The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States—Illinois

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Historical review and summary of areal, stratigraphic, structural, and economic geology of Mississippian and Pennsylvanian rocks in Illinois

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THE MISSISSIPPIAN AND PENNSYLVANIAN (CARBONIFEROUS) SYSTEMS IN THE UNITED STATES—ILLINOIS

By ELWOOD ATHERTON[1] and JAMES E. PALMER[1]

ABSTRACT

The Carboniferous equivalents in Illinois consist of two systems separated by an angular unconformity. The Mississippian System includes 40 formations grouped into 3 series. It is more than 975 m thick in southern Illinois and thins northward. Limestone is the dominant rock type. During formation of the sub-Pennsylvanian unconformity, valleys as deep as 140 m were cut in the top of the Mississippian. The Pennsylvanian System includes about 140 named members, grouped into 7 formations and 5 series, and is about 760 m thick, it has a maximum composite thickness of more than 1,000 meters. About half of the system is shale and two-fifths is sandstone and siltstone; extensive coal seams are a distinctive feature. A great thickness of rock was eroded during formation of the unconformity on the top of the Pennsylvanian. In the Mississippian, invertebrate fossils abound in most of the limestone and calcareous shale; in the Pennsylvanian, plant fossils are abundant in the coal and shale, and marine invertebrate fossils in the limestone. The Mississippian includes a siltstone delta built out into fairly deep water (about 300 m), but most of the strata were deposited in relatively shallow water. During the Pennsylvanian, the surface fluctuated above and below sea level, and extensive coal swamps formed at a number of horizons. The major tectonic event during the Carboniferous in Illinois was the subsidence of the autogeosynclinal Illinois basin; the maximum subsidence centered near the southern tip of the State. Oil in the Mississippian and coal in the Pennsylvanian are the major economic products.

INTRODUCTION

The Carboniferous equivalents in Illinois consist of the Mississippian and Pennsylvanian Systems. The Mississippian is estimated to consist of about 35 percent shale and siltstone, 10 percent sandstone, and 55 percent limestone and dolomite, nearly all deposited in a shallow marine environment. The Pennsylvanian is estimated to consist of about 50 percent shale, 40 percent sandstone and siltstone, 5 percent limestone, 1 to 2 percent coal, and the remainder, including siderite and chert, less than 1 percent. The environment alternated from marine to nonmarine in many cycles, and extensive coal swamps are a distinctive feature, particularly during the Pennsylvanian. The two systems are differentiated in Illinois not only by the overall character of their sediments and fossils, but also by the angular unconformity that separates them.

Illinois, an area of 146,020 km^2, is divided into 102 counties (fig. 1), surveyed on a rectangular grid system of townships. The stratigraphy of Illinois is summarized in Willman and others (1975), which is the source of most of the information and illustrations given here. The literature of Illinois geology through 1965 is indexed in Willman and others (1968).

The stratigraphic nomenclature used in this paper has not been reviewed by the Geologic Names Committee of the U.S. Geological Survey. The nomenclature used here conforms with the current usage of the Illinois State Geological Survey.

THE MISSISSIPPIAN SYSTEM

The Mississippian System is named for exposures that extend for about 650 km in the Mississippi River valley along the western margin of Illinois. Mississippian rocks occur in the subsurface over the southern two-thirds of the State, where they are overlain mostly by Pennsylvanian rocks. In the western part of the State, the Mississippian rocks are covered by glacial till, and in southernmost Illinois, they are concealed by Cretaceous gravel and sand. Outcrops occur mainly in the bluffs of the Mississippi, Illinois, and Ohio Rivers that border and bisect the State.

The Mississippian System attains a thickness of a little more than 975 m in southern Illinois (fig. 2). Northward thinning is partly due to deposition and is partly the result of erosional truncation during formation of a prominent sub-Pennsylvanian unconformity. During Mississippian time, the Illinois basin was open southward between the Ozark and Nashville positive areas so that many forma-

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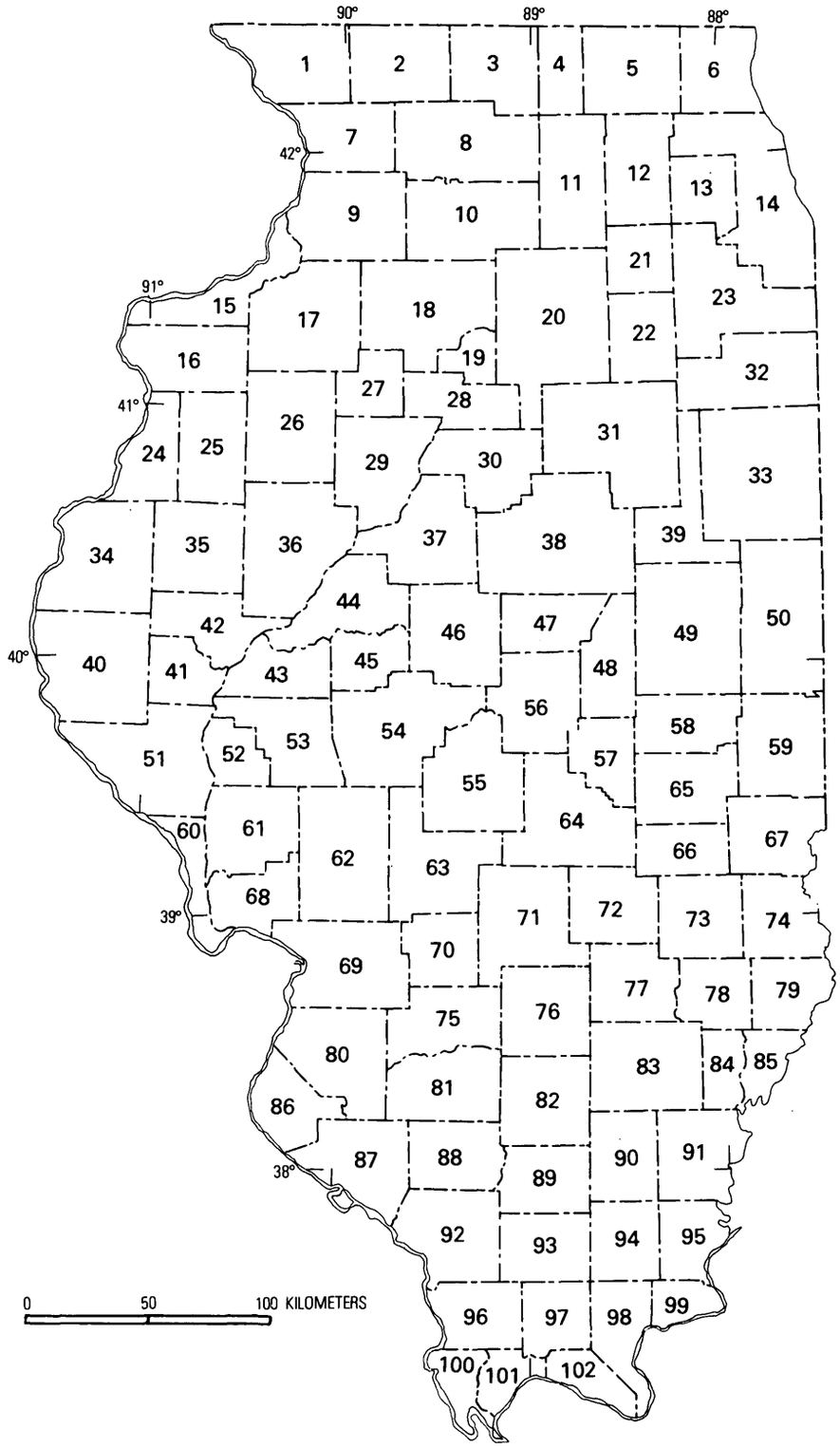


Adams	40	Lee	10
Alexander	100	Livingston	31
Bond	70	Logan	46
Boone	4	McDonough	35
Brown	41	McHenry	5
Bureau	18	McLean	38
Calhoun	60	Macon	56
Carroll	7	Macoupin	62
Cass	43	Madison	69
Champaign	49	Marion	76
Christian	55	Marshall	28
Clark	67	Mason	44
Clay	77	Massac	102
Clinton	75	Menard	45
Coles	65	Mercer	16
Cook	14	Monroe	86
Crawford	74	Montgomery	63
Cumberland	66	Morgan	53
De Kalb	11	Moultrie	57
De Witt	47	Ogle	8
Douglas	58	Peoria	29
Du Page	13	Perry	88
Edgar	59	Piatt	48
Edwards	84	Pike	51
Effingham	72	Pope	98
Fayette	71	Pulaski	101
Ford	39	Putnam	19
Franklin	89	Randolph	87
Fulton	36	Richland	78
Gallatin	95	Rock Island	15
Greene	61	St. Clair	80
Grundy	22	Saline	94
Hamilton	90	Sangamon	54
Hancock	34	Schuyler	42
Hardin	99	Scott	52
Henderson	24	Shelby	64
Henry	17	Stark	27
Iroquois	33	Stephenson	2
Jackson	92	Tazewell	37
Jasper	73	Union	96
Jefferson	82	Vermilion	50
Jersey	68	Wabash	85
Jo Daviess	1	Warren	25
Johnson	97	Washington	81
Kane	12	Wayne	83
Kankakee	32	White	91
Kendall	21	Whiteside	9
Knox	26	Will	23
Lake	6	Williamson	93
La Salle	20	Winnebago	3
Lawrence	79	Woodford	30

FIGURE 1.—Counties of Illinois.

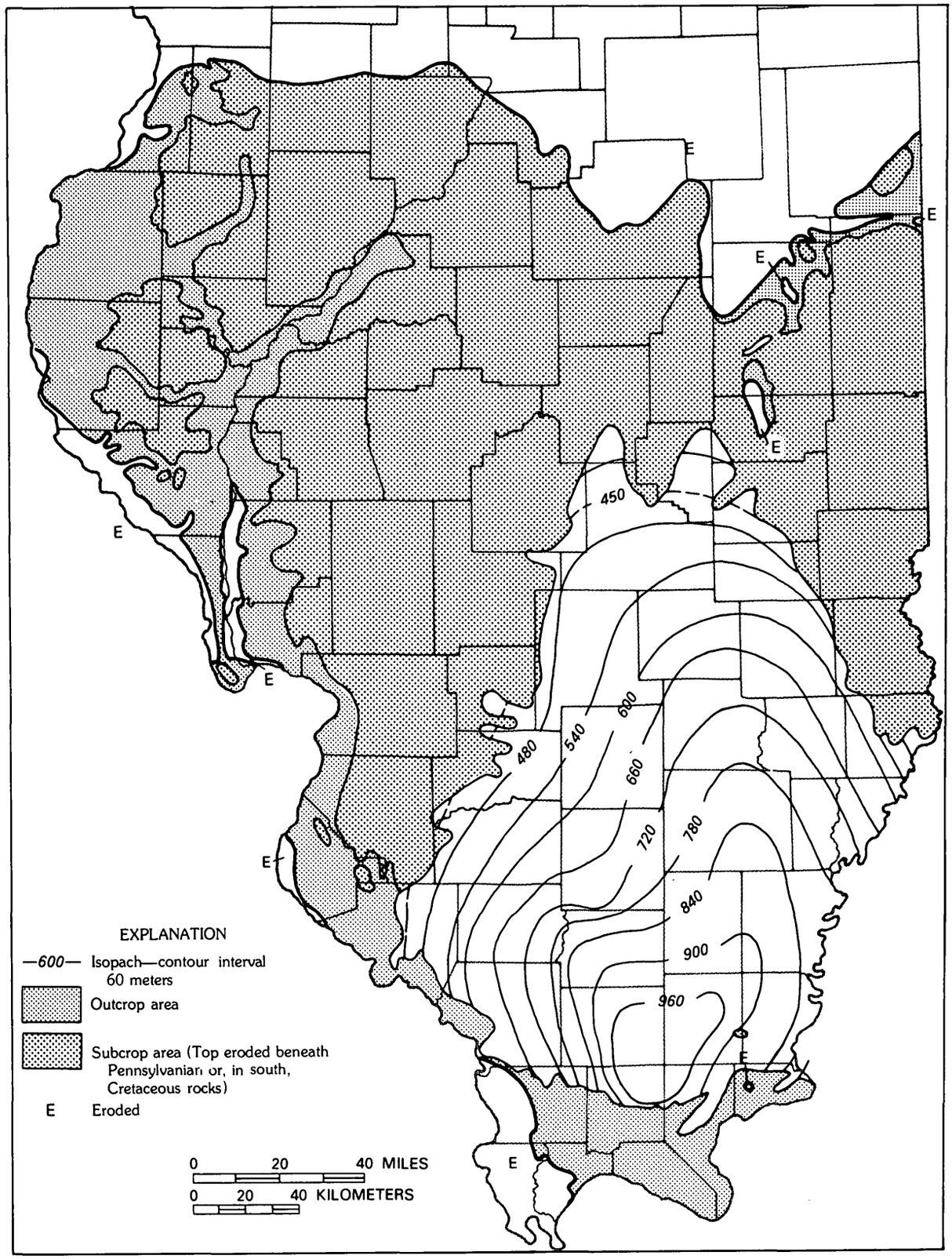


FIGURE 2.—Areal extent of the Mississippian System in Illinois. Thickness is shown where upper Chesterian strata are present (Willman and others, 1975).

tions originally thickened southward well beyond their present extent. Post-Mississippian uplift closed off the Illinois basin on the south, however, and erosion truncated the uptilted strata in southernmost Illinois.

In Illinois, the system is divided into three series. The lowermost, the Kinderhookian, consists mainly of normal marine fine-grained clastic sedimentary rocks. The relatively thick Valmeyeran, in the middle, includes biogenic limestone along the outer edges of the basin in western and northwestern Illinois but is represented by a thick siltstone delta in southwestern and central-eastern Illinois. The Chesterian Series, at the top, is thick and consists of limestone-shale and sandstone-shale formations that represent deltaic sediments deposited in patterns that are transitional to the cyclothems of the Pennsylvanian. Between the Mississippian and the Pennsylvanian is a major unconformity where valleys as deep as 135 m have been cut into Chesterian sedimentary rocks.

Fossils are abundant in the Mississippian. Productid and spiriferid brachiopods are useful for biostratigraphic zonation of much of the system. Blastoids, crinoids, and calcareous foraminifers provide a practical basis for correlation of Valmeyeran and Chesterian strata, and conodonts are the basis for biostratigraphic zonation throughout the system.

Tectonic activity, associated mainly with the Ozark uplift, controlled depositional patterns of the Kinderhookian and closed the epoch with broad uplift in western Illinois. Shallowing of the seas during Valmeyeran and Chesterian time culminated with widespread post-Mississippian erosion.

STRATIGRAPHY

KINDERHOOKIAN SERIES

The Kinderhookian Series consists mainly of silty marine shale overlain by the widespread Chouteau Limestone (fig. 3). The series, only 50 m thick at its maximum in western Illinois, is very thin in the eastern and southern parts of the Illinois basin (fig. 4). The shale of the Kinderhookian is combined with that of the underlying Devonian to constitute the New Albany Group. The base of the series commonly occurs within the shale sequence and can be identified only by paleontological means.

"Glen Park" Formation.—The "Glen Park" Formation of Illinois was at one time called the "Hamburg Oolite." It is not the same age as the type Glen Park of Missouri, the former being Mississippian and the latter Devonian, but a new name has not yet been introduced. It occurs only in western

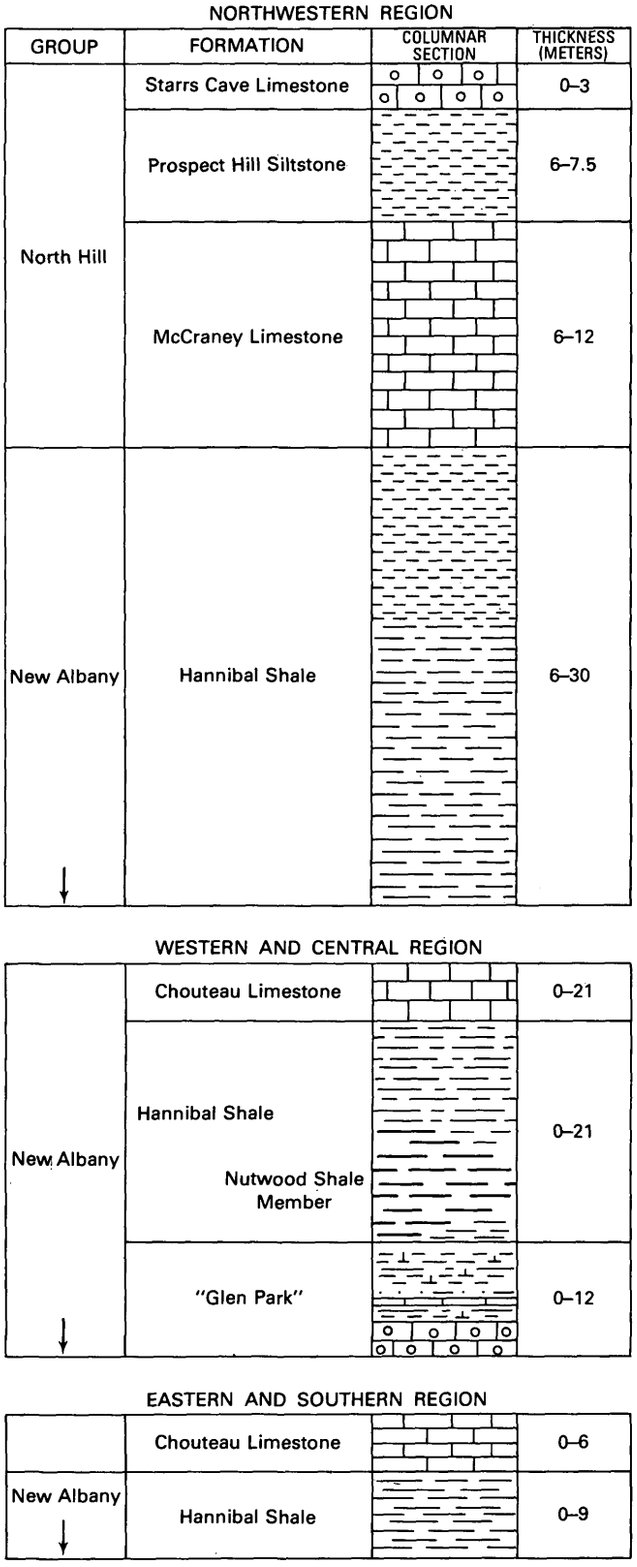


FIGURE 3.—Columnar section of the Kinderhookian Series (Willman and others, 1975).

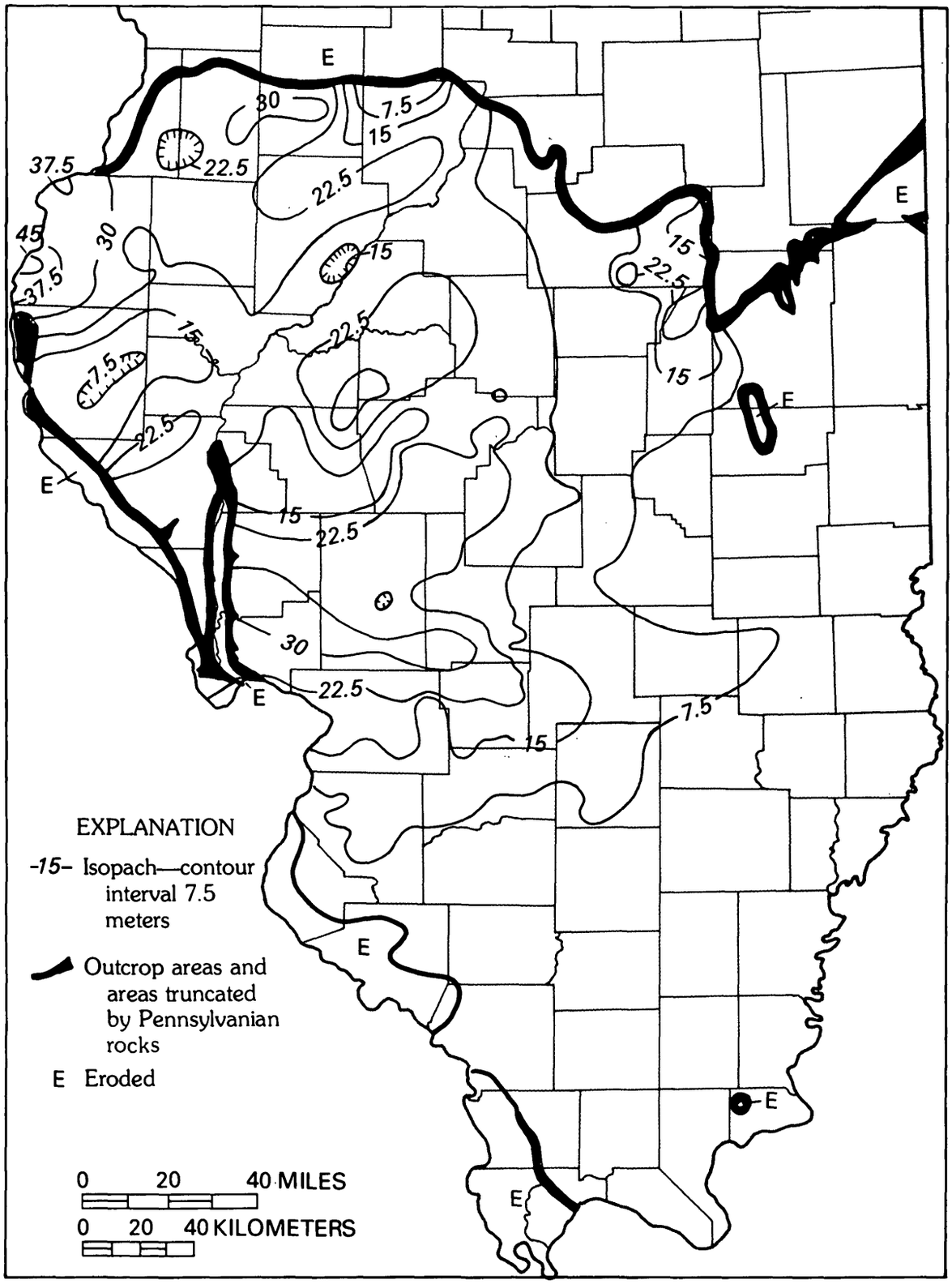


FIGURE 4.—Thickness of the Kinderhookian Series (Willman and others, 1975).

and central Illinois and is exposed in bluffs along the Mississippi and lower Illinois Rivers, where its thickness is less than 8 m. It is a highly variable unit, and conglomerate, sandstone, fine-grained limestone, oolite, siltstone, and shale represent nearshore facies. The contact with the underlying Devonian appears to be erosional.

