, which is typically 20 to 35 feet (6 to 11 m) thick but locally reaches 50 feet (15 m). The limestone weathers brown to gray with orange mottling and forms rough surfaces that crumble when struck. A variety of textures are present, but the unit shows a general transition from lime mudstone and wackestone in the lower part to bioclastic and oolitic packstone and grainstone in the upper part. The Glen Dean is the youngest formation in southern Illinois that commonly includes oolitic and crinoidal grainstone. Fossils are diverse and abundant: crinoids, blastoids, fenestrate and ramose bryozoans, compositid and spiriferid brachiopods, coral, ostracods, and foraminifera.

The contact to the Tar Springs Formation is locally erosional but gradational contacts are more widely seen. Intertonguing between sandy limestone of the Glen Dean and calcareous sandstone of the Tar Springs was observed in the Bloomfield quadrangle (Nelson 1993).

Tar Springs Formation. The Tar Springs Formation is composed of varying proportions of sandstone, siltstone, and shale; coal and mudstone are minor lithologies. This formation is moderately resistant to erosion, forming bluffs less conspicuous than those of the Cypress and Hardinsburg. The outcrop belt extends eastward from Mount Pleasant (in Union County), passes just south of Vienna, and exits the eastern border of Johnson County east of Grantsburg. Thickness is fairly consistent across the county. The extreme range is 60 to 130 feet (18 to 40 m), and the average is close to 100 feet (30 m).

The Tar Springs has a less consistent vertical succession than the Cypress and Hardinsburg. Some well records indicate the Tar Springs to be almost entirely shale. Other logs and outcrop sections show sandstone bodies ranging from a few feet to about 30 feet (9 m) thick at varying positions within the formation. The most prominent sandstone is in the upper Tar Springs in the Mt. Pleasant quadrangle, but eastward the thickest sandstone bodies are in the middle or lower part. Good outcrops in the Vienna (Nelson et al. 2004) and Bloomfield (Nelson 1993) quadrangles showed a series of upward-fining and upward-coarsening shale-to-sandstone sequences mostly about 15 to 30 feet (4.6 to 9 m). A basal sandstone in the Bloomfield quadrangle has calcite cement and intertongues with sandy limestone at the top of the Glen Dean.

Sandstone of the Tar Springs has typical Chesterian lithology: white to light gray on fresh surfaces, weathering gray to brown; very fine to fine-grained with a little medium sand. The sandstone is slightly micaceous and ferruginous. Bedding varies from very thin to thick and displays ripple marks, cross lamination and cross bedding, load casts, tool marks, shale rip-up clasts. Trace fossils are common, including *Planolites, Lockeia,* and the marine ichnofossil *Conostichus.* No marine invertebrates have been encountered. Thin coal commonly is present at or near the top of the Tar Springs, resting on rooted mudstone. Carbonaceous shale containing a variety of fossil plants also occurs near the top of the formation (Jennings 1976, 1977).

The contact with the Vienna Limestone generally is sharp.

Vienna Limestone. Stuart Weller (1920) named the Vienna Limestone for the courthouse town of Johnson County and described the type section in a small quarry near the west edge of town. That quarry was backfilled more than 30 years ago, so the type exposure is lost. A very good exposure that might serve as a reference section is in a railroad cut near Grantsburg, 0.6 mile (1.0 km) north of State Route 146. During the 1980s, the entire formation, including both contacts, was visible here.

Thickness of the Vienna increases from as little as 5 feet (1.5 m) in western Johnson County to as much as 50 feet (15 m) in the southeastern part of the Bloomfield quadrangle, perhaps a statewide maximum. Borehole logs show a range from 5 to 27 feet (1.5 to 8.3 m) thick. In most places in Johnson County, the Vienna is about 15 to 25 feet (4.6 to 7.6 m) thick and is almost entirely limestone. Most of the limestone is dark gray to dark brownish gray lime mudstone and wackestone that is highly siliceous and cherty, more so than any other Chesterian limestone. Thin sections reveal dolomite rhombs, abundant detrital silt, and intimate intermixing of silica and carbonate minerals. In outcrops chert is mostly dark brown and occurs as lenses and bands up to 1.0 foot (30 cm) in thickness. The Vienna Limestone weathers to red-orange clay residuum containing angular blocks of porous, tripolitic chert showing molds of crinoid stems and other fossils. Presence of this float enables mapping the Vienna where no fresh limestone exposures can be found.

The Vienna also includes non-cherty limestone, some of which is crossbedded crinoid-bryozoan packstone and grainstone that contains oolites. In the southeastern Bloomfield quadrangle, where the Vienna is thickest, interbedded shale and limestone overlies the main body of siliceous limestone. The shale is dark gray, thinly fissile clay-shale; the limestone is fossiliferous wackestone.

The Vienna has a typical but not prolific Chesterian fauna of articulate brachiopods, ramose and fenestrate bryozoans, rugose corals, and echinoderm fragments. Despite the high silica content of the limestone, petrographic study did not reveal sponge spicules.

The contact to the overlying Waltersburg Formation appears to be conformable and gradational, except in eastern Johnson County, where thick sandstone of the Waltersburg has an erosional lower boundary.

Waltersburg Formation. The Waltersburg a poorly exposed formation composed largely of shale in most of Johnson County, Thickness is mostly in the range of 30 to 60 feet (9 to 18 m), locally reaching 90 feet (27 m). In the southeastern part of the county near Grantsburg, however, the Waltersburg contains bluff-forming sandstone and thickens to as much as 120 feet (36 m).

Where the Waltersburg is thin it is dominantly dark gray shale that is fissile and silt-free to finely silty. Near the top of the formation the shale grades to siltstone or very fine sandstone that weathers orange to brown and is thinly bedded. Ripple marks and burrows and trails are common. On resistivity logs, the lower Waltersburg shale exhibits uniformly low readings similar to those of the lower Fraileys Member of the Golconda and the lower part of the Ridenhower Formation.

The thick bluff-forming sandstone is best developed near the Vienna Correctional Center in the Bloomfield quadrangle. The sandstone is very fine to fine-grained with a little medium sand. Beds are mostly 1 to 3 feet (30 to 90 cm) thick and display trough and planar crossbedding that consistently dips toward the west, southwest, and south. The thickest sandstone forms a belt that is roughly 1 mile (1.6 km) wide and trends toward the west-southwest. The lower contact is erosional, truncating the lower Waltersburg dark gray shale and locally cutting into the Vienna Limestone (Potter 1963, Nelson 1993). Dull-banded shaly coal as thick as 1 foot (30 cm) occurs near the top of the Waltersburg along the flanks of the thick sandstone trend in southeastern Johnson County. Associated carbonaceous shale contains well preserved fossil plants (Jennings 1976, 1977).

Exposures of the upper contact are uncommon. In the Bloomfield quadrangle, sandy limestone of the Walche Member (Menard) grades into burrowed sandstone at the top of the Waltersburg.

Potter (1962, 1963) examined the thick outcropping Waltersburg sandstone in Johnson and Pope counties and mapped the thickness of the sandstone in the subsurface of the Illinois Basin. The subsurface maps show elongate “ribbon” bodies of thick sandstone oriented toward the southwest. Potter (1963, p. 80) stated that thick Waltersburg sandstone appears to represent pro-delta marine deposits” within and overall deltaic model prevalent throughout the Carboniferous. We favor instead the hypothesis that the sandstone represents fluvial to estuarine sand deposited in valleys incised during a lowstand of sea level. Primary evidence includes the erosive lower contact, the unidirectional southwestdipping crossbeds (which Potter documented), and presence of coal on the upper flanks of the thick sandstone. The latter appears to rule out interpreting Waltersburg sandstone bodies as submarine channel sediments.

Menard Limestone. Composed of limestone with interbeds of shale and minor dolomite and non-fissile mudstone, the Menard Limestone exhibits consistent thickness and lithologic succession throughout Johnson County and the surrounding area. The two best exposures are a highway cut at the interchange of State Route 146 and Interstate 24 on the east side of Vienna, and railroad cuts at both ends of the tunnel about 2 miles (3 km) south of Robbs on the Glendale quadrangle. Other good exposures of limestone occur on south-facing hillsides and various parts of the county. The Menard erodes to a rolling topography. Sinkholes and springs are numerous.

Total thickness of the Menard ranges from 108 to 148 feet (33 to 45 m). Wherever good outcrops and subsurface records are available, six members (three of them formal) can be recognized. In ascending order, these are the Walche Limestone, the lower shale, the Scottsburg Limestone, the middle shale, the Allard Limestone, and the upper shale.

The basal ***Walche Limestone Member***, sometimes called "Little Menard", is 6 to 8 feet (1.8 to 2.4 m) thick and consist of argillaceous, silty to sandy limestone. No outcrops in Johnson County have been specifically identified as representing the Walche Member.

The ***lower shale member*** ranges from about 3 to 15 feet (0.9 to 4.6 m) thick and is mostly greenish gray, soft, weakly fissile shale containing lenses and beds of limestone a few inches (~5-10 cm) thick. Some of the limestone is highly fossiliferous, a coquina of brachiopods, bryozoans, echinoderms, and other invertebrates. Wing plates of *Pterotocrinus menardensis,* an index fossil for the Menard Limestone, occur in this lower shale, along with other longer-ranging "wing" plates (fig. **7b**). See the Paleontology section in this manuscript for more detail. Also *P. clorensis* was documented by Tobinski (2009) as being found in the Menard Limestone at 3 localities east of the study area,

The ***Scottsburg Limestone Member***, is about 25 to 35 feet (7.6 to 11 m) thick based on outcrop data, but well records show thickness as great as 60 feet (18 m) thick. Dark gray, dense, sublithographic limestone in hummocky beds 4 to 24 inches (10 to 61 cm) thick is the most characteristic lithology, but bioclastic and pelletal wackestone also occur in this unit. Some of the limestone is dolomitic and weathers yellowish gray to yellowish orange. Polygonal mud cracks and very thin rhythmic tidal laminations were noted in the Bloomfield quadrangle (Nelson 1993). Separating limestone layers are beds of dark gray, greenish gray, and olive-gray shale that is fissile and calcareous. Most shale layers are less than about 3 feet (90 cm), but the thickest reach 6 feet (1.8 m). Fossils are common, but not easy to separate from the limestone and identify.

The ***middle shale member***, 14 to 25 feet (4.3 to 7.6 m) thick. Its most distinctive feature is presence of waxy green shale or claystone, occasionally mottled with red. However, most of the shale resembles that found elsewhere in the Menard, alternating with lenses and thin beds of limestone.

The ***Allard Limestone Member*** has a thickness range from 32 to 50 feet (10 to 15 m) and is mostly limestone, with interbeds of shale ranging from a few inches (cm) to about 5 feet (1.5 m) thick. Still well exposed at the time of mapping, the type locality is in a cut along the Canadian National (formerly Illinois Central) Railroad is Sec. 1, T13S, R4E on the Glendale quadrangle (Swann 1963). Here and elsewhere in Johnson County, the limestone is medium to dark gray when freshly broken, weathering to light gray, smoothly rounded surfaces. Lime mudstone and skeletal wackestone are prevalent and occur in wavy or hummocky beds mostly ½ foot to 2 feet (15 to 60 cm) thick. However, grainstone that contains oolites and rounded, coated fossil grains also occurs in the Allard. Separating limestone layers are beds of medium gray to black and olive-gray shale that is soft, fissile, calcareous, and fossiliferous. The Allard contains a diverse assemblage of marine invertebrates, including brachiopods, bryozoans, crinoids, blastoids, and pelecypods. *Anthracopirifer increbescens, Composita subquadrata,* the razor clam *Pinna sp.,* and wing plates of *Pterotocrinus menardensis* all are plentiful, the latter being confined to the Menard.

The ***upper shale member*** varies from 0 to 25 feet (7.6 m) thick and consists of dark gray to black, fissile, calcareous clay-shale having interbeds of limestone that is argillaceous lime mudstone to wackestone. The thickest limestone layers are about 3 feet (1 m), most are much thinner and typically lenticular. Fossils, chiefly brachiopods, bryozoans, and pelmatozoans, are abundant and commonly weather free of the rock matrix.

The contact to the Palestine Formation is generally gradational where the basal Palestine is composed of shale and siltstone. Where the basal Palestine is sandstone, the contact tends to be erosional, and locally the upper shale member is truncated, Palestine sandstone resting on the Allard Member.

Palestine Formation. The Palestine Formation is composed of shale, siltstone, and sandstone and locally, thin coal and non-fissile mudstone. Thicknesses determined from boreholes and outcrops range from 35 to 106 feet (11 to 32 m). The succession is quite variable, from entirely shale to mostly sandstone in one or more units which either coarsen upward or downward. Outcrops are almost entirely sandstone, which forms ledges and small cliffs. Where sandstone is well developed, the Palestine caps small plateaus and cuestas. Information on shale and siltstone is confined to gullies, ravines, and cores.

Sandstone is white to light gray in fresh exposures, weathering various shades of yellow, orange, and brown. Grain size is very fine to fine, rarely medium. Sandstone is largely quartz arenite containing a few percent of feldspar, lithic fragments, and mica. Shale and siltstone commonly are interlaminated with sandstone. Sedimentary structures include planar, ripple, and cross lamination, small load casts, and slumped lamination. Burrows and other trace fossils are common in laminated sandstone. Devera (1991) reported *Cochlichnus, Locheia, Planolites,* and repichnia in the Glendale quadrangle. Knight (1968) reported molds of brachiopods in the upper Palestine in the Bloomfield quadrangle. Shale and siltstone are mostly medium to dark gray and laminated. Thin, shaly coal has been observed in the upper part of the formation and also near the middle. Accompanying coal is carbonaceous shale containing fossil plants (generally fragmentary) and non-fissile, rooted claystone and siltstone.

