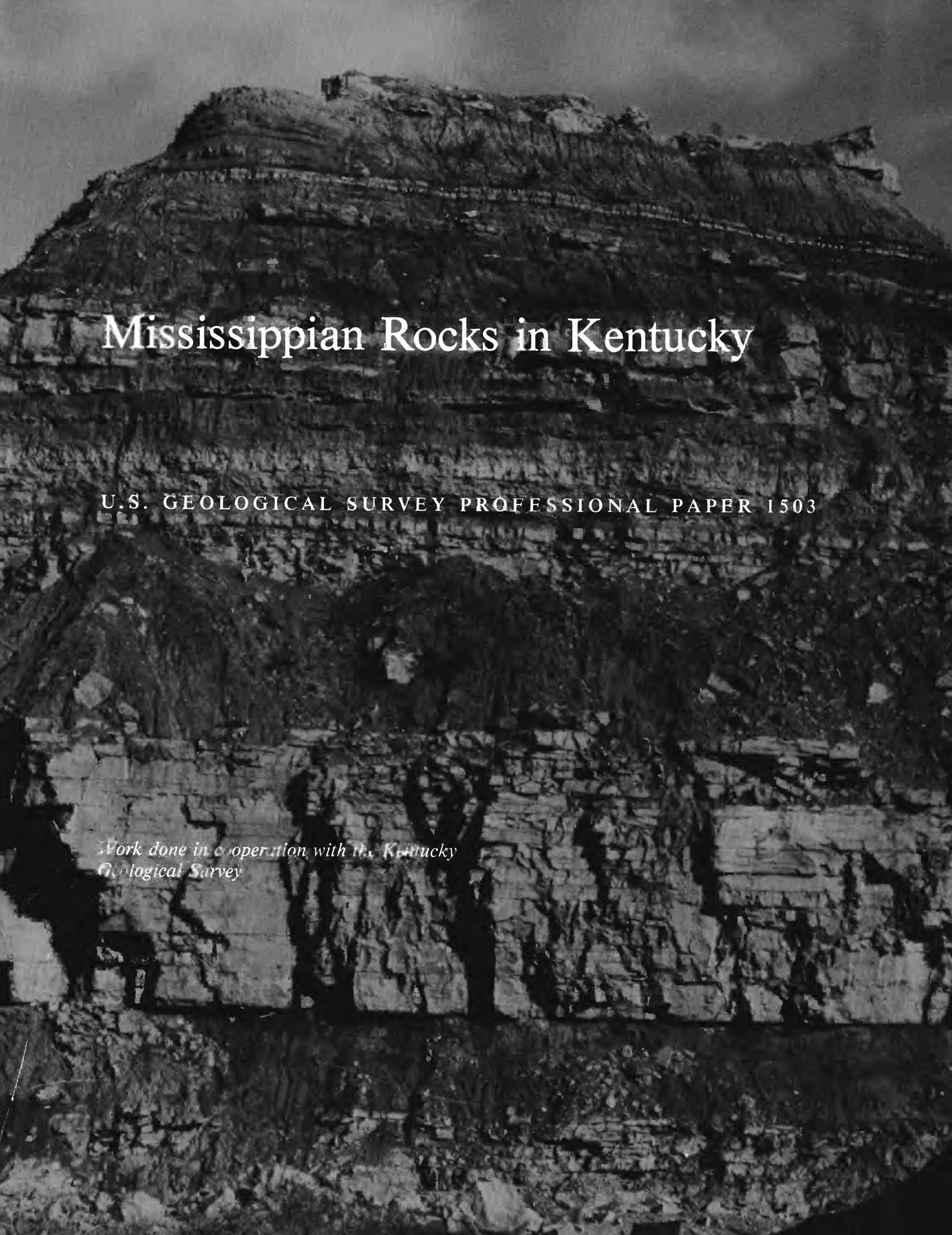

Mississippian Rocks in Kentucky

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1503

Work done in cooperation with the Kentucky Geological Survey

COVER.—Mississippian formations in Burnside quadrangle, Pulaski County, Kentucky; Monteagle Limestone, Hartselle Formation, Bangor Limestone, and Paragon (formerly Pennington) Formation.

Mississippian Rocks in Kentucky

By EDWARD G. SABLE *and* GARLAND R. DEVER, JR.

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Strata representing Kinderhookian, Osagean, Meramecian, and Chesterian Series and equivalents reflect largely marine deposition in shallow cratonic basins and on shelves and platforms

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MISSISSIPPIAN ROCKS IN KENTUCKY

By EDWARD G. SABLE and GARLAND R. DEVER, JR.[1]

ABSTRACT

Mississippian rocks in Kentucky reflect a history of largely marine deposition in shallow cratonic basins and on shelves and platforms. Strata represent the Kinderhookian, Osagean, Meramecian, and Chesterian Series and their equivalents. Maximum thicknesses of more than 2,800 feet of Mississippian strata were deposited in western Kentucky in the Eastern Interior basin, and about 2,000 feet in eastern Kentucky on the margins of the Appalachian basin. Positive structural features from which Mississippian strata have been largely eroded and which were alternately submergent and emergent during the Mississippian were the Cincinnati arch and parts of the adjacent Waverly arch. The area of the Pascola arch in westernmost Kentucky was a negative feature during most of Mississippian time. Variations in depositional thicknesses resulted from differential tectonic movements, from deposition on surfaces of uneven topographic relief, and locally, from subaerial and submarine erosion. Strata include a wide variety of complexly related detrital, chemical, and biologically derived sediments. Crustal instability within parts of the region is recorded by disconformities representing missing strata and by features interpreted to represent subaerial conditions, but few multiple hiatuses due to widespread epeirogenic movements or eustatic sea-level changes have been recognized within the stratigraphic succession.

Limestone and dolomite compose about two-thirds of the Mississippian rocks in Kentucky. Carbonate deposition, probably encroaching from the west, reached western Kentucky in Early Mississippian (Kinderhookian) time. During Osagean time deltaic sediments prograded westward as far as west-central Kentucky, and carbonates, which were initially restricted to western areas, spread as deposition of terrigenous detritus waned. Carbonate strata reached their maximum extent during Meramecian time. Although areally more restricted during Chesterian time, carbonate rocks periodically accumulated over large areas in and beyond the Eastern Interior basin and Appalachian basin. Evaporites and associated dolomitic strata were deposited during mid-Meramecian time and marked an episode of restricted circulation related to cratonic tectonism or eustatic changes.

Land-derived detrital rocks constitute about one-third of the total preserved Mississippian succession. The greatest volume of sediment was contributed from source areas in highlands northeast and east of the present Appalachians and in the eastern Canadian Shield areas; in Late Mississippian (Chesterian) time, a possible minor source area was a highland to the south or southwest of Kentucky. Large volumes of detritals from northeastern sources were deposited in Kentucky by major river systems and accumulated as deltaic complexes during deposition of the Lower Mississippian Borden Formation and in Late Mississippian (Chesterian) time. The Cincinnati arch, chiefly a barrier to sediment dispersal, may have contributed small amounts of detritus during very early Osagean and Meramecian time. Siliceous and cherty rocks are abundant in strata of Osagean age in southern and western Kentucky, and southern or eastern sources may have contributed clay-size detrital silica in these areas.

Marine sedimentary environments were mostly shallow to very shallow-water neritic over large areas during the Mississippian, but deeper water perideltaic neritic environments were present in western Kentucky during Kinderhookian, Osagean, and early Meramecian time. Seas are surmised to have opened and deepened southward and westward, with western connections to widespread Mississippian seas across and north of the Ozarks, and eastern connections to Appalachian areas through the Cumberland saddle of south-central Kentucky. Lower delta-plain environments characterized large areas of Kentucky periodically during Chesterian time.

In general, westward-deepening, low-energy environments are indicated by the fining grain size of Kinderhookian rocks, and shallower higher energy environments are indicated by coarser and better sorted rocks in Osagean and early Meramecian time. Deposits of middle Meramecian age indicate a low-energy environment, and alternations of high- and low-energy environments characterize Chesterian time. Mississippian rocks attest to a mild climatic regimen during the period, with aridity in mid-Meramecian time, and possibly an intermittently wet climate during Chesterian time.

Northeast- and northwest-trending structures, mostly inherited from Late Devonian time, characterize the Mississippian tectonic framework. Northeast-trending negative structural features responded most actively to tectonic stresses. Positive structural features such as the Cincinnati arch and Waverly arch influenced some Mississippian depositional patterns. Crosscutting linear features, now expressed as the Rough Creek and Kentucky River fault systems, were active fault zones or hinge lines during the Late Mississippian.

Tectonic movements affecting the region during Mississippian time probably included relative uplift and partial emergence of the Transcontinental arch west of Kentucky, and corresponding subsidence of a subparallel northeast-trending trough, the Michigan and Eastern Interior basins, following Kinderhookian time. Regional southwest- and west-dipping paleoslopes developed during Osagean time and persisted into Pennsylvanian time. Relative uplift of preexisting positive structural features resulted in restricted seas during Meramecian time. At about the close of Chesterian time, a major episode of southward tilting and general emergence took place, preceding deposition of Pennsylvanian sediments. These structural movements were accompanied by marked beveling of strata near basin margins and on some gentle uplifts within the basins, and by widespread channel-cutting.

INTRODUCTION

This report summarizes the lithostratigraphy of Mississippian rocks in Kentucky. It includes descriptive and nomenclatural discussions and some resulting environmental and tectonic interpretations.

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[1]Kentucky Geological Survey, Lexington, KY.

Many significant features described and discussed in this report are referenced to the 1961–1978 GQ maps or other relatively recent publications, although some of these features had been recognized by earlier workers. Where appropriate, the previous work is cited as well.

HISTORY OF INVESTIGATIONS

Summary reports on Mississippian rocks of Kentucky and adjoining States include chapters in Miller (1919), McFarlan (1943), and Cumings (1922), and reports by Weller and Sutton (1940), Swann (1963), Shaver and others (1970), Pryor and Sable (1974), Willman and others (1975), Sable (1979a), and Rice and others (1979). A sobering review of difficulties and inconsistencies pertaining to mappability of some formational contacts bearing on series and other time-equivalent boundaries, encountered during the 1960–1978 mapping program, was given by Pohl (1970).

The development of stratigraphic nomenclature of Mississippian strata in Kentucky and adjacent States falls into four general stages. During 1854–1900, systemic, series, and formational names for gross units based on lithology and faunal content were first introduced. Most stratigraphic names such as St. Louis and Ste. Genevieve were extended from adjoining States, although some, such as Knobstone and Mammoth Cave, were of Kentucky origin.

Between about 1900 and 1930, units were subdivided and in part renamed by workers such as Stuart Weller, E.O. Ulrich, and Charles Butts. Intensive systematic studies of macrofossil taxonomy and its use for correlation purposes marked this period. The Mississippian and Pennsylvanian outcrop belt along the margins of the Eastern Interior basin was mapped in relative detail by cooperative arrangement of State surveys (J.M. Weller and Sutton, 1940); and meaningful regional correlations, particularly of Upper Mississippian rock units, were accomplished.

During the period 1930–1960, concepts of time-equivalent but lithologically different sedimentary rock facies were stressed. Stockdale (1931, 1939) used these concepts in his studies of Lower Mississippian rocks in Indiana and Kentucky. Divisions and correlations of Upper Mississippian rock units in west-central and western Kentucky were refined by Stouder (1938, 1941) and McFarlan and others (1955), in eastern Kentucky by McFarlan and Walker (1956), and in nearby southern Indiana by Malott (1952). In northeastern Kentucky and adjoining States, a pioneer surface and subsurface regional study incorporating lithologic correlations of lowermost Mississippian and uppermost Devonian clastic units with interpretations of sedimentary environments and paleogeography was completed by Pepper and others (1954). In cooperative arrangement between the U.S. Geological Survey and the Commonwealth of Kentucky, all 7½-minute quadrangles in Kentucky were mapped topographically on a 1:24,000 scale, setting the stage for detailed geologic mapping.

Between 1960 and 1978, Kentucky was mapped geologically on 7½-minute quadrangles, at a scale of 1:24,000 (Cressman and Noger, 1981). Many refinements were made in Mississippian lithostratigraphic interpretations and nomenclature. During this period mappers recognized the Early Mississippian Borden delta complex and delineated its morphology. Relationships of Upper Mississippian strata in eastern Kentucky were also clarified during the mapping program. Mapping of major sandstone-filled channels in Chesterian rocks in western and west-central Kentucky led to development of a deltaic model of deposition like that previously interpreted for similar deposits in Illinois. Resource investigations by the Kentucky Geological Survey of oil, gas, limestone, and clays in Mississippian rocks accompanied the stratigraphic studies. Finally, other investigators in academic, industry, and government circles used the geologic maps as bases for research on Mississippian stratigraphic, sedimentation, faunal, and engineering studies—as evidenced by the many reports cited in this text.

Since 1978, further studies of Lower and Upper Mississippian rocks, mostly in eastern Kentucky, have been accomplished by Kentucky Geological Survey personnel and faculty and students from many universities. These studies continue, using the GQ maps as practical framework references.

SCOPE AND METHODS

Sources for this report are mainly published surface information. U.S. Geological Survey Geologic Quadrangle (GQ) maps, products of the 1960–1978 U.S. Geological Survey and Kentucky Geological Survey cooperative program, provided most of the basic data. Borehole data were obtained from published and unpublished reports and Kentucky Geological Survey files, and included sample-study logs, drillers' logs, and geophysical logs interpreted by us and other investigators. Paleontological determinations and use of identifiable fossils by field geologists are incorporated here mostly as practical biostratigraphic tools evaluated during the mapping program. Other data used in this report are cited from dissertations, theses, and other studies which developed concurrently with or subsequent to the mapping program, until about 1983. The reader is also directed to the most recent geologic map of Kentucky (McDowell and others, 1981; McDowell, 1986), which depicts the distribution of Mississippian rocks and those of other systems.

The bases for changes in Mississippian stratigraphic nomenclature during the 1960–1978 mapping program, such as those of the Borden Formation and its members, and new names for units of Meramecian and Chesterian age in southern and eastern Kentucky, are the criteria of mappability of lithologic units and of continuity of strata as proved or inferred by detailed mapping. However, suggested nomenclatural changes for some Mississippian units based on the above criteria have not been adopted, and therefore some nomenclatural inconsistencies remain. One of these is the continued use of the name Warsaw in Kentucky; another is the use of Chesterian formational names over wide areas within which some named units vary considerably in lithology. For the most part, however, Mississippian terminology in Kentucky used in the Geologic Quadrangle maps follows the Code of Stratigraphic Nomenclature (American Commission on Stratigraphic Nomenclature, 1961, 1970, 1983).

Regional thicknesses of Mississippian rock units, shown herein in figures 51–64, are based on approximate thicknesses calculated for each Geologic Quadrangle (GQ), thicknesses derived from data given in columnar sections and from measurements based on map patterns. Data from about 200 surface and subsurface stratigraphic sections were also incorporated. Plotting of lithofacies for individual units or intervals, in most cases, resulted in rather poor definition of trends; instead a more specific portrayal of lithic types such as sandstone, shale, and limestone and their approximate limits are shown in some thickness maps in this report.

Field photographs in this report were taken by G.R. Dever, Jr., in 1986 and 1987.

ACKNOWLEDGMENTS

W.W. Hagan, Director of the Kentucky Geological Survey, and his staff, and A.D. Zapp, P.W. Richards, W.W. Olive, and E.R. Cressman, successive Chiefs of the Kentucky Geology Branch of the U.S. Geological Survey, deserve special thanks for the successful implementation and completion of the cooperative mapping program.

We wish also to acknowledge the work done by the many U.S. Geological Survey field geologists who mapped Mississippian rocks in Kentucky. G.W. Weir, R.C. Kepferle, R.D. Trace, J.C. Philley, W.L. Peterson, R.Q. Lewis, Sr., D.H. Amos, R.C. McDowell, A.R. Taylor, and Benjamin Gildersleeve made special contributions to the description, measurement, analysis, and synthesis of Mississippian strata in several Kentucky areas.

GEOLOGIC FRAMEWORK

The centrally located Eastern Interior basin (fig. 1), also referred to as the Illinois Basin by some investigators (McDowell, 1986), is a major negative element of the eastern midcontinent region. It encompasses much of western Kentucky, Illinois, and Indiana, and parts of Missouri and west-central Tennessee. The western margin of the larger Appalachian basin trends southwest through eastern Kentucky. Major positive cratonic elements within Kentucky are the Cincinnati arch, including the Jessamine dome and Cumberland saddle, the east side of the Pascola arch, and the Waverly arch.

Maximum structural relief of the Precambrian surface in the Eastern Interior basin is about 8,500 ft; that of the Appalachian basin is about 15,000 ft in Kentucky, but is as much as 20,000 ft farther east (King, 1969). In the Eastern Interior basin, Mississippian strata are more than 2,700 ft thick in western Kentucky and about 3,300 ft thick in southern Illinois (Sable, 1979a); in the Appalachian basin they are as much as 2,000 ft thick in southeasternmost Kentucky and are more than 7,000 ft thick farther east in southwestern Virginia (de Witt and McGrew, 1979).

Mississippian rocks crop out near the major positive structures in Kentucky such as the Cincinnati arch, Pascola arch, and Waverly arch; a narrow belt of outcrop also occurs along the west side of Pine Mountain in southeastern Kentucky (fig. 2). Because of an extensive cover of Pennsylvanian rocks, however, most Mississippian strata in Kentucky occur in the subsurface.