Hannibal Shale.—The Hannibal Shale is a green to gray argillaceous siltstone grading to silty shale. In western Illinois, a siltstone facies about 12 m thick was once differentiated as the English River Formation, but the name has been dropped. In the southern part of the outcrop area, a lens of black shale is differentiated as the Nutwood Member. The Hannibal thins eastward from a maximum thickness of about 30 m in western Illinois. In eastern Illinois it is very thin or absent and is difficult to distinguish from the underlying Devonian Saverton Shale.

Chouteau Limestone.—The Chouteau Limestone is light brownish to greenish gray and lithographic to very fine grained. Locally, it is a fine-grained dolomite, and in a narrow belt it is red or pink. It is widespread across central and southern Illinois. Generally, it is 3 to 6 m thick, but it thickens to nearly 24 m locally in western Illinois. Its extensive occurrence, contact with overlying and underlying shale, and distinctive "kick" on electric logs make it an excellent marker bed in subsurface studies. Normally, it is conformable on the Hannibal Shale, but in southwestern Illinois locally it overlaps the Hannibal and lies unconformably on Devonian to Ordovician formations. The name "Rockford," applied to the formation in Indiana, was used for a while in southeastern Illinois, but the older name, "Chouteau," is now accepted for all Illinois.

North Hill Group.—The North Hill Group includes the McCraney Limestone at the base, the Prospect Hill Siltstone, and the Starrs Cave Limestone. It is extensive in Iowa, but in Illinois it is confined to a narrow belt east of the Mississippi River. It correlates with the Chouteau Limestone and is conformable on the Hannibal Shale, but it is unconformably overlain by the Burlington Limestone.

VALMEYERAN SERIES

The Valmeyeran Series is the thickest of the three Mississippian series (fig. 5). It includes rocks contemporaneous with the section from the base of the Meppen Limestone to the top of the Levias Member of the Renault Limestone (fig. 6). The Valmeyeran, especially the lower part, shows important facies changes (fig. 7) described later in the section "Environment of Deposition."

Meppen Limestone Formation. — The Meppen Limestone is dolomitic limestone, or calcareous dolomite that commonly contains many calcite geodes. It occurs in western Illinois from Calhoun County to Monroe County and has a maximum thickness of about 7 m. It is unconformable on the Chouteau, and is conformably overlain by the Fern Glen Formation. It was formerly called Sedalia in Illinois because of lithologic similarity to the Sedalia of Missouri, but the conodont faunas show that the Missouri Sedalia is Kinderhookian, whereas the Illinois Meppen is Valmeyeran.

Fern Glen Formation.—The Fern Glen Formation consists of red and green calcareous shale and of gray, green, and red limestone and dolomite that is partly argillaceous. Occurring in southwestern Illinois from Randolph County north to Jersey County and northeastward to Champaign County, the formation generally is less than 15 m thick, but in a few small areas it approaches 30 m. It overlaps the Meppen to rest on rocks as old as the Ordovician Maquoketa Shale Group and grades laterally and vertically into the Burlington Limestone.

Burlington Limestone Formation.—The Burlington Limestone occupies an irregular triangular area in western Illinois from Henderson County on the northwest to Jackson County on the south and Iroquois County on the east. Cropping out in the Mississippi River bluffs from Quincy to near Alton, Ill., the Burlington commonly is 30 to 45 m thick, but locally is as much as 60 m. To the southeast, it thins abruptly against the Borden Siltstone. In northwestern Illinois, the Burlington is very pure, coarsely crystalline, light-gray limestone containing a few beds of dolomitic limestone. Chert is common, especially in the middle and upper parts of the formation. Large crinoid stems are abundant, and some beds are almost entirely crinoid debris. Farther south, the Burlington becomes more cherty, crystalline limestone becomes less abundant, and fine-grained beds are more common. In the southern part of its extent, the Burlington and the overlying Keokuk are difficult to discriminate, except by their fossils; thus, they are generally referred to as the Burlington-Keokuk Limestone. The Burlington is conformable on the Fern Glen and Meppen and overlaps them to lie unconformably on older strata.

Keokuk Limestone Formation.—The Keokuk Limestone occupies much the same area as the Burlington and is 18 to 24 m thick over most of its extent. It is fossiliferous cherty limestone interbedded

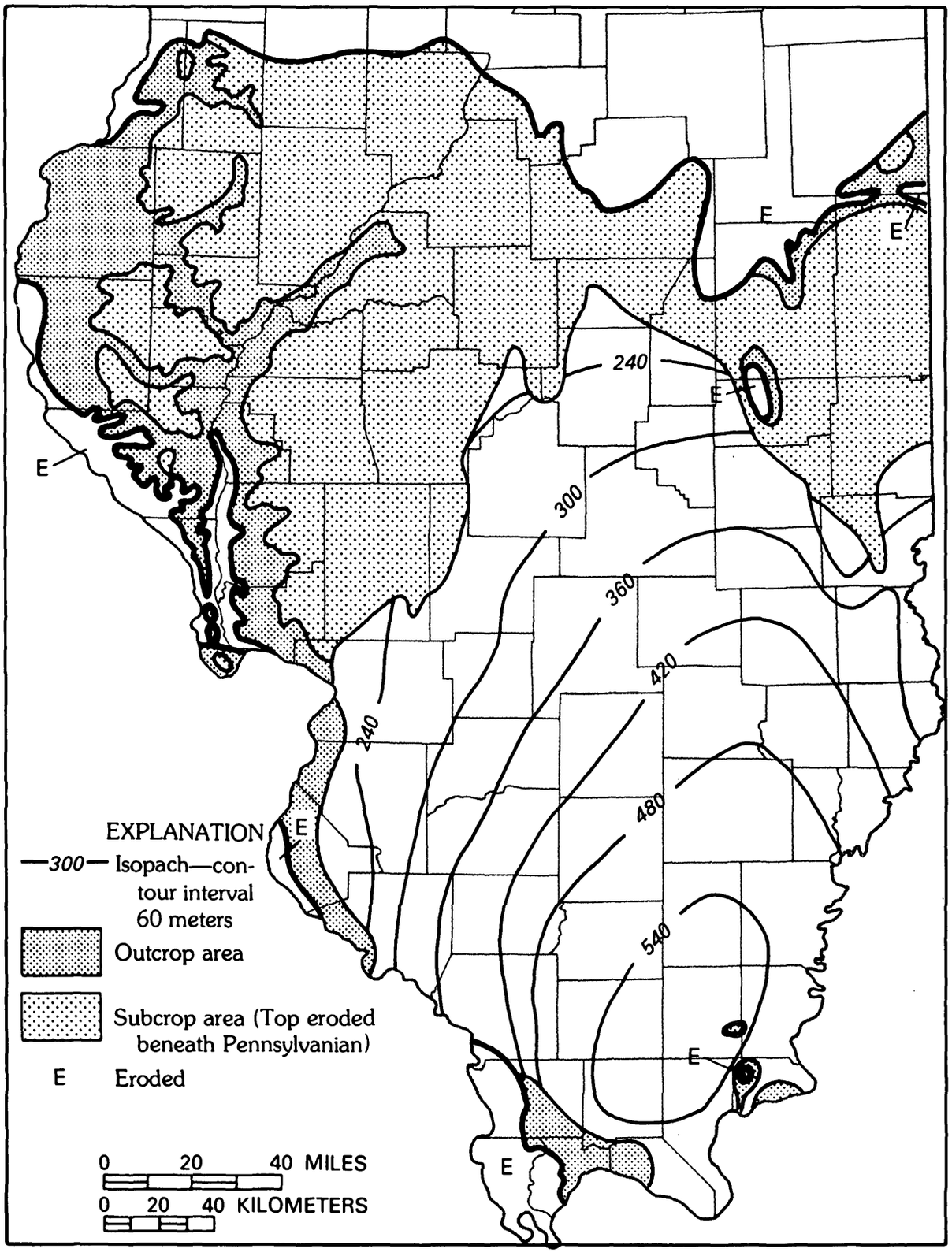


FIGURE 5.—Thickness of the Valmeyeran Series. Thickness is shown where Chesterian strata are present (Willman and others, 1975).

with fine-grained limestone, argillaceous dolomite, and calcareous gray shale. The Keokuk is generally thinner bedded and darker than limestone of the Burlington, and the shale partings are more numerous. Both formations are mainly biocalcarenites. In the type region, the lower 9 m of the Keokuk is very cherty and is differentiated as the Montrose Chert Member.

Borden Siltstone Formation.—The Borden Siltstone is gray to greenish-gray siltstone, glauconitic in part, grading to silty shale. The maximum thickness is about 200 m. The siltstone was deposited in a delta that enters Illinois in the vicinity of Edgar County in east-central Illinois and extends almost to the southwest border. Lenses of coarse siltstone and very fine sandstone near the base of the Borden are informally called the "Carper sand." A similar lens in central Illinois centering on Christian County is differentiated as the Bilyeu Member. The Bilyeu reaches a thickness of 45 m; a part extends westward beyond the Borden and into the Warsaw Shale as a member of the Warsaw. To the northwest, the Borden is separated from the Warsaw Shale by a vertical cutoff at the edge of the Burlington-Keokuk. To the south and east, the Borden is separated from the equivalent Springville Shale by a vertical cutoff along the line where the siltstone thins to less than 30 m.

Springville Shale Formation.—The Springville Shale is greenish-gray to dark brownish clayey shale. Locally, it is mottled red and green and has been informally called the "calico shale." The Springville is equivalent to the Borden but was deposited in deeper water. Near Jonesboro in Union County, the basal part of the Springville is differentiated as the State Pond Member. The member is a greenish-gray, soft, glauconitic shale containing phosphate nodules and is only about 40 cm thick. The member is a deepwater equivalent of the Fern Glen, Burlington, and Keokuk Limestones.

Fort Payne Formation.—The Fort Payne Formation is dark, very fine grained, siliceous, cherty limestone. Extending from the Ohio River to southwestern Clark County, the formation occurs only in southeastern Illinois and is rarely exposed. Slightly more than 180 m thick at the southern end of Pope County on the Ohio River, it thins northward and westward. The Fort Payne was deposited in a deepwater basin bordered by the foreset slopes of the Borden Siltstone delta in southern Illinois and overlies the Springville Shale, the Chouteau Limestone, or the lower part of the foreset slope of the Borden delta.

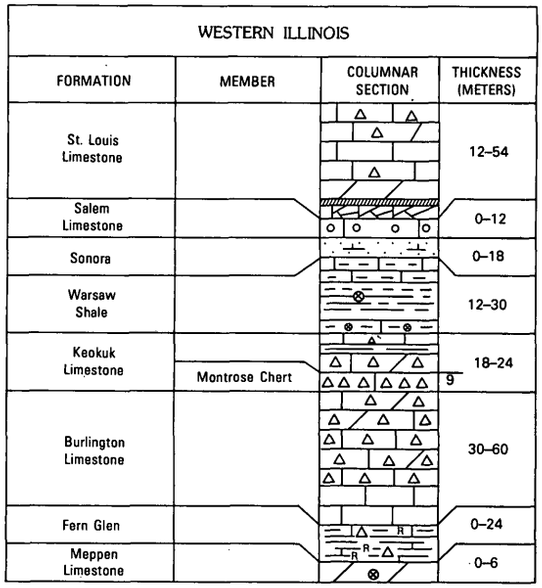
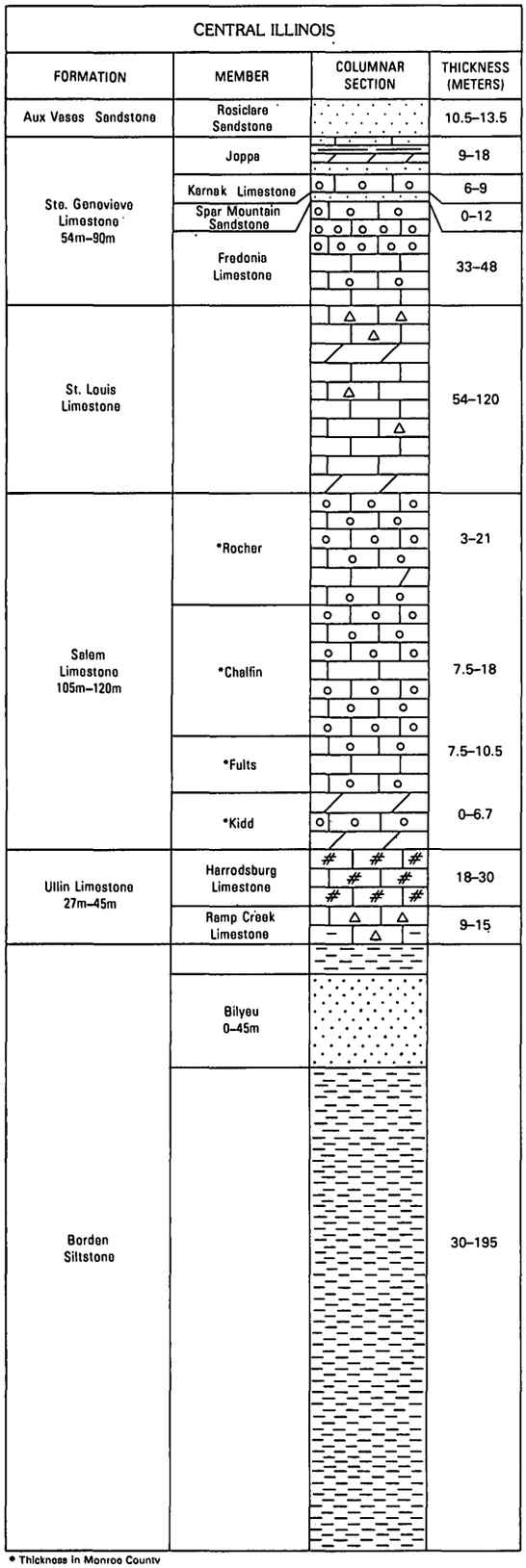


FIGURE 6.—Columnar section of the Valmeyeran Series in Illinois (Willman and others, 1975).

Ullin Limestone Formation.—The Ullin Limestone is mainly a light-colored bryozoan and crinoidal limestone. In southern Illinois, its maximum thickness is slightly more than 240 m in northern Hamilton County, and it is generally thick in a belt running northeast and southeast of that location. It thins away from this belt and pinches out to the northwest along an irregular line running from Jersey County to Champaign County. The Ullin overlies the Fort Payne Formation, but where the Fort Payne is absent it overlies the Borden, Springville, Warsaw, or Chouteau Formations. Generally, it can be divided into two members, the Ramp Creek Limestone Member, which is cherty, argillaceous limestone 0 to 150 m thick, and the Harrodsburg Limestone Member, which consists of light-colored bryozoan and crinoidal debris that is generally lighter colored, coarser grained, less cherty, and less argillaceous than the underlying Ramp Creek. More than 240 m thick in Hamilton County, the Harrodsburg thins northward and pinches out at the margin of the Ullin. The two members are similar in many places, and, in about one-third of the extent of the Ullin, they cannot be differentiated. The Ullin filled deepwater trenches between the foreset slope of the Borden delta and the depositional slope of the Fort Payne Formation.

Warsaw Shale Formation.—The Warsaw Shale consists of fossiliferous gray shale containing interbedded argillaceous limestone. Quartz geodes are common and locally abundant. The Warsaw grades



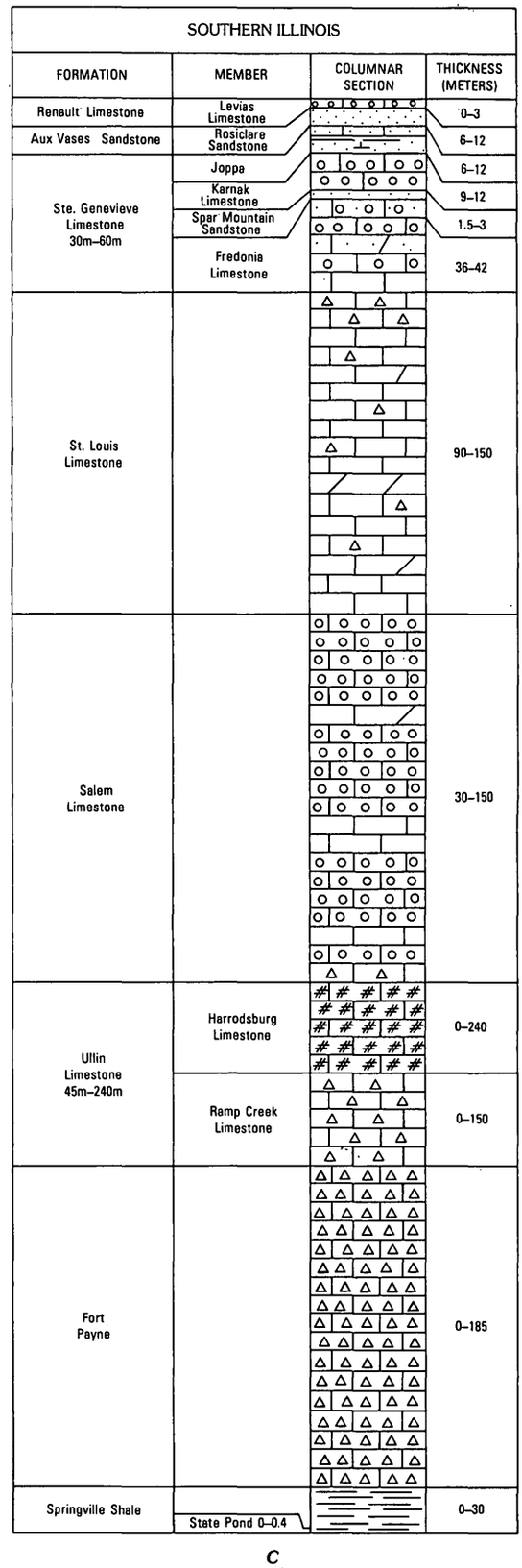


FIGURE 6.—Continued.

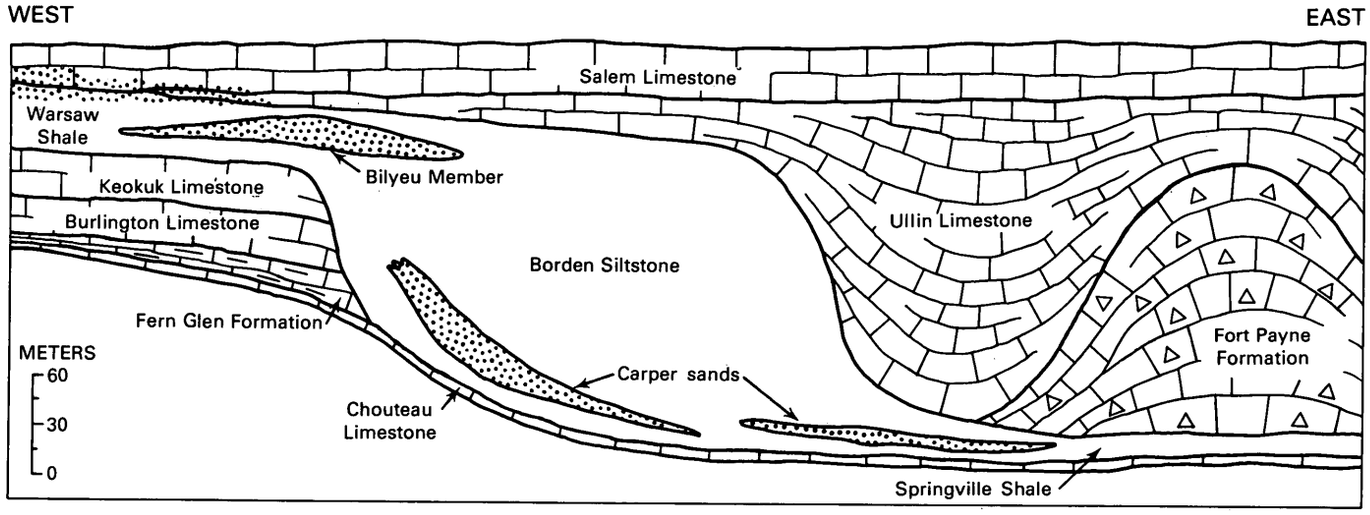


FIGURE 7.—Diagrammatic east-west cross section across central Illinois showing the Borden Siltstone delta (from Lineback, 1968).

eastward into the Borden Siltstone, from which it is separated by a vertical cutoff. It is nearly 30 m thick in western Illinois, where it crops out in the bluffs along the Mississippi and Illinois valleys and thickens to about 90 m in east-central Illinois. The corkscrew-like axes of *Archimedes* are very abundant. The Warsaw is overlain by the Sonora Formation or by the Ullin, Salem, or St. Louis Limestones.

Sonora Formation.—The Sonora Formation includes: sandstone, generally light buff, dolomitic, argillaceous, and fine grained; shale, generally greenish gray and sandy; dolomite, sandy to argillaceous, and sparsely fossiliferous. The lithology varies laterally and vertically, and is characteristically sandy. The Sonora is about 0.6 to 6 m thick and crops out in the bluffs of the Mississippi and its tributaries in Adams and Hancock Counties. Both Salem and St. Louis overlie the Sonora, and the latter contact varies from conformable to erosional. The Sonora grades laterally into the Salem Limestone and the upper part of the Warsaw Shale.

Salem Limestone Formation.—The Salem Limestone is mainly crossbedded biocalcarenite composed of fossil fragments, endothyrid foraminifers and other small fossils, and oolites or oolitic-like overgrowths. Minor components include sucrosic dolomite, dolomitic limestone, chert, sandstone, anhydrite, and gypsum. More than 150 m thick in northern White County, it thins to a line running from Jersey to Douglas County with only patches of Salem northwest of this zero line. The Salem overlaps the Ullin to lie on the Warsaw Shale or Sonora Formation. The upper part of the Salem grades laterally into the overlying St. Louis Limestone. In the outcrop area in western Randolph, Monroe, and St. Clair Counties the Salem is divided into four members: the Kidd (at the base), the Fults, the Chalfin, and the Rocher.

St. Louis Limestone Formation.—The St. Louis Limestone is typically a micritic to lithographic, cherty limestone, light to dark gray and brownish gray. It also includes beds of dolomite and evaporite deposits. One to three beds of gypsum and anhydrite occur extensively in the northern part of the subsurface St. Louis. Limestone breccias in the outcrop areas are regarded as indicating the former presence of evaporite layers. The St. Louis is about 150 m thick in southeastern Illinois, but it thins to the north and northwest to less than 60 m before being truncated by pre-Pennsylvanian erosion along a line running west from Edgar County to Mason and Cass Counties and then south along the Illinois River to Alton. Several large outliers are in the area from Fulton to Hancock and Adams Counties. The St. Louis is well exposed at Alton and north along the Illinois Valley and the Mississippi Valley south of St. Louis from St. Clair through Monroe to western Randolph Counties. Another good exposure is along the Ohio River in Hardin County in southeastern Illinois. Abundant sinkholes usually characterize the outcrop area of the St. Louis. In general, the St. Louis is darker, more cherty, finer grained, and much less oolitic than the overlying Ste. Genevieve Limestone. Locally, at the top of the formation, strata of St. Louis-type lithology are interbedded and intergrade with strata of Ste. Genevieve-type lithology, so that placement of the forma-

tion boundary is somewhat arbitrary. The contact is placed below the lowest prominent oolitic bed.