As shown in cores, the Palestine-Clore contact can be sharp or gradational and is either conformable or slightly disconformable.

Clore Formation. Thickness of the Clore, from well records, ranges from 90 to 145 feet (27 to 44 m). It is 121 feet (36.9 m) thick in the ISGS #1 James & Bonnie Jones stratigraphic test hole north of Vienna, where it was cored continuously.

The ***Cora Member*** is 30 to 75 feet (9 to 23 m) and consists mostly of shale, with thin limestone interbeds. Shale is dark gray to nearly black and also greenish and olive-gray, partly calcareous, and for the most part thinly fissile. It is mostly clay-shale, but silty shale and siltstone are present, especially in the lower part of the member. Limestone is argillaceous lime mudstone and skeletal wackestone that is medium to dark gray on fresh surfaces, weathering light olive to light brown. Whole fossils are plentiful in both shale and limestone. They include compositid, spiriferid, productid, and derbyid brachiopods; fenestrate, trepostome, and encrusting bryozoans, gastropods, pelmatozoans, and rare orthoconic cephalopods. Limestone beds are mostly less than 3 feet (0.9 m) thick and are exposed along ravines and on hillsides. Large masses of limestone move down slope due to slumping and soil creep.

The ***Tygett Sandstone Member*** occurs as either a single unit or as two or locally three sandstone units separated by shale and limestone. The Jones core north of Vienna exemplifies occurrence of three sandstone beds separated by limestone and shale (fig. 8, next page). Also, the ISGS # L-3 stratigraphic boring, just outside Johnson County in Union County, encountered two sandstone units and has been designated as the principal reference section for the Tygett Member (fig. 9). Thickness of the member varies from less than 30 feet (9 m) to as much as 80 feet (24 m) in the Lick Creek quadrangle and 70 feet (21 m) in the Glendale quadrangle, where three sandstones are present (Devera 1991). At most localities in Johnson County, sandstone of the Tygett Member forms upward-coarsening sequences that grade upward from shale at the base to sandstone at the top. Shale, siltstone, and sandstone commonly are interlaminated and interbedded. Sedimentary structures include planar, wavy, and ripple lamination, small load casts, and horizontal and vertical burrows. Sandstone generally resembles the Palestine: light gray (fresh), very fine to fine-grained, well sorted quartz arenite composed of subangular grains. Bedding thickness overall increases upward together with grain size. Commonly found at the tops of sandstone sequences in the Tygett are stigmarian root casts and the horseshoe-shaped trace fossil *Rhizocorallium.* Limestone and shale that separate sandstone intervals in the Tygett are lithologically similar to limestone and shale of the Cora Member.

The ***Ford Station Member*** ranges from about 25 to 55 feet (7.6 to 17 m) thick and includes a varied succession of shale and limestone. The two cores mentioned above both include the entire member (figs. 8, 9). A massive limestone bed, 5 to 16 feet (1.5 to 4.9 m) thick, occurs widely at or near the base of the member. This limestone is light to dark gray, slightly dolomitic lime mudstone to wackestone that contains brachiopods and echinoderm fragments. The upper Ford Station consists of interbedded limestone and shale. Limestone beds are mostly less than 3.3 feet (1.0 m) thick and again is argillaceous, partly dolomitic lime mudstone and wackestone that contains brachiopods, echinoderm fragments, pelecypods, and other fossils. Bedding varies from massive to nodular. Shale in the Ford Station is dark greenish and olive-gray to black, clayey to silty, calcareous and fossiliferous.

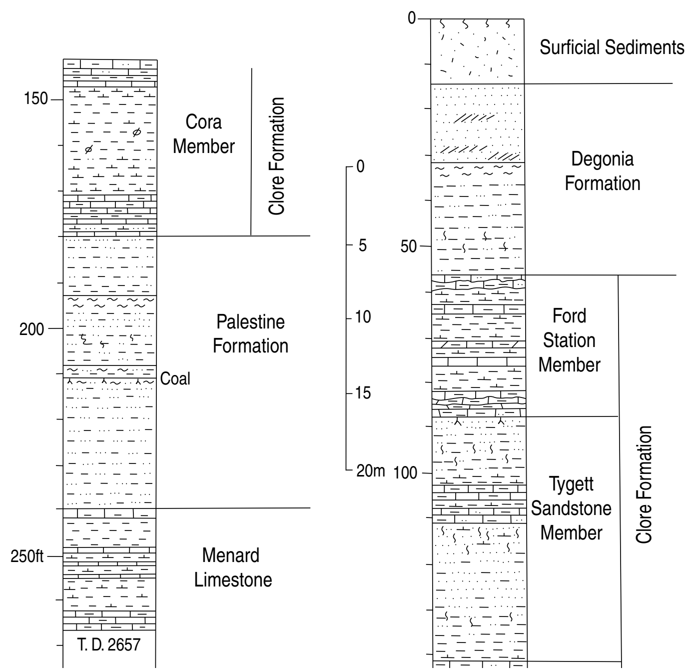


Figure 9 Graphic column of the ISGS #L-3 test hole, which was continuously cored. This core contains the principal reference section for the Tygett Sandstone member of the Clore Formation.

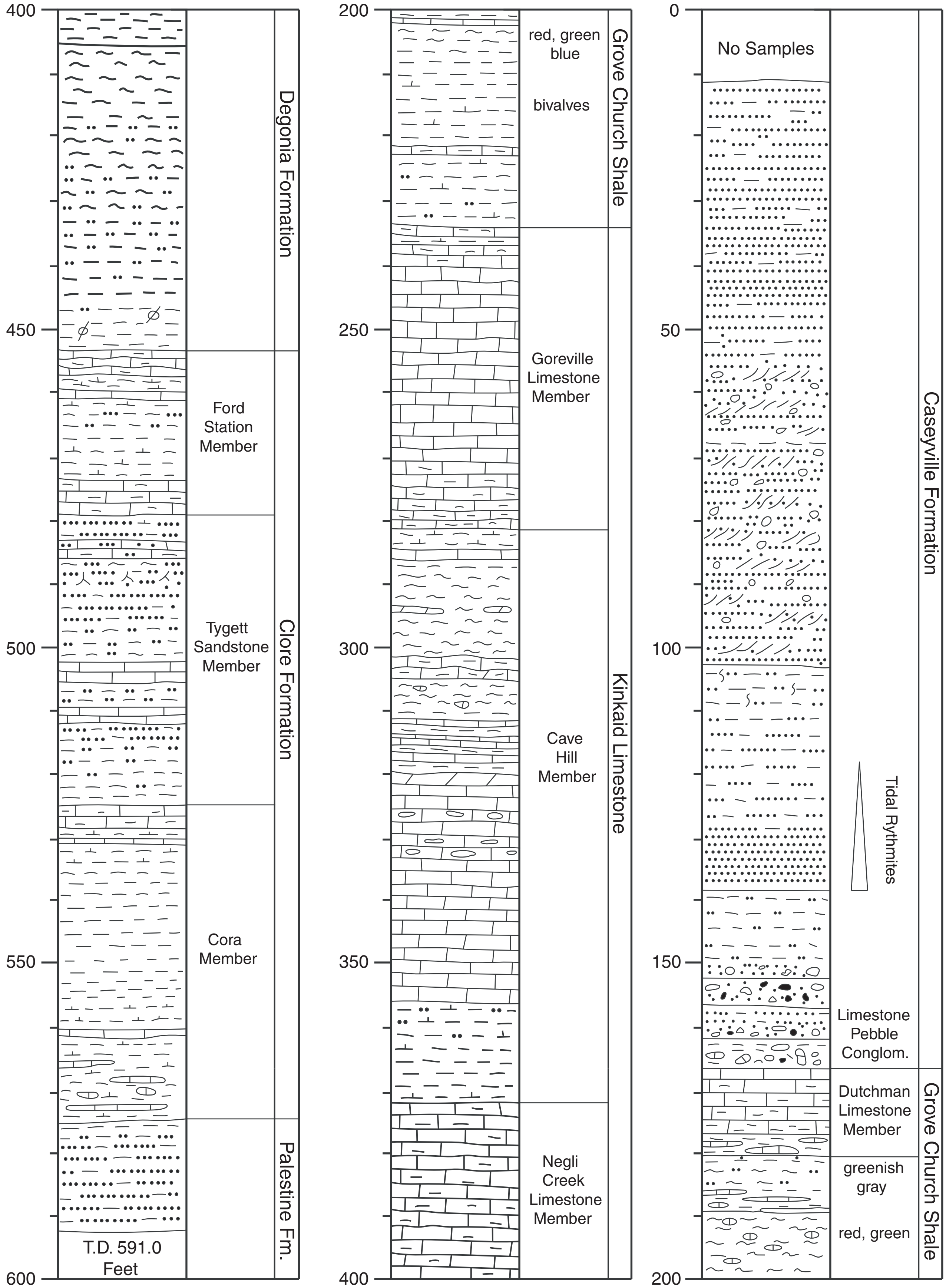


Figure 8 Graphic column of the ISGS #1 Jones test hole, which was continuously cored. This is the type section of the Dutchman Limestone Member and principal reference section of the Grove Church Shale.

Degonia Formation. In Johnson County the Degonia is a poorly exposed, slope-forming unit of mudstone, shale, siltstone, and thinly layered sandstone. Thickness ranges from about 35 to 65 feet (11 to 20 m). A continuous section 52.9 feet (16.1 m) thick was cored in the Jones boring north of Vienna (fig. 8). The Degonia was combined with other units on some of the 1:24,000-scale maps from which the county-wide geologic map (plate 1) was complied.

Mottled and variegated mudstone 10 to 15 feet (3 to 4.5 m) thick typically occurs at the top of the Degonia Formation. Dark red, purple, green, and yellow are the most prevalent colors. This "red shale" beneath the Kinkaid Limestone is an excellent marker in drillers' logs and sample studies from water wells and oil test holes. In the Jones core (fig. 8), the uppermost Degonia is dark gray shale that contains a few mytiloid bivalves and surprisingly, has an erosive lower contact marked by conglomerate of shale and limestone clasts.

The fine-grained clastic rocks that make up the rest of the Degonia carry more somber colors of gray, brown, and olive. These rocks range from silty shale through siltstone and very fine-grained, laminated to medium-bedded sandstone. Planar and ripple lamination and simple burrows commonly are present. Root impressions and poorly preserved plant stems, roots, and foliage are the only fossils. A large *Rhizodont* scale was found in Pope County within laminated sandstone beds of the Degonia. These large fish were freshwater, implying that these laminated, rooted sandstones were near-shore lake deposits.

The contact between the Degonia and the overlying Kinkaid Limestone is sharp to rapidly gradational and reflects a rapid rise in sea level.

Kinkaid Limestone. The Kinkaid is the youngest widespread Mississippian formation in Illinois. Originally, it included all limestone and shale overlying the Degonia Formation and underlying Pennsylvanian sandstone and shale of the Caseyville Formation. Swann (1963) separated a younger Mississippian unit, the Grove Church Shale, from the Kinkaid. However, Nelson et al. (1991, p. 13) reclassified the Grove Church as a member of the Kinkaid, and some subsequent authors followed this classification. In the present report the Grove Church returns to the rank of formation based on distinctive lithology and fauna in addition to historic precedent. Thus, the Kinkaid now comprises three formal members: the Negli Creek Limestone (oldest), the Cave Hill member, and the Goreville Limestone member at the top. Where fully present with the Grove Church Shale overlying, the Kinkaid is about 150 to 170 feet (46 to 52 m) thick. The Kinkaid was continuously cored in two ISGS stratigraphic tests, #1 Jones north of Vienna (fig. 8) and #L-2 near Lick Creek (fig. 10).

The ***Negli Creek Limestone Member*** is consistently 25 to 32 feet (7.6 to 9.8 m) and occurs as an interval of limestone

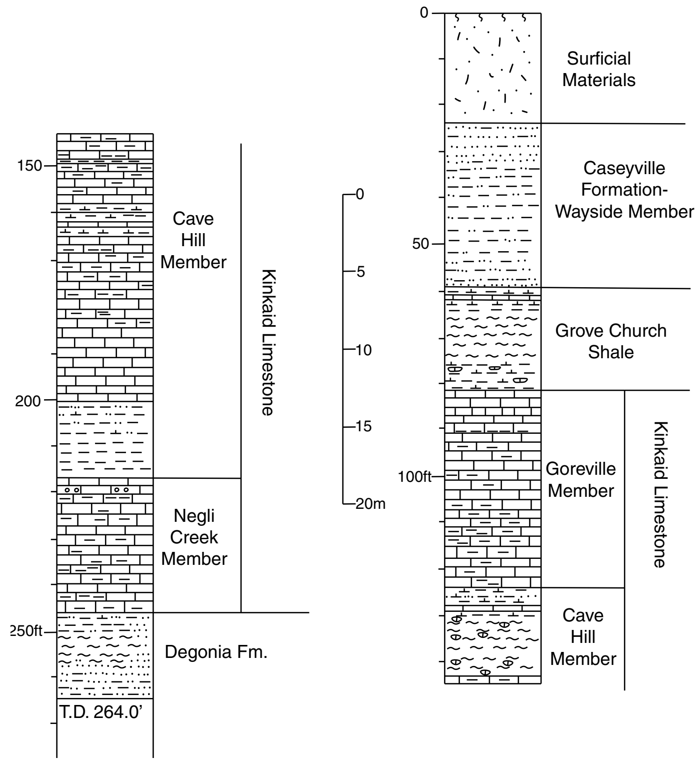


Figure 10 Graphic column of the ISGS #L-2 test hole, in which lower Caseyville, Grove Church, Kinkaid, and upper Degonia formations were cored.

without significant clastic interbeds. Limestone is medium to dark gray, weathering light gray with rough surfaces. As seen in the Jones core (fig. 8), an upward transition from lime mudstone in the lower part to wackestone and packstone in the middle part and in some cases, crinoidal and oolitic grainstone near the top, This succession implies that the Negli Creek represents a single upward-shoaling, transgressive-regressive cycle. Chert nodules are common, particularly in the lower part. Bedding tends to be wavy or hummocky, separated by shale partings. Gastropods, brachiopods, bryozoans, rugose corals, and crinoid fragments are common. An ecological proliferation epibole occurs in the Negli Creek. The diagnostic fossils *Girvanella* oncoids (filamentous algae), large bellerophontid gastropods, and the demosponge *Chaetetella* sp. are found together across the basin in this member. The Negli Creek is overlain by an unnamed dark gray shale that contains The upper contact is sharp.