Strata of Mississippian age constitute the bedrock in about two-thirds of the area of Kentucky, about 25,850 of the total 40,395 mi^2. The volume of Mississippian rocks in Kentucky is about 1,965 mi^3, of which roughly 60 percent are marine carbonate and siliceous rocks, and 40 percent are dominantly marine and marginal marine shale, siltstone, and sandstone.

Faults that displace Mississippian rocks are the east-southeast-trending Rough Creek–Shawneetown and Pennyrile fault systems in western Kentucky, and the colinear east-northeast-trending Irvine–Paint Creek fault system in eastern Kentucky. Numerous faults also strike north-northeast to east-northeast from the Mississippi Embayment of westernmost Kentucky and adjoining States. The Kentucky River fault system strikes

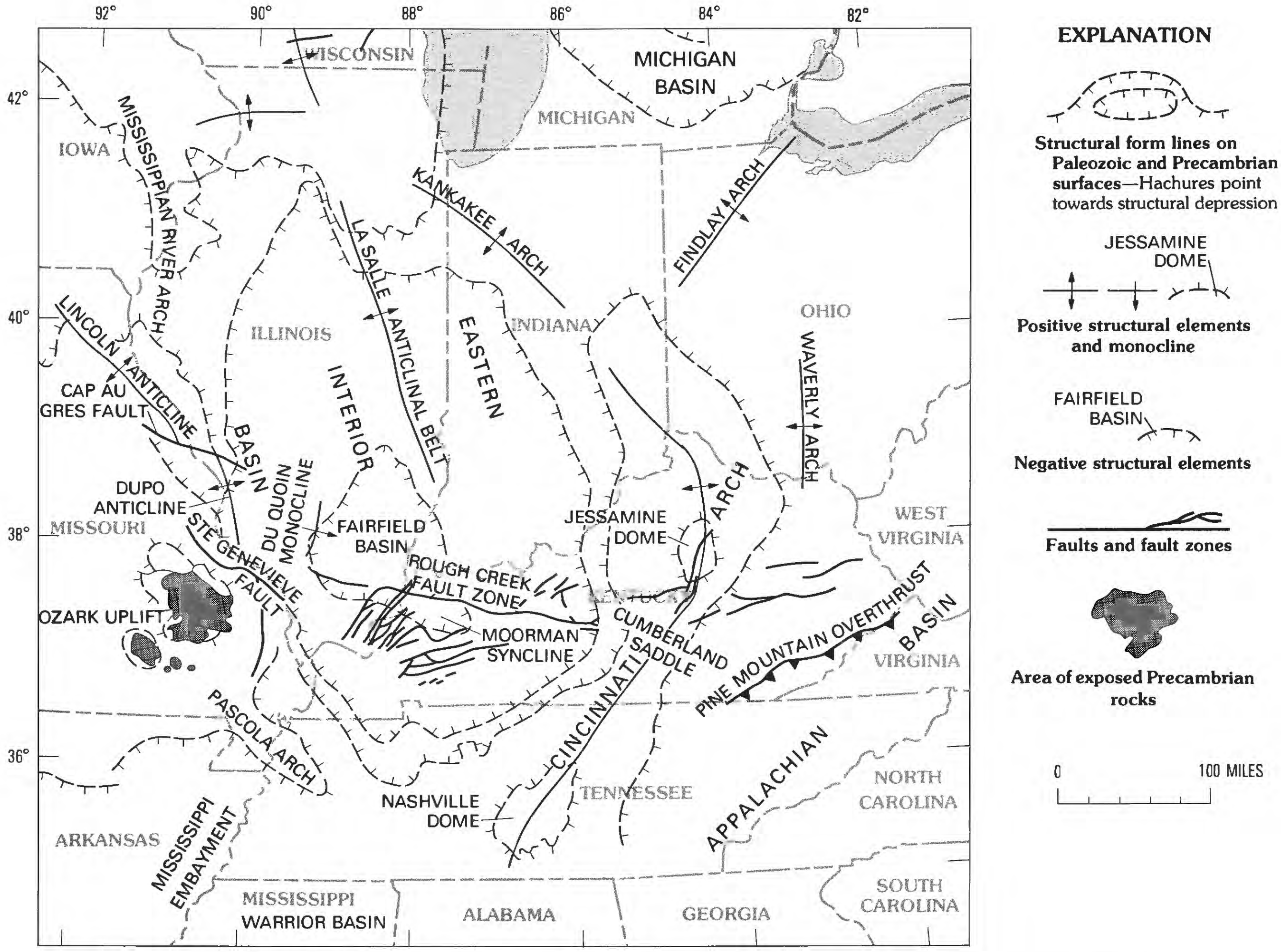


FIGURE 1.—Generalized structural elements of Kentucky and adjoining areas. Modified from Sable (1979a).

east-northeastward from the Jessamine dome of central Kentucky, and extends across eastern Kentucky in the subsurface. The easterly trending fault systems across Kentucky are considered to be related to the 38th parallel lineament (Heyl, 1972), possibly the trace of a major east-west basement fault. Movement along major faults shown on figure 1 displaces all Paleozoic rocks, but locally, earlier movements on these faults seem to have influenced at least Late Mississippian deposition.

Geographic divisions in Kentucky used in this report are along quadrangle boundaries. Mississippian rocks crop out mainly in the northeastern, east-central, south-central, west-central, western part of the central, and in the western geographic divisions (fig. 3). Mississippian surface exposures have been mapped in more than 360 Kentucky quadrangles (fig. 4 and table 1). In addition, selected outcrop and borehole sections of Mississippian rocks were used during report preparation (fig. 5; indexed in Varnes (1979)). The sections represented range from complete sections of Mississippian strata to partial sections representing rocks of a single Mississippian series.

Kentucky and surrounding areas were almost continuously inundated by Mississippian epeiric seas in which a variety of detrital and chemical sedimentary rocks were deposited. Terrigenously derived clastics were mostly deposited in deltas, and were derived from major source areas east, northeast, and perhaps south of Kentucky during the Mississippian. Carbonate deposits accumulated in areas adjoining lobes of detrital sediments or during times when little detritus was being transported. Arid climate and restricted circulation of shallow marine waters during the middle part of Mississippian time resulted in evaporite precipitation. In Late Mississippian time rhythmic alternations of carbonate- and detrital-dominated units characterized deposition on a relatively stable shelf in western

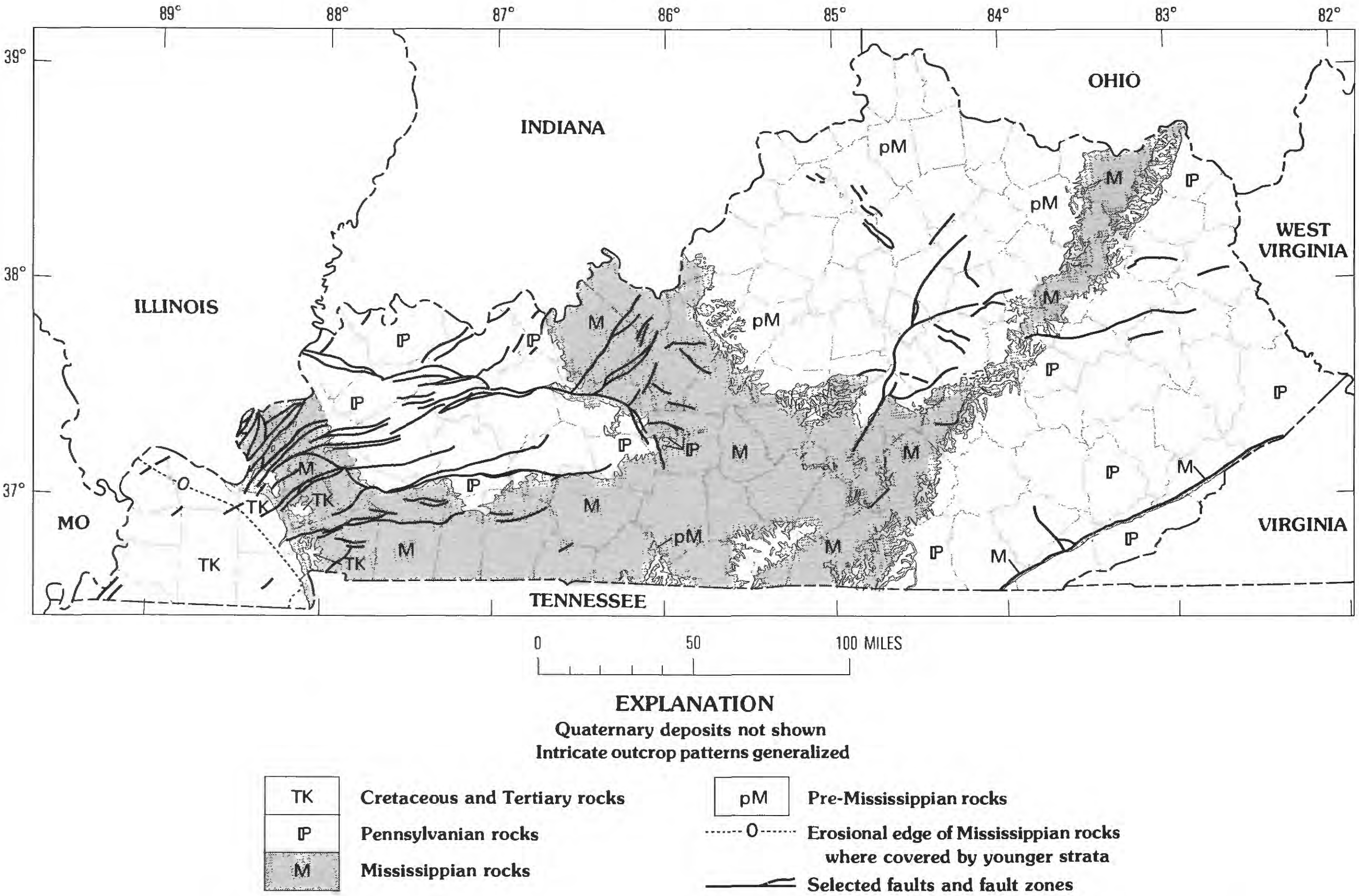


FIGURE 2.—Distribution of Mississippian, pre-Mississippian, and post-Mississippian rocks exposed in Kentucky.

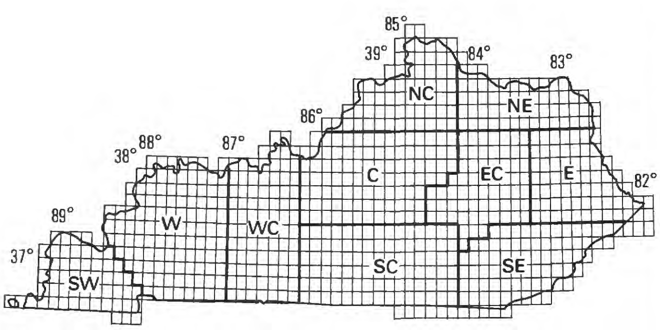


FIGURE 3.—Map of Kentucky showing 7½-minute quadrangle boundaries and geographic divisions used in this report (C, E, N, S, W refer, respectively, to central, east, north, south, and west).

Kentucky and to some extent on an unstable shelf in eastern Kentucky.

The Eastern Interior basin region, which includes central, west-central, and western Kentucky, contains the standard type section for the Mississippian System in North America. The Mississippian System divisions equate with the lower part of the Carboniferous System of Europe. The Mississippian Series in the United States include the Kinderhookian (Meek and Worthen, 1861), Osagean (Branner, 1888), Meramecian (Ulrich, 1904), and Chesterian (Worthen, 1860). These four series have been adopted by the U.S. Geological Survey and several State surveys in the Eastern Interior basin. The Illinois State Geological Survey currently uses a three-fold series subdivision, the Kinderhookian, Valmeyeran (combined Osagean and Meramecian), and Chesterian Series. In south-central and eastern Kentucky, the U.S. Geological Survey adheres to an informal two-fold designation: Lower (Kinderhookian and Osagean age equivalents), and Upper (Meramecian and Chesterian equivalents) Mississippian.

Classification of Mississippian and other Paleozoic strata in the region, other than conventional rock- and time-stratigraphic designations, are classifications by Megagroup (Swann and Willman, 1961) and Sequence (Sloss and others, 1949; Sloss, 1963; fig. 6 of this report). Although the Megagroup and Sequence concepts are

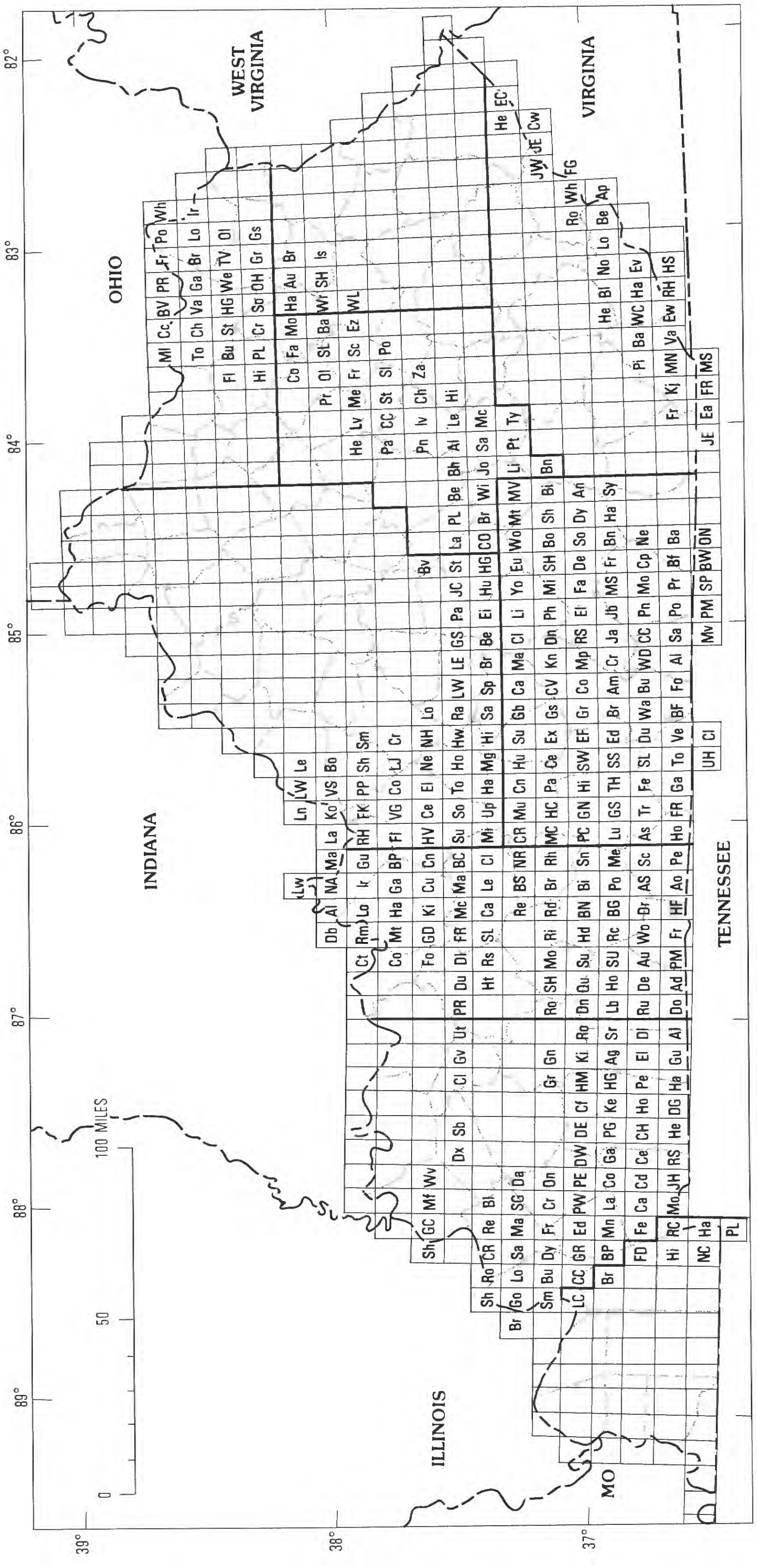


FIGURE 4.—Index map of Kentucky showing quadrangles in which Mississippian rocks are exposed. (See pl. 1 and table 1 for full quadrangle names.)