Ste. Genevieve Limestone Formation.—The Ste. Genevieve Limestone is mainly limestone in massive beds, much of which is oolitic and crossbedded. Some of the oolite is coarse and notably porous. In some oil fields, it is a reservoir rock and is informally called "McClosky lime." The limestone is generally light gray or light olive gray, but some oolitic rock is nearly white, and some of the lower part of the formation is gray or brownish gray. Chert is less abundant than in the St. Louis Limestone. Thin beds and lenses of sandstone and sandy limestone, some of which are widely traceable, occur mainly in the upper half of the formation. Locally, the limestone at the base of the formation is sandy, and near its western border the base is conglomeratic and rests unconformably on the eroded top of the St. Louis Limestone. The Ste. Genevieve is about 91 m thick in southern Illinois and is more than 61 m thick in south-central Illinois, thinning to the north and west to less than 30 m. It crops out from near Alton and St. Louis south along the Mississippi Valley and from Union County eastward across southern Illinois to Hardin County. Much of the formation is abundantly fossiliferous. The contact with the overlying Aux Vases Sandstone is conformable, but is marked by a series of downward steps to the west as limestone beds in the upper part of the Ste. Genevieve grade westward into sandstone of the Aux Vases. The Ste. Genevieve is divided into four members.

The Fredonia Limestone Member is mainly light gray, oolitic, crossbedded, and crinoidal limestone, but it includes some darker, lithographic limestone beds like those in the St. Louis. The Fredonia is generally 24 to 30 m thick, but north of Effingham County it thins rapidly to 6 m or less. The Spar Mountain Sandstone Member consists of sandstone and siltstone that grade to sandy or silty limestone. Locally, in the northern part of its extent, the sandstone is coarser than elsewhere and the sand grains are better rounded. The member extends throughout most of the area of the Ste. Genevieve. Its thickness is erratic, ranging from about 3 to 12 m, and the greater thicknesses are generally in the north. In the western part of the basin, where the overlying Karnak Member thins out, the Spar Mountain grades laterally into the Aux Vases Sandstone and is separated from it by a vertical cutoff. The Karnak Limestone Member is a persistent unit about 3 to 11 m thick, except that in western Washington County it wedges out into the Aux Vases Sandstone. The Joppa Member has a varied lithology, including beds of limestone, dolomite, sandstone, and shale, in part red and hematitic. It is 6 to 15 m thick. The Joppa is recognized in southeastern Illinois where limestone beds are present in the interval, but to the north and west the limestone beds thin out into sandstone regarded as Aux Vases.

Aux Vases Sandstone Formation.—The Aux Vases Sandstone consists of sandstone, siltstone, minor amounts of shale, and, locally, a little dolomite and limestone. The sandstone is light gray to greenish gray, calcareous, and grades to coarse siltstone. Locally, it is pink or red and hematitic. In southern Illinois, where the Joppa Member is recognized, the Aux Vases is commonly 6 to 12 m thick. To the north and west of this area, the Aux Vases includes Joppa equivalents and is correspondingly thicker, being about 18 to 24 m. In a small area where the Karnak is absent, the Aux Vases includes Spar Mountain equivalents and is 40 to 49 m thick. The thickness map of the Aux Vases shows discontinuities that reflect the areas where the base of the Aux Vases is stepped down. The Rosiclare Sandstone Member is the main body of the Aux Vases in southeastern Illinois where it overlies the Joppa Member of the Ste. Genevieve.

Renault Limestone Formation.—The Renault Limestone is a relatively thin but extensive formation. It averages about 2.5 m thick, thickening southward to 6 to 9 m and reaching slightly more than 12 m in Johnson County. The Renault consists of two members: the Levias Limestone Member, a relatively pure limestone, Valmeyeran in age; and the Shetlerville Limestone Member, a more or less sandy limestone, Chesterian in age. The Levias is a medium- to coarse-grained, white, oolitic limestone, containing some pink and light green ooliths. The basal 1 or 2 m are sandy. It is best developed in Hardin County in southeastern Illinois, where it commonly is 3 to 8 m thick, but it is less easily distinguished outside Hardin County and is recognized only sporadically north of Lawrence County and west of Franklin County. It contains *Platycrinites penicillus*, a fossil crinoid marking the uppermost part of the Valmeyeran Series. The Shetlerville Member is mostly brownish-gray or dark-gray limestone, partly oolitic, and somewhat sandy. The basal contact is sharp and may be unconformable. The member is about 5 to 6 m thick in the vicinity of Hardin County, and it makes up most, or all, of the Renault outside that area. The crinoid *Talarocrinus* is present, and marks the lower part of the Chesterian Series. The Popcorn Sand-

stone Bed in the base of the Shetlerville is dominantly sandstone. It has some shale and impure limestone and is about a meter thick. It occurs locally in Hardin County but is rarely found in Illinois outside that area.

CHESTERIAN SERIES

The Chesterian Series occupies the Illinois basin (fig. 8) from De Witt County on the north to the northern part of Johnson County on the south, and from Indiana on the east to within a few miles of the Mississippi River on the west. The series thickens southward to about 450 m in northern Johnson County. Nearly all the formations thicken southward to their truncated edges. The series is beveled by the sub-Pennsylvanian erosion surface. The outcrop belt extends along the Mississippi Valley from near Alton in western Madison County, southward to Union County, and thence eastward to Hardin County and the Ohio River. To the north and east of the vicinity of Alton, the margin of the Chesterian is overlapped by the Pennsylvanian System. The Chesterian includes 19 named formations plus the Shetlerville Member of the Renault Formation at the base (fig. 9). The Aux Vases Sandstone, long considered the basal formation of the Chesterian, is excluded, because it is below the top of the Valmeyeran *Platycrinites penicillus* Zone.

Yankeetown Sandstone Formation.—The Yankeetown Sandstone is chert and cherty sandstone at the type section, but in the subsurface in western Illinois it is a sandstone and shale unit. To the northeast, in Washington County, it becomes a thick sandstone, and to the southeast it changes to a limestone and shale unit. Although only about 6 m thick in the outcrop area, the Yankeetown thickens to about 30 m in southwestern Illinois but is only about 18 m thick over much of its extent.

Paint Creek Group.—The Paint Creek Group consists of the Downeys Bluff, Bethel, and Ridenhower Formations. The name is used in western Illinois where the Bethel, normally a sandstone, is a shale.

Downeys Bluff Limestone Formation.—The Downeys Bluff Limestone is white to light-brownish gray and crinoidal. Pink chert replaces many of the crinoid segments, especially in western Illinois. In southernmost Illinois, the Downeys Bluff consists of two benches separated by a thin shale, and generally is 6 to 9 m thick. The upper bench is typically cherty and the lower is slightly silty or very finely sandy. Farther north, the Downeys Bluff consists of only the upper of the two benches, generally is 2 to 3 m thick, but locally is 3 to 6 m thick.

West Baden Group.—The West Baden Group consists of the Bethel, Ridenhower, and Cypress Formations. The name is used in part of southeastern Illinois, where the Ridenhower is dominantly sandstone and difficult to separate from the sandstone formations above and below.

Bethel Sandstone Formation.—The Bethel Sandstone generally is 6 to 12 m thick in the northern and western part of its extent and thickens southeastward to about 30 m in northeastern Gallatin County. Dominantly sandstone, the Bethel grades to shale in western Illinois. The sandstone generally is slightly coarser grained than the other Chesterian sandstones. Locally, it includes a few small quartz pebbles and a basal conglomerate of limestone and shale pebbles. A prominent 5-m bed of red clay occurs along the outcrop belt in southwestern Illinois.

Ridenhower Formation.—The Ridenhower Formation is mainly shale, but also includes beds of limestone and sandstone that locally are thick. The limestone is diversified and has sandy, oolitic, crinoidal, and lithographic varieties. The proportion of limestone in the formation is greatest in western Illinois, and the proportion of sandstone is greatest in southeastern Illinois. The formation generally is 6 to 12 m thick, but at several places it is more than 24 m. In some parts of central and eastern Illinois, the formation divides into three members—the Beaver Bend Limestone (below), the Sample Sandstone, and the Reelsville Limestone—but in most of Illinois, these members cannot be recognized.

Cypress Sandstone Formation. — The Cypress Sandstone in western Illinois is generally less than 24 m thick, but in eastern Illinois it is more than 37 m thick and locally more than 61 m thick. Typically, the lower half to three-fourths of the formation consists of one or two bodies of massive sandstone. The upper part of the Cypress is more shaly than the lower; typically it is shale interbedded with thin to moderately thick sandstone and siltstone lenses. A fairly extensive red shale occurs about 3 m below the top of the Cypress. A thin coal occurs near the top of the Cypress in extreme southern Illinois. In northern and western Illinois, where the Cypress is relatively thin, the formation is nearly all shale, and has a high proportion of red and green shale.

Golconda Group.—The Golconda Group is a limestone-shale unit, consisting of the Beech Creek Limestone (below), the Fraileys Shale, and the Haney Limestone. A sandstone member is locally present in the Fraileys Shale.

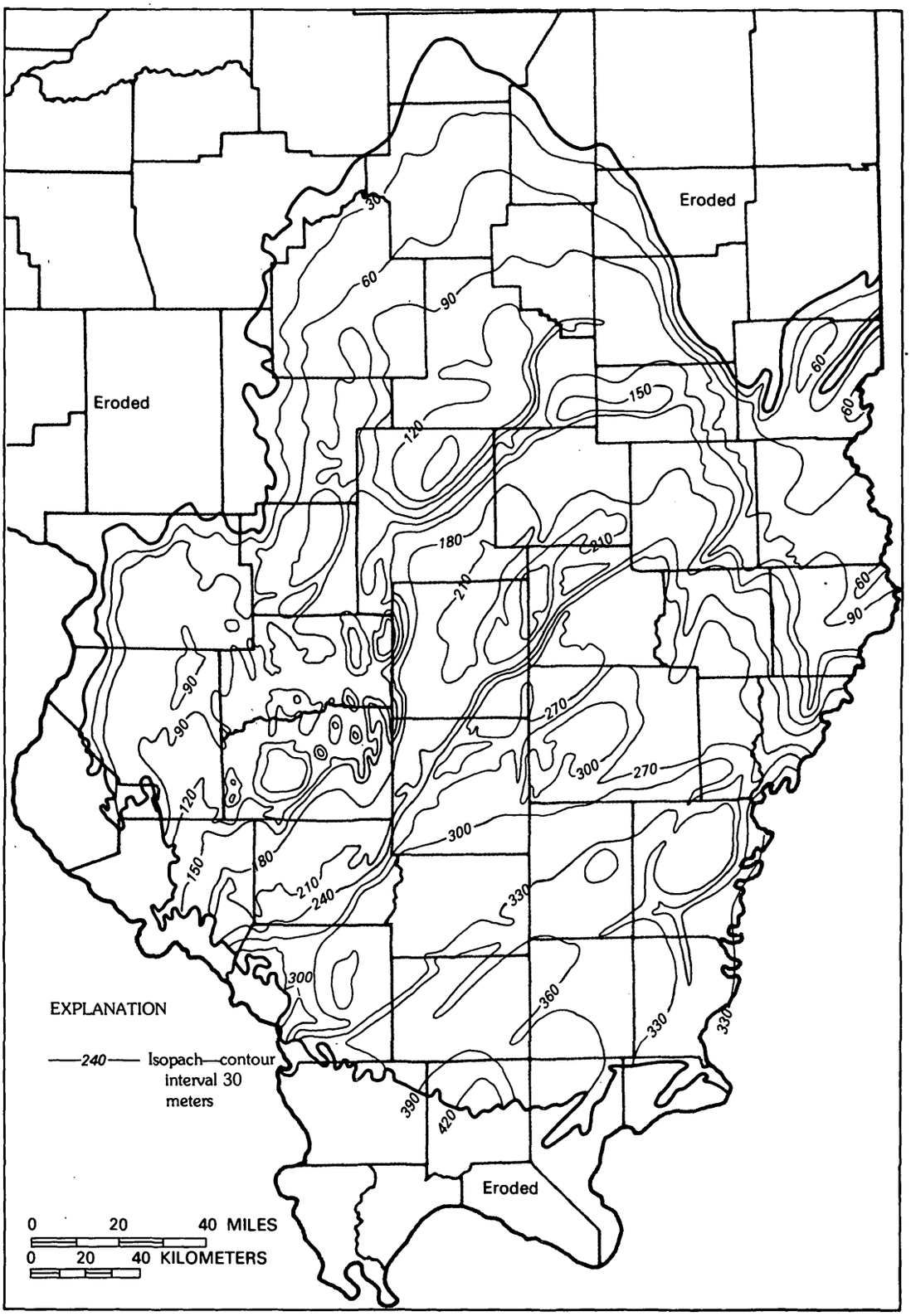


FIGURE 8.—Thickness of the Chesterian Series (Willman and others, 1975).

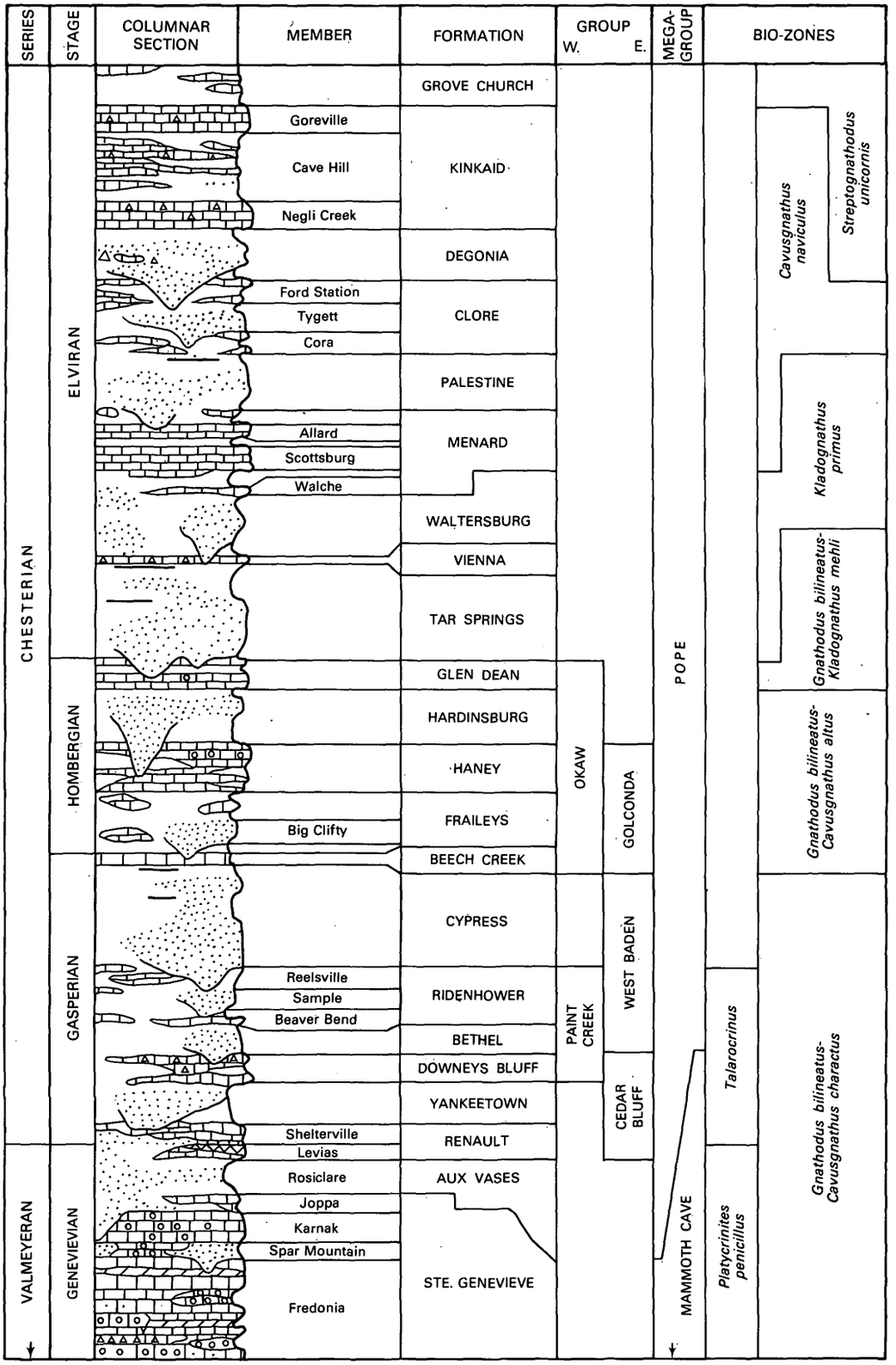


FIGURE 9.—Columnar section of the Chesterian Series (from Swann, 1963) showing biozones (from Collinson and others, 1971). In the columnar section, the blank areas are shale.

Okaw Group.—The Okaw Group consists of five formations from the Beech Creek through the Glen Dean Limestone. The Okaw is used only in western Illinois in an area having small limestone outcrops that are Haney or Glen Dean but that are difficult to differentiate.

Beech Creek Limestone Formation.—The Beech Creek Limestone is a relatively thin but persistent unit, commonly called the "Barlow lime." The lower part is argillaceous, dark brownish gray, dense to sublithographic limestone. The upper part is light brownish gray, fossiliferous, and oolitic in part. The Beech Creek thickens northward in contrast with the other Chesterian formations, which thicken southward. It is as much as 12 m thick in the north, but in Hardin County, in the south, it is shaly and locally absent or too thin to identify.

Fraileys Shale Formation.—The Fraileys Shale is as much as 30 m thick in Williamson County and thins northward to about 9 or 12 m thick before being beveled by the sub-Pennsylvanian erosion surface. It is dominantly shale, has sporadic limestone beds and, locally, a sandstone member. Most of the shale is dark gray; however, in the southern part of the Illinois basin, a persistent red shale occurs 1 or 2 m below the top of the Fraileys. Much of the limestone consists of lenses of fossil detritus, in part containing abundant red, orange, or green fossil fragments. The Big Clifty Sandstone Member enters Illinois from the east and thins out westward within a few tens of kilometers. The member is usually about 5 to 6 m thick and occurs near the middle of the Fraileys, or less commonly near the base.

Haney Limestone Formation.—Haney Limestone is about 30 m thick in southern Illinois and thins northward to less than 5 m. It is mainly limestone and some interbedded shale. The limestone is coarse grained, fossiliferous, and much of it is oolitic. In Randolph County, a 6-m bed of white oolite is informally named the "Marigold Oolite." To the northwest the Haney grades to a shale that is difficult to differentiate from the Fraileys or the Hardinsburg.

Hardinsburg Sandstone Formation.—Hardinsburg Sandstone has a thick-bedded sandstone facies and a thin-bedded shale and shaly sandstone facies. Much of the sandstone is light gray and very fine grained. In the thick bodies, the sandstone may be white and fine grained; in the thin bodies it may be gray or green and finer grained, in places grading to siltstone. About 10 m of red, green, and dark gray shale containing thin beds and nodules of red and brown, lithographic limestone and dolomite lie at the base of the Hardinsburg. Locally, this shale is cut out by an erosional surface that commonly separates it from the overlying sandstone facies so that sandstone rests directly on the Haney Limestone. In southeastern Illinois, the Hardinsburg is 18 to 25 m thick; to the northwest it thins to about 6 to 12 m.

Glen Dean Limestone Formation.—Shale separates the Glen Dean Limestone in the south into upper and lower limestone units. In the north only the lower unit generally persists, and the formation is correspondingly thinner. The limestone is coarse grained and fossiliferous; parts are oolitic, and some strata are cherty. In the south, the Glen Dean is 20 to 25 m thick. In the north, where only the lower limestone unit is present, the formation thins to only 2 to 6 m.

Tar Springs Sandstone Formation.—The Tar Springs Sandstone is nearly all sandstone, white to light gray, very fine to fine grained, and mostly friable but containing some well-cemented layers. Also present are: shale, dark gray and slightly carbonaceous; siltstone, medium to dark olive gray; and shaly sandstone, light to dark olive gray. Near the southern border of the Tar Springs, thin beds of coal occur locally near the top and middle of the formation. The thickness of the Tar Springs generally ranges from 23 to 40 m in thickness, but the maximum is more than 45 m. Near its northwestern border it thins to about 15 m.

Vienna Limestone Formation.—The Vienna Limestone is a thin limestone, mainly dark brownish gray and very fossiliferous. Much chocolate-brown chert is present in the outcrop, but chert is rare in the subsurface. The maximum thickness of the Vienna is about 9 m near its southern edge. About 48 km to the north, it thins to about 3 m; over most of its extent, it is about 1 m thick.

Waltersburg Formation.—The Waltersburg Formation is mainly dark gray, slightly carbonaceous shale, in part silty and sandy. A thin seam of coal is present locally near the top of the formation close to its southern border. Sandstone strata in the outcrop are characteristically well jointed. The Waltersburg generally is 15 to 23 m thick, but at the west it thins to less than 12 m and thickens to 36 m in a small area in Wayne County.

Menard Limestone Formation.—The Menard Limestone generally is 30 to 45 m thick in the southern, 24 to 30 m in the central, and 14 to 18 m in the northern and northwestern parts of its extent. The limestone is argillaceous, dark brownish gray to brown and buff, fine grained to lithographic, oolitic

in part, and cherty in part. Fine-to-coarse dark rounded grains give many beds a characteristic speckled appearance. The shale is calcareous, dark gray, and fossiliferous.

The Menard is readily divided into three limestone members. The Walche at the base is 1 to 3 m thick and occurs only in the southern part of the basin. The Scottsburg overlaps the Walche to the north, is 9 to 12 m thick in the south, and thins northward to about 2 m. The Allard thins from about 9 m in the south to 3 m in the north. The shale strata separating these members, and overlying the Allard, are not named units. The shale above the Allard is about 6 to 9 m thick in the south and 3 to 6 m in the north. Locally, especially in the north, the sub-Palestine erosion surface cuts into this shale and in places entirely through it.