The ***Cave Hill Member*** is 70 to 92 feet (21 to 28 m) thick in Johnson County. This unit itself is readily divisible into three units, which could be recognized as separate members. These units are a lower shale, a middle limestone with shale interbeds, and an upper shale and mudstone unit.
The lower shale of the Cave Hill is 12 to 16 feet (3.7 to 4.9 m) thick in the Lick Creek quadrangle and is medium to dark gray, greenish gray, and bluish gray. The lower part is soft, calcareous, and thinly fissile, containing abundant fossils that include fenestrate bryozoans, brachiopods, pelecypods,

gastropods, and echinoderm fragments. The diagnostic crinoid “wing” plate *Pterotocrinus tridecibrachiatus* is consistently found across the basin in this shale (fig. 7c). The upper part of the shale, as found in drill cores and quarry exposures, is silty shale that contains both marine fossils and fragmentary plant fossils. Both contacts are sharp as seen in small outcrops and cores, but exposures in the Southern Illinois Stone Company quarry near Buncombe reveal intertonguing between the lower shale and the middle limestone-shale unit.

The middle unit of the Cave Hill Member is 55 to 60 feet (17 to 18 m) thick. The best exposures are in active and abandoned quarries north of Buncombe on the Vienna quadrangle, as detailed by Nelson and Weibel (1996). Limestone is mostly medium to dark gray, weathering light gray to yellowish gray. Lime mudstone is the most prevalent lithology, but skeletal wackestone and packstone are present and crossbedded skeletal grainstone has been observed. Much of the lime mudstone is dense, sublithographic, and breaks with conchoidal fracture. Beds of dolostone and dolomitic limestone also are present. Bedding is thin to thick and partly nodular. Bands and lenses of dark gray to black, vitreous chert are conspicuous in the lower part of the unit. Fossils include gastropods and productid brachiopods. Shale interbeds in the middle Cave Hill are dark gray to greenish and olive-gray, clayey to finely silty, partly calcareous, and thinly laminated.

The upper Cave Hill is 13 to 18 feet (4.0 to 5.5.m) thick and composed of mottled and variegated claystone that is overlain in some places by gray, fossiliferous shale. Jacobson (1992, p. 32) described 13 feet (4.0 m) of calcareous, non-fissile claystone at the top of the Cave Hill in an abandoned quarry. The upper and lower 5 feet (1.5 m) of the interval were greenish gray, whereas the middle 3 feet (0.9 m) was dark red and contained “nodular masses of ocher-colored, highly argillaceous limestone”. It is interesting that the same type of shale occurs in some places directly above the multi-colored mudstone of the upper Degonia Formation. The variegated claystone is one of the few Chesterian units in Illinois that has yielded vertebrate fossils (fig. 7e). The lungfish *Tranodis* sp., a colosteid “amphibian”, and a microsaur were collected from calcareous nodules or possible burrows in the dark red mudstone (Schultze and Bolt 1996). The significance of this find is that this microsaur predates *Utaherpeton franklini,* which was the earliest known microsaur until the Schultze and Bolt find (Lombard and Bolt 1999) (See Paleontology Section in this manuscript for more information). Overlying the multi-colored claystone is dark gray, calcareous shale that contains myalinid bivalves and plant fragments. In an abandoned quarry below Johnson Ridge in eastern Johnson County, the shales of the uppermost Cave Hill yielded abundant specimens of the brachiopod *Rugosochonetes chesterensis,* an ecological epibole (Acme Zone or population burst). This occurrence was also observed at the Millstone Bluff quarry a few miles east in Pope County, Illinois. The contact between the Cave Hill and Goreville members is sharp.

The ***Goreville Limestone Member***, like the Negli Creek, is a single unit of limestone with local lenses of shale. Where not truncated by sub-Pennsylvanian erosion, the Goreville is 37 to 50 feet (11 to 15 m) thick. The limestone is light to medium gray and brownish gray and is dominantly wackestone and packstone with crinoids, bryozoans, and other fossils. Oolitic and crinoidal grainstone has been observed in the upper Goreville. In the Jones core (fig. **8**), the Goreville contains several upward-fining sequences (wackestone above, packstone or grainstone below), each 2 to 7 feet (0.6 to 2.1 m) thick. These suggest that the Goreville Member represents several transgressive-regressive cycles. Fossils include foraminifera, brachiopods, bryozoans, mollusks, ostracods, trilobites, and rugose corals. The edrioasteroid *Neoisorophusella lanei* occurs in the abandoned quarries at Buncombe, Illinois. Unusually large specimens of the “corkscrew” bryozoan *Archimedes* are characteristic of the Goreville across the outcrop belt. Conditions were optimal for these filter feeders at this time, so this zone in the upper part of the Goreville represents an ecological proliferation epibole or population burst over a broad area.The contact to the overlying Grove Church Shale is sharp and disconformable.

Grove Church Shale. The Grove Church Formation is the youngest representative of the Chesterian Series in the Illinois Basin. As described by Swann (1963, p. 44-45), the type section is near Cedar Grove Church in Sec. 31, T11S, R2E on the Lick Creek quadrangle in Johnson County. A far more complete section is the core from the ISGS #1 Jones stratigraphic boring in Sec. 17, T12S, R3E on the Vienna quadrangle. This section, including the Dutchman Limestone Member, is 67.9 feet (20.7 m) thick and is hereby designated as the principal reference section for the Grove Church.

The deeply incised unconformity at the base of the Pennsylvanian Subsystem has reduced the Grove Church to a series of erosional outliers confined to far southern Illinois. Even in Johnson County, this formation is more widely absent than present. As indicated by logs and a sample study, the maximum thickness is about 79 feet (24 m) in the Shure #1 Evans oil test hole. This is probably the maximum for the Illinois Basin. The Grove Church Formation comprises the Dutchman Limestone Member at the top and the lower or main body, which lacks a formal name and is composed primarily of shale and claystone, with thin interbeds of limestone.

Main body of Grove Church Shale. The main body of the Grove Church Shale is weakly resistant to erosion and largely occupies a covered interval, with surface exposures confined to a few gullies and ravines and to recent artificial excavations. The Jones core, which serves as principal reference section (Appendix A), and other cores supplement observations from outcrops.

In the Jones core (fig. 8) the main body is 53.7 feet (16.4 m) thick and is more than 90% shale and claystone, the remainder being limestone beds less than 0.7 foot (21 cm) thick. Shale, found mostly in the lower part, is dark gray and thinly fissile, clayey to slightly silty, partly calcareous, and sparsely fossiliferous. Several intervals of blocky to weakly fissile claystone to silty mudstone occur in the middle and upper part of the Grove Church. Greenish gray is the prevalent color, but the rock is mottled in gray and reddish gray. Hackly fracture, common slickensides, and brecciated textures indicate that these mudstones represent paleosols. Limestone textures vary from lime mudstone to wackestone, packstone, and algal boundstone. Brachiopods, bryozoans, and echinoderm fragments are plentiful.

The ISGS # GD-1 stratigraphic test hole, drilled about 4 miles (6½ km) northwest of Glendale, penetrated at least 45 feet (14 m) of the Grove Church**.** Unfortunately, the only core description on file is a rather hasty field log, and the hole did not penetrate far enough into the Kinkaid Limestone to positively identify the formation contact. As logged, the Grove Church is largely greenish gray shale that contains limestone nodules and common marine invertebrates. Limestone interbeds are argillaceous wackestone and packstone. Fossils include compositid and spiriferid brachiopods, fenestrate bryozoans, gastropods, pelecypods, and crinoid fragments. In shale 6 to 8 feet (1.8 to 2.4 m) above the base of the Grove Church occurs an index fossil unique to the Grove Church, the crinoid "wing" plate, *Pterotocrinus pegasus* **(**fig. 7d**).** Other fossils unique to the Grove Church are the conodont *Adetognathus unicornis,* the trilobite *Paladin grovechurchensis,* the foraminifer *Millerella chesterensis,* and several species of ostracodes (Cooper 1947). The fauna of the Grove Church is quite distinctive from that of the Kinkaid, revealing a transition between Pennsylvanian strata above and older Mississippian units below.

Another Grove Church core is that from ISGS # L-2, drilled about 2 miles (3 km) east of Lick Creek. Here the formation is 22.5 feet (6.9 m) thick and again is predominantly shale that is dark gray and greenish gray, with minor red and yellow mottling. Interbeds of limestone occur at the erosional top of the formation. Dark gray, carbonaceous shale containing plant remains, a lithology not reported elsewhere in the Grove Church, was logged about 5 feet (1.5 m) below the top of the unit.

Dutchman Limestone Member. The youngest Mississippian stratum in the Illinois Basin is limestone at the top of the Grove Church Shale, known from a few outcrops and boreholes in Johnson and neighboring counties. Nelson et al. (2004) named this unit the Dutchman Limestone Member (of the Kinkaid Limestone), after Dutchman Lake and Dutchman Creek about 5 miles (8 km) north of Vienna. Although formal naming was intended, we neglected to specify and describe a type section. Thus, we hereby formally name the unit as the Dutchman Limestone Member of the Grove Church Shale. Although good natural exposures of the member occur along hillsides south and southeast of the dam at Dutchman Lake (see Nelson et al. 2004), we specify the type section as the depth interval from 166.3 to 180.5 feet in the continuous core from the ISGS No. 1 Jones stratigraphic test hole (fig. 8), which was drilled about 1 mile (1.6 km) southeast of the dam in NE¼ NW¼ NE¼, Sec. 17, T12S, R3E. This same core contains the principal reference section of the entire Grove Church Shale, extending from 166.3 to 234.2 feet in depth. Core from the Jones test hole is archived and accessible to researchers at the Samples Library of the ISGS in Champaign and is filed under call number C-15256. Logs of the Jones well are filed in Geologic Records of the ISGS and can be partially accessed via the Survey's ILOIL online database. The API number for this hole is 120872072100. Edited from the original on file, description of the Dutchman Member type section and Grove Church reference section is presented here in Appendix A.

As observed in outcrops near Dutchman Lake and in the Jones core, the Dutchman Limestone Member ranges from 0 to about 15 feet thick and is composed of light to medium gray crinoidal wackestone and packstone with lesser amounts of lime mudstone and crossbedded crinoidal grainstone. The limestone is argillaceous and contains wavy parting of dark gray shale. Dark gray to black, dull-textured chert lenses make up as much as 10% of the rock. Bedding undulates; most beds are between 1 and 12 inches (2.5 to 30 cm) thick. In the Jones core, the Dutchman Member is 14.2 feet (4.3 m) thick and its basal 3.7 feet (1.1 m) consists of interbedded limestone and gray, calcareous shale. Chonetid brachiopods and fenestrate bryozoans are abundant in the upper part of the basal shaly unit, whereas only a few pectenoid bivalves were found near the base.

The upper contact of the Dutchman Member is the sub-Pennsylvanian unconformity, which presents impressive physical evidence. Limestone conglomerate 4.7 feet (1.4 m) thick overlies the Dutchman in the Jones core. The conglomerate is composed of subrounded, fossiliferous limestone clasts up to at least 2 inches (5 cm) across in a matrix of dark gray, soft, calcareous shale. An outcrop just below an old road near the SE corner of Sec. 7, T12S, R3E shows the contact of the Dutchman Limestone with overlying Pennsylvanian sandstone. Lenses of nodular, brecciated chert as thick as 2 feet (60 cm) separate the limestone from the sandstone.

Mississippian-Pennsylvanian boundary

Presence of a major unconformity separating Mississippian from Pennsylvanian rocks in the Illinois Basin has been known since the 19th century. Extensive exploration for oil and gas, and especially the advent of electric logging, enabled Bristol and Howard (1971) to map the subsurface unconformity in great detail. Controversy arose, however, with discovery of biostratigraphically useful marine invertebrate fossils – especially conodonts – straddling the boundary at the type locality of the Grove Church Formation in Johnson

County. Similarity of conodont faunas in the Grove Church and overlying Wayside Member of the Caseyville Formation led Rexroad and Merrill (1985) to conclude that sedimentation was continuous across the subsystem boundary in Johnson County.