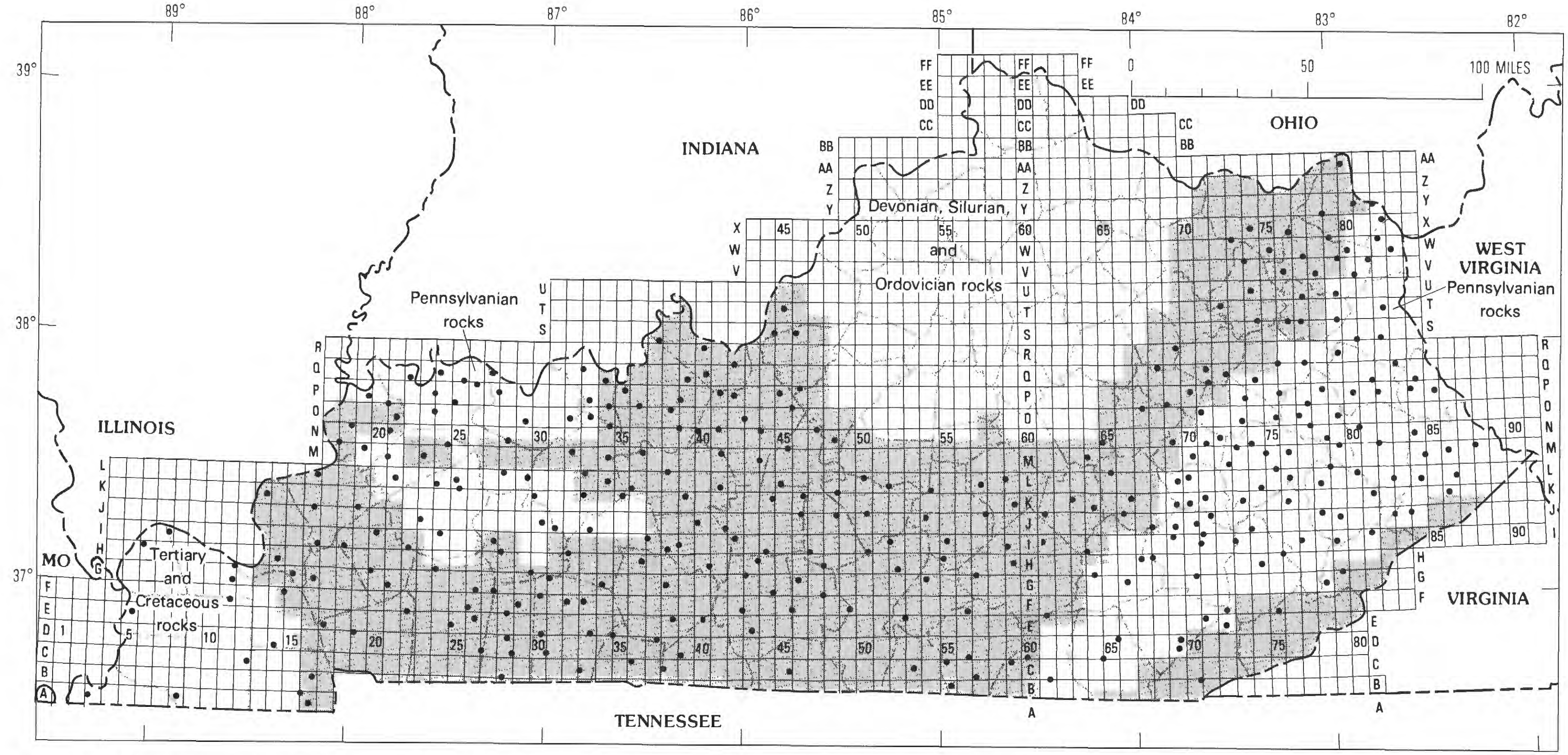


FIGURE 5.—Map of Kentucky showing control point localities (•) of Mississippian surface and subsurface information other than that from geologic quadrangle maps. Exposure areas of Mississippian rocks patterned. Lettered grid depicts Carter Coordinate system. For index to localities see Craig and Connor (1979, pl. 1) and Varnes (1979, p. 492–497).

TABLE 1.—*Kentucky 7½-minute U.S. Geological Survey geologic quadrangle (GQ) maps in which Mississippian rocks are exposed*
[See figs. 3 and 4 for geographic subdivisions and quadrangle abbreviations]

Quadrangle abbreviation	Quadrangle name	County/State	Author	GQ Number	Year published
		Southwestern Kentucky			
Br	Briensburg	Marshall	T.W. Lambert and L.M. MacCary.	327	1964
FD	Fairdealing	Marshall, Trigg, Lyon, and Calloway.	E.W. Wolfe	320	1964
Ha-PL	Hamlin–Paris Landing	Calloway	L.V. Blade	498	1966
Hi	Hico	Calloway and Marshall	W.W. Olive	332	1965
LC	Little Cypress	Livingston, Marshall, and McCracken/Ill.	D.H. Amos and E.W. Wolfe.	554	1966
NC	New Concord–Buchanan	Calloway	H.G. Wilshire	313	1964
RC	Rushing Creek	Calloway, Trigg, and Marshall.	D.A. Seeland and H.G. Wilshire.	445	1965
		Western Kentucky			
Ag	Allegre	Todd	Harry Klemic	446	1965
Al	Allensville	Todd and Logan/Tenn.	Harry Klemic	502	1966
BP	Birmingham Point	Lyon, Marshall, Livingston, and Trigg.	K.F. Fox, Jr., and W.W. Olive.	471	1966
Bl	Blackford	Crittenden, Webster, and Union.	D.H. Amos	873	1970
Bu	Burna	Livingston	D.H. Amos	1150	1974
Cd	Cadiz	Trigg	K.F. Fox, Jr.	412	1965
Ce	Caledonia	Trigg and Christian	G.E. Ulrich and Harry Klemic.	604	1966
Cl	Calhoun	McLean and Hopkins	W.D. Johnson, Jr., and A.E. Smith.	1239	1975
CC	Calvert City	Livingston and Marshall	D.H. Amos and W.I. Finch	731	1968
Ca	Canton	Trigg	K.F. Fox, Jr., and D.A. Seeland.	279	1964
CR	Cave in Rock	Crittenden	R.D. Trace	1201	1974
CH	Church Hill	Christian	G.E. Ulrich	556	1966
Co	Cobb	Trigg and Caldwell	D.A. Seeland	710	1968
Cr	Crider	Caldwell	W.B. Rogers and R.D. Trace.	1283	1976
Cf	Crofton	Christian and Hopkins	T.M. Kehn	1361	1977
Da	Dalton	Hopkins, Caldwell, Crittenden, and Webster.	J.E. Palmer	490	1966
DE	Dawson Springs SE	Christian and Hopkins	R.D. Trace	1365	1977
DW	Dawson Springs SW	Caldwell and Christian	D.E. Hansen	1061	1973
Dx	Dixon	Webster	D.E. Hansen	1293	1976
Dy	Dycusburg	Crittenden, Livingston, and Lyon.	D.H. Amos and W.H. Hays.	1149	1974
Ed	Eddyville	Lyon and Caldwell	W.B. Rogers	255	1963
El	Elkton	Todd	F.R. Shawe	650	1967
Fe	Fenton	Trigg and Marshall	R.W. Schnabel and J.S. MacKallor.	317	1964
Fr	Fredonia	Caldwell, Crittenden, and Lyon.	W.B. Rogers and W.H. Hays.	607	1967

TABLE 1.—*Kentucky 7½-minute U.S. Geological Survey geologic quadrangle (GQ) maps in which Mississippian rocks are exposed*—Continued

[See figs. 3 and 4 for geographic subdivisions and quadrangle abbreviations]

Quadrangle abbreviation	Quadrangle name	County/State	Author	GQ Number	Year published
		Western Kentucky—Continued			
Gv	Glenville	McLean and Daviess	W.D. Johnson, Jr., and A.E. Smith.	1046	1972
Go-Br	Golconda-Brownfield	Livingston	D.H. Amos	546	1966
Ga	Gracey	Trigg and Christian	W.H. Nelson and D.A. Seeland.	753	1968
Gr	Graham	Christian, Hopkins, and Muhlenberg.	T.M. Kehn	765	1968
GR	Grand Rivers	Lyon and Livingston	W.H. Hays	328	1964
Gn	Greenville	Muhlenberg	T.M. Kehn	907	1971
GC-Sh	Grove Center-Shawneetown	Union	J.E. Palmer	1314	1976
Gu	Guthrie	Todd/Tenn.	Harry Klemic	539	1966
HM	Haleys Mill	Christian, Muhlenberg, and Todd.	R.D. Trace	1428	1977
Ha	Hammacksville	Christian and Todd/Tenn.	Harry Klemic	540	1966
He	Herndon	Christian/Tenn.	Harry Klemic	572	1966
HG	Honey Grove	Christian and Todd	Harry Klemic	376	1965
Ho	Hopkinsville	Christian	Harry Klemic	651	1967
JH	Johnson Hollow	Trigg	Harry Klemic, G.E. Ulrich and S.L. Moore.	722	1968
Ke	Kelly	Christian	T.P. Miller	307	1964
Ki	Kirkmansville	Muhlenberg and Todd	T.M. Kehn	1421	1977
La	Lamasco	Lyon, Trigg, and Caldwell.	R.D. Sample	608	1967
Lo	Lola	Crittenden and Livingston.	R.D. Trace	1288	1976
Ma	Marion	Crittenden and Caldwell	R.D. Trace	547	1966
Mo	Model	Trigg County, Linton topographic quadrangle.	W.B. Rogers	409	1965
Mn	Mont	Lyon and Trigg	P.L. Weis and P.K. Theobald.	305	1964
Mf	Morganfield	Union	W.D. Johnson, Jr., A.E. Smith, and G.M. Fairer.	1269	1975
OG	Oak Grove	Christian/Tenn.	Harry Klemic	565	1966
Ol	Olmstead	Todd and Logan	G.E. Ulrich	553	1966
On	Olney	Caldwell and Hopkins	R.D. Trace and T.M. Kehn.	742	1968
PG	Pleasant Green Hill	Christian	W.H. Nelson	321	1964
Pe	Pembroke	Christian and Todd	S.L. Moore	709	1968
PE	Princeton East	Caldwell	R.D. Trace	1032	1972
PW	Princeton West	Caldwell and Lyon	R.D. Sample	385	1965
Re	Repton	Crittenden	D.A. Seeland	754	1968
RS	Roaring Spring	Trigg and Christian/Tenn.	Harry Klemic and G.E. Ulrich.	658	1967
Ro	Rosewood	Muhlenberg, Todd, and Logan.	T.M. Kehn	1445	1978

TABLE 1.—*Kentucky 7½-minute U.S. Geological Survey geologic quadrangle (GQ) maps in which Mississippian rocks are exposed*—Continued

[See figs. 3 and 4 for geographic subdivisions and quadrangle abbreviations]

Quadrangle abbreviation	Quadrangle name	County/State	Author	GQ Number	Year published
		Western Kentucky—Continued			
Sa	Salem	Crittenden and Livingston.	R.D. Trace	206	1962
Sb	Sebree	Webster	D.E. Hansen	1238	1975
SG	Shady Grove	Crittenden and Caldwell	R.D. Trace and J.E. Palmer.	880	1971
Sr	Sharon Grove	Todd and Logan	G.E. Ulrich	482	1966
Sh-Ro	Shetlerville-Rosiclare	Livingston and Crittenden.	D.H. Amos	400	1965
Sm	Smithland	Livingston	D.H. Amos	657	1967
Ut	Utica	McLean, Daviess, and Ohio.	W.D. Johnson, Jr., and A.E. Smith.	995	1972
Wv	Waverly	Union and Henderson	G.M. Fairer	1220	1975
		West-central Kentucky			
Ad	Adairville	Logan and Simpson/Tenn.	F.R. Shawe	569	1966
Ao	Adolphus	Allen/Tenn.	W.H. Nelson	299	1964
AS	Allen Springs	Allen and Warren	S.L. Moore	285	1963
Al-Db	Alton-Derby	Meade and Breckinridge	D.H. Amos	845	1970
Au	Auburn	Simpson and Logan	H.C. Rainey III	415	1965
BS	Bee Spring	Edmonson and Grayson	Benjamin Gildersleeve	757	1968
BC	Big Clifty	Grayson and Hardin	W C Swadley	192	1962
BP	Big Spring	Breckinridge, Meade, and Hardin.	W.L. Peterson	261	1964
BN	Bowling Green North	Warren	F.R. Shawe	234	1963
BG	Bowling Green South	Warren	F.R. Shawe	235	1963
Bi	Bristow	Warren and Edmonson	Benjamin Gildersleeve	216	1963
Br	Brownsville	Edmonson and Warren	Benjamin Gildersleeve	411	1965
Ca	Caneyville	Grayson	Benjamin Gildersleeve and W.D. Johnson, Jr.	1472	1978
Cl	Clarkson	Grayson	E.E. Glick	278	1963
Co-Ct	Cloverport-Cannelton	Hancock and Breckinridge/Ind.	M.H. Bergendahl	273	1965
Cn	Constantine	Hardin and Breckinridge	E.G. Sable	302	1964
Cu	Custer	Breckinridge and Hardin	D.H. Amos	1367	1977
De	Dennis	Logan	H.C. Rainey III	450	1965
Do	Dot	Logan/Tenn.	F.R. Shawe	568	1966
Dr	Drake	Warren, Simpson, and Allen.	S.L. Moore	277	1963
Du	Dundee	Ohio	G.H. Goudarzi and A.E. Smith.	688	1968
Dn	Dunmor	Logan, Muhlenberg, and Butler.	T.P. Miller	290	1964
FR	Falls of Rough	Grayson, Breckinridge, and Ohio.	W.D. Johnson, Jr.	1360	1977
Fr	Franklin	Simpson/Tenn.	F.R. Shawe	281	1963

TABLE 1.—*Kentucky 7½-minute U.S. Geological Survey geologic quadrangle (GQ) maps in which Mississippian rocks are exposed*—Continued

[See figs. 3 and 4 for geographic subdivisions and quadrangle abbreviations]

Quadrangle abbreviation	Quadrangle name	County/State	Author	GQ Number	Year published
		West-central Kentucky—Continued			
Fo	Fordsville	Hancock, Ohio, and Breckinridge.	M.H. Bergendahl and A.E. Smith.	295	1964
Ga	Garfield	Breckinridge	D.H. Amos	1278	1976
GD	Glen Dean	Breckinridge and Hancock.	G.H. Goudarzi	836	1970
Gu	Guston	Meade and Breckinridge	J.E. Palmer	1481	1978
Hd	Hadley	Warren and Butler	H.C. Rainey III	237	1963
Ha	Hardinsburg	Breckinridge	D.H. Amos	1232	1975
HF	Hickory Flat	Simpson and Allen/Tenn.	S.L. Moore	420	1965
Ho	Homer	Logan	Benjamin Gildersleeve	549	1966
Ht	Horton	Ohio	W.D. Johnson, Jr.	915	1971
Ir	Irvington	Breckinridge and Meade	D.H. Amos	1331	1976
Ki	Kingswood	Breckinridge	D.H. Amos	1447	1978
Lw	Leavenworth	Meade	D.H. Amos	941	1971
Le	Leitchfield	Grayson	Benjamin Gildersleeve	1316	1978
Lb	Lewisburg	Logan	H.C. Rainey III and R.C. Miller.	830	1969
Lo	Lodiburg	Breckinridge and Meade	R.K. Hose, E.G. Sable, and D.C. Hedlund.	193	1963
Mc	McDaniels	Grayson and Breckinridge.	W.D. Johnson, Jr.	1473	1978
Ma	Madrid	Hardin, Breckinridge, and Grayson.	W.D. Johnson, Jr.	1482	1978
Mt	Mattingly	Breckinridge/Ind.	L.D. Clark and M.D. Crittenden, Jr.	361	1965
Me	Meador	Warren, Allen, and Barren.	W.H. Nelson	288	1963
Mo	Morgantown	Butler and Warren	Benjamin Gildersleeve	1040	1972
NA-Ma	New Amsterdam–Mauckport	Meade/Ind.	D.H. Amos	990	1972
NR	Nolin Reservoir	Edmonson and Grayson	Benjamin Gildersleeve	895	1971
Ol	Olaton	Ohio, Grayson, and Breckinridge.	W.D. Johnson, Jr. and A.E. Smith.	687	1968
Pe	Petroleum	Allen/Tenn.	W.B. Myers	352	1964
PR	Pleasant Ridge	Ohio and Daviess	G.H. Goudarzi and A.E. Smith.	766	1968
Po	Polkville	Warren and Allen	Benjamin Gildersleeve	194	1962
PM	Prices Mill	Simpson and Logan/Tenn.	F.R. Shawe and H.C. Rainey III.	449	1965
Qu	Quality	Butler and Logan	Benjamin Gildersleeve	673	1968
Re	Ready	Edmonson, Grayson, and Butler.	Benjamin Gildersleeve	1263	1975
Rd	Reedyville	Butler, Edmonson, and Warren.	F.R. Shawe	520	1966
Rh	Rhoda	Edmonson	Harry Klemic	219	1963
Ri	Riverside	Butler and Warren	F.R. Shawe	736	1968
Ro	Rochester	Butler, Ohio, and Muhlenberg.	D.E. Hansen	1171	1974

TABLE 1.—*Kentucky 7½-minute U.S. Geological Survey geologic quadrangle (GQ) maps in which Mississippian rocks are exposed*—Continued
[See figs. 3 and 4 for geographic subdivisions and quadrangle abbreviations]