Palestine Sandstone Formation.—The Palestine Sandstone includes sandstone, shale, and siltstone. Much of the sandstone is gray, very fine grained, and more or less shaly. The sandstone in the thicker bodies is light gray to white and coarser grained. The shale is dark gray and generally silty to sandy. Much of this rock is slightly carbonaceous. In western Illinois, a thin coal is at the top of the Palestine at several localities. The Palestine tends to thicken slightly southward. Commonly it is 15 to 18 m thick, and it is thickest where massive, channel-phase sandstone bodies are present.

Clore Formation.—The Clore Formation is mainly shale throughout most of its extent, but the proportion of limestone increases southward. About 12 to 18 m thick near its northern and northwestern borders, it thickens southward to about 36 m in northern Johnson County. In many places the Clore is thinned by sub-Degonia channels; in some areas sub-Pennsylvanian channels cut into, or through, the Clore.

The Clore includes three members. The Cora Limestone Member (below), which consists of interbedded limestone and shale containing locally, sandstone lenses, is about 4 to 13 m thick. The Tygett Sandstone Member, which is sandstone containing minor amounts of shale, is 6 to 9 m thick over much of its extent. The Ford Station Limestone Member, which is limestone interbedded with shale and rare lenses of sandstone, is 6 to 15 m thick.

Degonia Sandstone Formation.—The Degonia Sandstone typically includes two beds of massive sandstone. The upper overlaps the lower, and locally both are absent. The shale in the Degonia is gray to dark gray, but red at the top of the formation. Thin seams of coal occur locally near the top and middle of the Degonia in southwestern Illinois. The thickness of the formation ranges from 45 m in western Illinois to as little as 6 m in the southeast. Sub-Pennsylvanian channels cut the Degonia into two large and many small areas.

Kinkaid Limestone Formation.—The Kinkaid Limestone is about 30 m thick in the north, thickening southward to about 51 m near its southern edge. Pre-Pennsylvanian erosion has cut the Kinkaid into many isolated areas. The thick upper and lower limestone members apparently were highly resistant to erosion because they cap the Chesterian over fairly large areas. Many slump blocks of the limestone are known to occur in the subsurface on the slopes of steep-walled sub-Pennsylvanian valleys.

The Kinkaid is divided into three members. The Negli Creek Limestone Member (at the base) is a massive limestone, cherty, brownish gray, containing scattered coarse fossil grains. The member is 11 m thick in Franklin County in the south and 5 m thick in Effingham County in the north. The Cave Hill Shale Member is a limestone and shale unit in which the proportion of limestone increases southward. The basal part is shale, dark gray, and locally black. The lower third of the member contains some silty shale, a little siltstone, and locally shaly sandstone. The middle part of the member contains a variety of carbonate rocks interbedded with a little shale. The upper part consists of calcareous dark gray and greenish gray shale above and red and green shale below. The Goreville Limestone Member is massive and resistant to erosion like the Negli Creek, but it is less extensive and is more dissected by pre-Pennsylvanian erosion. Average thickness of the Goreville is about 9 m, and thickness ranges from about 8 m in the north to nearly 15 m in the south.

Grove Church Shale Formation.—The Grove Church Shale, the uppermost formation in the Chesterian Series in Illinois, occurs only in patches in southern Illinois in Johnson, Pope, and Saline Counties. An unknown, but probably large, part was eroded before the Pennsylvanian was deposited in the area. The Grove Church is a gray, fossiliferous shale containing interbedded fossiliferous limestone. The maximum thickness known is about 20 m in northern Johnson County.

PALEONTOLOGY

The Mississippian System is named for exposures along the western margin of Illinois, and its fossils in this State have been intensively studied. The

shale of the Kinderhookian Series is relatively unfossiliferous, except for spores and conodonts, but the Chouteau Limestone (=Rockford of Indiana) at the top of the series is famous for its cephalopod fauna; part of this fauna is earliest Valmeyeran in age. Fossils are abundant and varied in most of the limestone and calcareous shale of the Valmeyeran and Chesterian Series. Brachiopods are numerous, and some formations consist mainly of crinoidal debris. Fenestrate bryozoan debris is abundant in some beds. *Archimedes* with its corkscrewlike axes is so common in some strata that the term "*Archimedes* limestone" was applied to several stratigraphic units in some early reports. *Composita trinuclea* is the commonest Mississippian brachiopod of southern Illinois. Endothyrids are abundant in the Salem Limestone. The coral assemblage zone *Lithostrotionella castelnaui* (="*Lithostrotion canadensis*") and *L. proliferum* is generally equivalent to the St. Louis Limestone. Conodonts are common to abundant and provide a basis for biostratigraphic zonation. More than 20 characteristic conodont faunas have been recognized in North American Mississippian rocks. In the Chesterian, plant megafossils are found in parts of the sandstones, and spores have been described from the thin coals and carbonaceous layers.

ENVIRONMENT OF DEPOSITION

The Kinderhookian Series thickens westward, and the siltstone component is thickest in western Illinois, suggesting that the main source of sediment was west of Illinois. At the base of the series, a local erosional unconformity that has about half a meter of relief on the top of the Devonian suggests a relatively short interval of emergence. Oolitic limestone of the "Glen Park" at the base of the series in central Illinois and oolitic limestone of the thin Starrs Cave at the top of the series in extreme western Illinois indicate shallow water at these times and places. The water may have been deeper to the south and east where the series is thinner. Here the amount of sediment going into the basin may have lead to the "starved" condition that developed later. The close of the Kinderhookian is marked by a minor erosional unconformity at the base of the Burlington Limestone in northwestern Illinois.

Early in Valmeyeran time, as the Illinois basin sank, important facies differences developed in the sediments (fig. 7). In western and northern Illinois where the water was shallow, fossiliferous limestone (Burlington-Keokuk) was deposited that built up a thick carbonate bank. To the south and east, mud was slowly deposited in the deepening basin (Springville Shale and basal Borden). A siltstone delta (Borden Siltstone) encroached from the northeast into this sediment-starved basin where water depths are estimated to have been from 183 to 305 m (Lineback, 1968). The deep-water basin, marginal to the delta on the southeast and south, was filled by the cherty, very siliceous Fort Payne Formation and the bryozoan-rich Ullin Limestone. After the delta had built up to about the level of the top of the Burlington-Keokuk bank, mud and silt swept westward across the surface of the Keokuk to be deposited in western Illinois as the Warsaw Shale.

Carbonate deposition prevailed during the rest of Valmeyeran time. The water was generally shallower than before, the shoreline was to the north, and water was deeper to the south. At times, the environment approached the sabkha-type, and evaporites and oolites were deposited. This was a time of extensive deposition of thick limestone formations.

Of the several types of rock composing the Salem, the most abundant and characteristic are fine- to coarse-grained calcarenite and fossil-fragmental limestone. Coiled Foraminifera, such as *Globoendothyra,* and other small fossils are abundant. Oolites and oolitic overgrowths are locally common. The former presence of local evaporite deposits is suggested by the brecciation of the overlying St. Louis Limestone. Beds of extra fine grained dolomite in the Salem also suggest a shallow-water environment.

The St. Louis Limestone also was deposited in shallow water. Typically, the limestone is very fine grained to lithographic and is locally brecciated; the dolomite is extra fine grained. Oolitic rock is much less common, and the carbonate is generally darker and more cherty in the St. Louis than in the underlying Salem or overlying Ste. Genevieve Limestone. Disseminated anhydrite and some fairly thick beds of gypsum and anhydrite occur. The transition from gypsum to anhydrite is related to depths of burial; below 450 m the evaporite is principally anhydrite.

The Ste. Genevieve Limestone was deposited in a shallow-water environment that favored the deposition of oolitic limestone in lenticular or barlike bodies at several levels. A few thin strata of sandy limestone, sandy calcarenite, or sandstone are fairly widely traceable, foreshadowing the alternation of sandstone and limestone characteristic of the Chesterian.

The Aux Vases Sandstone shows a facies relation with the upper part of the Ste. Genevieve Limestone in southwestern Illinois. Limestone strata in the upper part of the Ste. Genevieve thin and grade into sandstone in this area, so that the base of the Aux Vases is stepped down to include the thicker sand. The sand in the Aux Vases probably came from the north or northeast rather than from the Ozark area itself.

The Levias Limestone Member in southeastern Illinois was deposited in clear, shallow water. Except for the basal few centimeters that are sandy, the limestone is a relatively pure, coarse-grained oolite. The break with the overlying Chesterian is minor and is marked by an erosional surface of very slight relief and sandy beds at the base of the Shetlerville Member.

The Chesterian Series is characterized by an alternation of sand-shale formations and limestone-shale formations in an irregularly cyclical succession. This cyclicity is explained as resulting from the shifts of an east-southeast to west-northwest trending shoreline (fig. 10). When the sea transgressed northward, limestone was laid down in the Illinois basin; when the sea retreated, sand was deposited. The location of major sand bodies is a consequence of lateral shifts in the position of the distributaries of the river that carried sediment into the basin from the north. This river has been named the Michigan River (Swann, 1963); it may have brought sediment from northeastern Canada, but the location of the source is not definitely known. This picture of the paleogeography during Chesterian time developed from a study of features in the sandstone that indicate the direction of paleocurrents. Detailed mapping of the thickness of sandstone in several of the Chesterian formations has shown the position of the distributaries of the Michigan River (Potter, 1963). Changes in the rate of sediment supply have been attributed (Swann, 1964) to climatic control rather than tectonic control, and sediment yield has been controlled mainly by rainfall in the source area. Shoreline position was dependent on the shifting balance between the rate of sedimentation and the rate of sinking of the basin.

In general, the Chesterian formations, except for the Beech Creek Limestone, thicken southward to their truncated edges in southern Illinois; the proportion and thickness of the limestone in the limestone-shale formations also increase southward. The limestone strata in the lower part of the Chesterian (Glen Dean and older) are generally lighter colored

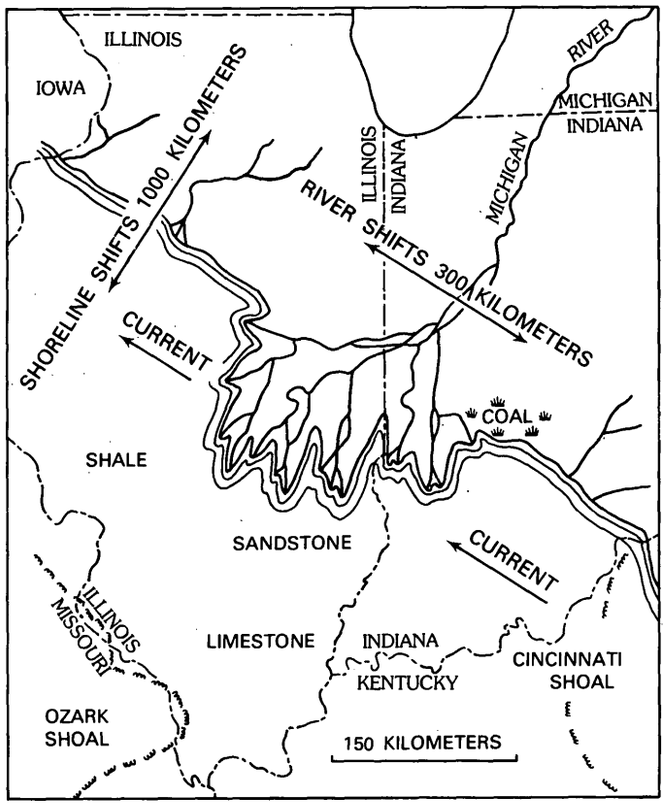


FIGURE 10.—Paleogeography at an intermediate stage during Chesterian sedimentation (from Swann, 1963).

and purer than the limestone in the upper part (Vienna and younger), and the amount of oolitic rock is much greater in the older formations. A coal swamp environment developed several times during the Chesterian. Thin coals occur in Jackson and Hardin Counties at the top of the Palestine Sandstone; in Johnson, Pope, and Hardin Counties at the top of the Waltersburg Sandstone; and in the southern part of the Illinois basin, at the top and near the middle of the Tar Springs and Cypress Sandstones.

TECTONIC DEVELOPMENT

The major tectonic event in Illinois during the Mississippian Period was the sinking of the Illinois basin which was greatest in southermost Illinois. During this period (and until the post-Pennsylvanian development of the Pascola arch) the Illinois basin was open to the south, and the maximum sinking during this time is southwest of the deepest part of the present basin.

At the close of the Devonian Period, the tectonic break was very minor, and local emergence was indicated by an erosional surface on the top of the

Louisiana Limestone (uppermost Devonian). A slight break between Kinderhookian and Valmeyeran Series is recorded along the western edge of the Illinois basin, where the Meppen Limestone (basal Valmeyeran) rests unconformably on the Chouteau Limestone (Kinderhookian). Absence of the Chouteau north of a line running from Calhoun County to the northeast may be a result of a slight upwarping of the Sangamon arch (fig. 11) at the close of the Kinderhookian, accompanied by truncation of the Chouteau. Slight doming of the Ozark region at this time was followed by overlap of the Valmeyeran onto rocks as old as Ordovician.

During the earlier part of Valmeyeran time in western Illinois, where the sea was shallower than it was farther south and east, buildup of the Burlington-Keokuk carbonate bank kept in balance with the sinking basin. Sinking outpaced sedimentation in eastern and southern Illinois, and that part of the basin became sediment-starved until the Borden Siltstone Delta was built out into the basin from the northeast. Near the close of the Valmeyeran, slight warping of the Ozark region is suggested by local erosion surfaces and by overlaps near the top and base of the Ste. Genevieve Limestone at the southwest edge of the Illinois basin.

The base of the Chesterian is marked by local erosion surfaces and by sandy beds. The base of the Cypress Sandstone tends more nearly to parallel the bedding of older units than it does the overlying Beech Creek Limestone, suggesting slight warping of parts of the basin during Cypress time. This, and similar, very minor nonparallelism of older and younger strata in the Chesterian, may be attributable to the differential compaction and draping of younger beds over thick sandstones. However, an abrupt thinning from west to east of the interval between the Downeys Bluff and the Beech Creek Limestones in the southern part of Crawford County in southeastern Illinois is more probably a result of local upwarping than of differential compaction. This monoclinal feature may be an early indication of the La Salle anticlinal belt. Other than this monocline, thickness maps of individual Chesterian and older Mississippian formations show no indication of contemporaneous development of the La Salle anticlinal belt. This major structural feature of Illinois mainly began during the interval of erosion that followed Chesterian deposition in the area.

ECONOMIC PRODUCTS

Oil.—As of December 31, 1976, the estimated original oil-in-place in Illinois was 8,968,692,000 barrels (1,220 million metric tons); the estimated ultimate recovery was 3,205,329,000 barrels (437 million metric tons). Of this Illinois oil, all Paleozoic, 6,766,392,000 barrels (922 million metric tons), or 75.4 percent of the original oil-in-place, and 2,582,443,000 barrels (352 million metric tons), or 80.6 percent of the estimated ultimate recovery, is from reservoirs in Mississippian strata.

A little more than 60 percent of the cumulative production of Mississippian oil is from sandstones in the Chesterian Series, and nearly half this production is contributed by the Cypress Sandstone. Of the other Chesterian sandstones, the Yankeetown ("Benoist"), Bethel, Tar Springs, and Waltersburg are the most important contributors. A little less than 40 percent of the cumulative production is from the Valmeyeran Series, and almost all this is from near the top of the series. Of this oil from the Valmeyeran, the Aux Vases Sandstone contributes about one-third, and the Ste. Genevieve Limestone about three-fifths. The most important reservoirs are in lenses of coarse oolitic limestone (McClosky lime) at several levels in the Fredonia Member of the Ste. Genevieve. Relatively small amounts of oil come from the Spar Mountain Sandstone Member of the Ste. Genevieve and from the Salem and Ullin Limestones.

Gas.—Production of natural gas in Illinois in 1976 was 1,556 million cubic feet (44 million cubic meters), of which only about one-sixth was from the Mississippian. Almost all the Mississippian gas production was from Chesterian sandstones. Eight of 39 active underground natural gas storage projects in Illinois use reservoirs in Mississippian rocks, but none of these 8 are among the relatively large projects in Illinois.

Fluorspar.—Illinois leads the other States in the production of fluorspar. In 1976, production was 129,000 metric tons. All the ore mined came from Hardin and Pope Counties in southern Illinois. The ore occurs in fissure veins and bedded replacement deposits in strata near the base of the Chesterian and near the top of the Valmeyeran Series.

Lead, zinc, and silver.—The fluorspar ore mined in Hardin and Pope Counties is treated to recover zinc, lead, and silver. In 1974, 3,720 metric tons of zinc, 447 metric tons of lead, and a small amount of silver were recovered.

Stone.—Stone production in Illinois in 1976 was 55,100,000 metric tons. Of this total, almost all

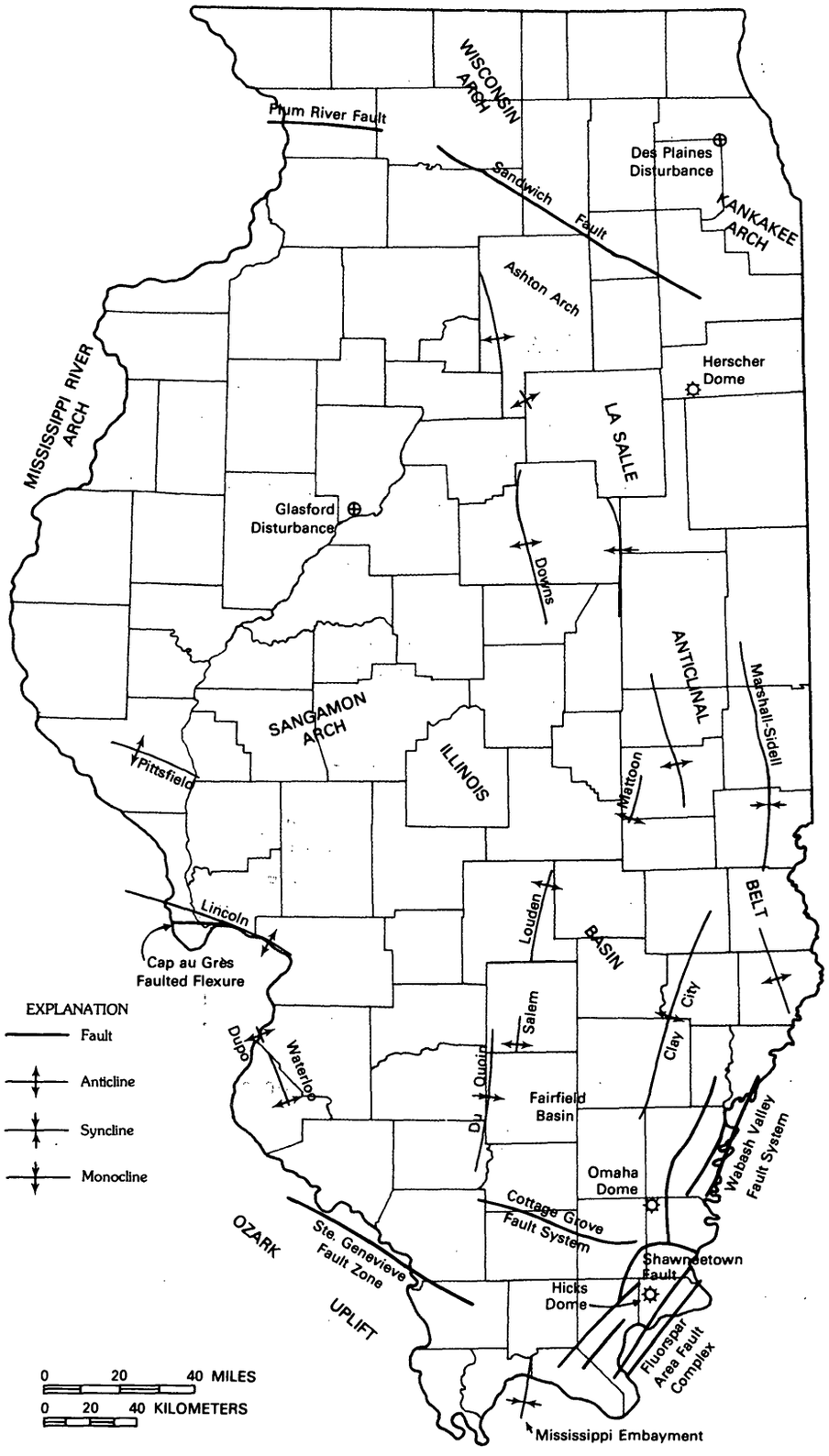


FIGURE 11.—Major tectonic features of Illinois. The Sangamon arch was a Paleozoic structure obscured by later structural movement.

crushed and broken limestone and dolomite, about one-sixth is from the Mississippian, and most of this is from the Valmeyeran. The middle part of the Mississippian System—from the top of the New Albany Shale Group, or the Borden Siltstone where present, up to the lowest sandstone or shale of Chesterian or late Valmeyeran age—is sometimes called the "Mississippi lime," or, more formally, the "Mammoth Cave Limestone Megagroup." This megagroup is an important source of limestone in Illinois, where it crops out along the western and southern borders of the State.

THE PENNSYLVANIAN SYSTEM

INTRODUCTION

The name "Pennsylvanian" was used in 1906 in the first report of the present Illinois State Geological Survey. The terms "Coal Measures" and "Upper Carboniferous," which were used before 1906, were gradually abandoned in later reports (fig. 12) The Pennsylvanian was classified as a series until it was recognized as a system in about 1925. Rock strata of the Pennsylvanian System lie at or near the surface in 86 of the 102 counties in Illinois, or in about two-thirds of the total area (95,291 of a total 146,020 km²).

Although Pennsylvanian strata of Illinois are commonly covered by unconsolidated Pleistocene glacial deposits, they are well exposed in various parts of the State in river valleys, stream valleys, and artificial cuts made during mining and construction of highways or railroads. Pennsylvanian strata are also exposed along the Illinois, Kaskaskia, Wabash, Sangamon, Spoon, and Embarras Rivers, and other smaller rivers and their tributaries. Erosion by streams emptying into the Mississippi and Illinois Rivers in western Illinois has produced numerous exposures. Many excellent exposures also occur in southern Illinois beyond the limits of Pleistocene glaciation. However, the single most important source of information concerning the Pennsylvanian System is the samples, records, and data at the Illinois State Geological Survey of many thousands of coal, oil, and water test holes.