Subsequent conodont studies by Jennings and Fraunfelter (1986) and Weibel and Norby (1992) disputed that finding, the latter authors finding evidence for a missing conodont zone between the Grove Church and Wayside. We note that the Grove Church at its stratotype is only about 16 feet (4.9 m) thick, the upper part being eroded beneath the Wayside Member. No investigation of conodonts or other fossils of the Dutchman Limestone Member has yet been undertaken. Such research might reduce the time gap between the youngest Mississippian and oldest Pennsylvanian in southern Illinois, but assuredly will not indicate that sedimentation was continuous. Outcrops in the Dutchman Lake area and the Jones core (fig. **8)** demonstrate a prominent unconformity in the basal Wayside, marked by conglomerate containing clasts of the Grove Church Formation.

Moreover, occurrence of continuous sedimentation where the Grove Church is preserved in southern Illinois would be illogical. As Bristol and Howard (1971) mapped, the Grove Church is preserved only on the interfluves or divides that separate the system of incised valleys marking the unconformity. Continuous sedimentation took place offshore, south of the Illinois Basin in the rapidly subsiding Ouachita trough and Arkoma foreland basin.

Carboniferous System – Pennsylvanian Subsystem
Caseyville Formation

The Caseyville Formation includes thick well-indurated sandstone layers that are resistant to erosion. Hence, the Caseyville forms a prominent south-facing escarpment and holds up the highest hills in Johnson County. The best exposures of the Caseyville are in Ferne Clyffe State Park south of Goreville and in roadcuts along Interstate 24 about 3 miles (5 km) north of Vienna. Just across the border in Union County, another set of roadcuts along Interstate 57 south of the Goreville interchange also provide good views of the Caseyville.

The Caseyville is composed of sandstone, siltstone, shale, minor conglomerate and coal, and rare limestone. Sandstone of the Caseyville is predominantly quartz arenite that is white to light gray on fresh surfaces and very fine to coarse-grained, containing common granules and small pebbles of quartz. Sandstone commonly has sucrosic texture and the sand grains bear sparkly quartz overgrowths. The presence of sand coarser than fine-grained distinguishes the Caseyville from any of the Mississippian sandstones with which the Caseyville may lie in contact. The nearly pure quartz sandstone of the Caseyville differs from the less mature, micaceous sublitharenite and litharenite found in the overlying Tradewater Formation. Although the mineralogic change is gradational, this is the primary criterion used to separate the Caseyville from the Tradewater. That is to say, the top of the Caseyville has been mapped at the highest occurrence of quartz arenite (Nelson 1989).

Thickness of the Caseyville Formation in Johnson County ranges from about 150 to 400 feet (45 to 120 m). The unit exceeds 300 feet (90 m) throughout the Goreville and Lick Creek quadrangles; the minimum thickness is recorded in the Bloomfield quadrangle. Thickness variation reflects both depth of incision into Mississippian strata and tectonic subsidence rates. Thinning of the Caseyville in the Bloomfield area possibly reflects contemporaneous uplift on the McCormick anticline, as proposed by Potter (1957).

As presently classified (Nelson 2020) the Caseyville in southern Illinois contains three members. These are the Wayside Member at the base, the Battery Rock Sandstone overlying the Wayside, and the Pounds Sandstone at the top of the formation. Strata between the Pounds and Battery Rock members formerly were called the Drury Member, but that name has been abandoned and the rocks it referred to are presently unnamed. One named bed, the Gentry Coal Bed, occurs locally in Johnson County.

Wayside Member. The Wayside Member (Lamar 1925) comprises all strata between the base of the Caseyville Formation and the base of the Battery Rock Sandstone Member. Where the Battery Rock is absent, the Wayside loses its identity. The Wayside Member was mapped on some of the 7.5-minute geologic quadrangles that cover Johnson County. As Nelson (2020) remarked, the Wayside Member does not have a type section. Roadcuts along Interstate 57 in Secs. 24 and 25, T11S, R1E, Union County on the Lick Creek quadrangle show almost the entire Wayside Member and serve as its principal reference section. These roadcuts have been featured in field trip guidebooks (Ethridge et al. 1973, Palmer and Dutcher 1979). Another excellent exposure of the Wayside is in a north-trending ravine near the southwestern corner of the Goreville quadrangle (Jacobson 1992, p. 24). Also, the entire Wayside Member, 59.1 feet (15.0 m) thick, was cored in the ISGS #1 Jones borehole in Sec. 31, T11S, R2E on the Vienna quadrangle.

Because both contacts of the Wayside are disconformities, thickness of the member varies markedly within short distances. Ranges determined from outcrop and drill-hole data are: 30 to 140 feet (9 to 36 m) in the Creal Springs quadrangle, 50 to 100 feet (15 to 30 m) in the Goreville quadrangle, 30 to 145 feet (9 to 37 m) in the Lick Creek quadrangle, 30 to 100 feet (9 to 30 m) in the Bloomfield quadrangle, and 25 to 130 m in the Vienna quadrangle.

The Wayside is composed primarily of fine-grained, thinly layered clastic rocks that form slopes below the cliffs of the Battery Rock Member. Sandstone and shale or siltstone commonly alternate rhythmically in laminae and thin beds. Some of the rhythmic lamination, as seen in outcrops north of Vienna and in the Jones core, probably reflects tidal activity. Current and interference ripple marks, load casts, and ball-and-pillow structures are common.

The Wayside also includes thicker, lenticular sandstone bodies that form ledges and small cliffs. Such sandstone tends to be fine-grained and thick-bedded to massive, locally containing quartz granules and pebbles. Several of these sandstone bodies, termed "lentils", were named and mapped by quadrangle mappers. Jacobson (1992) named the Omar sandstone lentil, which is as thick as 40 feet (12 m) near the southwestern corner of the Goreville quadrangle. In the Lick Creek quadrangle to the west, the Buck Branch sandstone lentil of Nelson and Weibel (1996) may be equivalent to the Omar. The Buck Branch lentil attains a thickness of 40 feet (12 m) and its base is 50 to 60 feet (15 to 18 m) above the base of the Caseyville. The Keller sandstone lentil occurs farther west and occupies approximately the same stratigraphic position as the Buck Branch. Exposures in the limestone quarries near Buncombe reveal channel-form sandstone bodies up to 15 feet (4.5 m) thick and 300 feet (90 m) wide, in the lower part of the Wayside.

Conglomerate composed of pebbles and cobbles of Mississippian fossiliferous limestone and chert, together with shale, sandstone, and siderite, occurs locally in the lower to basal part of the Wayside. The Jones core contains this type of conglomerate, which also is found in outcrops near Dutchman Lake. Thin coal and carbonaceous shale containing plant fossils has been observed in the upper part of the Wayside Member.

Burrows and other trace fossils are common in thin-bedded strata of the Wayside. Diverse trace fossils occur in the I-57 roadcut, including *Conostichus*, which indicates marine deposition (Nelson and Weibel 1996). Well preserved plant fossils have been collected at several localities in the Goreville and Lick Creek quadrangles ((Jennings and Fraunfelter 1986, Jacobson 1992, Nelson and Weibel 1996). Marine invertebrates are uncommon, but extensive collections were made near Cedar Grove Church in Secs. 30 and 31, T11S, R2E (Rexroad and Merrill 1986, Jennings and Fraunfelter 1986, Weibel and Norby 1992). The fauna includes conodonts, coelenterates, brachiopods, pelecypods, gastropods, cephalopods, an arthropod, and crinoid columnals.

In most places, the contact with the overlying Battery Rock Sandstone is a marked disconformity, the Battery Rock filling channels eroded into the Wayside. Where the Battery Rock is thin, the contact may be gradational.

Battery Rock Sandstone Member. The Battery Rock is the older of two Caseyville sandstone members that forms widespread scenic bluffs and ledges in southern Illinois. It is especially well developed in Ferne Clyffe State Park, where it forms bluffs as high as 120 feet (36 m). The unit thickens further westward to 140 feet (43 m) in the southeastern part of the Lick Creek quadrangle, and then it gradually thins to zero in eastern Union County (Nelson and Weibel 1996).

In most exposures, the Battery Rock contains plentiful quartz pebbles that range up to about 1 inch (25 mm) in diameter. Locally, lenses of quartz-pebble conglomerate are present. Bedding is generally thick and exhibits wedge-planar, tabular planar, and trough crossbedding in sets up to 6 feet (1.8 m) thick. Paleocurrents are oriented toward the northwest, west, southwest, and south. The sandstone is locally massive and exhibits contorted lamination that probably reflects rapid de-watering of the sediment. Where the Battery Rock is thin, it is finer grained and more thinly layered. The only fossils are impressions and coalified traces of plant stems and logs, probably driftwood.

The upper contact of the Battery Rock Member generally is gradational from fine-grained sandstone below to laminated siltstone and shale in the unnamed interval above.

Unnamed interval. Between the resistant Battery Rock and Pounds Sandstone members is a generally slope-forming and poorly exposed succession of fine-grained and thinly layered clastic rocks. Early in the mapping program, we called this interval the Drury Member, following usage introduced by Lamar (1925). Mapping in Union and western Johnson County, however, disclosed that the Drury Member of Lamar belongs largely to the Tradewater Formation rather than to the Caseyville (Jacobson and Weibel 1993, Weibel and Nelson 1993, Nelson and Weibel 1996). Usage of "Drury Member" therefore was discontinued, and no new name has been applied to the rocks between the Battery Rock and Pounds sandstones.

Thickness of the unnamed interval varies from less than 20 feet (6 m) to about 120 feet (36 m) across Johnson County. No regional thickness trends are apparent. Thickness variations reflect the uneven lower surface, the strongly disconformable upper contact, and possibly local variations in subsidence rate. Locally, the Pounds and Battery Rock sandstones are directly superimposed and the unnamed interval is absent.

Good exposures of the unnamed interval are few. Even in the roadcuts along the interstate highways, the unit is largely covered. Jacobson (1992, p. 25) described a nearly complete exposure about 70 feet (21 m) thick along a county road in the NE¼ of Sec. 36, T11S, R2E in the Goreville quadrangle. The lower ~42 feet (~13 m) is an upward-fining sequence of silty sandstone, siltstone, and shale, whereas the upper 25 to 30 feet (7.6 to 9 m) is ledge-forming, medium to thick-bedded sandstone that contains common to abundant quartz pebbles. Jacobson informally called this sandstone the Dutchman Creek sandstone lentil and mapped it where it forms cliffs and ledges. This unit resides near the middle of the unnamed interval and has an erosive lower contact. Another nearly continuous section 90 feet (27 m) thick was measured in a ravine west of I-57 in the Lick Creek quadrangle (E½ SW¼ and SE¼ NW¼, Sec. 14, T11S, R1E). The section comprises two upward-fining, sandstone-to-shale sequences of nearly equal thickness. Near the top of the upper sequence is sandstone that contains root casts and is overlain by shale that yields plant fragments (Nelson and Weibel 1996).

The Gentry coal bed occurs sporadically in the lower part of the unnamed interval. Shaly coal 14 to 24 inches (36 to 61 cm) thick was observed at several places in eastern Johnson and western Pope County on the Stonefort quadrangle. At these localities the coal lies 3 to 10 feet (1 to 3 m) above the top of the Battery Rock Sandstone. Coal 0.9 foot (27 cm) thick occurs at a similar position in the big roadcut along Interstate 64 about 3 miles (5 km) north of Vienna. Shale overlying this coal contains well preserved plant fossils (Nelson et al. 2004). Coal also has been observed in the upper part of the unnamed interval in a few places.

The contact with the overlying Pounds Sandstone Member generally is erosional, the Pounds filling channels cut into the fine clastic rocks beneath. Outcrops in the southwestern part of the Stonefort quadrangle and several drill-hole records indicate that the Pounds fills valleys eroded into the Battery Rock Sandstone, removing the unnamed interval entirely.

Pounds Sandstone Member. The Pounds Sandstone is nearly continuous across Johnson County and excellent exposures can be seen in the roadcuts along I-24 and I-57 in addition to Ferne Clyffe State Park. The Pounds closely resembles the Battery Rock in lithology, except that quartz pebbles tend to be smaller and less abundant in the younger sandstone. As in the Battery Rock, trough and planar cross-bedding is prevalent, with paleocurrents toward the west, southwest, south, and southeast. Portions of the sandstone are massive but may exhibit contorted lamination suggestive of slumping or rapid de-watering of the sediment.

Fossils are uncommon. Only nondescript burrows and poorly preserved plant remains, mainly stems, were observed during mapping.

The Pounds Sandstone forms bluffs up to 100 feet (30 m) high in Ferne Clyffe State Park and elsewhere in the Goreville quadrangle. The Pounds also is well developed in the eastern part of the Lick Creek quadrangle, where it forms cliffs and ranges from 30 to 80 feet (9 to 24 m) thick. Entering Union County west of I-57, the Pounds becomes discontinuous and disappears near the western edge of the quadrangle. The same situation continues into the eastern part of the Makanda quadrangle in Union County, where the Caseyville and Tradewater formations were mapped as a single unit (Jacobson and Weibel 1993).

The top of the Pounds Sandstone generally is considered to represent the top of the Caseyville Formation. In most places, this contact is gradational through an upward-fining succession from sandstone below to siltstone and shale above. Locally, rooted mudstone (underclay) beneath the Reynoldsburg Coal Member of the Tradewater rests directly on the Pounds Sandstone. The most readily accessible exposure of the contact is in the roadcuts along Interstate 24 (see Palmer and Dutcher 1979, p. 90.)