Quadrangle abbreviation	Quadrangle name	County/State	Author	GQ Number	Year published
		West-central Kentucky—Continued			
Rc	Rockfield	Warren, Logan, and Simpson.	H.C. Rainey III	309	1964
Rm	Rome	Breckinridge	M.D. Crittenden, Jr., and R.K. Hose.	362	1965
Rs	Rosine	Ohio, Grayson, and Butler.	W.D. Johnson, Jr.	928	1971
Ru	Russellville	Logan	R.C. Miller	714	1968
Sc	Scottsville	Allen	K.B. Ketner	184	1962
SG	Smiths Grove	Warren, Edmonson, and Barren.	P.W. Richards	357	1964
SL	Spring Lick	Ohio, Butler, and Grayson.	Benjamin Gildersleeve and W.D. Johnson, Jr.	1475	1978
Su	Sugar Grove	Butler, Warren, and Logan.	T.P. Miller	225	1963
SH	South Hill	Butler and Ohio	S.L. Moore	1180	1974
SU	South Union	Logan, Warren, and Simpson.	Harry Klemic	275	1963
Wo	Woodburn	Simpson and Warren	F.R. Shawe	280	1963
		Central Kentucky			
Br	Bradfordsville	Taylor and Marion	S.L. Moore	1386	1977
Be	Bradfordsville NE	Marion, Casey, and Taylor.	S.L. Moore	1396	1977
Bo	Brooks	Bullitt and Jefferson	R.C. Kepferle	961	1972
Ce	Cecilia	Hardin	R.C. Kepferle	263	1963
Co	Colesburg	Hardin and Bullitt	R.C. Kepferle	602	1967
Cr	Cravens	Bullitt and Nelson	W.L. Peterson	737	1968
El	Elizabethtown	Hardin and Larue	R.C. Kepferle	559	1966
Ei	Ellisburg	Casey	S.L. Moore	1397	1977
Fl	Flaherty	Hardin and Meade	W C Swadley	229	1963
FK	Fort Knox	Jefferson, Meade, Hardin, and Bullitt.	R.C. Kepferle and E.G. Sable.	1375	1977
GS	Gravel Switch	Boyle, Marion, and Casey	S.L. Moore	1506	1978
HG	Halls Gap	Lincoln	G.W. Weir	1009	1972
Ha	Hammonville	Larue and Hart	F.B. Moore	1051	1972
Hi	Hibernia	Green, Larue, and Taylor	S.L. Moore	1352	1976
Ho	Hodgenville	Larue and Nelson	F.B. Moore	749	1968
Hw	Howardstown	Larue, Nelson, and Marion.	R.C. Kepferle	505	1966
HV	Howe Valley	Hardin	R.C. Kepferle	232	1963
Hu	Hustonville	Casey and Lincoln	R.Q. Lewis, Sr., and A.R. Taylor.	916	1971
JC	Junction City	Boyle, Lincoln, and Casey	L.D. Harris	981	1972
LE	Lebanon East	Marion	S.L. Moore	1508	1978
LJ	Lebanon Junction	Bullitt, Nelson, and Hardin.	W.L. Peterson	603	1967
LW	Lebanon West	Marion	S.L. Moore	1509	1978
Lo	Loretto	Nelson, Marion, and Washington.	W.L. Peterson	1034	1972

TABLE 1.—*Kentucky 7½-minute U.S. Geological Survey geologic quadrangle (GQ) maps in which Mississippian rocks are exposed*—Continued

[See figs. 3 and 4 for geographic subdivisions and quadrangle abbreviations]

Quadrangle abbreviation	Quadrangle name	County/State	Author	GQ Number	Year published
		Central Kentucky—Continued			
Le	Louisville East	Jefferson	R.C. Kepferle	1203	1974
LW-Ln	Louisville West and Lanesville	Jefferson	R.C. Kepferle	1202	1974
Mg	Magnolia	Green, Hart, and Larue	F.B. Moore	1280	1975
Mi	Millerstown	Grayson, Hart, and Hardin.	F.B. Moore	417	1965
Ne	Nelsonville	Larue, Hardin, and Nelson.	W.L. Peterson	564	1966
NH	New Haven	Nelson and Larue	W.L. Peterson	506	1966
Pa	Parksville	Boyle and Casey	S.L. Moore	1494	1978
PP	Pitts Point	Bullitt and Hardin	R.C. Kepferle	1376	1977
Ra	Raywick	Marion, Nelson, and Larue.	R.C. Kepferle	1048	1973
RH-La	Rock Haven–Laconia	Meade/Ind.	C.F. Withington and E.G. Sable.	780	1969
Sa	Saloma	Taylor, Marion, and Larue.	S.L. Moore	1351	1976
Sm	Samuels	Bullitt and Nelson	R.C. Kepferle	824	1969
Sh	Shepherdsville	Bullitt	R.C. Kepferle	740	1968
So	Sonora	Hardin and Larue	F.B. Moore	492	1965
Sp	Spurlington	Marion and Taylor	S.L. Moore	1181	1974
St	Stanford	Lincoln, Boyle, and Garrard.	F.R. Shawe and P.B. Wigley.	1137	1974
Su	Summit	Hardin and Grayson	F.B. Moore	298	1964
To	Tonieville	Larue and Hardin	F.B. Moore	560	1966
Up	Upton	Hart, Hardin, and Larue	F.B. Moore	1000	1972
VS-Ko	Valley Station–Kosmosdale	Jefferson and Bullitt	R.C. Kepferle	962	1972
VG	Vine Grove	Hardin and Meade	R.C. Kepferle	645	1967
		South-central Kentucky			
Al	Albany	Clinton and Cumberland/Tenn.	R.Q. Lewis, Sr., and R.E. Thaden.	550	1966
Am	Amandaville	Cumberland, Adair, and Russell.	A.R. Taylor	186	1962
An	Ano	Pulaski and Laurel	H.K. Stager	171	1962
As	Austin	Allen and Barren	S.L. Moore	173	1961
Ba-ON	Barthell–Oneida North	McCreary	J.B. Pomerene	314	1964
Bf-BW	Bell Farm and Barthell Southwest	McCreary and Wayne, Scott/Tenn.	J.H. Smith	1496	1978
Bl	Billows	Pulaski, Rockcastle, and Laurel.	N.L. Hatch, Jr.	228	1963
BF	Blacks Ferry	Monroe and Cumberland	Richard Van Horn and W.R. Griffitts.	803	1969
Bo	Bobtown	Pulaski	R.Q. Lewis, Sr., A.R. Taylor, and G.W. Weir.	1102	1973
Br	Breeding	Adair, Cumberland, and Metcalfe.	A.R. Taylor	287	1964

TABLE 1.—*Kentucky 7½-minute U.S. Geological Survey geologic quadrangle (GQ) maps in which Mississippian rocks are exposed*—Continued

[See figs. 3 and 4 for geographic subdivisions and quadrangle abbreviations]

Quadrangle abbreviation	Quadrangle name	County/State	Author	GQ Number	Year published
		South-central Kentucky—Continued			
Bu	Burkesville	Cumberland	J.M. Cattermole	220	1963
Bn	Burnside	Pulaski, McCreary, and Wayne.	A.R. Taylor, R.Q. Lewis, Sr., and J.H. Smith.	1253	1975
Ca	Campbellsville	Taylor and Adair	A.R. Taylor	448	1965
CV	Cane Valley	Adair, Taylor, and Green	C.H. Maxwell and W.B. Turner.	369	1964
Cn	Canmer	Hart	R.C. Miller	816	1969
Ce	Center	Green, Hart, Metcalf and Barren.	R.C. Miller and S.L. Moore.	693	1967
Cl	Clementsville	Casey and Adair	A.R. Taylor and R.Q. Lewis, Sr.	1033	1972
Co	Columbia	Adair	R.Q. Lewis, Sr., and R.E. Thaden.	249	1963
Cp	Coopersville	McCreary and Wayne	R.Q. Lewis, Sr., and A.R. Taylor.	1315	1976
Cr	Creelsboro	Russell, Adair, Clinton, and Cumberland.	R.E. Thaden and R.Q. Lewis, Sr.	204	1963
CR	Cub Run	Hart, Grayson, and Edmonson.	C.A. Sandberg and C.G. Bowles.	386	1965
CC	Cumberland City	Clinton, Wayne, and Russell.	R.Q. Lewis, Sr., and R.E. Thaden.	475	1965
De	Delmer	Pulaski	R.Q. Lewis, Sr.	909	1971
Du	Dubre	Cumberland, Monroe, and Metcalfe.	R.Q. Lewis, Sr.	676	1967
Dn	Dunnville	Adair, Casey, and Russell.	C.H. Maxwell	367	1965
Dy	Dykes	Pulaski	J.H. Smith	1197	1974
EF	East Fork	Metcalfe, Adair, and Green.	J.M. Cattermole	413	1965
Ed	Edmonton	Metcalfe	J.M. Cattermole	523	1966
El	Eli	Russell, Pulaski, and Casey.	R.E. Thaden and R.Q. Lewis, Sr.	393	1965
Eu	Eubank	Lincoln, Casey, and Pulaski.	R.Q. Lewis, Sr., A.R. Taylor, and G.W. Weir.	1096	1973
Ex	Exie	Green	S.L. Moore	752	1968
Fa	Faubush	Pulaski and Russell	R.E. Thaden and R.Q. Lewis, Sr.	802	1969
FR	Fountain Run	Allen, Monroe, and Barren/Tenn.	Warren Hamilton	254	1963
Fr	Frazer	Pulaski and Wayne	R.Q. Lewis, Sr.	1223	1975
Fe	Freedom	Monroe and Barren	S.L. Moore	349	1964
Fo	Frogue	Cumberland and Clinton/Tenn.	R.Q. Lewis, Sr.	675	1967
Ga	Gamaliel	Monroe	D.E. Trimble	253	1963
GN	Glasgow North	Barren	D.D. Haynes	339	1964
GS	Glasgow South	Barren	S.L. Moore and R.C. Miller	416	1965

TABLE 1.—*Kentucky 7½-minute U.S. Geological Survey geologic quadrangle (GQ) maps in which Mississippian rocks are exposed*—Continued

[See figs. 3 and 4 for geographic subdivisions and quadrangle abbreviations]

Quadrangle abbreviation	Quadrangle name	County/State	Author	GQ Number	Year published
		South-central Kentucky—Continued			
Gr	Gradyville	Adair, Green, and Metcalfe.	A.R. Taylor	233	1963
Gb	Greensburg	Green and Taylor	A.R. Taylor, S.J. Luft, and R.Q. Lewis, Sr.	739	1968
Gs	Gresham	Green, Adair, and Taylor	A.R. Taylor	421	1965
Ha	Hail	McCreary and Pulaski	J.H. Smith, J.B. Pomerene, and R.G. Ping.	1058	1973
Hi	Hiseville	Barren and Metcalfe	D.D. Haynes	401	1965
Ho	Holland	Allen/Tenn.	W.H. Nelson	174	1962
HC	Horse Cave	Barren and Hart	D.D. Haynes	558	1966
Hu	Hudgins	Green and Hart	R.C. Miller and S.L. Moore.	834	1969
Jb	Jabez	Russell and Wayne	R.E. Thaden and R.Q. Lewis, Sr.	483	1966
Ja	Jamestown	Russell and Wayne	R.E. Thaden and R.Q. Lewis, Sr.	182	1962
Kn	Knifley	Adair	C.H. Maxwell	294	1964
Li	Liberty	Casey	A.R. Taylor and R.Q. Lewis, Sr.	946	1971
Lu	Lucas	Barren and Allen	D.D. Haynes	251	1963
MC	Mammoth Cave	Edmonson, Hart, and Barren.	D.D. Haynes	351	1964
Ma	Mannsville	Taylor, Adair, and Casey	A.R. Taylor	562	1966
Mt	Maretburg	Rockcastle, Pulaski, and Lincoln.	S.O. Schlanger	338	1965
MS	Mill Springs	Wayne, Pulaski, and Russell.	R.Q. Lewis, Sr.	1057	1972
Mi	Mintonville	Casey and Pulaski	R.Q. Lewis, Sr., and A.R. Taylor.	1198	1974
Mo	Monticello	Wayne	A.R. Taylor	1319	1976
Mp	Montpelier	Adair and Russell	R.Q. Lewis, Sr., and R.E. Thaden.	337	1964
MV	Mount Vernon	Rockcastle	S.O. Schlanger and G.W. Weir.	902	1971
Mu	Munfordville	Hart	S.L. Moore	1055	1973
Ne	Nevelsville	McCreary and Wayne	J.H. Smith	1326	1976
Pa	Park	Hart, Barren, and Metcalfe.	S.L. Moore and D.D. Haynes.	634	1967
PC	Park City	Barren, Edmonson, and Warren.	D.D. Haynes	183	1962
Pr-SP	Parmleysville and Sharp Place	Wayne and McCreary/Tenn.	A.R. Taylor	1405	1977
Pn	Parnell	Wayne	R.Q. Lewis, Sr., and S.J. Luft.	861	1970
Ph	Phil	Casey, Russell, and Pulaski.	C.H. Maxwell	395	1965

TABLE 1.—*Kentucky 7½-minute U.S. Geological Survey geologic quadrangle (GQ) maps in which Mississippian rocks are exposed*—Continued
[See figs. 3 and 4 for geographic subdivisions and quadrangle abbreviations]

Quadrangle abbreviation	Quadrangle name	County/State	Author	GQ Number	Year published
		South-central Kentucky—Continued			
Po-PM	Powersburg and Pall Mall	Wayne and Clinton/Tenn.	R.Q. Lewis, Sr.	1377	1977
RS	Russell Springs	Russell and Adair	R.Q. Lewis, Sr., and R.E. Thaden.	383	1965
Sa-Mv	Savage and Moodyville	Clinton and Wayne	R.Q. Lewis, Sr.	1318	1976
Sy	Sawyer	Whitley, McCreary, Laurel, and Pulaski.	W.P. Puffett	179	1962
SH	Science Hill	Pulaski, Casey, and Lincoln.	A.R. Taylor and R.Q. Lewis, Sr.	1105	1973
Sh	Shopville	Pulaski and Rockcastle	N.L. Hatch, Jr.	282	1964
So	Somerset	Pulaski	R.Q. Lewis, Sr.	1196	1974
SL	Sulphur Lick	Monroe, Metcalfe, and Barren.	L.D. Harris	323	1964
SW	Sulphur Well	Metcalfe and Green	J.M. Cattermole	555	1966
SS	Summer Shade	Metcalfe and Barren	W.J. Hail, Jr.	308	1964
Su	Summersville	Green	S.L. Moore	870	1970
TH	Temple Hill	Barren	S.L. Moore and R.C. Miller.	402	1965
To-UH	Tompkinsville and Union Hill	Monroe, Clay/Tenn.	I.J. Witkind	937	1971
Tr	Tracy	Barren, Monroe, and Allen.	S.L. Moore	217	1963
Ve-Cl	Vernon-Celina	Monroe and Cumberland	R.Q. Lewis, Sr.	966	1972
Wa	Waterview	Cumberland and Metcalfe	J.M. Cattermole	286	1963
WD	Wolf Creek Dam	Clinton, Russell, and Cumberland.	R.Q. Lewis, Sr., and R.E. Thaden.	177	1962
Wo	Woodstock	Lincoln, Pulaski, and Rockcastle.	G.W. Weir and S.O. Schlanger.	776	1969
Yo	Yosemite	Casey and Lincoln	A.R. Taylor and R.Q. Lewis, Sr.	910	1971
		East-central Kentucky			
Al	Alcorn	Jackson, Estill, and Madison.	C.L. Rice	963	1972
Ba	Bangor	Rowan, Morgan, Menifee, and Bath.	D.K. Hylbert and J.C. Philley.	947	1971
Be	Berea	Madison, Rockcastle, and Garrard.	G.W. Weir	649	1967
Bn	Bernstadt	Laurel and Rockcastle	N.L. Hatch, Jr.	202	1963
Bh	Bighill	Madison, Jackson, and Rockcastle.	G.W. Weir, K.Y. Lee, and P.E. Cassity.	900	1971
Br	Brodhead	Rockcastle, Lincoln, and Garrard.	J.L. Gualtieri	662	1967
CC	Clay City	Powell and Estill	G.C. Simmons	663	1967
Ch	Cobhill	Estill, Lee, and Powell	D.C. Haney	1347	1976
Co	Colfax	Bath and Fleming	R.C. McDowell	1332	1976
CO	Crab Orchard	Lincoln	J.L. Gualtieri	571	1967

TABLE 1.—*Kentucky 7½-minute U.S. Geological Survey geologic quadrangle (GQ) maps in which Mississippian rocks are exposed*—Continued

[See figs. 3 and 4 for geographic subdivisions and quadrangle abbreviations]