<table>
<tr><th colspan="2">Worthen 1875</th><th colspan="2">S. Weller 1906</th><th>DeWolf 1910</th><th>Shaw and Savage 1912</th><th>Wanless 1929, 1931a</th><th>Wanless and J. M. Weller 1932</th><th>Wanless 1939
J. M. Weller 1940</th><th colspan="2">Kosanke and others 1960
Willman and others 1975</th></tr>
<tr><td rowspan="11">COAL MEASURES</td><td rowspan="3">Upper</td><td rowspan="11">PENNSYLVANIAN</td><td rowspan="3">Upper</td><td rowspan="3">McLeansboro Formation</td><td rowspan="3">McLeansboro Formation</td><td rowspan="3">Formations subdivided into cyclical units called "Suites"; later called "Cyclical Formations"

McLeansboro Formation</td><td rowspan="3">Cyclical units called "Cyclothems"

McLeansboro Formation</td><td rowspan="3">McLeansboro Group</td><td>Mattoon Formation</td><td rowspan="3">McLeansboro Group</td></tr>
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Bond Formation
Shoal Creek Limestone Member</td></tr>
<tr><td>Modesto Formation</td></tr>
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<tr><td rowspan="4">Carbondale Group</td><td rowspan="2">Carbondale Formation</td></tr>
<tr><td>No. 6 coal
Petersburg Formation</td><td rowspan="2">Carbondale Formation</td><td rowspan="2">Carbondale Formation</td><td rowspan="2">Carbondale Formation</td></tr>
<tr><td>No. 5 coal
LaSalle Formation
No. 2 coal</td><td>Colchester (No. 2) Coal Member</td></tr>
<tr><td>Lower</td><td>Lower</td><td>Palzo Sandstone</td><td>Spoon Formation</td></tr>
<tr><td></td><td></td><td>Pottsville Formation</td><td>Pottsville Formation</td><td>Pottsville Formation</td><td>Pottsville Formation</td><td>Tradewater Group
Grindstaff Sandstone</td><td>Bernadotte Sandstone Member
Abbott Formation</td><td rowspan="3">McCormick Group</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td>Caseyville Group</td><td>Pounds Sandstone Member
Caseyville Formation</td></tr>
</table>

FIGURE 12.—Development of the classification of the Pennsylvanian System in Illinois (from Kosanka and others, (1960). In Wanless (1939) and Weller (1940), the McLeansboro and Carbondale Groups were divided into cyclothems, and the Caseyville and Tradewater Groups in southern Illinois were divided into seven formations. In several reports from 1940 to 1950, the base of the McLeansboro was put at the top of the No. 6 Coal. Cyclothems are retained in a separate cyclical classifications. Units bounding the groups and formations are in italics (Willman and others, 1975).

BOUNDARIES OF THE PENNSYLVANIAN SYSTEM

A major angular unconformity separates the Mississippian System from the Pennsylvanian System in Illinois. The configuration of the erosion surface separating the two systems has been studied extensively by workers at the Illinois State Geological Survey (Siever, 1951; Wanless, 1955; and Bristol and Howard, 1971). They identified a series of broad southwestward-trending valleys as much as 140 m deep and commonly several kilometers wide that evidently were formed by subaerial erosion (fig. 13).

A post-Pennsylvanian, pre-Pleistocene erosion surface that defines the upper limit of Pennsylvanian deposits in Illinois was formed by pre-Pleistocene stream erosion and later was modified by Pleistocene glaciation and Holocene stream erosion. Gulfian (Upper Cretaceous) rocks overlie Pennsylvanian strata in a small area in Adams, Pike, and Brown Counties in western Illinois.

GENERAL CHARACTERISTICS OF PENNSYLVANIAN STRATA

Pennsylvanian strata attain a maximum thickness of about 760 m in Wayne County, southeastern Illinois (fig. 14). If thickest sections are considered for each formation, the composite thickness of strata is about 1,000 m. The formations are generally thickest in southeastern Illinois and become thinner toward northern and northwestern Illinois.

Some lower strata of the Pennsylvanian System are present only in southern and central Illinois and are overlapped by younger formations in the north. At some locations on the La Salle anticline, the three lowest formations (Caseyville, Abbott, and Spoon) are absent and the St. Peter Sandstone (Middle Ordovician) directly underlies the Colchester (No. 2) Coal, which is at the base of the Carbondale Formation. In the area of Rock Island and Mercer Counties in extreme northwestern Illinois, however, the three lowest formations of the Pennsylvanian System are well developed.

About 90 to 95 percent of the Pennsylvanian System in Illinois consists of clastic rocks. Siltstone, shale, and underclay constitute about 40 percent of the lower part of the system and 65 to 70 percent of the middle and upper parts. In the lower part, sandstone constitutes about 60 percent of the strata; in the middle and upper parts, it constitutes only about 25 percent of the strata. Limestone is rare in lowermost Pennsylvanian strata but in some areas constitutes as much as 5 to 10 percent of the upper two-thirds of the system. Limestone is especially common in the Bond Formation, where individual beds as much 15 m thick have been recognized. Coal, one of the least abundant lithic units of the Pennsylvanian System, constitutes no more than 2 percent of rock strata in most areas.

More than 500 units of sandstone, siltstone, shale, limestone, coal, and clay are distinguishable in the Pennsylvanian strata of Illinois (Willman and others, 1975). The abruptness and great number of vertical changes in lithology indicate that changes in depositional environment were rapid. Some of the coal, underclay, and limestone, although rather thin, are the most persistent lateral units of the Pennsylvanian System. If Indiana and Kentucky are included, several coal and limestone beds can readily be correlated over a distance of about 560 km in the Illinois basin. On the basis of these marker beds, intervening strata that show substantial lateral variations can also be correlated over considerable distances.

STRATIGRAPHY

ABSAROKA SEQUENCE

The Absaroka Sequence, which was named for the Absaroka Mountains in northeastern Wyoming and southern Montana, includes the Pennsylvanian System of Illinois. The base of the sequence is the major unconformity at the base of the Pennsylvanian System in Illinois, and the top of the sequence is the major unconformity at the base of the Cretaceous System (Willman and others, 1975). The Absaroka Sequence, represented only by Pennsylvanian-age strata in Illinois, consists predominantly of clastic sediments and contains numerous minor unconformities produced through erosion by deeply entrenched valley systems and by entrenchment of river distributaries in deltaic sediments.

MORROWAN SERIES

The type exposure of the Morrowan Series is on Hale Mountain, Washington County, Ark., near the community of Morrow, for which the series was named. Both nonmarine and marine strata are included in the series. In Illinois, the Morrowan Series includes only the Caseyville Formation (Willman and others, 1975) (fig. 15).

McCormick Group.—The McCormick Group in Illinois includes strata of the Caseyville and Abbott Formations, which extend from the base of the Pennsylvanian to the top of the Bernadotte Sandstone Member. The group derives its name from exposures near McCormick, Pope County, in southern Illinois. The McCormick Group has a maximum

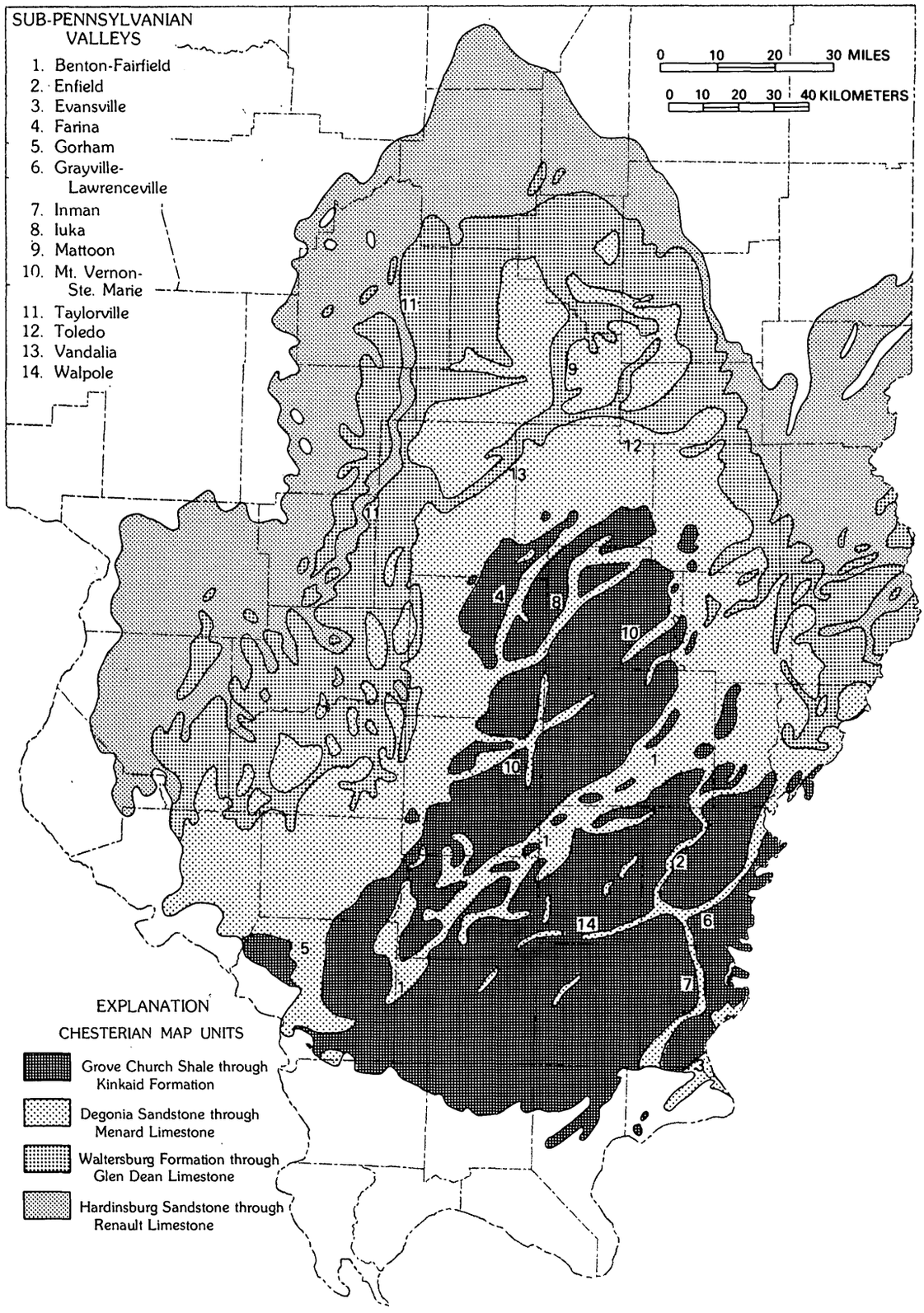

FIGURE 13.—Paleogeologic map of sub-Pennsylvanian Chesterian surface in Illinois (from Howard, in press).

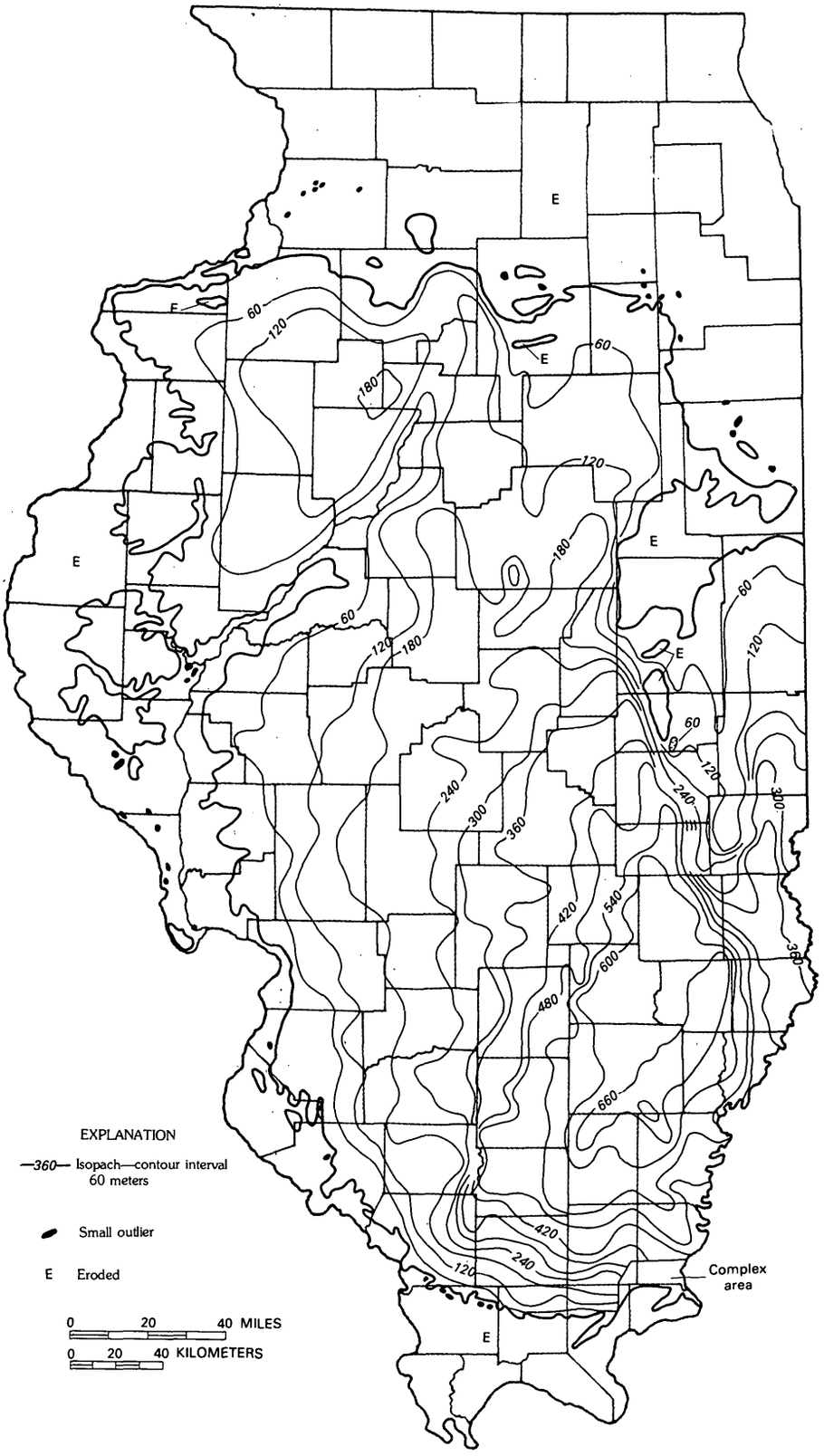

FIGURE 14.—Thickness of the Pennsylvanian System.

thickness of at least 180 m in southern Illinois, but it thins northward to about 60 m and is absent in large areas of western and northern Illinois. The McCormick Group consists of about 50 to 60 percent sandstone, about 40 percent or more sandy shale, and a few thin nonpersistent limestones and coals. The sandstones commonly form cliffs, are extensively cross bedded, and contain a high percentage of quartz.

The McCormick Group is predominantly devoid of animal fossils, although a few calcareous sandstones and shale zones and one limestone member that contain marine invertebrate fossils have been recognized. Log casts of *Lepidodendron* sp., *Calamites* sp., and *Sigillaria* sp. are common in fine-grained sandstone of the lower part of the McCormick Group.

Caseyville Formation.—The Caseyville Formation was named by Owen (1856, p. 48) for the community of Caseyville on the Ohio River in southwestern Union County, Ky., which is near the site of the type locality. Rock sections for definition of the formation were "measured from outcrops on the Illinois shore of the Ohio River between the mouth of the Saline River and Gentry's Landing below Battery Rock" in Hardin County (Lee, 1916, p. 15–16). Strata from the base of the Pennsylvanian System to the top of the Pounds Sandstone Member are included in the Caseyville Formation.

The Caseyville Formation is commonly about 100 m thick in southern Illinois. Where the formation has filled pre-Pennsylvanian bedrock valleys, it may be as much as 150 m thick. The Caseyville Formation was deposited only in southern and southeastern Illinois and in parts of Mercer and Rock Island Counties in northwestern Illinois, where it locally attains a thickness of more than 30 m (fig. 16). It is overlapped by the Abbott Formation; maximum combined thickness of the Caseyville, Abbott, and Spoon Formations in southern Illinois is more than 360 m (fig. 17).

Sandstone is the most common constituent of the Caseyville Formation, but the formation also contains abundant siltstone and shale. Because of local variations in lithology, individual beds of the formation can usually be traced only for short distances. The sandstones are predominantly quartzose and contain very little clay or mica. Quartz granules and pebbles, usually less than 12 mm in diameter, are scattered throughout the sandstones and may be in local deposits of conglomerate. Individual sandstones may be as much as 30 m thick and commonly display prominent, rather uniform cross-bedding with dip to the west, south, or southwest, parallel to the direction of elongation of the sand bodies (Willman and others, 1975).

Shale, silt shale, and siltstone beds are common in the Caseyville Formation. Most are medium to dark gray where unweathered and orange brown on weathered surfaces. Coarse siltstone and fine-grained sandstone beds are commonly ripple bedded. Shale associated with the coals is usually dark. In northwestern Illinois, the Caseyville is composed of medium-gray to dark-gray brittle shale interbedded with silty shale and, in a few places, a clean quartz sandstone.

Although several thin and lenticular coals are present in the Caseyville Formation, only the Gentry Coal Member of southeastern Illinois has been named. At least seven impure coals that are individually as much as 60 cm thick have been recognized in the Caseyville Formation of Rock Island and Mercer Counties.

The Caseyville Formation, in contrast with younger Pennsylvanian strata, contains almost no limestone beds. The Sellers Limestone Member, which is known from only one exposure near Sellers Landing, Hardin County, Ill., on the west bank of the Ohio River, is the only named limestone member; it contains a variety of invertebrate marine fossils. Other recognized members of the Caseyville Formation are the Lusk Shale, the Wayside Sandstone, the Battery Park Sandstone, the Drury Shale, and the Pounds Sandstone.

The Caseyville Formation of Illinois is correlative with the lower part of the Mansfield Formation of Indiana and all but the upper 1 or 2 m of the Caseyville Formation of Kentucky. Three State parks in southern Illinois and several parks in western Kentucky and Indiana are in Caseyville outcrop areas of outstanding natural beauty. The high sandstone cliffs and associated rugged topography form some of the most scenic areas of the Midwest.

ATOKAN SERIES

The Atokan Series in Illinois includes only strata of the Abbott Formation of the McCormick Group. The lower and upper boundaries of the series are established at the top of the Pounds Sandstone Member and the top of the Bernadotte Sandstone Member, respectively. Although fossil-bearing strata are present in the Atokan Series in Illinois, they are not used to define its boundaries (Willman and others, 1975).

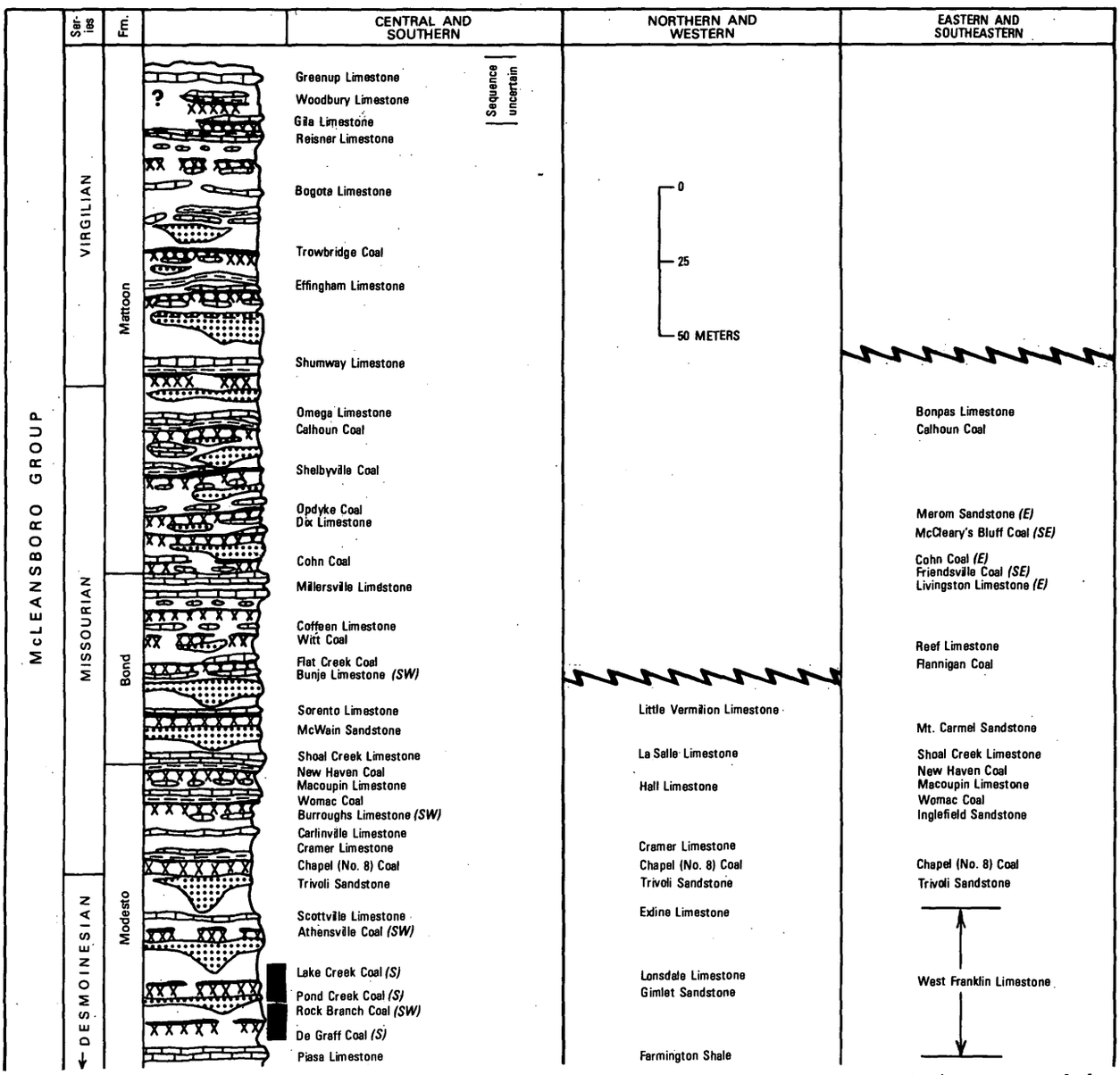

FIGURE 15.—Classification of the Pennsylvanian System. In the graphic column, blank space indicates gray shale. Named members are listed to the right of the graphic column.

Abbott Formation.—The type section of the Abbott Formation of the McCormick Group is defined from exposures near Abbott Station on the Illinois Central Gulf Railroad, Pope County, Ill. Only the prominent sandstones and some coals of the Abbott Formation have been named. Because the bordering sandstone members may be missing locally, both the top and the base of the Abbott Formation are commonly difficult to identify in the subsurface.

The Abbott Formation overlaps the Caseyville Formation and is the basal Pennsylvanian formation throughout much of Illinois. The Abbott is overlapped by the Spoon Formation in northern and northeastern Illinois and on some prominent anticlinal structures. Thickness of the Abbott Formation ranges from a maximum of 100 m in southern Illinois to less than 30 m in western Illinois.