Tradewater Formation

The youngest bedrock in Johnson County belongs to the Tradewater Formation. Like the Caseyville Formation, the Tradewater is composed of alternating units of resistant sandstone and less resistant finer grained clastics (shale, siltstone, and non-fissile mudstone), together with thin but commonly distinctive layers of limestone, black shale, and coal. As currently defined, the Tradewater Formation extends from the top of the Caseyville to the base of the Davis Coal Member in Illinois (fig. 11).

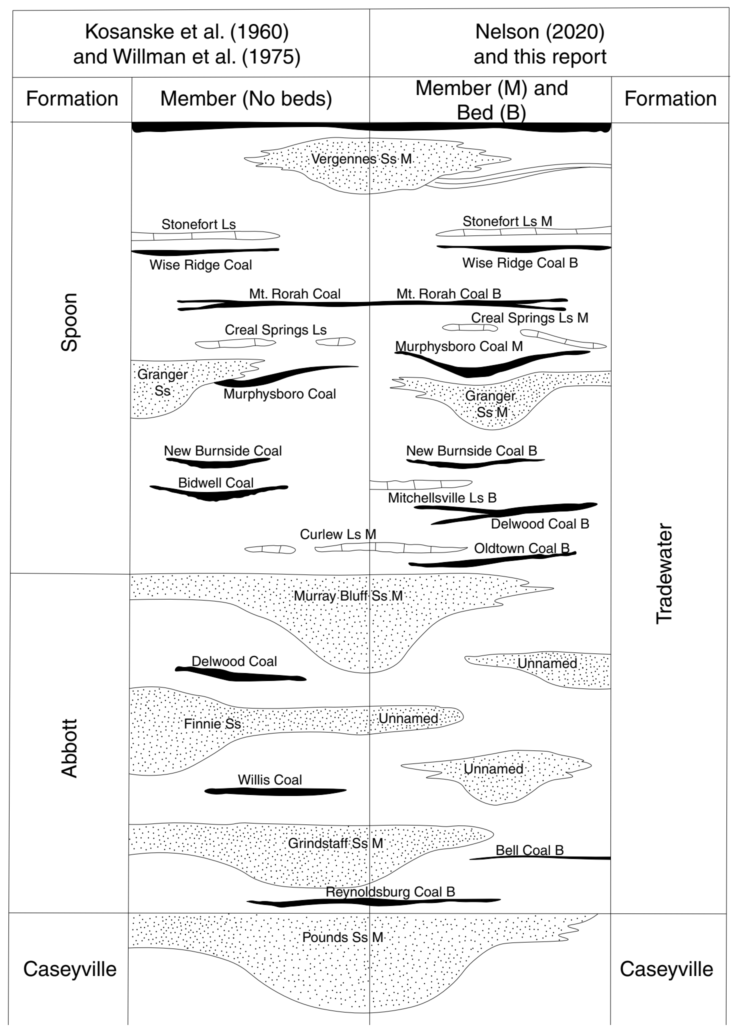


Figure 11 Chart comparing Pennsylvanian classification of Kosanke et al. (1960) with that used in the present report. The nomenclature shown at the right was gradually adopted during the mapping program between the 1980s and the 2010s. The chart is not drawn to scale.

Geologists who mapped 7.5-minute quadrangles in Johnson County during the 1980s and 1990s grappled with how to classify the strata of the Tradewater. Previously, Kosanke et al. (1960) and Willman et al. (1975) divided these rocks into two formations, the Abbott, (older) and the Spoon (fig. 11). Those authors defined the formation contact as the top of the Murray Bluff Sandstone Member, which has its type section in southwestern Saline County (Sec. 35, T11S, R5E, Eddyville 7.5-minute quadrangle. When we traced the Murray Bluff Sandstone from its type locality 4 miles (6.4 km) west to the railroad cut that serves as the type section of the Abbott Formation, we discovered that Kosanke et al. had misidentified the Murray Bluff in the railroad cut. Entering Johnson County a short distance farther west, we lost the Murray Bluff altogether. Thus, this sandstone is unsuitable as a formation contact. No other suitable horizon being found, we decided to discontinue use of Abbott and Spoon formations and revert to the older usage of Tradewater Formation, which encompasses both Abbott and Spoon. This change in nomenclature was officially ratified for use throughout Illinois and western Kentucky by the Tri-State Committee (2001).

Mapping in Johnson and neighboring counties further disclosed that several smaller units within the Tradewater Formation, designated as members and beds, had been incorrectly positioned or lacked sufficient lateral continuity and lithologic identity to justify formal recognition. During the same process, several new distinctive units were identified and formally named as members and beds. The summary of these efforts has been incorporated into ILSTRAT (Nelson 2020) and is explained below, beginning at the bottom of the Tradewater succession.

Reynoldsburg Coal Bed. The coal lies near the base of the Tradewater Formation and formerly was mined in small underground and open pits near Reynoldsburg in east-central Johnson County. The best exposure is in roadcuts on both sides of I-24 in NE¼ NE¼, Sec. 8, T12S, R3E (Ethridge et al. 1973, Palmer and Dutcher 1979). In eastern Johnson County the coal varies from a streak to at least 3.0 feet (90 cm) thick, and it may reach 3.5 feet (107 cm). Some core records indicate two layers of coal separated by claystone. The last mine closed in 1978. The Reynoldsburg contains a fossil spore flora distinct from that of the younger Bell Coal Bed, and Peppers (1996) considered the Morrowan-Atokan stage boundary, and also the Langsettian and Duckmantian (Westphalian A and B, respectively) substages in western European chronology, to lie between the two coals.

Separating the Reynoldsburg from the younger Bell Coal Bed is an interval of clastic rocks 40 to 70 feet (12 to 21 m) thick. Gray shale and siltstone comprise most of the interval, but exposures are few. Sandstone varies from very fine-grained, micaceous, and argillaceous or silty to very coarse-grained rock that resembles Caseyville sandstone and forms bluffs up to 40 feet (12 m) high (Trask and Jacobson 1990). In a roadcut along Interstate 24, sandstone overlying the Reynoldsburg contains a variety of trace fossils that are mostly attributed to bivalves and suggest a brackish to freshwater environment (Devera 1989).

Bell Coal Bed. The Bell coal bed first was mined and described in western Kentucky, where some geologists considered it to mark the top of the Caseyville Formation. A coal bed lying 40 to 70 feet (12 to 21 m) above the Reynoldsburg Coal in the Creal Springs quadrangle was named the Tunnel Hill Coal Bed during the mapping project (Trask and Jacobson 1990). Palynological analysis by Russel A. Peppers indicated that the Tunnel Hill Coal correlates with the Bell, and so the latter name has been adopted. Outcrops, mine exposures, and drilling records indicate that the Bell has a maximum thickness of about 28 inches (71 cm) in the Creal Springs area and is generally dull and shaly. This coal bed has not been encountered elsewhere in Johnson County. Overlying the Bell is either an upward-coarsening, shale-to-sandstone sequence, or sandstone having an erosive lower contact. Both rock types contain trace fossils and rare invertebrate fossils having brackish to marine affinities (Devera 1989).

Grindstaff Sandstone Member. Butts (1925) named the Grindstaff Sandstone for exposures in Grindstaff Hollow, Gallatin County, and sandstone of similar character and stratigraphic position occurs intermittently westward across southern Illinois. Thickness ranges up to about 90 feet (27 m), but the unit is lenticular. The sandstone that forms the "streets" in Giant City State Park and at Panther Den, also in Union County, is believed to be the Grindstaff (Nelson 2013.

The sandstone is light to medium gray, mostly fine- to medium-grained, and tends to form rounded ledges and cliffs. Its composition approaches quartz arenite, but mica and other non-quartz components are more conspicuous than in Caseyville sandstone and the quartz granules are smaller and less numerous. Some outcrops display large-scale crossbedding, whereas others show nearly massive sandstone that may contain convolute lamination indicative of soft-sediment deformation. In the Goreville quadrangle, the Cedar Creek sandstone lentil is extensively burrowed and contains a variety of trace fossils, including the marine indicators *Conostichus* and *Zoophycos* (Jacobson 1992). Large-scale crossbedding in a roadcut on I-57 south of the Goreville interchange exhibits neap-spring tidal couplets in the foreset beds (Kvale and Archer 1991).

"Middle Abbott" sandstone and shale. As envisioned by Kosanke et al. (1960), a single sandstone unit, the Finnie Sandstone Member, occupied the middle part of the Abbott Formation (fig. 11). Reinforcing this position, geologic maps of Hardin and eastern Pope counties (Baxter et al. 1963 1967, Baxter and Desborough 1965) portrayed the Finnie Member as a mappable unit. However, mapping in western Pope and eastern Johnson counties (Trask and Jacobson 1990, Nelson and Lumm 1990a and 1990b) disclosed that several discontinuous, lenticular bodies of sandstone occupied the “Finnie” interval. Moreover, palynological investigation of coal beds associated with the type Finnie and Grindstaff sandstones suggested that the two units are one and the same (Peppers and Popp 1979). Based on these findings, usage of “Finnie Sandstone Member” in Illinois has been discontinued, and the various sandstone lentils between the Grindstaff and Murray Bluff sandstone members are left unnamed (Nelson et al. 1991).

Strata containing marine body fossils and trace fossils occur widely in the “middle Abbott” interval of Johnson County. Marine rocks include units informally designated as the Cedar Creek sandstone lentil and the Olive shale member in the Stonefort, Creal Springs, and Goreville quadrangles (Devera 1989, Nelson and Lumm 1990b, Trask and Jacobson 1990, Nelson et al. 1991, Jacobson 1992) and probably extend into the Lick Creek quadrangle, as shown by core drilling (Nelson and Weibel 1996). The sandstone dubbed Cedar Creek is intensively bioturbated and includes the ichnofossils *Conostichus, Rhizocorallium*, and *Zoophycos*, which have strong marine affinities. Burrowed sandstone appears to intergrade laterally with shale that contains a similar suite of ichnofossils and also thin limestone beds that bear diverse marine invertebrates: brachiopods, crinoids, bryozoans, bivalves, cephalopods, ostracods, trilobites, and conodonts.

These marine fossils occupy an interval ranging from about 10 feet (3 m) above the Bell Coal to at least 90 feet (27 m) above the Bell. Casts of brachiopods, bryozoans, and crinoids also occur in the basal Murray Bluff Sandstone in two cores drilled in the Goreville quadrangle (Jacobson 1992). Thus, they probably belong to two or more cycles of sedimentation.

The only named marine unit in the lower part of the Tradewater Formation is the Lead Creek Limestone Member, which extends intermittently along the eastern margin of the Illinois Basin in western Kentucky and southwestern to west-central Indiana. The Lead Creek itself comprises as many as four beds of limestone separated by clastic rocks, paleosols, and coal beds; thus also representing multiple cycles of deposition. Using conodont biostratigraphy, P.H. Heckel (2017) has distinguished among the limestone “benches” of the Lead Creek in southern Indiana. The genus *Declinognathodus*, recovered from thin limestone at a depth of 125 feet (38 m) in the ISGS #C-3 drill core, is characteristic of the lowest bench of the Lead Creek. In #C-3, the limestone resides approximately 10 feet (3.0 m) above the Tunnel Hill (Bell) Coal Bed. Thus, younger marine rocks of the “middle Abbott” in Johnson County are likely correlative of higher “benches” of the Lead Creek Limestone.

Murray Bluff Sandstone Member. As mentioned above, the Murray Bluff Sandstone is named for a locality in southwestern Saline County, where it is about 115 feet (35 m) thick. Westward into Johnson County this unit thins, ranging from less than 10 feet (3 m) to about 40 feet (12 m) in the Creal Springs quadrangle. In the Goreville quadrangle the Murray Bluff is 20 to 60 feet (6 to 18 m) thick and is well exposed at the spillway of Lake of Egypt and in bluffs along Beaver Creek in Sec. 16, T11S, R3E. Continuing westward through the Lick Creek quadrangle, sandstone believed to be Murray Bluff forms cliffs up to 60 feet (18 m) high and was 150 feet (45 m) thick in a drill core (Nelson and Weibel 1996).
The Murray Bluff is an iron-rich sandstone that commonly exhibits Liesegang bands on outcrops. Although quartz is the most abundant mineral, mica, feldspar, and lithic fragments are conspicuous. Grain size can be fine to coarse; quartz granules and small pebbles are locally present. Bedding can be thin to massive. Planar and trough crossbedding and ripple marks commonly are developed. Where the sandstone is thick, grain size tends to decrease upward and the lower contact is erosive. Gradational contacts with enclosing fine clastics are seen where the Murray Bluff is thinner.

Oldtown Coal Bed. Nelson et al. (1991) gave the name Oldtown Coal bed to a seam exposed in a railroad cut about 1.2 miles (1.9 km) east of the northeast corner of Johnson County in Sec. 5, T11S, R5E, Pope County. The coal also was exposed at the time of mapping in natural outcrops and small mines west of the railroad in the Creal Springs quadrangle. Thickness ranges from a streak to at least 3.0 feet (90 cm) and may reach 3.5 feet (1.1 m). Based on fossil spores, Russel A. Peppers correlated the Oldtown Coal approximately with the Rock Island Coal of northwestern Illinois and the Minshall Coal of Indiana. Peppers (1996) placed the Atokan-Desmoinesian stage boundary and also the Bolsovian-Asturian substage boundary a short distance above the Rock Island and Minshall coals.

Marine limestone or sandstone overlying the Rock Island Coal and its correlatives is widely but sporadically distributed through the Illinois Basin. Names for the marine unit include Seville Limestone in northwestern Illinois, Perth Limestone in Indiana, Curlew Limestone in western Kentucky, and Boskydell marine zone (informal) in the Carbondale, Illinois area. However, no marine rock has been observed or reported at this position in Johnson County.