Quadrangle abbreviation	Quadrangle name	County/State	Author	GQ Number	Year published
		East-central Kentucky—Continued			
Ez	Ezel	Morgan and Menifee	G.N. Pipiringos, S.C. Bergman, and V.A. Trent.	721	1968
Fa	Farmers	Rowan, Fleming, and Bath.	R.C. McDowell	1236	1975
Fr	Frenchburg	Menifee and Powell	H.P. Hoge	1390	1977
He	Hedges	Clark	D.F.B. Black	1235	1975
Hi	Heidelberg	Lee, Estill, and Owsley	D.F.B. Black	1340	1977
Iv	Irvine	Estill	H.P. Hoge, P.B. Wigley, and F.R. Shawe.	1285	1976
Jo	Johnetta	Rockcastle and Jackson	J.L. Gualtieri	685	1968
La	Lancaster	Lincoln and Garrard	G.W. Weir	888	1971
Le	Leighton	Estill, Jackson, and Lee	D.C. Haney and C.L. Rice.	1495	1978
Lv	Levee	Montgomery, Clark, and Powell.	R.C. McDowell	1478	1978
Li	Livingston	Rockcastle, Laurel, and Jackson.	W.R. Brown and M.J. Osolnik.	1179	1974
Mc	McKee	Jackson and Owsley	G.W. Weir and M.D. Mumma.	1125	1973
Me	Means	Menifee, Montgomery, and Powell.	G.W. Weir	1324	1976
Mo	Morehead	Rowan	H.P. Hoge and J.R. Chaplin.	1022	1972
Ol	Olympia	Bath and Menifee	R.C. McDowell and G.W. Weir.	1406	1977
PL	Paint Lick	Garrard, Madison, and Lincoln.	G.W. Weir	800	1969
Pa	Palmer	Estill, Clark, Madison, and Powell.	G.C. Simmons	613	1967
Pn	Panola	Estill and Madison	R.C. Greene	686	1968
Pt	Parrot	Jackson and Laurel	D.F. Crowder	236	1963
Po	Pomeroyton	Wolfe, Menifee, and Morgan.	G.W. Weir and P.W. Richards.	1184	1974
Pr	Preston	Bath and Montgomery	G.W. Weir and R.C. McDowell.	1334	1976
SL	Salt Lick	Rowan, Bath, and Menifee.	J.C. Philley	1499	1978
Sa	Sandgap	Jackson	J.L. Gualtieri	1100	1973
Sc	Scranton	Menifee	D.C. Haney and N.C. Hester.	1488	1978
Sl	Slade	Powell, Menifee, and Wolfe.	G.W. Weir	1183	1974
St	Stanton	Powell and Estill	G.W. Weir	1182	1974
Ty	Tyner	Jackson, Clay, and Laurel	G.L. Snyder	247	1963
Wi	Wildie	Garrard and Rockcastle	J.L. Gualtieri	684	1968
Za	Zachariah	Estill, Lee, Powell, and Wolfe.	D.F.B. Black	1452	1978

TABLE 1.—*Kentucky 7½-minute U.S. Geological Survey geologic quadrangle (GQ) maps in which Mississippian rocks are exposed*—Continued

[See figs. 3 and 4 for geographic subdivisions and quadrangle abbreviations]

Quadrangle abbreviation	Quadrangle name	County/State	Author	GQ Number	Year published
		Northeastern Kentucky			
Br	Brushart	Greenup and Lewis	C.S. Denny	324	1964
Bu	Burtonville	Fleming and Lewis	R.H. Morris	396	1965
Ch	Charters	Lewis	R.H. Morris	293	1965
Cc-BV	Concord-Buena Vista	Lewis	R.H. Morris	525	1966
Cr	Cranston	Rowan, Fleming, and Lewis.	J.C. Philley, D.K. Hylbert, and H.P. Hoge.	1212	1975
Fl	Flemingsburg	Fleming and Mason	J.H. Peck	837	1969
Fr	Friendship	Lewis and Greenup	R.L. Erickson	526	1966
Ga-PR	Garrison and Pond Run	Lewis and Greenup, Scioto/Ohio.	J.R. Chaplin and C.E. Mason.	1490	1978
Gr	Grahn	Carter	K.J. Englund	1262	1976
Gs	Grayson	Carter	C.L. Whittington and J.C. Ferm.	640	1967
Gp-Ir	Greenup-Ironton	Greenup and Boyd	Ernest Dobrovolny, J.C. Ferm, and S.O. Eroskay.	532	1966
HG	Head of Grassy	Lewis	R.H. Morris	484	1966
Hi	Hillsboro	Fleming and Bath	J.W. Mytton and R.C. McDowell.	876	1970
Lo	Load	Greenup	J.A. Sharps	519	1966
MI	Manchester Islands	Lewis	J.H. Peck and K.L. Pierce.	581	1966
Ol	Oldtown	Greenup and Carter	C.L. Whittington and J.C. Ferm.	353	1965
OH	Olive Hill	Carter	K.J. Englund and J.F. Windolph, Jr.	1270	1975
PL	Plummers Landing	Fleming and Rowan	R.C. McDowell, J.H. Peck, and J.W. Mytton.	964	1971
Po-Wh	Portsmouth-Wheelersburg-New Boston	Greenup, Scioto/Ohio	R.A. Sheppard	312	1964
So	Soldier	Carter, Lewis, and Rowan.	J.C. Philley, D.K. Hylbert, and H.P. Hoge.	1233	1975
St	Stricklett	Lewis, Fleming, and Rowan.	R.H. Morris	394	1965
To	Tollesboro	Lewis and Fleming	J.H. Peck	661	1967
TV	Tygarts Valley	Greenup and Carter	R.A. Sheppard	289	1964
Va	Vanceburg	Lewis/Ohio	R.H. Morris and K.L. Pierce.	598	1967
We	Wesleyville	Carter and Lewis	J.C. Philley and J.R. Chaplin.	1305	1976
		Eastern Kentucky			
Au	Ault	Elliott, Carter, and Rowan.	A.O. DeLaney and K.J. Englund.	1066	1973
Br	Bruin	Elliott and Carter	K.J. Englund and A.O. DeLaney.	522	1966
Ha	Haldeman	Rowan, Carter, and Elliott.	S.H. Patterson and J.W. Hosterman.	169	1961

TABLE 1.—*Kentucky 7½-minute U.S. Geological Survey geologic quadrangle (GQ) maps in which Mississippian rocks are exposed*—Continued

[See figs. 3 and 4 for geographic subdivisions and quadrangle abbreviations]

Quadrangle abbreviation	Quadrangle name	County/State	Author	GQ Number	Year published
		Eastern Kentucky—Continued			
Is	Isonville	Elliott, Morgan, and Lawrence.	K.J. Englund and A.O. DeLaney.	501	1966
SH	Sandy Hook	Elliott and Morgan	K.J. Englund and A.O. DeLaney.	521	1966
WL	West Liberty	Morgan	K.J. Englund, J.W. Huddle, and A.O. DeLaney.	589	1967
Wr	Wrigley	Morgan, Rowan, and Elliott.	J.W. Hosterman, S.H. Patterson, and J.W. Huddle.	170	1961
		Southeastern Kentucky			
Ba	Balkan	Bell and Harlan	A.J. Froelich and J.F. Tazelaar.	1127	1973
Be-Ap	Benham and Appalachia	Harlan and Letcher, Lee/Va.	A.J. Froelich and B.D. Stone.	1059	1973
Bl	Bledsoe	Leslie and Harlan	Bela Csjetey, Jr.	889	1971
EC	Elkhorn City-Harman	Pike/Va.	D.C. Alvord and R.L. Miller.	951	1972
Ev	Evarts	Harlan	J.F. Tazelaar and W.L. Newell.	914	1974
Ew	Ewing	Harlan and Bell/Va.	K.J. Englund and others	172	1961
Fr-Ea	Frakes-Eagen	Bell and Whitley	W.L. Newell	1249	1975
HS	Hubbard Springs	Harlan	J.F. Tazelaar and W.L. Newell.	914	1974
JE	Jellico East	Whitley	C.L. Rice and W.L. Newell	1264	1976
He-Cw	Hellier and Clintwood	Pike/Va.	D.C. Alvord	950	1971
Ha	Harlan	Harlan	A.J. Froelich and E.J. McKay.	1015	1972
He	Helton	Leslie, Harlan, and Bell	D.D. Rice	1227	1975
JE	Jenkins East	Pike and Letcher	D.E. Wolcott	1210	1974
JW	Jenkins West	Letcher and Pike/Va.	C.L. Rice	1126	1973
Kj-FR	Kayjay and Fork Ridge	Bell and Knox, Campbell and Claiborne/Tenn.	C.L. Rice and E.K. Maughan.	1505	1978
Lo	Louellen	Harlan, Letcher, and Perry.	A.J. Froelich	1060	1973
MN	Middlesboro North	Bell	K.J. Englund, J.B. Roen, and A.O. DeLaney.	300	1964
MS	Middlesboro South	Bell/Tenn. and Va.	K.J. Englund	301	1964
No	Nolansburg	Harlan, Letcher, and Leslie.	Bela Csjetey, Jr.	868	1970
Pi	Pineville	Bell and Knox	A.J. Froelich and J.F. Tazelaar.	1129	1974
RH	Rose Hill	Harlan	E.K. Maughan and J.F. Tazelaar.	1121	1973
Ro	Roxana	Harlan and Letcher	E.K. Maughan	1299	1976
Va	Varilla	Bell and Harlan/Va.	K.J. Englund, E.R. Landis, and H.L. Smith.	190	1963
WC	Wallins Creek	Harlan and Bell	A.J. Froelich	1010	1972
Wh-FG	Whitesburg and Flat Gap	Letcher/Va.	C.L. Rice and D.E. Wolcott	1119	1973

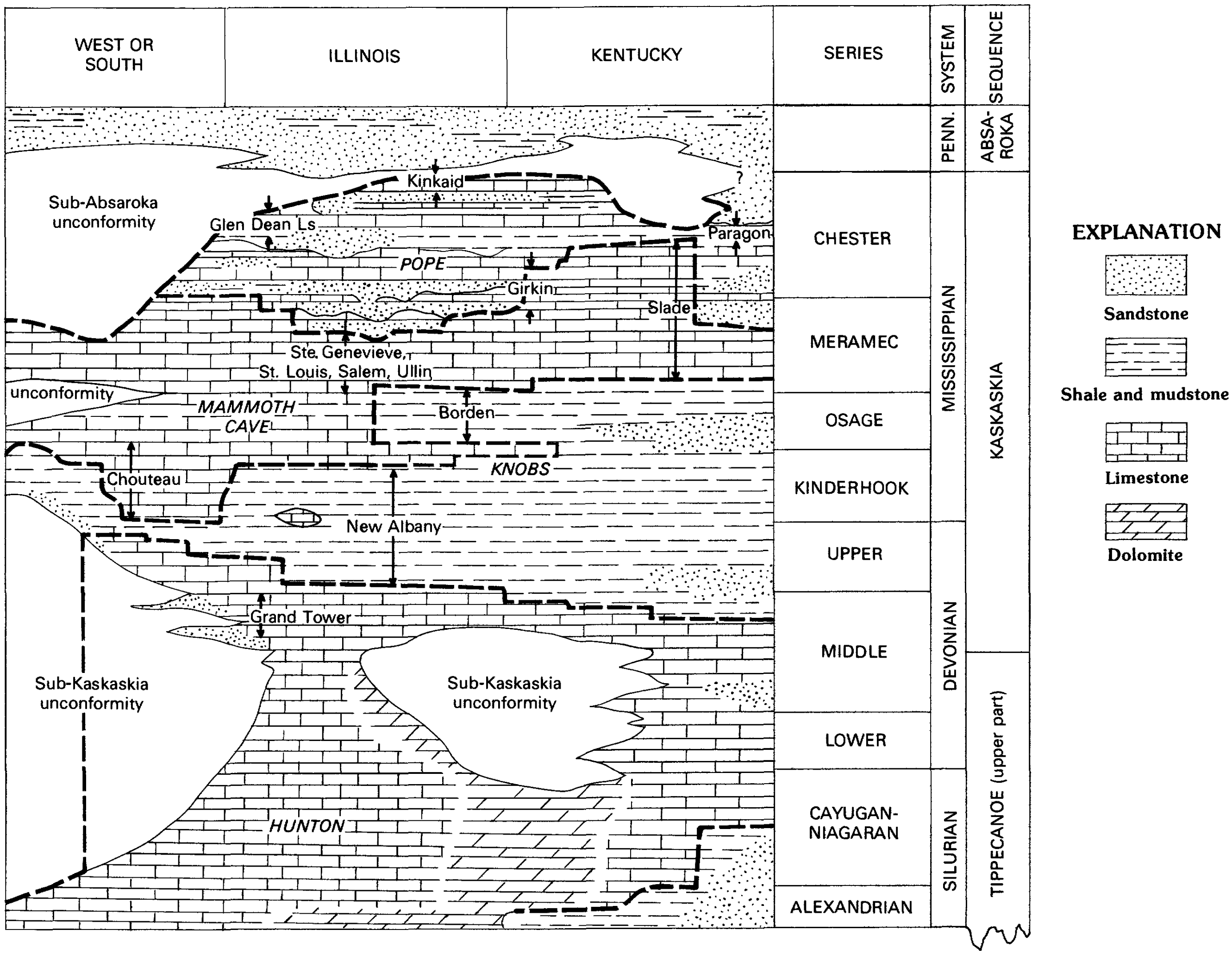


FIGURE 6.—Pre-Pennsylvanian-post-Ordovician Megagroups (capitalized italic) and Sequences in the Eastern Interior basin and adjoining areas (modified from Swann and Willman, 1961).

valuable in establishing broad lithogenetic, tectonic, and time frameworks within which Mississippian events can be placed, this report discusses Mississippian history in detail that requires conventional, specific rock and time divisions.

The following discussion on stratigraphy of the Mississippian System in Kentucky stresses lithostratigraphy, and includes discussion of depositional environments, and paleotectonic implications.

Interstate and intrastate correlations of the Mississippian strata of Kentucky based on reports by Pryor and Sable (1974) and by Rice and others (1979) are shown in figures 7 and 8. Although regional correlations are principally lithostratigraphic, based on field mapping, microfauna and macrofauna have been useful both in a lithostratigraphic sense and as tools in defining time-unit boundaries. (See section, "Paleontology.")

Representative sections of Mississippian rocks and an interpretative cross section showing vertical and lateral relationships constitute figure 9.

PHYSIOGRAPHY, OUTCROP, AND SCENIC FEATURES

Mississippian strata underlie four of Kentucky's six principal physiographic regions: The Knobs, Mississippian Plateau, Western Coal Field, and Cumberland Plateau (fig. 10). The Knobs region is a narrow, arcuate belt of conical hills around the periphery of the Blue Grass Region of central Kentucky, a lowland underlain by early Paleozoic rocks. The Knobs are erosional remnants, composed mostly of Lower Mississippian (Osagean) shale and siltstone, standing along the front

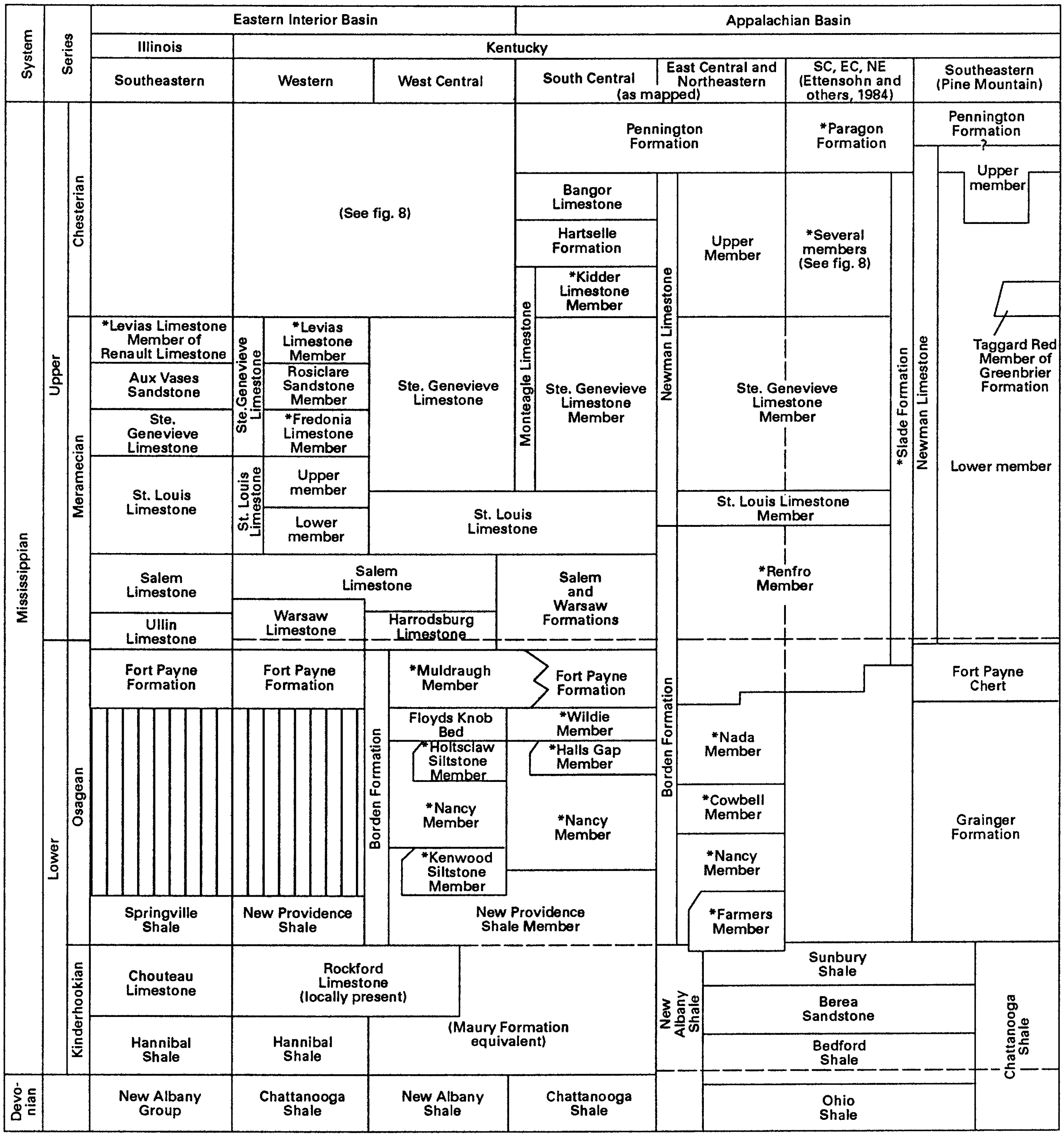


FIGURE 7.—Stratigraphic nomenclature of the Mississippian System in Kentucky and Illinois. Asterisk (*) indicates type section in Kentucky. Modified from Pryor and Sable (1974) and Rice and others (1979).

of the Cumberland or Pottsville Escarpment across east-central Kentucky and along the front of Muldraugh Hill across west-central and south-central Kentucky. Muldraugh Hill is a limestone-capped east-facing escarpment forming the east border of the Mississippian Plateau region.