The Abbott Formation is a transitional unit between the underlying Caseyville Formation and younger strata. Basal sandstones of the Abbott closely resemble those of the Caseyville Formation, whereas middle and upper Abbott sandstones are generally thinner, contain more interstitial clay and mica, and contain no more than a few quartz

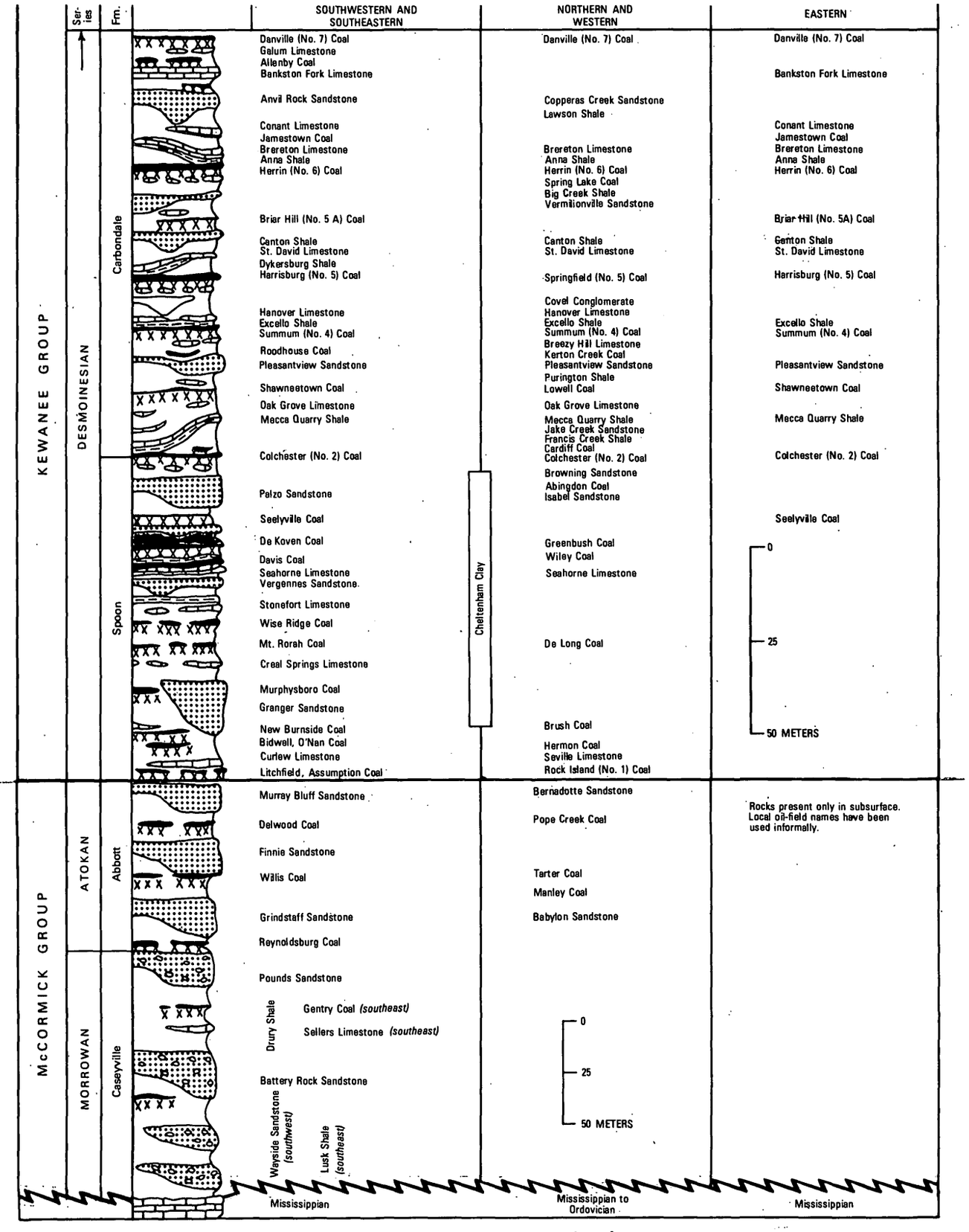

FIGURE 15.—Continued.

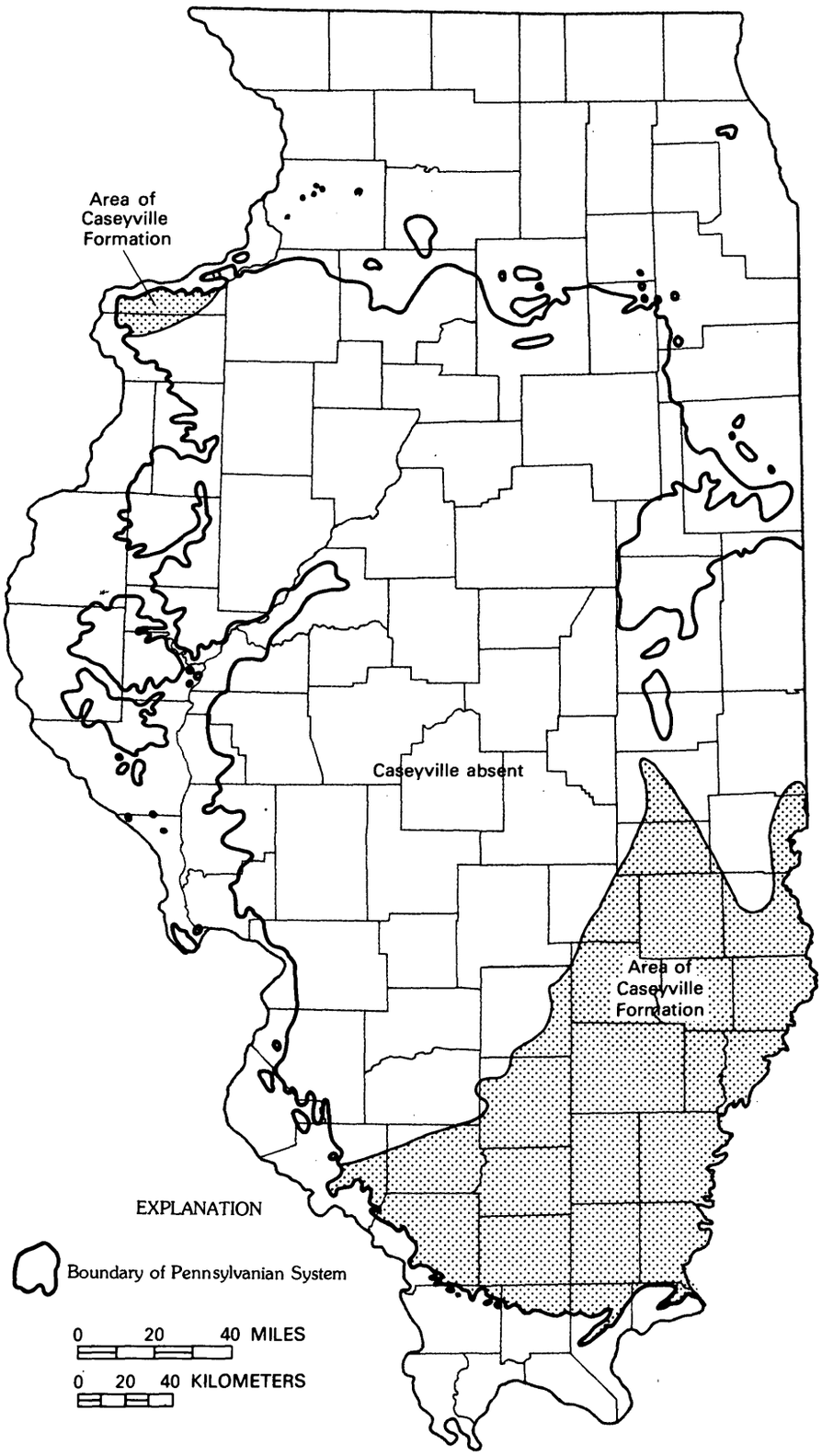

FIGURE 16.—Extent of the Caseyville Formation (from Wanless, 1955).

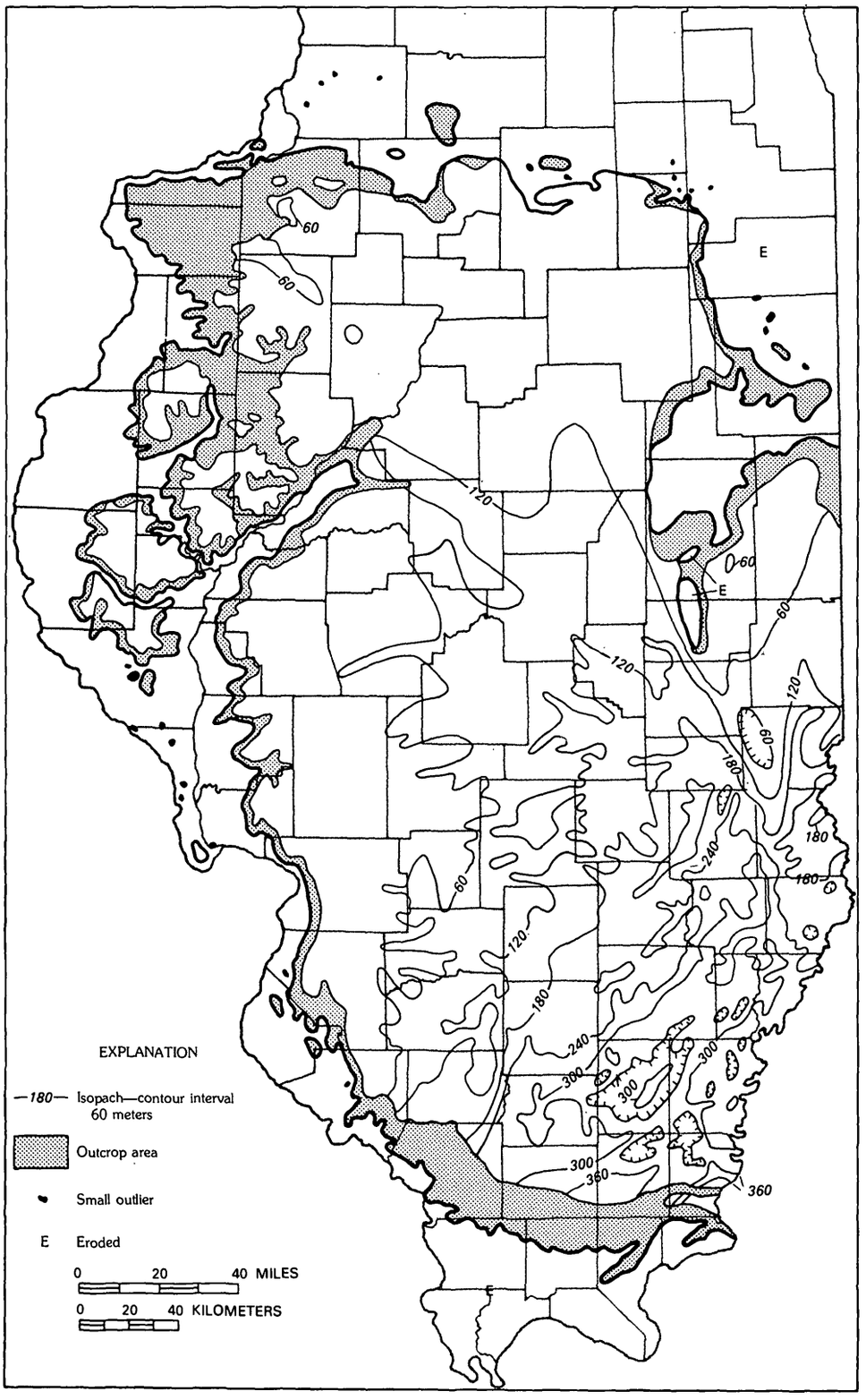

FIGURE 17.—Combined thickness of the Caseyville Formation (from Wanless, 1955).

granules and pebbles. Coals are generally thicker and more persistent in the Abbott Formation than in the underlying Caseyville but not as well developed or extensive as in younger formations. The uppermost sandstones of the Abbott Formation are similar to the relatively impure sandstones of the overlying Spoon Formation.

Named members of the Abbott Formation are the Reynoldsburg Coal, Grindstaff Sandstone, Babylon Sandstone, Manley Coal, Willis Coal, Tarter Coal, Finnie Sandstone, Delwood Coal, and Pope Creek Coal. The Abbott Formation is equivalent to the upper part of the Mansfield and virtually all the Brazil Formation of Indiana, and to the upper 1 or 2 m of the Caseyville Formation and the lower part of the Tradewater Formation in western Kentucky.

DESMOINESIAN SERIES

The Desmoinesian Series comprises the Spoon and Carbondale Formations of the Kewanee Group and the lower part of the Modesto Formation of the McLeansboro Group.

Kewanee Group.—The Kewanee Group consists of the Spoon and Carbondale Formations and is named for Kewanee, Henry County, in western Illinois, where the two formations are well exposed. The Kewanee Group overlies the Abbott Formation in normal sequence, but in northern and northeastern Illinois, where the Abbott is missing, the unit lies on strata ranging in age from Valmeyeran (Middle Mississippian) to Champlainian (Middle Ordovician).

More than 99 percent of the mapped coal reserves of Illinois are contained in the Kewanee Group. The well-developed cyclothems and the broad extent of many relatively thin lithologic units (marine limestone, black fissile shale, coal, and underclay) are distinctive of the Kewanee Group.

Spoon Formation.—The Spoon Formation of the Kewanee Group is defined from exposures in a road and railroad cut in western Fulton County, Ill. (NW¼ sec. 22, T. 6 N., R. 1 E.), near the Spoon River, from which the name of the formation is derived. The base of the formation is defined as the top of the Bernadotte Sandstone of western Illinois or the Murray Bluff Sandstone of southern Illinois. The upper boundary of the formation is the base of the Colchester (No. 2) Coal (fig. 12). The formation is as much as 100 m thick in southern Illinois, but it thins substantially in northern and western Illinois, where it ranges from 1 or 2 m to less than 30 m in thickness. The lowermost extensive limestones and coals of the Pennsylvanian System are in the Spoon Formation, but they are generally thinner than similar units of overlying Pennsylvanian strata. The sandstone of the Spoon Formation contains more mica and clay than the sandstone of the underlying Abbott Formation and reflects a gradual decrease in sediment maturity that is continued in younger Pennsylvanian strata. The coals are neither as thick nor as persistent as those of the Carbondale Formation but are markedly thicker and more extensive than those of the Abbott Formation. The Spoon Formation correlates with the uppermost part of the Linton Formation in Indiana and with the upper part of the Tradewater Formation and the lower part of the Carbondale Formation in western Kentucky. The named members of the formation include 18 coals, 5 limestones, and 5 sandstones (fig. 15).

Carbondale Formation.—The Carbondale Formation of the Kewanee Group is named for Carbondale, Jackson County, Ill., which is near outcrops of the formation in southern Illinois. Three outcrops in Fulton County, western Illinois (SE¼NE¼ sec. 1, T. 7 N., R. 4 E.; NW¼NE¼NW¼ sec. 20, T. 8 N., R. 3 E.; and SW. cor. sec. 21, T. 8 N., R. 3 E.) were established by Kosanke and others (1960, p. 34 and 46) as the type sections for the formation. The base of the Colchester (No. 2) Coal is defined as the base of the Carbondale Formation, and the top of the Danville (No. 7) Coal marks the upper boundary.

The gray silty shales and sandstones display abrupt lateral variations in thickness and are largely responsible for variations in thickness of strata between the coals and other persistent units. The formation is more than 120 m thick near outcrop areas in southern Illinois but is less than 45 m thick in western and northeastern Illinois (fig. 18).

Sandstones of the Carbondale Formation commonly are deposited in elongated channel systems and may be as much as 30 m thick. Thinner sheet-type deposits are also common. The sandstones, which are slightly more argillaceous than sandstones of the Spoon Formation, are classified as subgraywackes. Gray silty shale is the most abundant rock unit in the Carbondale Formation. Sideritic nodules and bands are abundant in the shales. The relatively thin but widespread marine limestones are gray to dark gray, argillaceous, and fossiliferous. Black fissile shales, usually less than 60 cm thick, are associated with the marine limestones and commonly contain a marine- to brackish-water invertebrate fauna similar to that in the limestones. A light gray, nodular limestone, usually devoid of

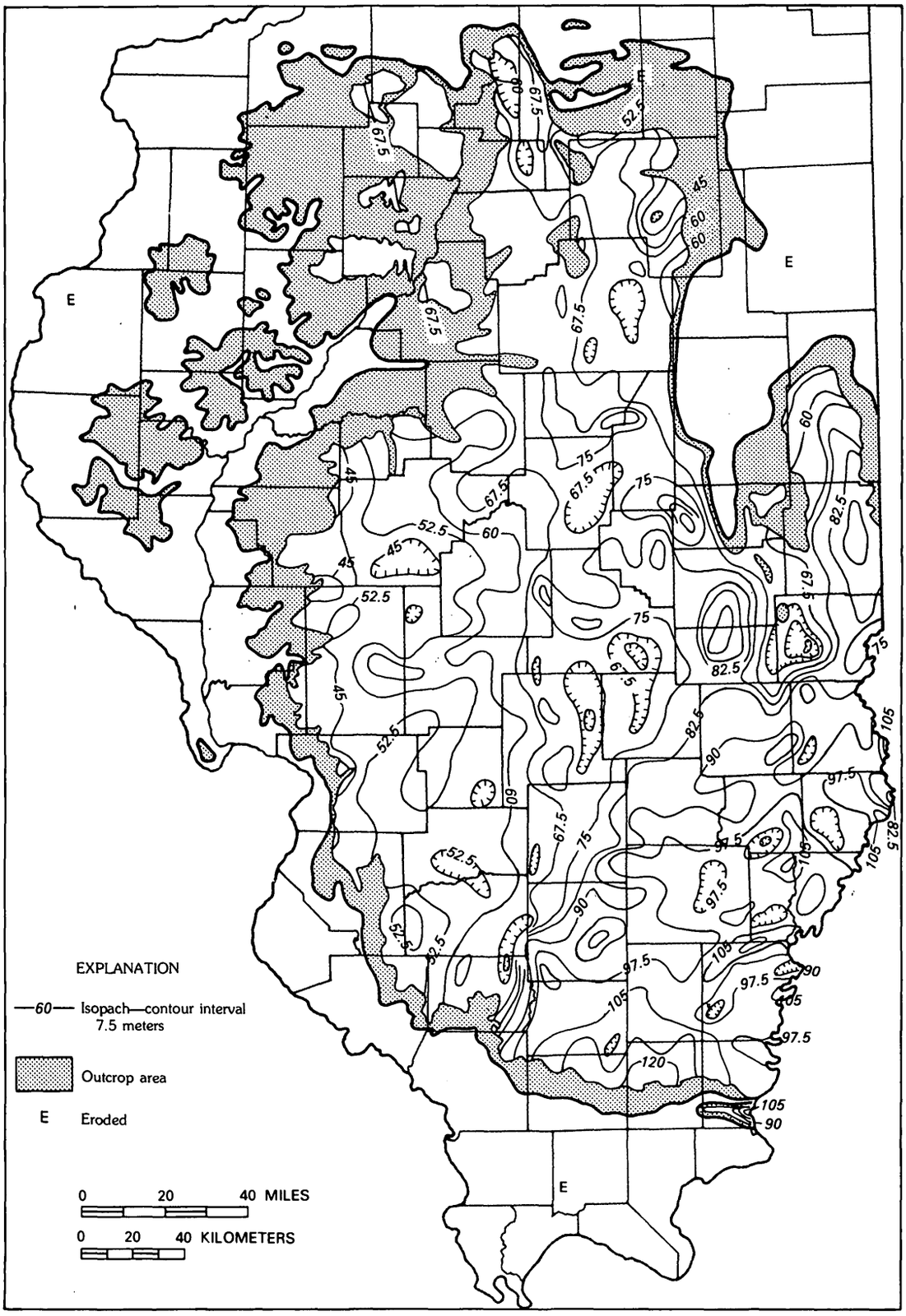

FIGURE 18.—Thickness of the Carbondale Formation (Willman and others, 1975).

marine fossils, occurs in the basal part of the widespread underclays.

The principal coals of Illinois, the Herrin (No. 6), the Springfield-Harrisburg (No. 5), the Colchester (No. 2), and the Danville (No. 7), listed in order of economic importance, are within the Carbondale Formation. The lower 15 m of the Sturgis Formation and the upper part of the Carbondale Formation of western Kentucky correlate with the Carbondale Formation. In Indiana, approximately the same interval of strata as in Illinois is assigned to the Carbondale Formation. The named members of the formation in Illinois include 14 coals, 9 limestones, 9 shales, 5 sandstones, and 1 conglomerate (fig. 15).

McLeansboro Group.—The McLeansboro Group consists of three formations—the Modesto, Bond, and Mattoon—and includes all Pennsylvanian strata in Illinois above the top of the Danville (No. 7) Coal, which is the base of the group. The group is named for the city of McLeansboro, Hamilton County. The type section consists of 247 m of Pennsylvanian strata in a diamond drill core from a test hole near McLeansboro (SE¼SW¼SW¼NE¼ sec. 25, T. 4 S., R. 5 E.). An additional 120 m of strata younger than those in the type section drill hole have been recognized in the deeper part of the Illinois basin in Jasper County, and still younger strata have been identified in western Kentucky.

Coals of the McLeansboro Group are generally thinner and less extensive than those of the Kewanee Group. Coals as thick as 1 m have been reported, although most are less than 30 cm thick. Limestones are generally thicker, more numerous, more predominantly marine, and less argillaceous than those of the Kewanee Group. Rock strata of the McLeansboro Group are also known by the same name in Indiana and correlate with all but the lowest part of the Sturgis Formation of Kentucky.

Modesto Formation.—The type locality for the Modesto Formation comprises four outcrops described by Payne (1942) and Ball (1952) near Modesto, Macoupin County, where nearly all of the formation is exposed. The base of the Modesto Formation is the top of the Danville (No. 7) Coal, and the formation extends to the base of the Shoal Creek Limestone Member or La Salle Limestone Member. The Modesto Formation is about 140 m thick in southern Illinois but thins to about 60 m in northern Illinois and to less than 40 m in the vicinity of the La Salle anticline in east-central Illinois (fig. 19). The coals of the Modesto Formation are generally thinner than those of the underlying Carbondale Formation, but are widespread. The limestones are generally thicker and less argillaceous, and some are commonly associated with red claystone and shale. Much of the Modesto Formation consists of gray shale, although channel sandstone deposits are as much as 24 m thick in some areas. The Modesto Formation correlates with part of the Sturgis Formation of western Kentucky and the Patoka Formation of Indiana. The named members of the formation include 8 coals, 10 limestones, 3 sandstones, and 1 shale (fig. 15).