Delwood Coal Bed. Named for a small community in Pope County (Eddyville quadrangle), the Delwood Coal was believed to underlie the Murray Bluff Sandstone (Kosanke et al. 1960). However, outcrop mapping and core drilling demonstrated that the Delwood is younger than the Murray Bluff and also lies above the Oldtown Coal (Nelson et al. 1991). Palynological investigation by Peppers (1996) confirmed that conclusion. The Delwood coal varies considerably in thickness, reaching a maximum of 71 inches (180 cm) in a borehole near Creal Springs. A claystone layer that varies from a few inches (~10 cm) to about 1.5 feet (45 cm) commonly is present, suggesting that the coal may split apart.
New Burnside Coal Bed. The New Burnside Coal formerly was mined together with the Delwood Coal from small open pits near its namesake community. Trask and Jacobson (1990) mapped the coal through an area roughly 3 miles (5

km) square in northeastern Johnson and southeastern Williamson County. Where exposed, the New Burnside Coal ranged from a few inches (~10 cm) to 54 inches (137 cm) thick and lay 8 to 25 feet (2.4 to 7.6 m) above the Delwood Coal. Separating the two coal beds were strata of shale, sandstone, and conglomerate. The relationship of the New Burnside Coal to the Mitchellsville Limestone has not been determined because the limestone does not occur near New Burnside. Possibly, the Delwood and New Burnside represent a single layer of coal that locally splits apart.

Mitchellsville Limestone Bed. Nelson et al. (1991) gave the name Mitchellsville Limestone to a unit that crops out near Mitchellsville in southern Saline County. Earlier authors, including Butts (1925), identified this limestone as the Curlew Member; but physical stratigraphy and microfossils demonstrate that the Mitchellsville is younger than the Curlew. The early Desmoinesian fusulinid *Beedeina leei* is characteristic of the Mitchellsville (Dunbar and Henbest 1942, Thompson et al. 1959) and does not occur in the Curlew. Conodonts also have been extracted from the Mitchellsville, but do not help in pinning down the unit's age (Heckel 2013). The Mitchellsville is cherty, siliceous limestone 1 to 5 feet (30 to 150 cm) thick that varies from lime mudstone to fossiliferous lime mudstone. The unit is known from boreholes and outcrops in Gallatin, Pope, and Saline counties but no definite occurrences have been found in Johnson County.

Granger Sandstone Member. Although the Granger Sandstone was named for a locality in western Kentucky, Kosanke et al. (1960) described a principal reference section of this unit in an old quarry east of Creal Springs in Williamson County, within 1.2 miles (1.9 km) of the Johnson County border. The sandstone is present in northeastern Johnson County, but it has not been mapped. Because of uncertainty as to its stratigraphic position, Nelson et al. (1991) used the moniker "golden sandstone" for a unit that is now believed to be the Granger. Abstracting the description from Nelson et al. (1991), the sandstone is fine to coarse-grained, poorly sorted, and contains a few quartz granules. The rock is rather friable and erodes to smooth, rounded outcrops commonly encrusted with iron oxide. Mica, weathered feldspar grains, lithic fragments, and interstitial clay are plentiful. This sandstone is likely a lithic arenite. Bedding is mostly thick to massive and crossbedding is common. Thickness varies from about 20 to 70 feet (6 to 21 m).

In the Goreville quadrangle, Jacobson (1991) gave the informal name "Bethlehem sandstone member" to sandstone 10 to 30 feet (3 to 9 m) thick lying about 40 to 60 feet (12 to 18 m) above the Murray Bluff Sandstone. Jacobson mapped this sandstone capping some of the divides between ravines around the southern part of Lake of Egypt. Based on its stratigraphic position, the Bethlehem sandstone may be the Granger.

Murphysboro Coal Member. Well-developed in Jackson County, where it was mined extensively, the Murphysboro Coal occurs sporadically elsewhere in southern Illinois. The coal occurs as pods or lenses, possibly filling abandoned channels, and locally is thick enough to mine. Several small, abandoned underground and surface mines exploited a coal seam believed to be the Murphysboro near the village of New Burnside (Trask and Jacobson 1990). The only well documented mine was a slope operated by Fred Smith during the 1930s. The coal reportedly was about 3.5 feet (1.1 m) thick and lay 45 feet (14 m) below the surface. Russel Peppers examined fossil spores from coal samples collected at mine waste piles; the spores were consistent with the coal being Murphysboro (Nelson et al. 1991). Where it was mined, the Murphysboro lay directly above the Granger Sandstone and 20 to 30 feet (6 to 9 m) above the New Burnside Coal.

Creal Springs Limestone Member. Kosanke et al. (1960) named the Creal Springs Limestone and described its type section in an old quarry east of the town, in Sec. 25, T10S, R3E, Williamson County. At this locality, the limestone varies from 4 to 24 inches (10 to 60 cm) thick and the Murphysboro Coal, which should lie below the limestone, is not developed. The limestone crops out elsewhere in the vicinity and also was encountered in drill cores. Trask and Jacobson (1990) mapped it in small areas. No definite exposures have been reported in Johnson County. Nelson et al. (1991, p. 38) wrote, "The Creal Springs Limestone is medium to dark gray, argillaceous, and composed of whole brachiopods, gastropods, fusulinids, and echinoderm fragments in micritic matrix. Chert nodules are abundant and the limestone is totally silicified in places."

Mt. Rorah Coal Member. This coal formerly was mined and has been mapped east of Creal Springs near the northeastern corner of Johnson County and in the adjoining part of Williamson County (Trask and Jacobson 1990). Cores, outcrops, and mine exposures showed the coal to range from less than 1 foot (30 cm) to about 45 inches (1.1 m) thick and commonly contained one or more layers of claystone as thick as 1 foot (30 cm). An interval 10 to 20 feet (3 to 6 m) thick of medium gray, clayey to silty shale and non-fissile claystone separated the Mt. Rorah Coal from the Creal Springs Limestone below. Overlying the coal was "dark gray to black, silt-free, carbonaceous shale, which grades upward to gray silty shale, siltstone, and sandstone", topped by the underclay of the Wise Ridge Coal. Interval between the Mt. Rorah and Wise Ridge coals varies from 20 to 26 feet (6.1 to 7.9 m) (Nelson et al. 1991, p. 39).

Wise Ridge Coal Member. The Wise Ridge is thin (rarely more than 12 inches, 30 cm) but widely persistent in southern Illinois and western Indiana. Exposures in the Creal Springs area showed bright-banded and blocky to thinly laminated coal overlying soft, rooted, non-fissile claystone. The coal was too thin to mine by itself but was commonly exposed in the overburden of mines that sought the Mt. Rorah Coal.

Veale shale member. Directly overlying the Wise Ridge Coal and underlying the Stonefort limestone is shale that is dark gray, greenish gray, and black, commonly mottled, and thinly laminated. Thickness in the area near Creal Springs varies from about 3 to 30 feet (0.9 to 3.0 m). Readily identified by "hot" readings on gamma-ray logs, this dark shale has been traced across large areas of southern and eastern Illinois and western Indiana. The name Veale shale member has been introduced on the basis of core drilling in Veale Township, Daviess County, Indiana (Nelson 2020). Together with the similar Carrier Mills Shale above, the Veale shale is an important subsurface marker unit.

Stonefort Limestone Member. Named for the town of Stonefort in southwestern Saline County, this unit has been traced extensively using borehole records in southern and eastern Illinois and in western Indiana. In its type area, including the northeastern corner of Johnson County, the Stonefort "varies from a few inches [~10 cm] to a little less than 2 feet [~60 cm] thick. It is medium to dark brownish gray, shaly, and fine grained with scattered coarse fossil fragments and whole fossils. The fauna includes brachiopods, pelecypods, gastropods, rugose corals, and crinoid fragments. The limestone typically forms a single bed or two beds separated by a shale parting. In some places it is nodular." (Nelson et al. 1991, p. 40.)

Separating the Stonefort Limestone from the next younger named unit, the Carrier Mills Shale, is soft shale and/or claystone that is 5 to 15 feet (1.5 to 4.5 m) thick and mottled in light gray, green, and red, colors that are unusual in this part of the Pennsylvanian succession.

Carrier Mills Shale Member. Nelson et al. (1991) named the Carrier mills Shale and described its type section in a cut along an abandoned railway near Stonefort, a short distance northeast of Johnson County. The shale is black, hard, thinly fissile, and contains laminae and small lenses of phosphatic minerals. On gamma-ray logs it produces extremely high or "hot" readings, enabling correlation across large areas of Illinois, Indiana, and western Kentucky. However, the only definite outcrops of the Carrier Mills Shale in Johnson County are on Wise Ridge (Sec. 3, T11S, R4E), where it lies directly beneath the Granger Sandstone (Trask and Jacobson 1990). Elsewhere in the county, this distinctive unit has been eroded at the bedrock surface.

Vergennes Sandstone Member. The youngest member of the Tradewater Formation present in Johnson County is the Vergennes Sandstone, which caps Wise Ridge in Sec. 3, T11S, R4E near the northeastern corner of the county (Trask and Jacobson 1990). When we mapped that area circa 1990, we referred to this unit informally as the "sub-Davis sandstone" because it lies a short distance below the base of the Davis Coal, which by definition is the base of the Tradewater Formation. As described by Nelson et al. (991), the Vergennes Sandstone is commonly 30 to 40 feet (9 to 12 m) thick and attains a maximum of about 60 feet (18 m). Lithologically the Vergennes is similar to the Granger Sandstone: micaceous lithic arenite that is friable and poorly sorted. Bedding is mostly thick and crossbedding is commonly developed. The lower contact is erosive and in places is marked by conglomerate shale, coal, and siderite pebbles.

Structural Geology

Johnson County lies along the southern margin of the Illinois Basin. Bedrock strata regionally dip slightly east of north. Modifying this pattern are two significant, faulted anticlines separated by a syncline, and two zones of high-angle normal faulting. Relationship of faults and folds in Johnson County with those of neighboring counties is portrayed on a map (fig. 12).

New Burnside Anticline

The New Burnside anticline extends across southern Saline and northwestern Pope counties into northeastern Johnson County (fig. 12), a distance of approximately 18 miles (29 km). The eastern part of the fold trends nearly east-west. Entering Johnson County, it curves to a southwest heading, turning to the south at its southern terminus at Tunnel Hill. Thus, the New Burnside anticline runs parallel with the larger McCormick anticline, which lies about 5 miles (8 km) southeast.

In Johnson County the anticline is smoothly arched in profile (map sheet 2, cross section), contrasting with the sharp-crested and box-shaped profiles seen at points to the east (Nelson et al. 1991). The fold is moderately asymmetrical, having dips of 10º to 30º on the northwest and 5º to 20º on the southeast flank. Structural relief decreases gradually east and west from a maximum of 300 to 350 feet (~100 m) near New Burnside. Strata deformed at the surface belong entirely to the Tradewater Formation.

Crossing the axis of the New Burnside anticline are five northeast-striking faults that form an *en echelon* pattern (plate 1, geologic map). Four have their southeast sides downthrown; one the northwest side. Trask and Jacobson (1990) interpreted them as reverse faults based on "intense deformation of the strata in and near the fault plane", including one example of overturned bedding. However, Nelson et al. (1991, p. 68) stated, "The four eastern faults [in Johnson County] probably are simple normal faults;" however, "the westernmost fault has drag inconsistent with stratigraphic offset", suggesting that the southeast side was first raised and then lowered. Small faults that are cleanly exposed, as in railroad cuts, are mostly normal, but some are high-angle reverse. Striations and other slip indicators indicate dip-slip displacements, except on some fractures that strike perpendicular to the anticlinal axis and have very small displacements. Joints along the New Burnside anticline show a primary trend of N 40-50º E, parallel to the fold axis, and a secondary trend close to perpendicular with the axis.