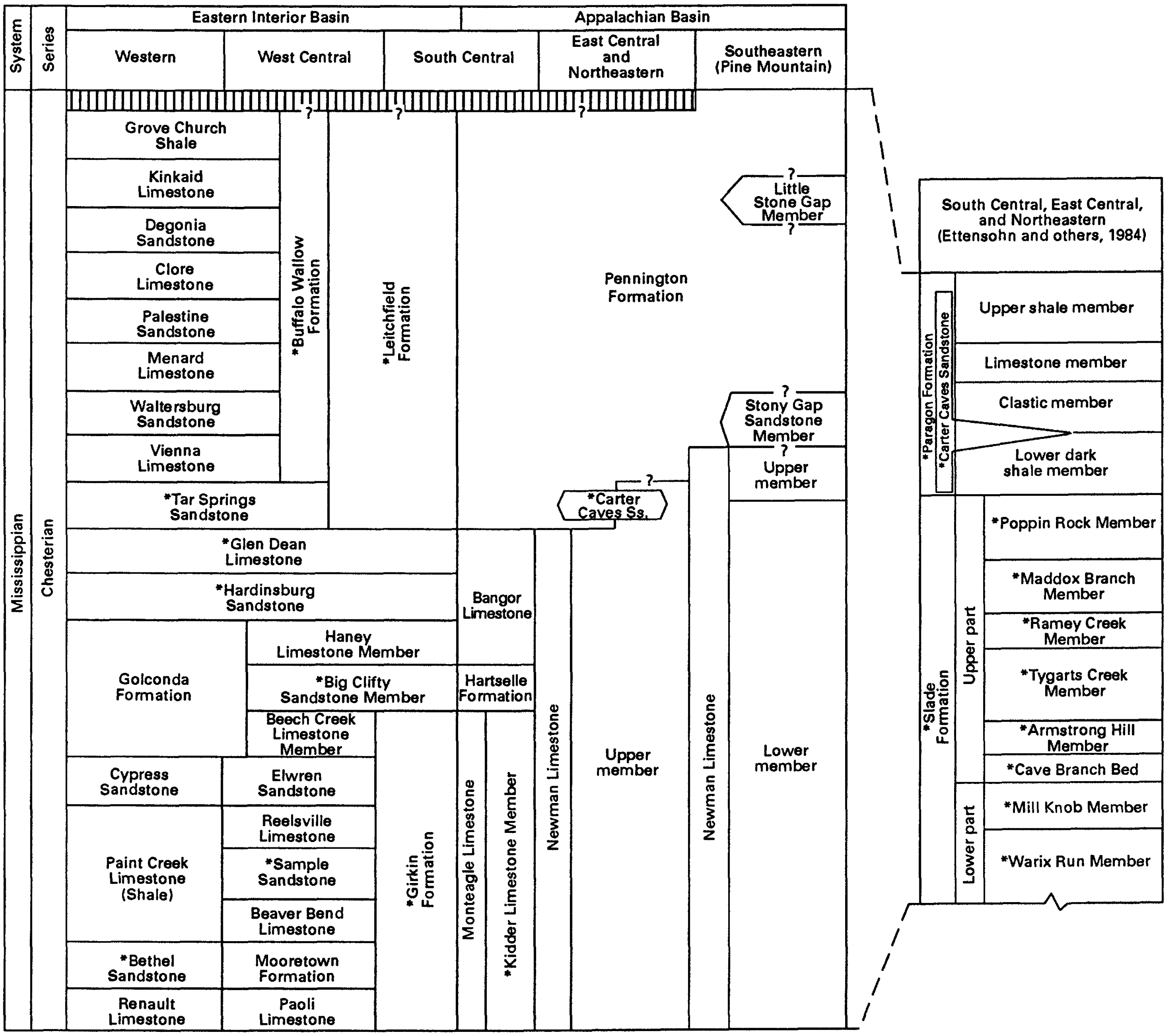


FIGURE 8.—Stratigraphic nomenclature of the Chesterian Series and equivalent strata in Kentucky. Asterisk (*) indicates type section in Kentucky. Based on Pryor and Sable (1974).

The Mississippian Plateau region is a broad, arcuate belt around the Western Coal Field. It extends eastward to the Pottsville Escarpment where the Mississippian outcrop becomes a narrow belt across east-central and northeastern Kentucky. The region consists of two principal parts divided by the Dripping Springs Escarpment, an east- and south-facing ridge generally capped by the Big Clifty Sandstone Member of the Golconda Formation (Chesterian). The outer, eastern part is a broad plain of low relief, locally with karst development where underlain by St. Louis and Ste. Genevieve Limestones (Meramecian); the western portion of this plain is commonly called the Pennyroyal or Pennyrile. The inner, western part of the Mississippian Plateau region is a dissected upland of moderate relief underlain by limestone, sandstone, and shale (Chesterian), locally called the Sand Hills country.

The Western Coal Field, part of the Eastern Interior basin, is a gently rolling to hilly upland underlain by Pennsylvanian (Morrowan-Virgilian) shale, sandstone,

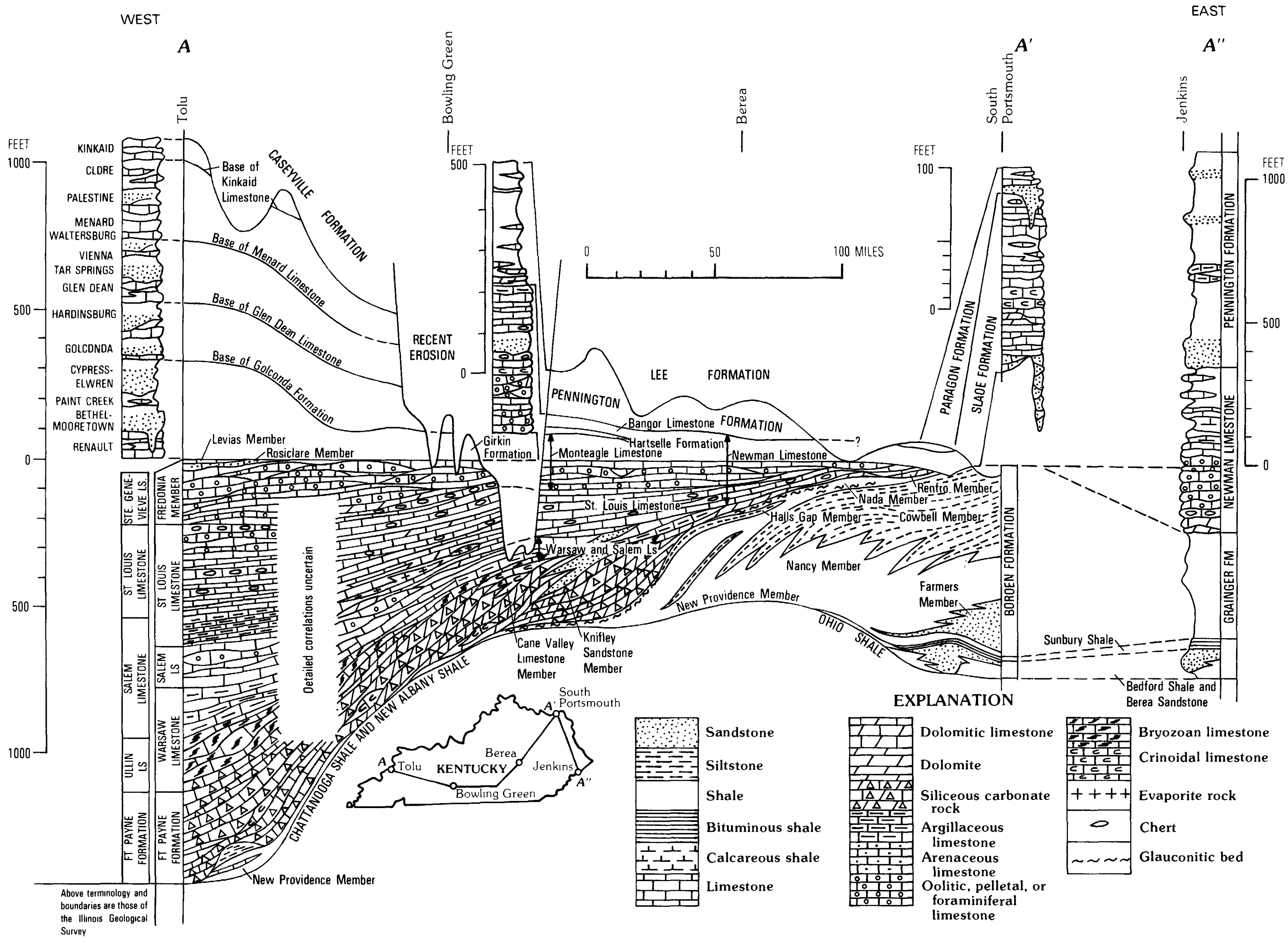


FIGURE 9.—Mississippian rock units and relationships in Kentucky. All scales approximate; modified from Rice and others (1979, p. F6).

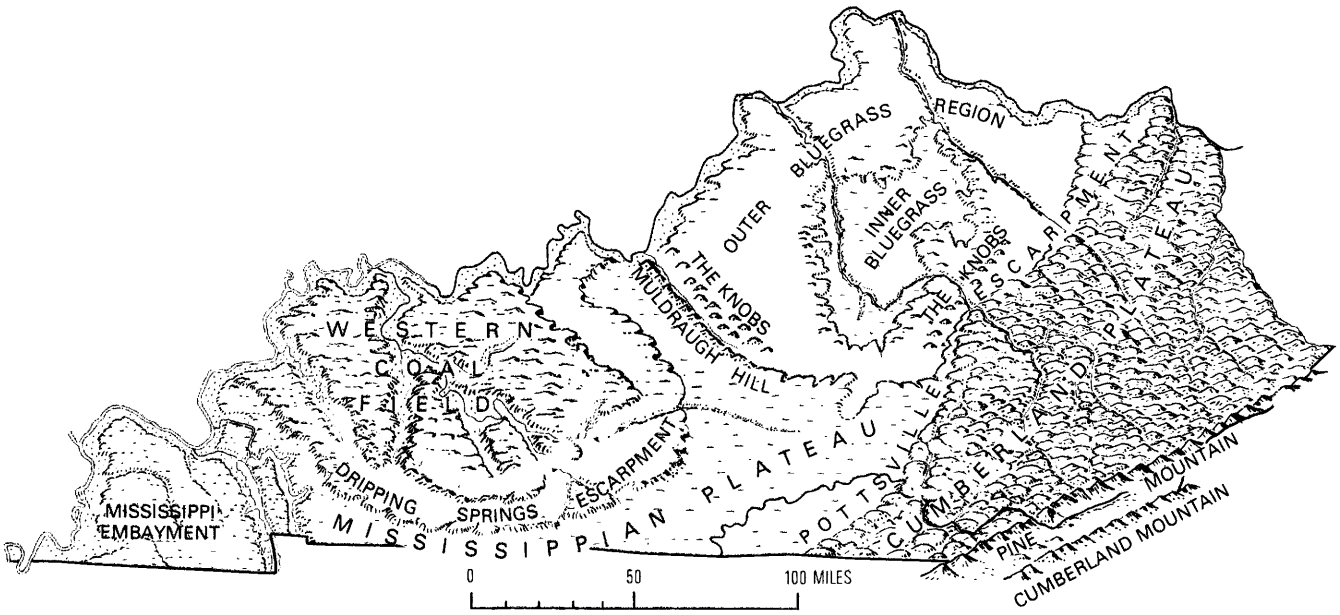


FIGURE 10.—Physiographic diagram of Kentucky (modified from Lobeck, 1929).

and economically important coal. The resistant thick Caseyville Formation of Pennsylvanian (Morrowan) age forms ridges and cliffs along parts of the coal field border, and these make up a subdued and intermittent topographic escarpment in that area.

In eastern Kentucky, the Cumberland Plateau is an intricately dissected upland of V-shaped valleys underlain by Pennsylvanian (Morrowan-Virgilian) shale, sandstone, and coal. It is bordered on the west by the Pottsville Escarpment, a northwest-facing ridge made up largely of Mississippian limestones and siltstones, and capped by sandstone of the Upper Mississippian and Lower Pennsylvanian Lee Formation. Relief increases abruptly in southeasternmost Kentucky. Pine and Cumberland Mountains, two northeast-trending ridges with relief as much as 2,200 ft, consist largely of thick Mississippian clastic and carbonate rocks capped by very thick Lower Pennsylvanian (Morrowan) sandstone and underlain by Devonian organic shale.

Weathering and erosion of Mississippian rocks in Kentucky have produced a variety of scenic features of interest to both laymen and geologists (McFarlan, 1958). The Mississippian Plateau of western Kentucky is an internationally known classic karst region, with a broad sinkhole plain and extensive systems of underground drainage and caverns, including the Mammoth Cave–Flint Ridge cave system (Livesay, 1953), developed in the St. Louis, Ste. Genevieve, and Girkin Limestones. In eastern Kentucky, limestone caves are locally developed in the Monteagle and Newman Limestones and Slade Formation along and northwest of the Pottsville Escarpment. These include the Carter Caves (McGrain, 1954) in northeastern Kentucky and the Sloans Valley cave system (Malott and McGrain, 1977) near the southern border of the State.

The conical hills of The Knobs standing above the outer Blue Grass Region lowlands form a strikingly unique example of an erosional landscape, remnants of the uplands left behind the retreating Muldraugh Hill and Pottsville escarpments (McGrain, 1967).

Mississippian rocks are well exposed in many roadcuts along highways in Kentucky such as the Bluegrass, Western Kentucky, Cumberland, and Mountain Parkways, U.S. Interstate 65 south of Louisville, U.S. Interstate 75 south of Berea, and Interstate 64 east of the Licking River. These and other exposures are described in several field conference guidebook articles, for example, Weir (1970); Ohio and Kentucky Geological Societies (1968); Sable and Peterson (1966); Smith and others (1967); Lewis (1963); Ferm and others (1971); Dever and others (1977); Lewis and Potter (1978); and Ettensohn and Dever (1979). Locations of selected exposures of Mississippian strata and information about them are shown in figure 11, and keyed to quadrangle maps and referenced publication information in table 2.

DEVONIAN AND MISSISSIPPIAN ROCKS

Units discussed in this section are those which underlie known Early Mississippian strata and are:

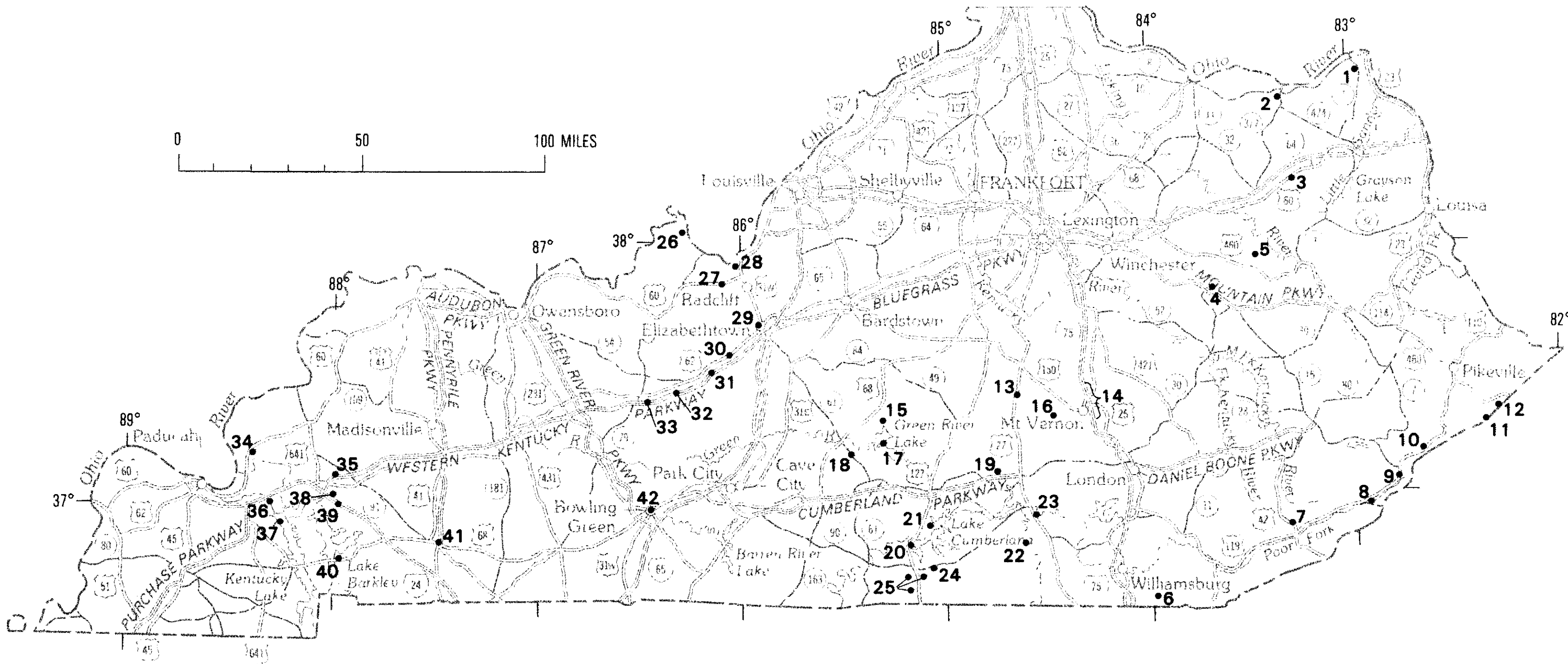


FIGURE 11.—Locations of selected exposures of Mississippian rocks in Kentucky, pertinent highway routes, and other features (numbers 1–42 keyed to locations in table 2).