MISSOURIAN SERIES

The Missourian Series of the Pennsylvanian System is named for the State of Missouri and includes rocks in Illinois from the top of the Trivoli Sandstone Member to a position 1 or 2 m below a coal that underlies the Shumway Limestone Member. The upper part of the Modesto Formation, all the Bond Formation, and about half of the Mattoon Formation are included in the Missourian Series.

Bond Formation.—The Bond Formation of the McLeansboro Group is named for Bond County in southwestern Illinois. Seven separate outcrops in Bond, Christian, and Montgomery Counties constitute the type section. The Bond Formation averages about 75 m thick; it ranges in thickness from less than 45 m in eastern Illinois to more than 90 m in southeastern Illinois (fig. 20). The base of the Bond Formation is defined at the base of Shoal Creek Limestone Member, or the La Salle Limestone Member, and its upper boundary is the top of the Millersville or Livingston Limestone Member. Substantial parts of the formation consist of calcareous clays and limestone. The bounding limestone members are the thickest and include the purest limestones in the Pennsylvanian System of Illinois. The upper limestone is as much as 15 m thick and the lower limestone is locally as much as 9 m thick; both are extensively quarried. Gray shale is the most abundant lithic constituent of the formation, but thick channel sandstones are also abundant locally. Red claystones and shales occur in the Bond Formation and are best developed in northern Illinois. The formation correlates with a part of the Sturgis Formation in western Kentucky and is also called "Bond" in Indiana. The named members of the formation include nine limestones, three coals, and two sandstones (fig. 15).

VIRGILIAN SERIES

The Virgilian Series of the Pennsylvanian System consists of all strata above a position 1 or 2 m below

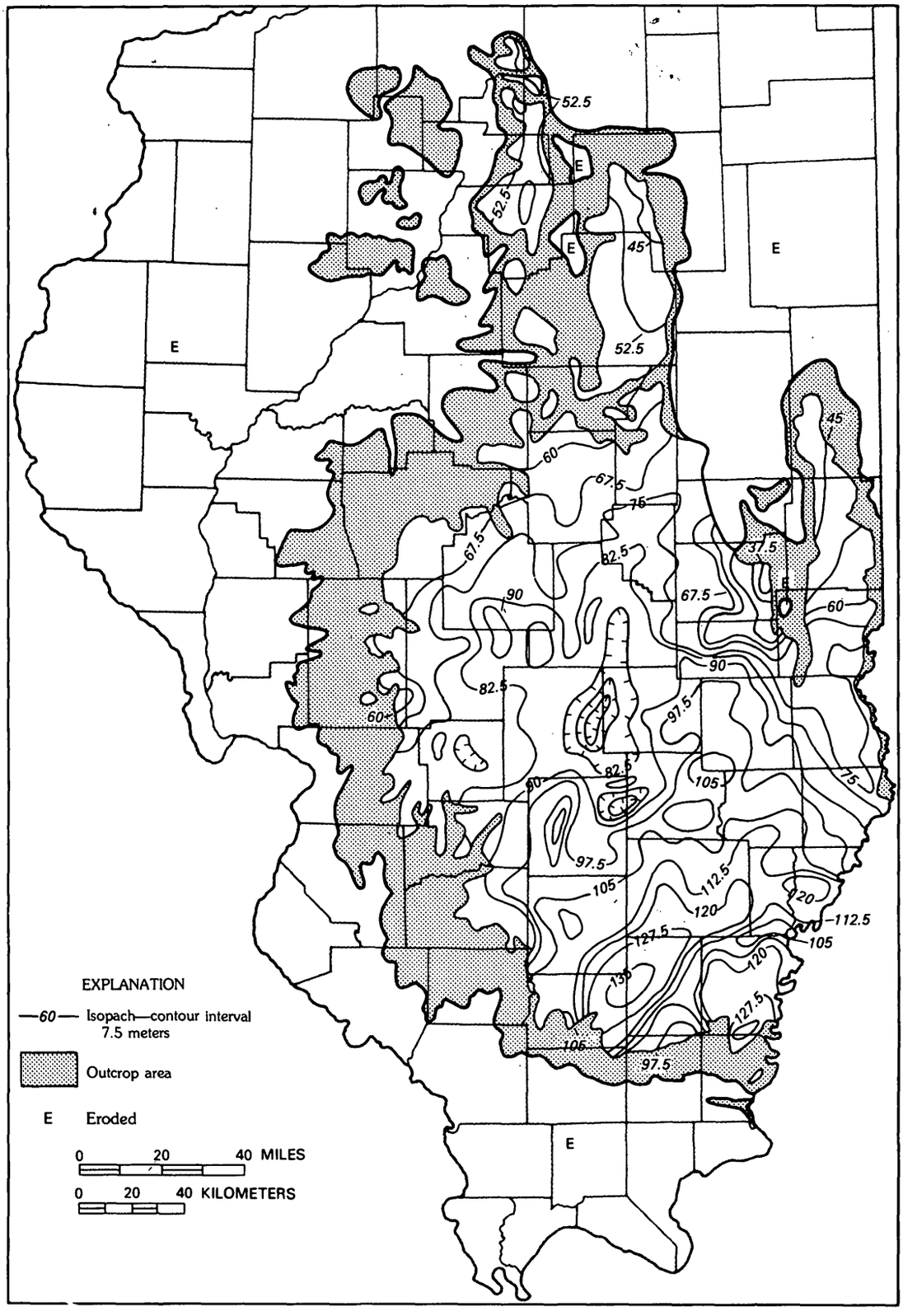

FIGURE 19.—Thickness of the Modesto Formation (Willman and others, 1975).

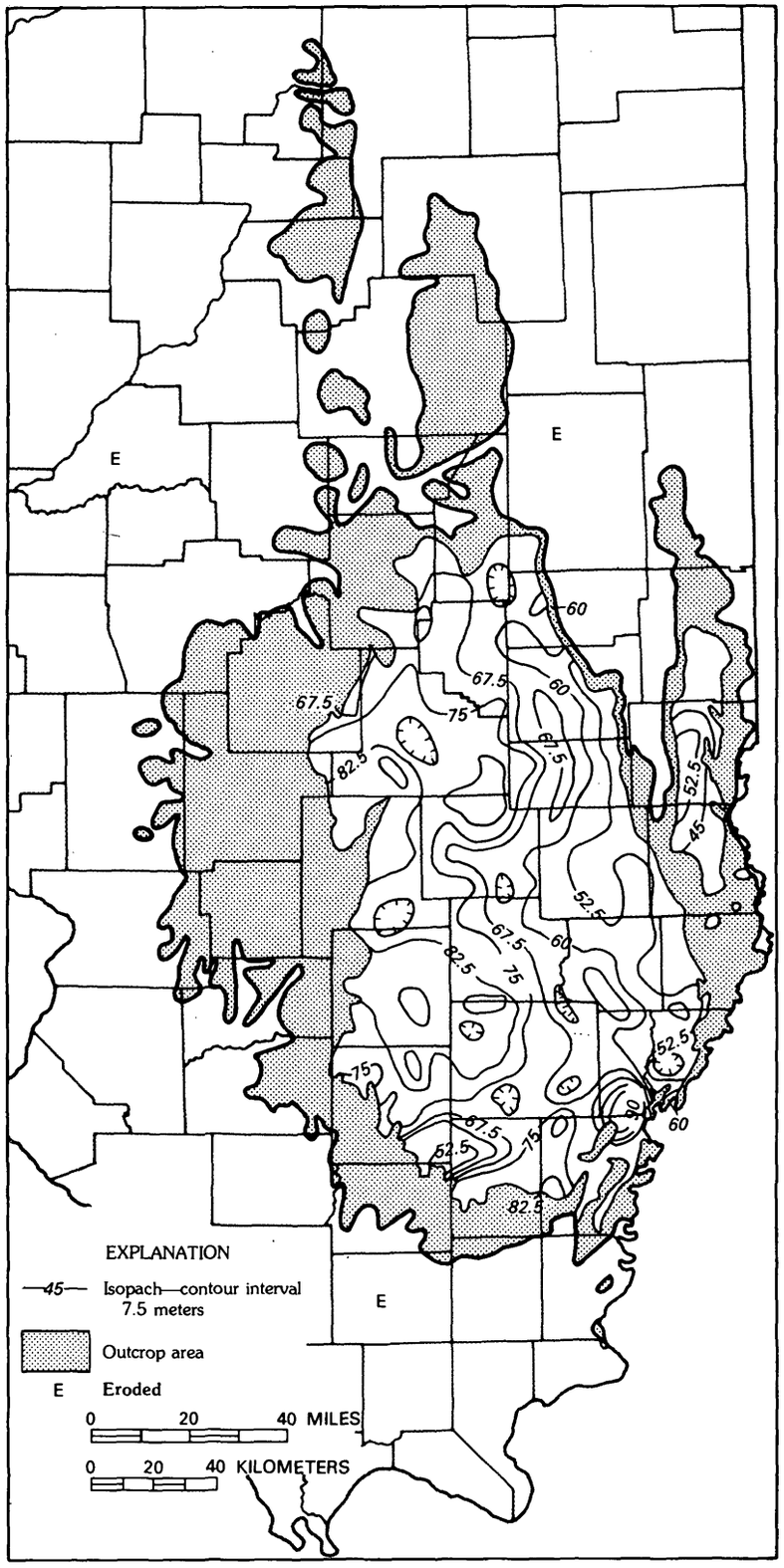

FIGURE 20.—Thickness of the Bond Formation (Willman and others, 1975).

the coal that is just below the Shumway Limestone Member. It includes the youngest Pennsylvanian-age rocks in Illinois.

Mattoon Formation.—The Mattoon Formation of the McLeansboro Group is named for the city of Mattoon, Coles County, Ill., which is located in the general outcrop area of the formation. The base of the formation is the top of the Millersville or Livingston Limestone Member; its upper boundary is an erosion surface largely covered by Pleistocene glacial deposits. No type section has been designated for the formation. A reference section for the lower 90 m of the formation has been defined in Illinois State Geological Survey Control Well 191, an oil test boring from Clay County on file at the Survey (Kosanke and others, 1960, p. 40, 83, and 84). The greatest thickness of strata of the Mattoon Formation in Illinois, slightly more than 180 m, is in Jasper County in the central part of the Illinois basin (fig. 21).

The Mattoon Formation consists largely of thick gray shales, several well-developed sandstones, black fissile shales, limestones, coals, and underclays. Most geologic data on the formation are derived from drill holes, since outcrops are widely scattered and exposed sections are relatively thin. The limestone units and coals of the Mattoon Formation are believed to be at least as persistent as others of the McLeansboro Group, but their extent cannot be determined from the limited information available. Several tan argillaceous limestones less than 1½ m thick contain only ostracodes and spirorbis. Others, including the Omega and Greenup Limestone Members, contain abundant marine fossils and are moderately thick.

The Mattoon Formation is equivalent to the upper part of the Sturgis Formation in Kentucky, but more than 200 m of strata younger than the youngest Mattoon rocks are present in the Sturgis Formation. The lowermost 45 m of Mattoon strata extend into Indiana. The named members of the formation include 10 limestones, 7 coals, and 1 sandstone (fig. 15).

CYCLOTHEMS IN ILLINOIS STRATIGRAPHY

The first clear description of cycles of strata that are now termed "cyclothems" was presented by Udden (1912) for an area in western Illinois near Peoria. He recognized a succession of strata, including coal, which was repeated almost perfectly four times. Subsequent studies indicated that repeated sequences of sedimentary strata characterize large parts of the Pennsylvanian System from at least western Pennsylvania to northern Texas. These sequences were first referred to simply as "cycles of sedimentation" by Udden (1912) and Weller (1930, 1931). Wanless and Weller believed a special term was needed for these cycles and in 1932 (p. 1003, footnote) proposed the term "cyclothem" to designate "a series of beds deposited during a single sedimentary cycle of the type that prevailed during the Pennsylvanian Period." The term won immediate acceptance and was soon in widespread use.

Although the idealized cyclothem sequence (fig. 22) is rarely complete, the units that are present retain the same relative position in sequence. Cyclothems have their greatest use in Illinois stratigraphy in aiding determination of the genetic significance of units and in detailed correlation and field mapping of Pennsylvanian strata.

The cyclothem was removed from the rock-stratigraphic classification of the Illinois State Geological Survey in 1960 (Kosanke and others, 1960) and is now included as a separate cyclical classification.

PALEONTOLOGY

Most information concerning paleontology of the Pennsylvanian System has been obtained from limestone, coal, black carbonaceous shale, and underclay limestone. Sandstone and siltstone locally may contain plant impressions and fragments, but are commonly nonfossiliferous.

The most common invertebrate macrofossils are brachiopods, crinoids, gastropods, and pelecypods. Corals, cephalopods, trilobites, foraminifers, bryozoans, and worms are also present. Biostratigraphic zones in the Pennsylvanian in Illinois are based on fusulinids, ostracodes, and spores. Floral zones for Illinois and other parts of the United States were described by Read and Mamay (1964).

Coal-bearing Pennsylvanian strata of Illinois have been fairly precisely correlated from spores and pollen in the coals. Palynological studies of other lithologic units have not been extensive, however. Major time-stratigraphic intervals are delineated by their most abundant spore taxa and by the occurrrence of certain genera and species that have relatively short stratigraphic ranges. Coals in the Illinois basin can generally be closely correlated by the study of spores.

MORROWAN SERIES

Marine fossils are rare in the Morrowan Series of Illinois, but a Morrowan fauna has been recog-

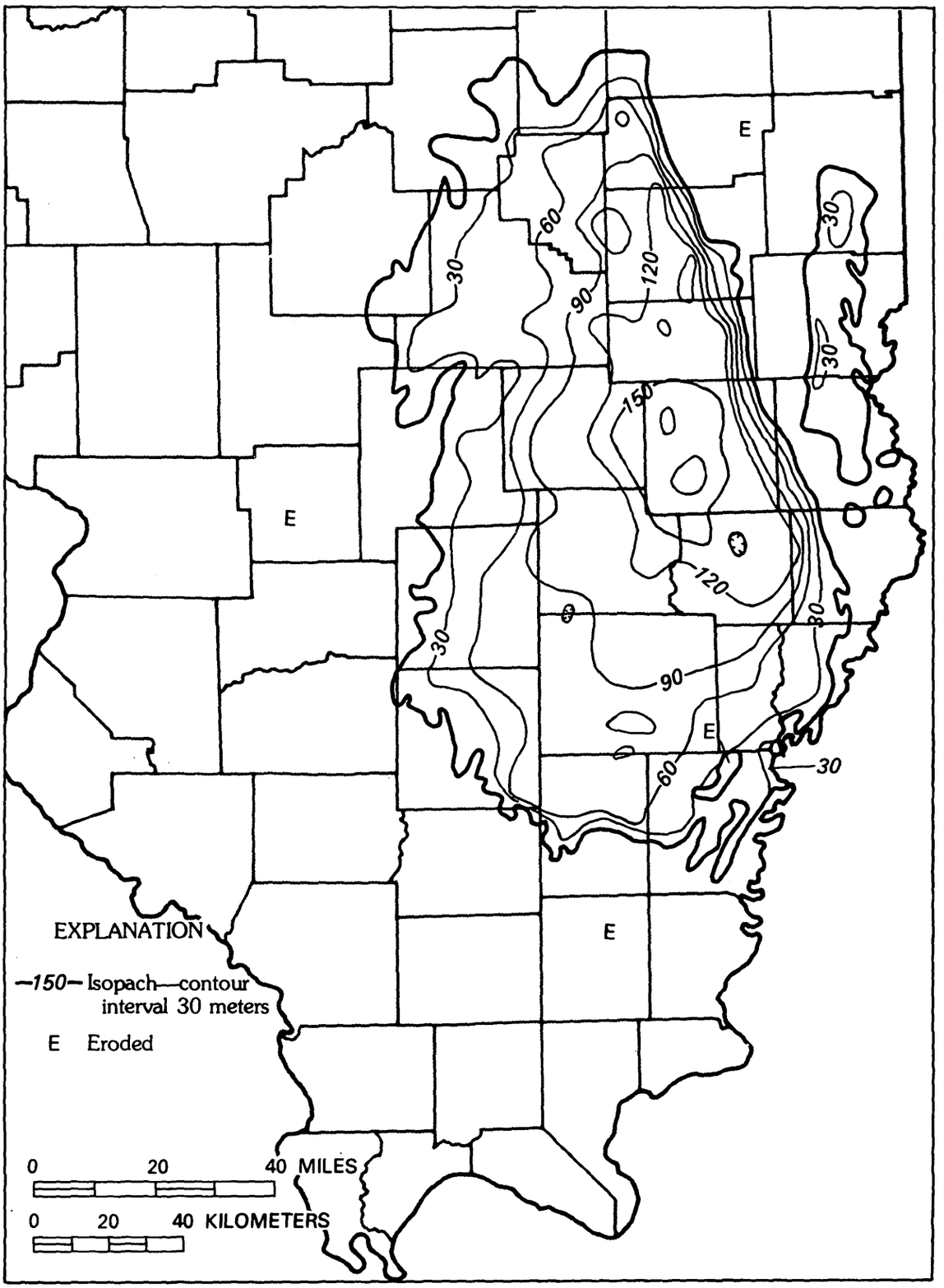

FIGURE 21.—Thickness of the Mattoon Formation (Willman and others, 1975).

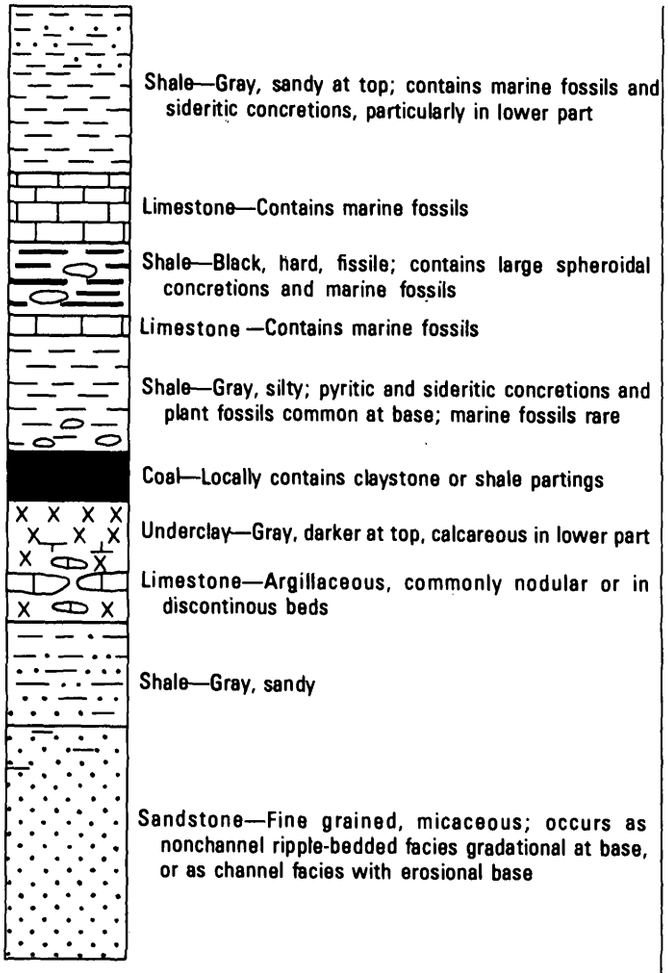

FIGURE 22.—Arrangement of lithologic units in a cyclothem (from Willman and Payne, 1942).

nized in an exposure of the Sellers Limestone Member in southeastern Illinois.

The compression plant fossils, *Neuropteris tennesseeana* and *Mariopteris pygmaea* of the Morrowan Series are in Zone 6 of Read and Mamay (1964). The roof shale of the Baldwin coal, which occurs in the Morrowan type section of Arkansas, contains a plant-impression flora similar to that above the Gentry Coal Member in southeastern Illinois. The relative ages of strata within the Morrowan Series in Illinois can best be determined from spores, which are abundant in Morrowan Series rocks of Illinois, especially in the coals. The Morrowan Series is dominated by the genus *Lycospora*, which in some coals constitutes as much as 80 percent of the spore population. Spores of herbaceous lycopods—*Densosporites, Cristatisporites,* and *Radizonates*—are also abundant.

ATOKAN SERIES

Where marine rocks are abundant, the Atokan Series is commonly characterized as the two subzones of the earliest fusiform fusulinids, *Profusulinella* and *Fusulinella,* and the top is defined as the strata below the first appearance of *Fusulina* and *Wedekindellina*; some confusion has developed because *Fusulina* has been reported in the Atokan of the type area in Arkansas.

Plant fossils for the Atokan Series are in Zone 7, *Megalopteris* spp. and in Zone 8, *Neuropteris tenufolia* of Read and Mamay (1964). Spore assemblages are the best means for correlating the Atokan strata in Illinois with Atokan strata of other areas. They are of greater diversity and their genera are more abundant and more evenly distributed than in the Morrowan Series. *Laevigatosporites, Calamites, Florinites,* and *Punctatisporites* increase in the upper part at the expense of *Lycospora,* which with *Densosporites*—especially *D. annulatus* and *Cristatisporites indignibundus*—is common in the lower part of the Atokan. Certain species of *Radiizonates* and *Torispora* are useful in defining the upper part.

DESMOINESIAN SERIES

Fusulinids are abundant in many of the limestones in Illinois, and the Desmoinesian Series is defined as the *Fusulina* Zone. *Fusulina* is confined to the Desmoinesian Series except for one reported occurrence in Atokan rocks of Arkansas. Several other invertebrates, such as *Mesolobus, Chaetetes,* and *Prismopora,* are seldom found above the top of the Desmoinesian, and certain of their species are confined to this series. The upper boundary is difficult to determine in much of Illinois, because an interval at the top of the Desmoinesian and the base of the Missourian is barren of fusulinids.

Neuropteris rarinervis in Floral Zone 9 and *Neuropteris flexuosa* and *Pecopteris* spp. in Zone 10 of Read and Mamay (1964) are included in the Desmoinesian Series. In Illinois, this series contains the thickest and most widespread coals, and *Lycospora* is the dominant spore. This genus abruptly disappears at the top of the Desmoinesian. *Thymospora pseudothiessenii,* which appears in the bottom third, also disappears at the top of the Desmoinesian. *Densosporites* occurs only in the lower half of the Desmoinesian, and *Schopfites* is diagnostic of approximately the middle third. A marked change in the spore flora is found at the Desmoinesian-Missourian boundary.