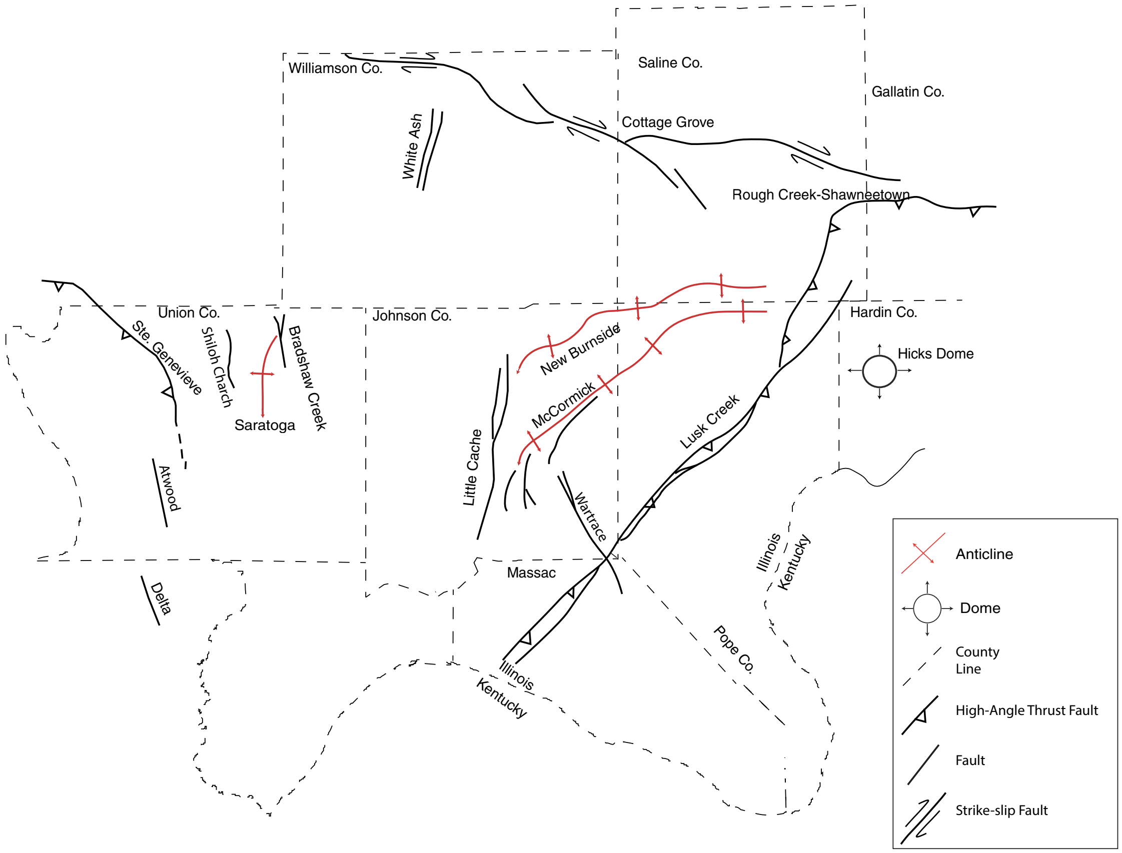


Figure 12 Map showing selected folds and faults in Johnson County and surrounding area.

McCormick Anticline

The McCormick anticline is about 5 miles (8 km) southeast of the New Burnside anticline and runs parallel with the latter, curving from southwest to south near its southern terminus. Features of the two anticlines are closely similar. The McCormick has slightly greater structural relief (up to about 350 feet or 107 m in Johnson County) and steeper dips, as much as 65º on the northwest flank and 45º on the southeast flank. Typical dips, however, are 20º to 35º and 5º to 10º, respectively. Near the Johnson-Pope county border, the McCormick structure features sharp flexures and faulted hinges. Relief and flanking dips diminish gradually, and the fold becomes more smoothly arched toward the southwest. The fold axis turns to a due south heading as the anticline plunges and terminates.

Faults along the McCormick structure are longer than those on the New Burnside fold. Although these faults again run *en echelon*, they curve along trend, paralleling the fold axis and then curving toward the south and in two cases, bifurcating. Most faults are normal, but several exhibit reverse slip. As on the New Burnside anticline, some faults associated with the McCormick appear to have undergone two episodes of displacement, first reverse and second normal. Evidence includes drag folds opposite to the sense of stratigraphic offset, and faults that bound narrow slices of upthrown rock. Again, drag folds and striations indicate dip-slip displacements and there are two sets of joints, the primary set parallel and the second set perpendicular to the fold axis (Nelson et al. 1991).

Potter (1957) described unusual breccia and overthrusts on opposite flanks of the McCormick anticline in railroad cuts about 0.6 mile (1 km) east of the Johnson-Pope county line on the Stonefort quadrangle. Exposed near the north portal of the tunnel, the breccia consists of lenses of sandstone, as large as 100 feet (30 m) long and 15 feet (4.6 m) thick, in a matrix of shale-pebble conglomerate. Most of the sandstone lenses display subhorizontal bedding and structures such as ripple marks and crossbedding. Some sandstone lenses, however, were rotated and folded. At the south portal in upper Caseyville Formation are south-verging thrust faults that ramp upward from horizontal detachments. Potter proposed that breccia and thrust faults formed as a consequence of landsliding as the anticline rose during Early Pennsylvanian sedimentation. Apparent thinning of the Caseyville Formation close to the fold axis, as determined by our mapping, further suggests Early Pennsylvanian uplift. However, the evidence remains inconclusive. Clearly, most of the folding and faulting along the McCormick structure took place after Caseyville and lower Tradewater strata were fully lithified.

In Nelson et al. (1991) and also in Nelson (1995c) we alluded to a proprietary seismic reflection profile interpreted as depicting thrust faults, detached within the Paleozoic sedimentary succession, beneath the McCormick and New Burnside anticlines. We did not view the seismic profile(s) ourselves but relied on sketches made by a colleague who actually inspected the data. A more reliable source is the regional seismic reflection profile published by C.J. Potter et al. (1995) (fig. 13). Regarding the McCormick anticline, these authors wrote (p. 13), "Folding affects strata from the Mississippian (exposed at the surface) down through the [Cambrian and Ordovician] Knox. Nelson (1991) interpreted this folding to be driven by west-directed horizontal movement along a decollement in the Knox. The seismic data show that the folding is cored by a basement-cutting(?) blind thrust fault [labeled "K" in fig. 13]. This fault cuts the Eau Claire [Cambrian] 2 km northwest of the position where the Shawneetown fault cuts the Eau Claire and dips easterly at about 30º. Both the Shawneetown fault and fault "K" almost certainly penetrate the top of the [Precambrian crystalline] basement, although the seismic data do not explicitly show this because the net offset is small and there is not a strong reflection marking the top of basement there."

Battle Ford syncline

A long, sinuous syncline that parallels the New Burnside anticline has been named the Battle Ford syncline. The axes of the two folds are about 0.6 to 1.2 mile (1 to 2 km) apart, the separating increasing toward the east. Northwest flank of the syncline has an average dip of about 10 degrees, whereas the southeast flank, barely perceptible in the field, dips at most a few degrees. Trough of the syncline in most places lies at higher elevation than the base of the northwest limb of the anticline. Thus, it appears the Battle Ford fold is mainly a syncline "by default", produced by the uplift of New Burnside and McCormick anticlines on either side.

Little Cache fault zone

Nelson et al. (1991) gave the name "Little Cache fault zone" to a belt of normal faults running north-south near the Little Cache River. Mapped length of the zone is about 12 miles (19 km) and width ranges from about 0,5 to 1.0 mile (0.8 to 1.6 km). In most places two or three parallel faults have been mapped, either forming grabens or stepping down to the east. Maximum throw is 280 feet (85 m) in Sec. 15, T12S, R3E on the Bloomfield quadrangle (Nelson 1993). Formations displaced at the surface range from the Cypress Formation (Mississippian) to the Tradewater (Pennsylvanian). Fault surfaces dip 70 to 85 degrees and exhibit dip-slip striations. For the most part, breccia and drag are absent or confined to narrow zones. No mineralization has been noted or reported.

Complications occur south of Vienna, on the Vienna quadrangle (Nelson et al. 2004). As shown by cross sections (fig. 14), faults in the area have undergone "scissoring" with the west side downthrown stratigraphically, yet drag folding along the faults indicates the east side moved down. Such a geometry could reflect either strike-slip movement, or dip-slip movement with a reversal in the direction of throw. Given the presence of vertical slip indicators, the latter explanation is preferred, and fits with other structures in the area.

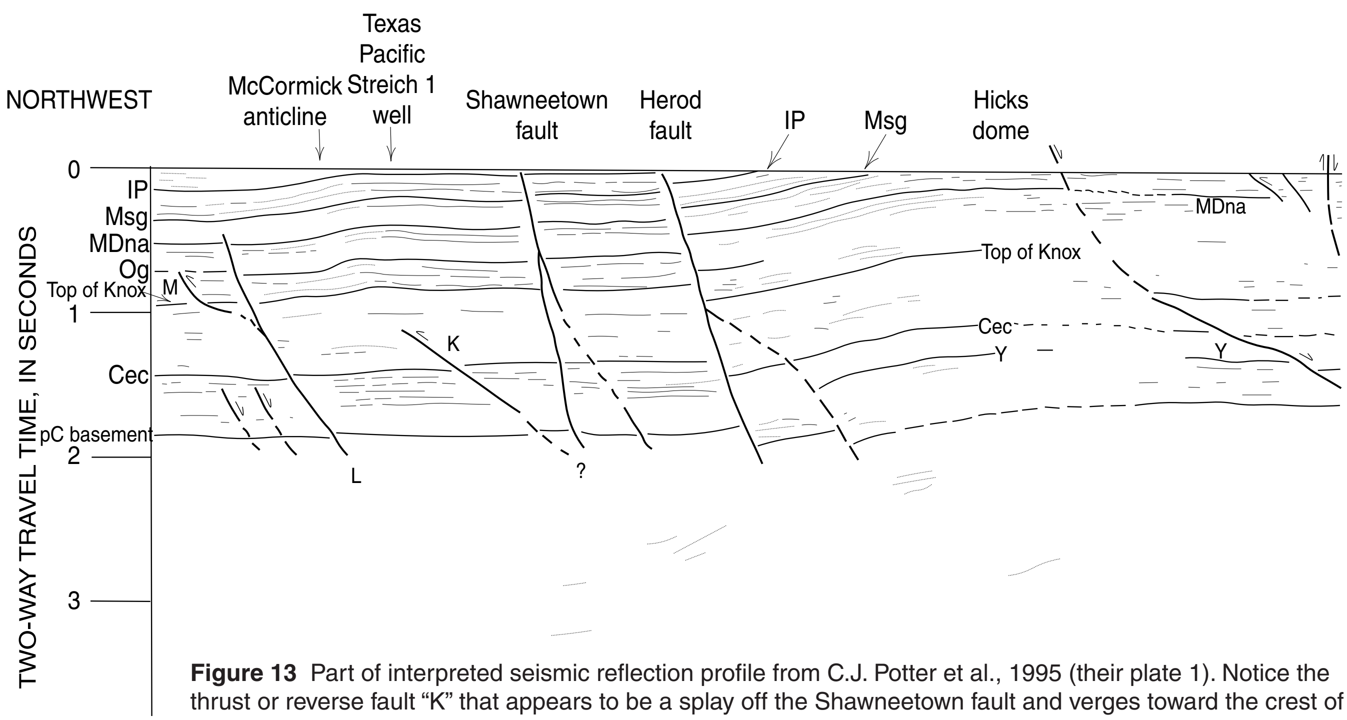


Figure 13 Part of interpreted seismic reflection profile from C.J. Potter et al., 1995 (their plate 1). Notice the thrust or reverse fault "K" that appears to be a splay off the Shawneetown fault and verges toward the crest of the McCormick anticline.

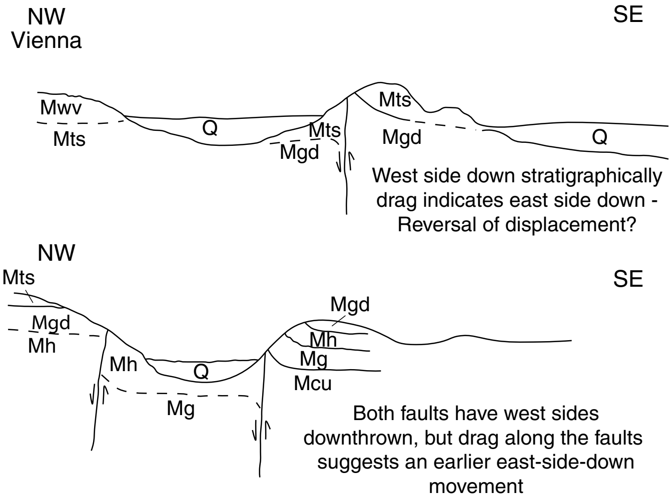


Figure 14 Cross sections of two faults near southern end of Little Cache fault zone, south of Vienna.

A small anticline-syncline pair is in line with the northern termination of the Little Cache fault zone. These folds likely reflect northward continuation of faulting at depth.

Wartrace fault zone

Nelson (1993) gave the name "Wartrace[1] fault zone" to a pair of faults that outline a graben trending north-northwest in the Bloomfield quadrangle. The faults outline a central block that is downthrown 100 to 150 feet (30 to 45 m). Breccia, closely spaced jointing, and drag folding are present but no actual fault surfaces were found. A proprietary seismic reflection profile that crosses the fault zone shows the faults to be nearly vertical and extend through the entire Paleozoic sedimentary succession.

Outcrop-scale anticlines

More than a dozen "miniature" or outcrop-scale anticlines have been mapped in the southern Bloomfield (Nelson 1993, 1995a) and Glendale (Devera 1991) quadrangles in eastern Johnson County. The best exposed example is in a railroad cut near Robbs on the Glendale quadrangle. These structures are sharp-crested, hinge-like buckles that range from a few feet (~1-2 m) to about 50 feet (15 m) wide. Axial trends are diverse and mostly do not parallel larger nearby structures. Dips on the flanks can be as steep as 90º . Thrust or reverse faults are visible in the cores of several. Chesterian formations from the Hardinsburg through the Clore are deformed.

Structural interpretation

In order to fully appreciate the structural geology of Johnson County, a look at a larger area of southern Illinois is necessary (fig. **12**). Key elements in regional structure lie to the east: the Lusk Creek fault zone and the Rough Creek-Shawneetown fault system. The Lusk Creek runs northeast through Massac and Pope counties, linking with the Rough Creek-Shawneetown, which makes an abrupt bend to a due east heading and continues into western Kentucky. These fracture zones share a common history that began with rifting during the Cambrian Period. Seismic reflection data (Bertagne and Leising 1991, C.J. Potter et al. 1995) demonstrate that Cambrian strata thicken markedly on the southeast side of the Lusk Creek and south side of the Rough Creek-Shawneetown fault systems. Thus, these faults originated as normal faults, active during Cambrian sedimentation. A second episode of faulting took place during the Alleghenian orogeny in late Pennsylvanian to Permian time. Involving compression directed toward the northwest, this episode elevated the crustal block southeast of the faults, converting normal faults to reverse faults. In a third episode of deformation, poorly constrained in time, relaxation of compression and/or crustal extension allowed the uplifted block to drop back down, in a second episode of normal faulting (Nelson and Lumm 1987, Weibel et al. 1993).