TABLE 2.—*Selected exposures of Mississippian rocks in Kentucky*

[Numbers of sections keyed to map, fig. 11]

	Stratigraphic units exposed	U.S. Geological Survey Geologic Quadrangle Maps	Location and access	Features	Pertinent references
			Northeastern Kentucky		
1.	Lee Borden Nada Cowbell Nancy	Portsmouth GQ-312 (Sheppard, 1964); Friendship GQ-526 (Erickson, 1966).	South Portsmouth section. South on U.S. Hwy. 23, southeast on Ky. Hwy. 7, west on blacktop, north at first junction.	Gradational contacts. Nada red and green shales.	Calvert, Bernhagen, and others (1968).
2.	Borden Nancy Farmers Sunbury Berea Bedford	Vanceburg GQ-598 (Morris and Pierce, 1967).	Apple Tree Hill section, Ky. Hwy. 59.	Bedding features *Zoophycos* (*Taonurus*) fucoid in Borden.	Ohio Geological Society–Geological Society of Kentucky (1968, p. 56–57).
3.	Lee and Breathitt Paragon Carter Caves Slade Borden Renfro Nada Cowbell Nancy Farmers Sunbury Bedford Ohio	Grahn GQ-1262 (Englund, 1976); Olive Hill GQ-1270 (Englund and Windolph, 1975); Soldier GQ-1233 (Philley and others, 1975); Cranston GQ-1212, (Philley and others, 1975); Morehead GQ-1022 (Hoge and Chaplin, 1972); Farmers GQ-1236 (McDowell, 1975).	Numerous roadcuts and outcrops along Interstate Hwy. 64 between milepost 132 (east of Licking River) and U.S. Hwy. 60 interchange.	Detrital rocks of Bedford, Sunbury, Borden, Carter Caves, Paragon. Complex carbonate-rock sequence in Renfro and Slade. Upper and lower systemic boundaries. Nature of upper boundary (gradational vs. erosional) is controversial.	Philley (1970); Ferm and others (1971); Ettensohn and Dever (1979, p. 84–162); Chaplin (1980); Ettensohn (1981).
			East-central and southeastern Kentucky		
4.	Lee and Breathitt Paragon Slade Borden Renfro Nada Cowbell Nancy New Albany	Clay City GQ-663 (Simmons, 1967); Stanton GQ-1182 (Weir, 1974a); Slade GQ-1183 (Weir, 1974b).	Mountain Parkway from Interchange with Ky. Hwy. 1057 eastward to 2.1 mi east of Slade interchange with Ky. Hwy. 11.	Solution-collapse features in Slade Formation filled with shale and sandstone of lower tongue of Breathitt. Representative Slade and Breathitt. Complete Slade section is present along the parkway.	Dever (1971).
5.	Lee and Breathitt Paragon Slade Borden Renfro Nada Cowbell Nancy Farmers New Albany (also Sunbury and Bedford)	Stanton GQ-1182 (Weir, 1974a); Means GQ-1324 (Weir, 1976); Frenchburg GQ-1390 (Hoge, 1977b); Scranton GQ-1488 (Haney and Hester, 1978); Ezel GQ-721 (Pipiringos and others, 1968); Bangor GQ-947 (Hylbert and Philley, 1971); Salt Lick GQ-1499 (Philley, 1978).	Numerous roadcuts and adjacent quarry sections along Ky. Hwys. 15, 213, 36, 1274, 801, and U.S. Hwy. 460.	Erosional features and depositional patterns in Slade and Paragon related to intra-Mississippian tectonism.	Dever and others (1977).
6.	Lee Pennington Newman Fort Payne Grainger	Frakes-Eagan GQ-1249 (Newell, 1975).	Roadcuts along Ky. Hwy. 1595.	Fort Payne Chert underlain by Floyds Knob glauconite.	
7.	Pennington Newman Grainger Chattanooga	Bledsoe GQ-889 (Csejtey, 1971).	Roadcuts and quarry along U.S. Hwy. 421, north side of Pine Mountain.	See quadrangle map columnar section.	Hauser and others (1957, p. 13–16); Wilpolt and Marden (1959, p. 622–625).
8.	Lee Pennington Newman Grainger	Louellen GQ-1060 (Froelich, 1973).	Hurricane Gap section. Roadcuts and quarries along Ky. Hwy.160.	See quadrangle map columnar section.	Wilpolt and Marden (1959, p. 631–636).

TABLE 2.—*Selected exposures of Mississippian rocks in Kentucky*—Continued

[Numbers of sections keyed to map, fig. 11]

	Stratigraphic units exposed	U.S. Geological Survey Geologic Quadrangle Maps	Location and access	Features	Pertinent references
	East-central and southeastern Kentucky—Continued				
9.	Lee Pennington Newman Grainger	Whitesburg–Flat Gap GQ-1119 (Rice and Wolcott, 1973).	Roadcuts and quarry along U.S. Hwy. 119, north side of Pine Mountain.	See quadrangle map columnar section.	
10.	Pennington Newman Grainger	Jenkins West GQ-1126 (Rice, 1973).	Pound Gap section. Roadcuts and quarry along U.S. Hwy. 23.		Wilpolt and Marden (1959, p. 645–648).
11.	Newman Grainger Sunbury Berea Ohio	Hellier–Clintwood GQ-950 (Alvord, 1971).	Secondary road and quarry along Mountain Branch; south side of Ky. Hwy. 197.	See quadrangle map columnar section.	Smith and others (1967, p. 11–13).
12.	Lee Pennington Newman	Elkhorn City–Harman GQ-951 (Alvord and Miller, 1972).	Secondary road along Blue Head Branch and quarry near head of Rough Branch; south side of Ky. Hwy. 197.	See quadrangle map columnar section.	Smith and others (1967, p. 14–16).
	Southern central and south-central Kentucky				

13.	Salem
	Borden
	  Muldraugh
	  Floyds Knob
	  Nancy
	Halls Gap
		Halls Gap GQ-1009 (Weir, 1972).	Halls Gap Section U.S. Hwy. 27 at Halls Gap.	Typical Borden of this area overlain by Salem.	Weir (1970, p. 33–35, 43–44).

14.	Paragon
	Slade
	Borden
	  Renfro
	  Wildie
	    (Floyds Knob)
	  Halls Gap
	  Nancy
		Wildie GQ-684 (Gualtieri, 1968a); Mount Vernon GQ-902 (Schlanger and Weir, 1971).	Renfro Valley interchange. Interstate Hwy. 75 and U.S. Hwy. 25. Roadcuts along 4 miles of U.S. Hwy. 25 north from interchange and roadcuts along 1.5 mi of Interstate Hwy. 75 south from interchange.	Renfro type section and upper Borden. Glauconite in Wildie. Representative Newman.	Weir (1970, p. 38–40, 45–46); Ettensohn and Dever (1979, p. 170–181).

15.	Fort Payne	Mannsville GQ-562 (Taylor, 1966).	Ky. Hwy. 76, north of bridge across Baker Branch.	Representative Fort Payne; Floyds Knob exposure.	Sedimentation Seminar (1972).
16.	Science Hill Sandstone Member	Maretburg GQ-338 (Schlanger, 1965).	Roadcuts in Science Hill along Ky. Highway 70, Rockcastle County. Probably same as section 33 of Lewis and Taylor (1979).		Lewis and Taylor (1979).
17.	Fort Payne Knifley	Cane Valley GQ-369 (Maxwell and Turner, 1964).	Fisher Bend Bluff north of Green River Reservoir. Difficult access.	Knifley type section.	Sedimentation Seminar (1972) (Section 1).
18.	Fort Payne Cane Valley	Cane Valley GQ-369 (Maxwell and Taylor, 1964).	Quarry along Butler Branch on Ky. Hwy. 55.	Cane Vallsy type section.	Kepferle and Lewis (1974).

19.	Monteagle
	St. Louis
	Salem and Warsaw
	Borden
	  Muldraugh
	  Floyds Knob
	  Nancy
		Delmer GQ-909 (Lewis, 1971a).	Cumberland Parkway east of Fishing Creek (Lake Cumberland); about 3 mi west of West Somerset. Quarries in Monteagle Limestone on Smith and Hale Knobs south of Ky. Hwy. 80.	Bedded-appearing chert in Muldraugh. Large-scale foreset beds in Borden. Stromatolitic beds in St. Louis. Relict-evaporite features in lower St. Louis. Salem and Warsaw unit calcarenite and dolomite.	Dever and Moody (1979b).

TABLE 2.—*Selected exposures of Mississippian rocks in Kentucky*—Continued

[Numbers of sections keyed to map, fig. 11]

	Stratigraphic units exposed	U.S. Geological Survey Geologic Quadrangle Maps	Location and access	Features	Pertinent references
	Southern central and south-central Kentucky—Continued				
20.	Fort Payne	Creelsboro GQ-204 (Thaden and Lewis, 1973); Wolf Creek Dam GQ-177 (Lewis and Thaden, 1962).	West side of Wolf Creek Dam and roadcuts along Ky. Hwy. 1730.	Representative Fort Payne.	Lewis and Potter (1978).
21.	Salem and Warsaw unit Fort Payne Cane Valley	Jamestown GQ-182 (Thaden and Lewis, 1962); Jabez GQ-483 (Thaden and Lewis, 1966).	Shores of Lake Cumberland near Lake Cumberland State Park.	Carbonate mud mounds and crinoidal limestone bodies in Fort Payne. Jabez Sandstone Member of Fort Payne.	Lewis and Potter (1978).
22.	Monteagle Kidder	Frazer GQ-1223 (Lewis, 1975).	Ky. Hwy. 790, south of Kidder.	Kidder Limestone Member type section; Hartselle Formation composed of shale.	Lewis (1971b).
23.	Breathitt Paragon Bangor Hartselle Monteagle Kidder	Burnside GQ-1253 (Taylor and others, 1975).	Roadcuts along 2 mi of U.S. Hwy. 27 north of Sloans Valley. Strunk Construction Co. quarry, east side of U.S. Hwy. 27, south of Tatesville.		Ettensohn and Chesnut (1979a, 1979b).
24.	Hartselle Monteagle Kidder Ste. Genevieve St. Louis	Cumberland City GQ-475 (Lewis and Thaden, 1965).	Roadcuts east of Cartwright along Ky. Hwy. 90 and along secondary road leading southward to Poplar Mountain.	Ste. Genevieve completely exposed.	
25A.	Monteagle Kidder Ste. Genevieve St. Louis	Albany GQ-550 (Lewis and Thaden, 1966).	Wago quarry, east of Ky. Hwy. 639, north of Wago ¾ mi.		Lewis and Potter (1978, p. 39–41).
25B.	Monteagle Kidder Ste. Genevieve	Albany GQ-550 (Lewis and Thaden, 1966).	Huddleston quarries, east side of U.S. Hwy. 127, 2.5 mi north of Albany.	Complete, or nearly complete Kidder and Ste. Genevieve sections near western limit of Appalachian basin.	McFarlan and Walker (1956, p. 13).
25C.	Hartselle Monteagle Kidder Ste. Genevieve	Albany GQ-550 (Lewis and Thaden, 1966).	Gaddie Shamrock, Inc. quarry, north side of Ky. Hwy. 1590, west of Albany 1.5 mi.		
	Western, central, and west-central Kentucky				
26.	Elwren Reelsville Sample-Mooretown Paoli Ste. Genevieve	New Amsterdam–Mauckport GQ-990 (Amos, 1972).	Battletown quarry east of Ky. Hwy. 228, north of Battletown ½ mi.	Best exposures of Ste. Genevieve in region. Aux Vases(?) equivalent.	Stokley and McFarlan (1952, p. 64–68).
27.	St. Louis Salem	Rock Haven–Laconia GQ-780 (Withington and Sable, 1969).	U.S. Hwy. 60 at Grahamton	Rarely exposed St. Louis section.	
	Upper part of Salem and lower part of St. Louis are well exposed in at least two other localities: Vulcan Materials Co. Brandenburg quarry, east side of Ky. Hwy. 933. Rock Haven–Laconia GQ-780 (Withington and Sable, 1969) Roadcuts along Ky. Hwy. 1638 west of Doe Run Mill. Rock Haven–Laconia and Guston GQ's. Guston GQ-1481 (Palmer, 1978)				
28.	St. Louis Salem Harrodsburg Borden	Fort Knox GQ-1375 (Kepferle and Sable, 1977).	Round Hollow section, U.S. Hwy. 31W north of Muldraugh.	Shaly Salem. Reference section of Harrodsburg. Muldraugh with crinoidal limestone beds.	Sable, Kepferle, and Peterson (1966).

TABLE 2.—*Selected exposures of Mississippian rocks in Kentucky*—Continued

[Numbers of sections keyed to map, fig. 11]

Stratigraphic units exposed	U.S. Geological Survey Geologic Quadrangle Maps	Location and access	Features	Pertinent references
Western, central, and west-central Kentucky—Continued				
29A. Harrodsburg Borden Muldraugh Floyds Knob Nancy	Elizabethtown GQ-559 (Kepferle, 1966b).	Bluegrass Parkway about 4 to 6 mi east of Elizabethtown.	Large roadcuts.	
29B. Harrodsburg Muldraugh	Elizabethtown GQ-559 (Kepferle, 1966b).	Vulcan Materials Co. Elizabethtown quarry north of U.S. Hwy. 62, 2¾ mi northeast of Elizabethtown.	Striking foreset bedding in Muldraugh.	Kepferle, Peterson, and Sable (1964, p. 31-32).
29C. Salem Harrodsburg Muldraugh	Elizabethtown GQ-559 (Kepferle, 1966b); Colesburg GQ-602 (Kepferle, 1967).	Tunnel Hill section; Louisville and Nashville Railroad cuts northeast of Tunnel Hill.	Classic localities.	Butts (1917, 1922); Stockdale (1939).
30. Chester units Paoli to Big Clifty	Summit GQ-298 (Moore, 1964a).	U.S. Hwy. 62, ½-1 mi east of Summit.	Fair exposures. USGS core hole here (Moore, 1964b). Big Clifty asphaltic sandstone in quarries of Summit.	
Western Kentucky				
31. Big Clifty to Glen Dean	Big Clifty GQ-192 (Swadley, 1962).	Scattered cuts along U.S. Hwy. 62 and Western Kentucky Parkway.	Geologic map does not show Western Kentucky Parkway. Fossiliferous Glen Dean in railroad cuts at West Clifty.	Vincent (1975, p. 50-51, 64).
32. Leitchfield	Leitchfield GQ-1316 (Gildersleeve, 1978).	Western Kentucky Parkway; first cuts west of Leitchfield interchange.	Seldom exposed poorly resistant section; partly overgrown and slumped.	Williamson and McGrain (1979, p. 34-35).
33. Caseyville Leitchfield	Caneyville GQ-1472 (Gildersleeve and Johnson, 1978).	Western Kentucky Parkway.	Excellent Pennsylvanian-Mississippian contact exposures.	Williamson and McGrain (1979, p. 33-34); Whaley and others (1979, p. 42-44).
34. Renault Ste. Genevieve	Burna GQ-1150 (Amos, 1974).	Barrett quarry U.S. Hwy. 60; 5 mi north of Smithland, then 1½ mi southeast on secondary road.		Dever and McGrain (1969, p. 100-109).
35. Tar Springs to Cypress	Olney GQ-792 (Trace and Kehn, 1968).	Western Kentucky Parkway 3½-4½ mi east of Princeton.		Trace (1981).
36. Salem Warsaw Fort Payne	Grand Rivers GQ-328 (Hays, 1964); Calvert City GQ-731 (Amos and Finch, 1968).	Reed Crushed Stone Co. quarry U.S. Highway 62 at Lake City.		Dever and McGrain (1969, p. 48-57).
37. Fort Payne	Grand Rivers GQ-328 (Hays, 1964); Birmingham Point GQ-471 (Fox and Olive, 1966); Fenton GQ-311 (Schnabel and MacKallor, 1964); Fairdealing GQ-320 (Wolfe, 1964).	Best exposures are along Kentucky Lake shoreline. Residuum and poor exposures along and near U.S. Hwy. 68.	Generally only residuum exposed; chert content 20-30-40 percent.	

An excellent exposure of Fort Payne (interbedded chert and limestone) is present on the east shore of Lake Barkley in a roadcut along Ky. Hwy. 295, west of Old Kuttawa.
Eddyville GQ-255 (Rogers, 1963).