MISSOURIAN SERIES

The Missourian Series is characterized by earlier forms of the genus *Triticites*, which is the subgenus *Kansanella* of Thompson. Floral zones are not as well defined in Illinois, where the Missourian and the overlying Virgilian together constitute Zones 11 and 12 (zone of *Odontopteris* sp.) (Read and Mamay, 1964). Delineation of the ranges of spore taxa in the Missourian and Virgilian Series has not been determined with the same degree of accuracy as in the remainder of the Pennsylvanian because the stratigraphic relation of many of the coals has not been worked out in detail. Small spores of ferns and seed ferns, many less than 30 μm in diameter, are prolific in most of the Missourian and Virgilian coals. The taxa are classified as *Punctatisporites minutus, Laevigatosporites minutus,* and species of *Cyclogranisporites* and *Apiculatisporis. Endosporites* is abundant in many of the coals.

VIRGILIAN SERIES

The Virgilian Series includes strata containing fusulinids of the genus *Triticites* that are more advanced than the subgenus *Kansanella* found in lower strata. The upper limit is placed just below the first appearance of the Permian genera *Pseudoschwagerina* and (or) *Schwagerina,* but neither have been found in the Illinois basin. The spores and plant-compression fossils in Virgilian rocks of Illinois are not well known.

ENVIRONMENTS OF DEPOSITION

Pennsylvanian-age strata of the Illinois basin were deposited in a slowly subsiding trough that remained open to the south until post-Pennsylvanian time. The trough was bounded on the east by the Cincinnati arch and on the southwest by the Ozark uplift. The present closed basin was formed through uplift of the Pascola arch after close of the Pennsylvanian Period and sometime prior to late in Cretaceous time, as indicated by the presence of late Cretaceous strata of the Gulfian Series in southern Illinois, which unconformably overlie uplifted Pennsylvanian strata.

At the beginning of Morrowan time, the area that is now the Illinois basin was crossed by a series of southwestward flowing streams whose valleys were cut to depths as much as 140 m below adjacent uplands (fig. 13). These streams deposited large quantities of clastic sediments of the Caseyville Formation in the southern part of the Illinois basin, which was then open to the south. Medium- to coarse-grained sandstone containing scattered white quartz pebbles was deposited in the stream channels, which apparently underwent substantial lateral shifting of position during sedimentation. Mudstone, siltstone, and shale were deposited on floodplains adjacent to channels and also in lakes, marshes, and deltas.

Sandstone of the Caseyville Formation is highly quartzose and was evidently derived from reworked older Paleozoic strata. Distinctive characteristics of the Caseyville Formation are extreme local variability of strata and the predominance of medium- and coarse-grained clastic deposits.

Both channel-fill and sheetlike sandstones were deposited in Illinois during the Atokan Epoch. The channel sandstone apparently filled numerous fluvial and distributary channels of deltas. Crossbedding orientations suggest that most coarse clastic deposits were derived from an easterly source. Sheetlike sandstone may have been deposited largely as interdistributary sands of deltas, or as upper delta plain deposits. The Bernadotte Sandstone Member of western Illinois is a typical sheetlike sandstone that contains abundant root (Stigmaria) impressions; this indicates that it served as a soil for vegetation that produced the Rock Island (No. 1) Coal. Dark-gray mudstones of both northwestern and southern Illinois contain clay ironstone concretions and appear to have formed in interdistributary bays and lagoons. Atokan-age sediments show a progressive increase in clay and mica content; this indicates that source areas may have been stripped of sedimentary cover and that micaceous metamorphic rocks were supplying detritus.

Minor marine transgressions occurred only in the eastern part of the Illinois basin during Atokan time. The Fulda and Ferdinand Limestone Members of the Mansfield Formation in Indiana and at least two unnamed limestone beds in western Kentucky were deposited in these seas. No equivalent strata are known in Illinois.

Depositional environments of the Desmoinesian Epoch reflect a marked transition from relatively irregular fluviatile-deltaic processes to remarkably uniform regional cycles in which nearly identical depositional environments extended without interruption for hundreds of kilometers, virtually the full extent of the Illinois basin at times. During Desmoinesian time, more marine transgressions occurred in the Illinois basin than in the Appalachians, and more nonmarine strata were deposited than in areas to the west (Wanless, 1975, p. 85). Accordingly, the nature and variability of Pennsylvanian System cyclic sedimentation is better developed in

the Illinois basin than elsewhere in the United States.

Because the transgressions and regressions were relatively uniform, a single generalized depositional sequence that characterizes depositional environments of much of the Desmoinesian Epoch in the Illinois besin was described by Wanless (1975, p. 85).

Beginning with a time of maximum transgression, marine lime mud was deposited eastward from northern Missouri and Iowa into the Illinois basin, where it graded laterally into clay muds of a broad gently sloping shoreline that may have extended nearly parallel to the Cincinnati arch. At numerous points landward from the shoreline, streams fed clastic deposits into shallow seas and buried the recently deposited lime mud; construction began of a broad platform of interassociated prodelta and deltaic deposits on which a large coal swamp would later be established. Basal deposits of this unit were commonly phosphatic nodules and some fossil detritus, which graded upward into dark shale and fine, evenly laminated siltstone.

In some areas, mud of the advancing shelf-deltaic complex was eroded by river distributaries, and streams later filled some of the eroded channels with sand. As the constructional period ended, the broad shelf probably stood at or near sea level. Vegetation developed on exposed clay or sand and in shallow-water areas. In extensive areas where the water table was sufficiently high, peat accumulated.

Closely following peat accumulation in some parts of the Illinois basin was the deposition of irregular bodies of gray mudstone or shale. This deposition preceded the reestablishment of a complex marine environment. The gray shale occurs in lenses and pods, which in some areas apparently are randomly distributed but elsewhere are adjacent to large fluvial distributary channels. The gray shale bodies show evidence of erosion prior to burial by overlying marine strata. The lowermost 1 or 2 m of the gray shale locally contain impressions and casts of tree trunks, apparently in position of original growth, and woody fragments and inclusions, which suggests rapid burial of a peat swamp.

The gray shale seems to be predominantly of nonmarine origin; the shale evidently formed in association with fluvial processes (such as crevasse splays and natural levees) and as lacustrine deposits of ponded areas that existed relatively briefly before complete submergence of the peat swamps.

Following local deposition of the gray shale and limited erosion, possibly by the transgressing seas, the first sediment deposited was a black organic-rich mud that became a highly fissile, nonplastic carbonaceous shale. The shale commonly contains fish remains, inarticulate brachiopods, conodonts, and pectinoid pelecypods. The black shale is generally not present where the underlying gray shale exceeds 8 m in thickness. This fact suggests a maximum water depth of about 8 m during deposition.

After deposition of the black mud, a deeper marine environment developed. Deposits from that environment were generally lighter colored, more calcareous sediments that gradually changed to marine lime muds as water depth increased, thus completing the cycle. Advancement of prodelta mud initiated a new but similar cycle of deposition. Although many basic similarities can be recognized in the different cycles of deposition, no two are identical. The recognition of specific differences between individual cycles allows reliable correlation of individual beds over distances of several hundred kilometers.

At the beginning of the Missourian Epoch, the east-central part of the United States appears to have been more emergent than at any other time during the Middle Pennsylvanian (Wanless, 1975, p. 88). The Illinois region was subjected to erosion by many meandering rivers, whose channels were later filled with sand. As many as eight successive deltas, which consisted predominantly of mudstone and sandstone apparently derived from the northeast or north, were formed during the early part of the Missourian Epoch. No data are available concerning deltaic sedimentation late in Missouri time, but as many as six or seven deltas appear to have formed.

Numerous widespread marine transgressions, which resulted in the deposition of the thickest Pennsylvanian-age marine limestone of Illinois, are distinctive of the Missourian Epoch. Wanless (1975, p. 89) correlated these limestones with thicker limestone of the Forest City basin in the northern midcontinent region and limestones of the northern Appalachian basin, and he believed them to represent eastward transgressions of the sea for at least 1,600 km.

Mudstone and sandstone deposits of the Virgilian Epoch resemble those of the Missourian Epoch and probably represent continued deposition of fluviatile or deltaic channel deposits overlying prodelta mudstone (Wanless, 1975, p. 91). At least seven marine transgressions, probably from the west, occurred during Virgilian time, but the limestones

are commonly thin and are not as extensive as those deposited during the Missourian Epoch.

No record is available of rock strata in Illinois that may have been deposited in latest Pennsylvanian or later time, prior to deposition of Upper Cretaceous strata in southern Illinois. A strongly downfaulted graben in western Kentucky opposite Shawneetown, Ill., contains 640 m of rock strata that lie above the Shoal Creek Limestone Member (Palmer, 1976). The uppermost 460 m of these strata are not present in Illinois, and data from current studies suggest that the strata, in part, may be of Permian age (T. M. Kehn, oral commun., 1977). Damberger (1971) estimated that the depth of burial of the Herrin (No. 6) Coal Member in southeastern Illinois may have been 1,370 m or more. Because the present maximum thickness of strata overlying the No. 6 Coal in Illinois is about 400 m, more than 970 m of rock strata may have been removed by erosion.

TECTONIC DEVELOPMENT

Most major structural features of Illinois originated or had important growth and development during the Pennsylvanian Period. The systematic thinning or thickening of strata in the vicinity of active structures provides most evidence of growth. The buried erosion surface developed upon Mississippian-age strata in the Illinois basin, which was mapped by Bristol and Howard (1971), also gives evidence of tectonic activity.

The La Salle anticlinal belt consists of about 25 anticlines, synclines, and domes extending from La Salle County in northern Illinois to Lawrence County in southeastern Illinois, a distance of more than 320 km.

Old Pennsylvanian-age rocks deposited directly upon strongly uplifted and beveled late Mississippian strata indicate substantial tectonic movement along the La Salle anticlinal belt during the hiatus preceding deposition of the Pennsylvanian System. Clegg (1965) reported progressive movement throughout Pennsylvanian time and an interval of intensive uplift of all Pennsylvanian strata, that took place in either very late Pennsylvanian or post-Pennsylvanian time.

Much of the area of the La Salle anticlinal belt must have been a peninsula or archipelago during early Pennsylvanian time because no Caseyville-age strata were deposited, and the Abbott and Spoon Formations are much thinner there than elsewhere (fig. 17). The Carbondale Formation also shows moderate thinning (fig. 18). Relatively thick marine limestone of the Modesto and Bond Formations, which pass entirely across the anticlinal belt, indicate complete submergence of the area late in Pennsylvanian time. The crests of higher anticlinal and domed structures were truncated by stream erosion and are now covered by Pleistocene glacial deposits.

The Du Quoin monocline and associated Salem and Louden anticlines extend along the western margin of the Fairfield basin for nearly 160 km. The monocline forms a hinge line seperating gently dipping strata to the west from more deeply dipping rocks at the western margin of the Fairfield Basin. The monocline has local structural relief of about 150 m at the horizon of the Herrin (No. 6) Coal, and more than 300 m in rocks of late Mississippian age.

The Du Quoin monocline did not develop until after deposition of youngest Chesterian Series strata; maximum growth appears to have occurred during early and middle Pennsylvanian time. The monocline was active during deposition of both the No. 5 and No. 6 Coals and influenced coal thicknesses. The western limit of thick No. 5 Coal generally occurs at the margin of the monocline. The eastern boundary of thick No. 6 Coal in south-central Illinois is along the axes of the Salem and Loudon anticlines, which are located on the northern extension of the Du Quoin monocline in south-central Illinois. However, in southern Illinois the monocline appears not to have influenced thickness of the No. 6 Coal, possibly because no differential movement occurred during deposition of the coal.

Some large structures, such as the Centralia and Assumption anticlines, underwent major growth and uplift before deposition of Pennsylvanian strata, and some continued to grow during the Pennsylvanian Period. Others, including the Salem and Louden anticlines and deeper structures within the Fairfield basin, appear to have completed all growth and development after deposition of Pennsylvanian strata. The Illinois basin remained open to the south until after deposition of the youngest of the Pennsylvanian strata.

The southern part of the Illinois basin was strongly uplifted sometime after deposition of youngest Pennsylvanian strata and prior to deposition of oldest Upper Cretaceous rocks. This uplift was more than 3,000 m at the crest of the Pascola arch, located about 160 km south of the southern boundary of Illinois, and diminished northward. The southern margin of Illinois was uplifted about 760 m.

The precise age and duration of this uplift is unknown, but may have continued over a long period because stratigraphic studies indicate that the Pascola arch was nearly continuously eroded to base level during uplift.

Major compressional thrusting of strata from the south or southeast and some concurrent uplift produced the Rough Creek-Shawneetown-Cottage Grove fault system and Hicks dome. This deformation occurred during the interval of uplift of the southern part of the Illinois basin and may have been associated with the uplift.

ECONOMIC PRODUCTS

Coal.—At least 75 coals have been identified in the Pennsylvanian System of Illinois. Coals underlie about 65 percent of the land area of the State. Resource estimates have been completed for about 25 coals that are considered to be of minable thickness (more than 70 cm thick), and approximately 20 of the coals have been mined commercially.

A total of nearly 147 billion metric tons of coal in the category of identified resources has been determined from mine, drill-hole, and outcrop data. These resources constitute the largest deposit of identified bituminous coal in any State in the United States.

Approximately 53 million metric tons of coal were produced by Illinois mines in 1976, and total production from 1833 to the end of 1976 was about 4.2 billion metric tons. As of 1977, 60 mines were in operation in Illinois, the largest number of which are in the southern part of the State.

Illinois coal extends through the complete range of the high volatile bituminous coals. The central and northern part of the State is underlain by high volatile C bituminous coal. Rank increases progressively southeastward; a small area in southeastern Illinois contains high volatile A bituminous coal. Illinois coal generally has a high sulfur content (3 to 5 percent), although several areas have been identified where coal has a sulfur content of 0.5 to 1.5 percent.

Oil.—The first major oil fields in Illinois, discovered at shallow depths in Pennsylvanian rocks along the La Salle anticline, were developed between 1903 and 1913 and resulted in annual production of 33.1 million barrels (4,500,000 metric tons) in 1910. Since these early discoveries, approximately 600 oil fields have been discovered in Illinois, and 85, or about 14 percent, produce oil from Pennsylvanian rocks. Oil has been obtained from 14 productive zones in the Modesto, Carbondale, Spoon, Abbott, and Caseyville Formations.

Original oil-in-place in Pennsylvanian rocks is estimated to be about 1.6 billion barrels (218,000,000 metric tons). Total oil production through 1975 was about 390 million barrels (53 million metric tons). Ultimate recovery of oil from Pennsylvanian rocks is estimated to total 431 million barrels (59 million metric tons).

Gas.—Of 82 relatively small gas fields that have been discovered in Illinois, 38 have produced gas from Pennsylvanian rocks. Two hundred forty-one million cubic meters of gas, or about 34 percent of estimated total commercial gas production for Illinois, has been produced from rocks of the Pennsylvanian System.

Limestone.—More than 20 limestone beds of the Pennsylvanian System, some of which are more than 8 m thick, underlie much of the State. Thirty-four active quarries produced about 8.2 million metric tons of limestone from Pennsylvanian rocks in 1975. Although production of limestone from Pennsylvanian rocks is relatively small, many quarries are of considerable economic importance locally, because they are in areas where no other sources of limestone are readily available.

Clay.—Clay from Pennsylvanian rocks of Illinois has been used for brick manufacture since about 1818 and for tile, building block, sewer pipe, terra cotta, flue liners, stoneware, refractories, bonding clays for foundry sands, and lightweight aggregate.

In 1975, slightly more than 907,000 metric tons of clay were produced from the Pennsylvanian System for brick and tile manufacture and for use as lightweight aggregate. Buff-burning deposits, which are restricted to the Spoon and Abbott Formations, yield clay at the northern and western margins of the Illinois basin. In the central part, extensive deposits of red-burning clay and shale are essentially unlimited sources of common clay.

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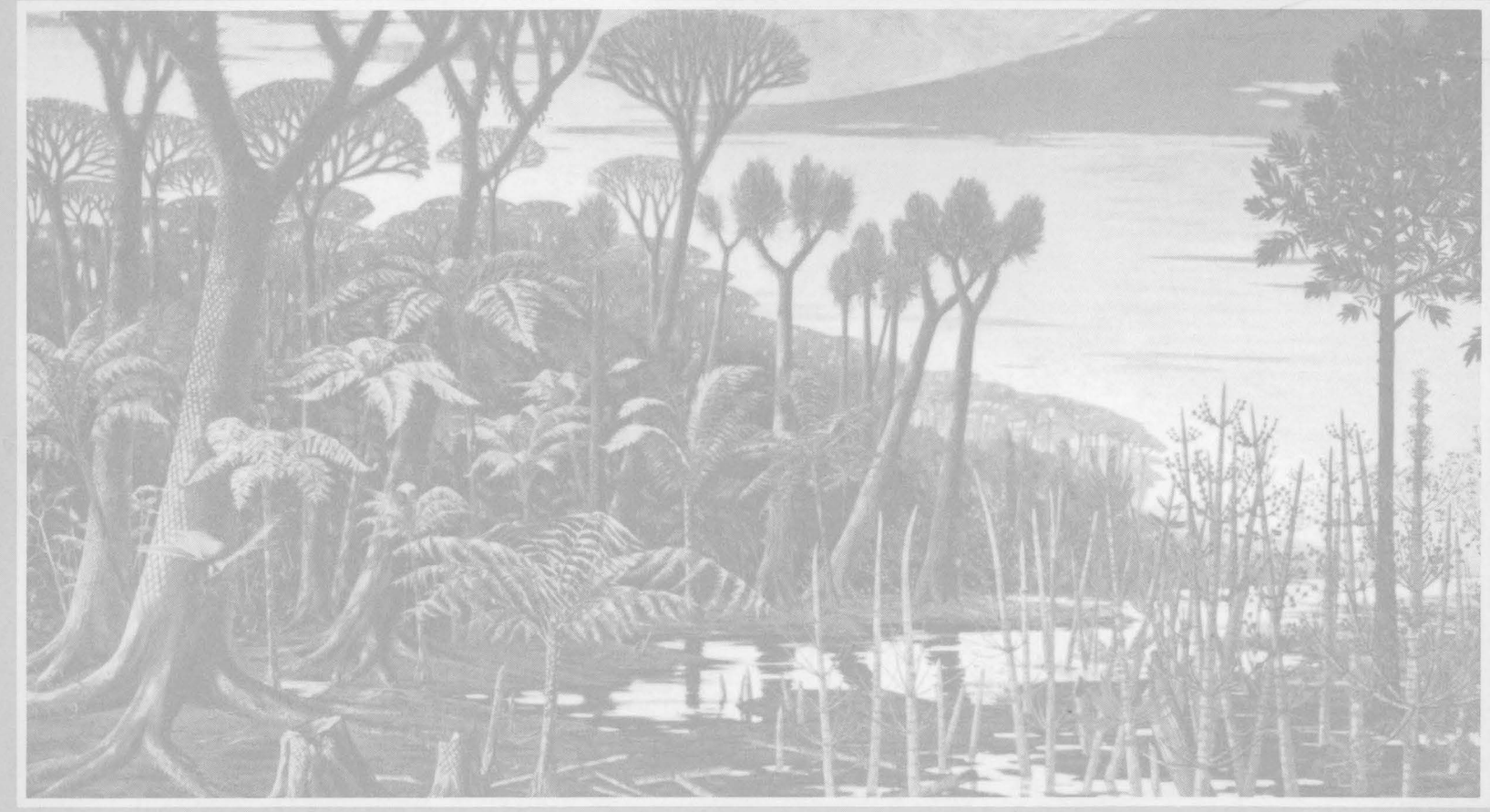
The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States



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ON THE COVER

Swamp-forest landscape at time of coal formation: lepidodendrons (left), sigillarias (in the center), calamites, and cordaites (right), in addition to tree ferns and other ferns. Near the base of the largest *Lepidodendron* (left) is a large dragonfly (70-cm wingspread). (Reproduced from frontispiece in Kukuk, Paul (1938), "Geologie des Niederrheinisch-Westfälischen Steinkohlengebietes" by permission of Springer-Verlag, New York, Inc.)

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FOREWORD

The year 1979 is not only the Centennial of the U.S. Geological Survey—it is also the year for the quadrennial meeting of the International Congress on Carboniferous Stratigraphy and Geology, which meets in the United States for its ninth session. This session is the first time that the major international congress, first organized in 1927, has met outside Europe. For this reason it is particularly appropriate that the Carboniferous Congress closely consider the Mississippian and Pennsylvanian Systems; American usage of these terms does not conform with the more traditional European usage of the term "Carboniferous."

In the spring of 1976, shortly after accepting the invitation to meet in the United States, the Permanent Committee for the Congress requested that a summary of American Carboniferous geology be prepared. The Geological Survey had already prepared Professional Paper 853, "Paleotectonic Investigations of the Pennsylvanian System in the United States," and was preparing Professional Paper 1010, "Paleotectonic Investigations of the Mississippian System in the United States." These major works emphasize geologic structures and draw heavily on subsurface data. The Permanent Committee also hoped for a report that would emphasize surface outcrops and provide more information on historical development, economic products, and other matters not considered in detail in Professional Papers 853 and 1010.

Because the U.S. Geological Survey did not possess all the information necessary to prepare such a work, the Chief Geologist turned to the Association of American State Geologists. An enthusiastic agreement was reached that those States in which Mississippian or Pennsylvanian rocks are exposed would provide the requested summaries; each State Geologist would be responsible for the preparation of the chapter on his State. In some States, the State Geologist himself became the sole author or wrote in conjunction with his colleagues; in others, the work was done by those in academic or commercial fields. A few State Geologists invited individuals within the U.S. Geological Survey to prepare the summaries for their States.

Although the authors followed guidelines closely, a diversity in outlook and approach may be found among these papers, for each has its own unique geographic view. In general, the papers conform to U.S. Geological Survey format. Most geologists have given measurements in metric units, following current practice; several authors, however, have used both metric and inch-pound measurements in indicating thickness of strata, isopach intervals, and similar data.

This series of contributions differs from typical U.S. Geological Survey stratigraphic studies in that these manuscripts have not been examined by the Geologic Names Committee of the Survey. This committee is charged with insuring consistent usage of formational and other stratigraphic names in U.S. Geological Survey publications. Because the names in these papers on the Carboniferous are those used by the State agencies, it would have been inappropriate for the Geologic Names Committee to take any action.

The Geological Survey has had a long tradition of warm cooperation with the State geological agencies. Cooperative projects are well known and mutually appreciated. The Carboniferous Congress has provided yet another opportunity for State and Federal scientific cooperation. This series of reports has incorporated much new geologic information and for many years will aid man's wise utilization of the resources of the Earth.

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