Viewed in this context, the New Burnside and McCormick anticlines are products of the same compressive episode that induced reverse faulting along the Lusk Creek fault zone. The anticlines themselves, and the reverse faults that accompany them (fig. 14), reflect crustal shortening directed toward the northwest. As outlined above, normal faulting along the anticlines took place later and apparently coincides with the second episode of normal movement along the Lusk Creek and Rough Creek-Shawneetown fault systems.

Referring again to map sheet 1 and fig. 12, notice how the New Burnside and McCormick anticlines both terminate on the west close to the north-trending Little Cache fault zone. Moreover, the western ends of both folds curve into parallelism with the fault zone. Thus, the Little Cache served as a westward barrier to fold propagation and existed at least as a basement structure before the anticlines commenced to form. As mentioned above, near its southern end the Little Cache shows evidence for both reverse faulting and later normal faulting, the same sequence of events inferred for the Lusk Creek fault zone and both anticlines.

The Little Cache fault zone is one of several small, north-striking zones of normal faulting in far southern Illinois. Others include the Bradshaw Creek, Shiloh Church, Atwood, and Delta faults in Union County and the White Ash fault zone in Williamson County. Farther north, many large structural features have north-south trends, among them the Du Quoin monocline and the Salem, Louden, and Clay City anticlines.

The Wartrace fault zone in Johnson County has a rather unusual trend of north-northwest. It is nearly perpendicular to the Lusk Creek fault zone and to the New Burnside and McCormick anticlines. Relation of the Wartrace faults to the other named structures is unclear, although as noted above, the Wartrace faults evidently reach Precambrian basement.

[1] Named for a nearby community. According to Callary (2009), origin of this curious name is uncertain, but it probably refers to an Indian warpath or war trail.

That observation allows for these faults to be related to a pre-Mississippian structural grain.

Finally, the 13 outcrop-scale anticlines of eastern Johnson County all lie between the Lusk Creek fault zone and the McCormick anticline. We have not found similar structures elsewhere in southern Illinois. These small, tight folds and accompanying thrust faults clearly are products of localized horizontal compressive stress. Their diverse axial trends, however, complicate the problem of relating them to nearby larger compressional structures. A non-tectonic origin for the little anticlines does not seem plausible.

Paleontology

Important fossils found in Johnson County include vertebrates from the Cave Hill Member of the Kinkaid Limestone. An abandoned quarry in the northwestern part of the Vienna Quadrangle has produced the oldest known microsaur known to science as of this publication. Microsaurs, meaning "small lizards", were an extinct paraphyletic order of tetrapods from the late Carboniferous and Permian Periods. Microsaurs were well-adapted to living on dry land. The Cave Hill microsaur was found in association with the lungfish *Tranodis* and an amphibian belonging to the Colosteidae. The nodule containing these vertebrates is reposited at the University of Kansas (KU), Museum of Natural History, curation # KUVP 113202 was collected in 1984 by KU workers (Lombard and Bolt 1999).

The red-purple mudstone encasing the bones yields a yellow-brown halo around the black bone material **(**fig. **7e).** Fossil lungfish of the genus *Tranodis* was also found in the red mudstone of the Cave Hill Member. Living lungfish are well-known to dig burrows during prolonged periods of dry conditions or high heat where they exhibit a reduction in metabolic activity called estivation. They hibernate in their cocoon-like burrows until wet and cooler conditions return. This creates a vivid picture of what conditions were like in the Late Mississippian of Illinois. Alternating wet and dry periods were common where red and green mudstones were deposited and underwent soil formation. *Tranodis* is also known from the late Chesterian Buffalo Wallow Formation in Hancock County, Kentucky, where the oldest lungfish found preserved in their burrows were documented (Criswell 2010).

Other significant fossils found in Johnson County include a group of crinoids that can be identified by specific plates called "wing" plates that occur on the crinoid genus *Pterotocrinus.* As shown by rare complete specimens, wing plates radiated from the calyx of the crinoid. These plates can be useful in mapping, especially in faulted areas. Currently four species out of numerous named species have been found to be biostratigraphically useful. The species *P. capitalis* has been only found in the Fraileys Shale Member of the Golconda Formation (Sutton 1934, Devera and Tobenski 2016). It is a bulbous "wing" plate (fig. 7a) that is unique and quite different from any other species of Pterotocrinus. Another helpful "wing" plate is Pterotocrinus menardensis, which is unique to the Menard Limestone. However, a morphologically very similar species, named P. clorensis , was though to beis restricted to the Clore Formation. Tobinski (2009) found P. clorensis in the Menard Limestone at 3 locations east of the study area.These almost circular, flattened plates are useful for distinguishing both Menard and Clore formations from other Chesterian limestones (fig. 7b). Another useful index fossil is P. tridecibrachiatus, which has only been found in the basal shale of the Cave Hill Member of the Kinkaid. This plate occurs at the same horizon at numerous localities across the basin. Lastly, the "wing" plate of P. pegasus (fig. 7d) is unique to the Grove Church Shale. We must note that Gutshick (1965) misidentified the stratigraphic horizon of *P. pegasus*. He called it the "Upper *Pterotocrinus* zone" in the upper Cave Hill Member, but our mapping demonstrated that the locality actually resides near the base of the Grove Church Shale above the Goreville Limestone Member in an abandoned quarry east of Robbs, Illinois at Millstone Bluff.

Epibole

The term "epibole" has been mentioned several times in the Stratigraphy section of this report. As first used by Buckman (1893) and revived and redefined by Brett and Baird (1997), this word refers to an abundance zone or deposits accumulated during a *hemera,* a unit of geologic time corresponding to the acme of one or more species. Trueman (1923) defined epibole as a time-stratigraphic term to encompass the expression of the hemera in a section or to imply an acme or maximum abundance of a particular species in strata. Event-bed chronostratigraphy has greater resolution of time between biostratigraphic ranges (Brett and Baird 1997). A part of their redefinition of the term epibole they classify different types of epiboles as taphonomic, ecologic and incursion types (See Brett and Baird 1997). So epiboles represent thin intervals from a bedding plane to a few meters and are stratigraphic signature of local to regional biological events.

Mineral Resources

The only active quarrying in Johnson County takes place at the Cypress Quarry, which is situated at the north edge of the Cache River valley about 3 miles (5 km) south of the town of Cypress. Stone has been quarried on this site since the 1930s. The present operator is Shawnee Stone, a subsidiary of Shakespeare Oil, an Illinois company founded in 1950. Limestone is quarried here for a variety of uses. Quarried here is the entire thickness of the Ste. Genevieve Limestone, about 135 feet (41 m), and the uppermost part of the St. Louis Limestone (Honeywell 2012).

Coal mining took place on a small scale at numerous sites in northeastern Johnson County from the late 19th century (probably) through about 1980. The early mines were shallow underground operations, whereas surface mining took place from the 1950s through about 1980. Coal beds extracted included the Reynoldsburg (oldest), Tunnel Hill or Bell, Bidwell or Delwood, New Burnside, and possibly the Murphysboro. All of these beds are lenticular and vary in thickness and quality. Details of the mines are available in Myers and Chenoweth (2009) and Obrad and Chenoweth (2010).

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Appendix A

Type section of Dutchman Limestone Member and principal reference section of Grove Church Formation from ISGS #1 James & Bonnie Jones core (Sec. 17, T12S, R3E). Modified from original description by John Nelson, on file at ISGS. All depths in feet.

Thickness	Top	Bottom	Description
			Caseyville Formation, Wayside Member (lower part)
10.3	128	138.3	Sandstone, light gray, fine to medium grained, a little coarse sand near base. Ragged coaly partings throughout. At base conglomerate 0.6 foot thick of angular shale, siderite, and sandstone pebbles. Contact sharp.
11.6	138.3	149.9	Shale with siltstone laminae, dark gray silty shale and light gray siltstone, siltstone decreases from 25-35% near top to zero near base. Laminae are planar, parallel, very thin, and rhythmic. Horizontal sand-filled burrows abundant. Plant fragments near base. Contact sharp.
2.5	149.9	152.4	Conglomeratic sandstone, gray to dark red (hematitic), quartz granules and pebbles to small cobbles of claystone, shale, ironstone, and chert in sandstone matrix. Intervals of very fine-grained shaly sandstone alternate with conglomerate. Contact sharp.
4	152.4	156.4	Conglomerate, gray, rounded clasts of shale, sandstone, chert, and crinoidal limestone in matrix of quartz sandstone containing quartz granules. Largely clast-supported. Contact sharp.
2.9	156.4	159.3	Sandstone, light gray, very fine-grained quartz arenite with 10-20% laminae of medium to dark gray silty shale. Contorted lamination in upper one foot; remainder has ripple and cross lamination. Contact sharp.
2.4	159.3	161.7	Conglomerate, like next-to-last unit. Lower contact sharp.
4.6	161.7	166.3	Limestone conglomerate, clasts of crinoidal limestone from granule size to 2 inches (5 cm), subrounded with highly irregular shapes. Matrix is claystone that is dark gray, soft, weakly fissile, and slightly calcareous. Contact sharp.
			Grove Church Shale, Dutchman Limestone Member (14.2 feet; 4.33 m)
10.5	166.3	176.8	Limestone, medium-light gray near top to medium-dark gray near base, crinoidal packstone and wackestone, coarser and more argillaceous downward and changing from wackestone above to packstone below. Bedding is thin to medium, wavy to nodular, dark gray shale partings separate beds. Contact sharp.
3.7	176.8	180.5	Shale and limestone interbedded, roughly equal proportions; shale medium-dark gray and calcareous, limestone similar to above, in nodules, lenses, and thin beds. Upper part is highly fossiliferous with fenestrate bryozoans, chonetid brachiopods, and echinoderm fragments. Lower part sparsely fossiliferous, mainly pectenoid bivalves. Contact sharp.
			Grove Church Shale, main body (53.7 feet, 16.4 m)
1.3	180.5	181.8	Shale, very dark gray, calcareous, thinly fissile, silt-free, bryozoans near top and ostracods(?) in lower part. Contact intertongues on small scale.
3.7	181.8	185.5	Mudstone, dark greenish gray, mottled, calcareous, very silty at top, grading to silt-free below. Massive to weakly fissile, slickensided; unidentified fossil fragments near top. Contact gradational.
3.5	185.5	189	Shale with limestone interbeds, mottled dark gray and greenish gray calcareous shale and skeletal wackestone and packstone that is nodular. Brachiopods, bryozoans, echinoderm fragments common. Roughly equal parts shale and limestone with thickest limestone bed at base. Contact sharp.
1.4	189	190.4	Claystone, dark greenish gray, upper part calcareous and weakly fissile, lower part noncalcareous and massive with hackly fractures and slickensides. Contact gradational.
8	190.4	198.4	Claystone, dark reddish gray with gray and green mottling; massive, slickensided, mostly not calcareous. Brecciated carbonate and chert nodules occur throughout. Contact sharp and irregular.
0.9	198.4	199.3	Claystone, greenish gray, massive, slickensided, slightly calcareous, small limestone nodules in lower part. Contact gradational.

Appendix A , continued

Thickness	Top	Bottom	Description
0.5	199.3	199.8	Limestone, medium gray packstone to algal(?) boundstone, nodular with green interstitial clay, echinoderm and shell fragments. Contact gradational.
0.5	199.8	200.3	Shale, mottled dark gray and greenish gray, fissile, calcareous, silt-free. Brachiopods and bivalves numerous. Contact sharp.
0.7	200.3	201	Limestone, medium-dark brownish gray, microgranular, dolomitic, unidentified fossil fragments, faintly nodular. Contact sharp.
1	201	202	Claystone, dark greenish gray, red mottling near base; massive, slickensided, slightly calcareous. Contact gradational.
8	202	210	Shale, banded and mottled dark reddish gray, bluish gray, and bluish green. Upper part mostly red, weakly fissile, and slickensided; lower part mostly gray and fissile, without slickensides. Slightly silty throughout. Contact gradational.
11.4	210	221.4	Shale, dark gray, thinly fissile, silt-free, mostly non-calcareous. Several thin sideritic bands in lower half. Band of fossil debris, mainly pectenoid bivalves, at 216.9 feet. Contact gradational.
1.3	221.4	222.7	Limestone and shale, shale top and bottom, limestone in middle, gradational contacts. Limestone is skeletal and pelletal packstone that is burrowed and argillaceous. Brachiopods, fenestrate bryozoans, and echinoderm fragments abundant. Contact gradational.
11.5	222.7	234.2	Shale, dark gray, thinly fissile, finely silty, slightly calcareous, no fossils found. Contact rapidly gradational.
			Kinkaid Limestone, Goreville Limestone Member (47.5 feet, 14.5 m)
47.5	234.2	281.7	Limestone, medium to dark gray skeletal wackestone and packstone and light gray crinoidal grainstone, portions show cycles 2 to 6 feet (0.6 to 1.8 m) thick grading from grainstone at base to wackestone at top. Fossils are crinoid fragments, brachiopods, and Archimedes. Dark gray shale occurs as wavy partings, laminae, and thin interbeds.