TABLE 2.—*Selected exposures of Mississippian rocks in Kentucky*—Continued

[Numbers of sections keyed to map, fig. 11]

	Stratigraphic units exposed	U.S. Geological Survey Geologic Quadrangle Maps	Location and access	Features	Pertinent references
			Western Kentucky—Continued		
38.	Renault Ste. Genevieve	Princeton East GQ-1032 (Trace, 1972).	Kentucky Stone Co. Princeton quarry via Ky. Hwy. 91, 2¾ mi southeast of Princeton, Ky.	Fredonia, Rosiclare, Levias, and Renault distinguished.	Dever and McGrain (1969, p. 118–133).
39.	Chester series	Princeton East GQ-1032 (Trace, 1972).	Walches Cut. Illinois Central Railroad, via Ky. Hwy. 91 and secondary roads, about 4 mi east-southeast of Princeton, Ky.	Classic locality. Dipping beds, in part faulted. Renault to Kinkaid.	
40.	Salem Warsaw	Canton GQ-279 (Fox and Seeland, 1964).	Kentucky Stone Co. Canton quarry U.S. Hwy. 68, 1 mile east of Canton.	Core drill site (Warsaw to Chattanooga). See quadrangle map columnar section.	Dever and McGrain (1969, p. 27–41 and fig. 6).
41.	Bethel Renault Ste. Genevieve	Hopkinsville GQ-651 (Klemic, 1967).	Christian Quarries quarry, east side of Hopkinsville, south of U.S. Hwy. 68.		Dever and McGrain (1969, p. 168–175).
42.	Tradewater Caseville Leitchfield Glen Dean Hardinsburg Golconda Girkin Ste. Genevieve	Morgantown GQ-1040 (Gildersleeve, 1972); Sugar Grove GQ-225 (Miller, 1963); Hadley GQ-237 (Rainey, 1963); Rockfield GQ-309 (Rainey, 1964).	Green River Parkway, from interchange with U.S. Hwy. 231 at Bowling Green, northward to interchange with U.S. Hwy. 231 at Morgantown.	Good exposures of Chesterian units, particularly Beech Creek Member of the Golconda Formation.	

(1) of known Devonian age (Ohio Shale and in part, Chattanooga Shale), (2) known to span the Devonian-Mississippian systemic boundary (New Albany Shale and in part Chattanooga Shale), and (3) of equivocal age relationships in which investigators are not in total agreement about the position of the boundary (Bedford Shale and Berea Sandstone).

NEW ALBANY, CHATTANOOGA, AND OHIO SHALES

Rocks of Middle and Late Devonian age which underlie Early Mississippian strata in Kentucky are mainly "black shale" units consisting of organically rich, fissile shale and thin-bedded siltstone. Three nomenclatural units, the New Albany, Chattanooga, and Ohio Shales, are laterally continuous with one another; their names have been extended into Kentucky from Indiana, Tennessee, and Ohio respectively. Nomenclatural boundaries of these units cropping out in Kentucky arbitrarily coincide with mapped 7½-minute quadrangle boundaries. In general, the name New Albany Shale is used across central and into east-central Kentucky; the Chattanooga is present in western, southwestern, southern west-central, south-central, and southeastern Kentucky; and the Ohio Shale is restricted to the exposure belts in northeastern and east-central areas.

Maximum thicknesses of the Ohio, Chattanooga, and New Albany Shales, the lower part of the Knobs Megagroup (Swann and Willman, 1961), are more than 440 ft in western Kentucky (Schwalb and Potter, 1978), and more than 1,700 ft in extreme eastern Kentucky (Fulton, 1979; fig. 12 of this report). The units thin to less than 40 ft thick along the Cincinnati arch, which was a relatively positive area during the Middle and Late Devonian; they are known to be absent in at least two locations in south-central Kentucky, where Mississippian rocks overlie Ordovician and Silurian strata (Potter, 1978). The two correspondingly negative areas of thick accumulations on either side of the arch are the Moorman syncline in western Kentucky, and the western flank of the Appalachian basin depositional trough in eastern Kentucky. Thickness variations of the Devonian shale units along the Rough Creek fault system north of the Moorman syncline indicate pre-Mississippian tectonic activity there (Schwalb and Potter, 1978).

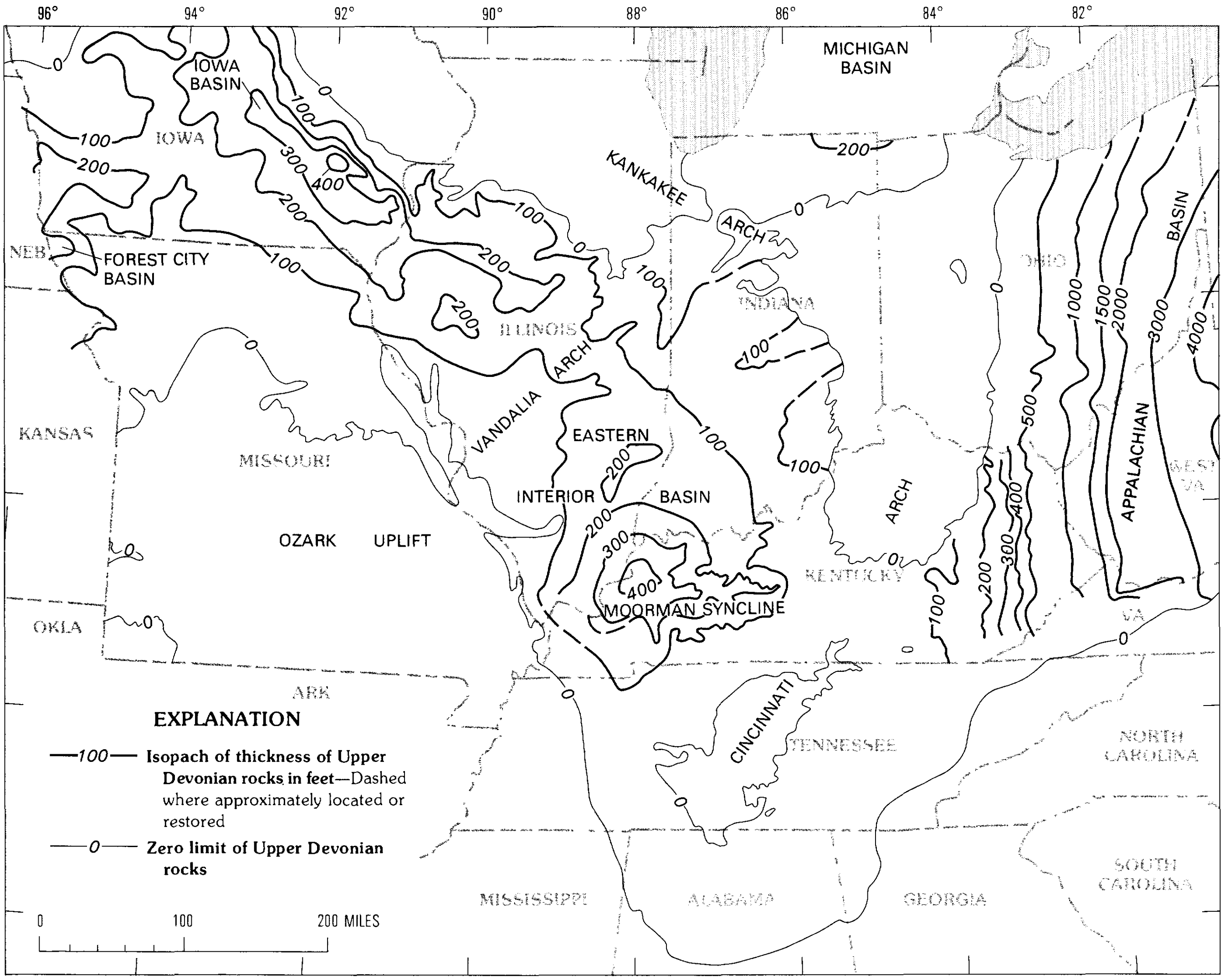


FIGURE 12.—Thickness of Upper Devonian rocks and their relationship to major structural elements in the east-central United States (from Sable, 1979; Schwalb and Potter, 1978; Potter, 1978; Fulton, 1979, de Witt and McGrew, 1979).

BEDFORD SHALE AND BEREA SANDSTONE

The Bedford Shale and Berea Sandstone (Newberry, 1870) overlie the Ohio and Chattanooga Shales in eastern Kentucky with apparent conformity. Together, they form a wedge which thins southwestward in east-central Kentucky (McDowell and Weir, 1977). The Berea is mappable from the Ohio border as far south as Stricklett and Head of Grassy quadrangles (Morris, 1965b; 1966a); the Bedford extends farther southward and during mapping was recognized as far as the vicinity of the Means quadrangle (Weir, 1976). In the subsurface of eastern Kentucky, the Bedford has been traced as far south as Knox County in southeastern Kentucky (Kepferle and others, 1978) and pinches out to the southwest.

The Bedford Shale is principally gray to greenish-gray claystone with pyritic nodules and thin siltstone layers. The overlying and intertonguing Berea Sandstone is light-gray to buff, very fine to fine grained subgraywacke sandstone. Oscillation ripple marks trending generally N. 50° W. to due west (Morris, 1965a, 1966b; Morris and Pierce, 1967), crossbedding, and penecontemporaneous deformation features are common. Grains are predominantly subangular quartz with minor chert, feldspar, and rock fragments. Combined maximum thickness of Bedford and Berea strata is less than 200 ft in eastern and southeastern Kentucky (fig. 52), which indicates two minor depocenters corresponding to the Red Bedford and Virginia-Carolina deltas of Pepper and others (1954). Thickness trends indicate a general west to southwest paleoslope.

A classic regional analysis of these units in Ohio and West Virginia was given by Pepper and others (1954), but extended only into northeasternmost Kentucky. The Bedford and Berea are discrete units in some areas of northeastern Kentucky, but elsewhere they intertongue and the Berea is in part a submarine channel fill in the Bedford (Morris, 1966a; Morris and Pierce, 1967; fig. 13 of this report). They thin and apparently grade into dark shales of the uppermost Chattanooga and New Albany Shales (Elam, 1981). Overlying thin Sunbury equivalents extend southwestward as the uppermost beds of the Chattanooga into south-central Kentucky and northern Tennessee (Elam, 1981).

In northeastern Kentucky, lithofacies and thickness distribution of sandstone-dominated lobes (de Witt and McGrew, 1979; fig. 52 of this report) suggest westerly and southwesterly transport directions for the Bedford and Berea sediments from source areas east and northeast of the present Appalachian Mountains (Pepper and others, 1954). The sandstones were derived probably from earlier Paleozoic detrital rocks (Pepper and others, 1954, p. 91, 95). The ripple marks of N. 50° W. to due west trend in the Berea of this area and throughout a large adjacent area of southern Ohio have been ascribed to northeasterly prevailing winds (Bucher, 1919; Pepper and others, 1954, p. 91) or shoreline coastal control (Hyde, 1911). Crossbedding and sandstone-filled channels characterize the sequence, and indicate deposition in a shallow-water deltaic complex. Sole markings in some sandstones suggest that they were deposited by density currents, probably at the delta front (Wilson, 1950; Rich and Wilson, 1950).

In southeastern Kentucky, the Bedford and Berea are mappable units southward to the Roxana (Maughan, 1976) and Benham (Froelich and Stone, 1973) quadrangles. In the eastern Kentucky subsurface, they thin to a combined thickness of less than 10 ft along a north-trending line from Leslie to Wolfe Counties.

DEVONIAN-MISSISSIPPIAN SYSTEMIC BOUNDARY

In Kentucky, southern Indiana, and Tennessee, the Devonian-Mississippian boundary can be determined fairly closely although its position in northeastern and southeastern Kentucky has been strongly debated. The uppermost part of the New Albany Shale in its type area of southern Indiana spans the boundary (Huddle, 1934; Campbell, 1946; Lineback, 1968a). Beds of Kinderhookian age are represented in the top approximately 3 ft of the New Albany where the New Albany totals about 100 ft thick. The base of the lowest Kinderhookian bed coincides closely with a subtle lithologic break. In the upper 3 ft, which comprise the Underwood, Henryville, and Jacobs Chapel beds (Campbell, 1946) of the uppermost New Albany, conodonts are of Kinderhookian age. A similar section occurs in Kentucky in the Louisville West quadrangle (Kepferle, 1974), but in the adjacent Brooks quadrangle to the southeast (Kepferle, 1972b), conodonts in the upper 4 ft of the New Albany are of probable Late Devonian age. All conodont collections from the uppermost beds of the New Albany of central Kentucky farther south either

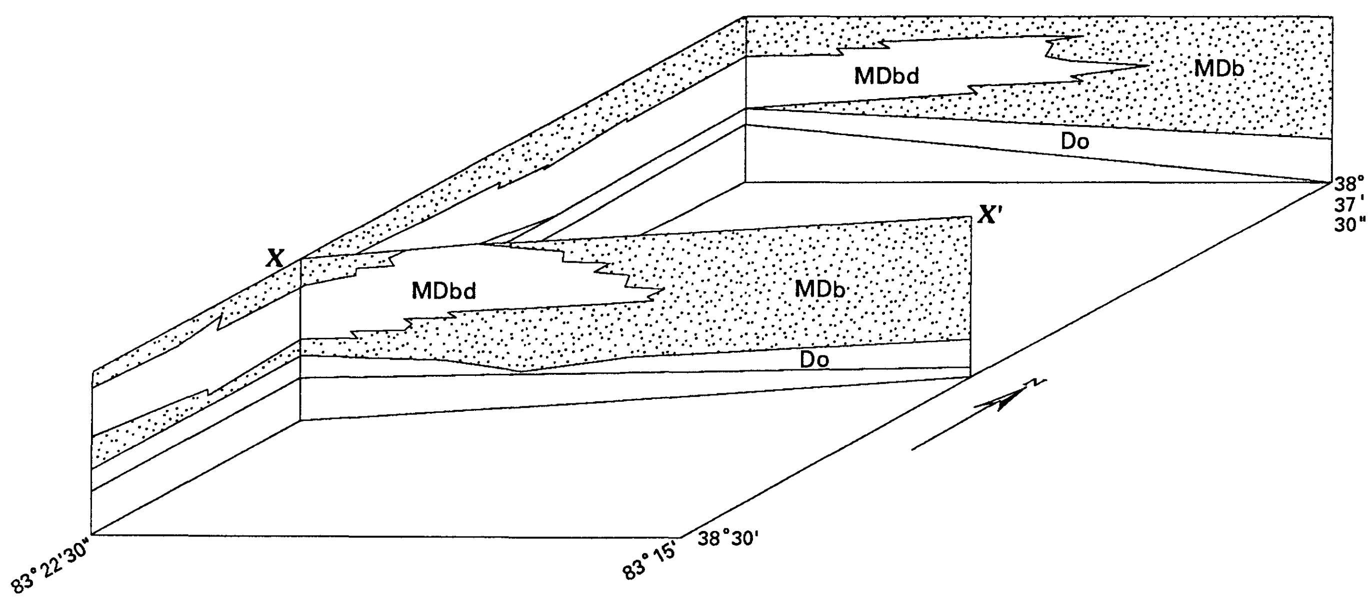


FIGURE 13.—Generalized relationships between Berea Sandstone (MDb) and Bedford Shale (MDbd) in Vanceburg quadrangle, northeastern Kentucky (Morris and Pierce, 1967). Berea Sandstone thickens eastward, fills channel cut in Ohio Shale (Do) as shown in panel *X–X'*. Vertical exaggeration about ×60.

indicate a probable Late Devonian age or are nondiagnostic (J.W. Huddle, written commun., 1967).

The position of the Devonian-Mississippian boundary in northeastern Kentucky is extrapolated from exposures in Ohio, and was interpreted by de Witt (1970), using conodont and floral evidence, to lie within the basal few feet of the Bedford-Berea detrital wedge that separates the Sunbury Shale of Mississippian (Kinderhookian) age from the underlying Late Devonian Ohio Shale. More recent spore evidence (Eames, 1978) indicates that the boundary lies between the Berea-Bedford and the Sunbury Shale in northeastern Ohio. The systemic boundary in northeastern Kentucky is also considered by Sandberg (1981) to lie at the base of the Sunbury Shale.

Conodonts from beds in the Sunbury Shale, the uppermost part of the New Albany Shale, and basal beds of the Fort Payne Formation in east-central, central, and south-central Kentucky are shown in tables 3–6 of this report. Their distribution indicates that the uppermost beds of the New Albany in east-central Kentucky at least as far south as the Berea and Bighill quadrangles are of probable Sunbury (Kinderhookian) age. Southward in Kentucky, conodonts from the uppermost beds of the New Albany are nondiagnostic in places; and beds of the basal Borden and Fort Payne Formations (Maury Formation equivalent) contain conodonts of Kinderhookian age in some localities and Late Devonian age in others (Hass, 1956). Very slow deposition and gaps in conodont assemblages seem to have characterized the Devonian-Mississippian boundary conditions in south-central and parts of central Kentucky. In some areas, a hiatus above the uppermost beds of the New Albany Shale is indicated by conodonts of probable upper Burlington (Osagean) age in the basal beds of the Borden Formation (Rexroad and Scott, 1964).

The evidence suggests that deposition was generally continuous across the Devonian-Mississippian boundary in the northern part of northeastern and central Kentucky, but that during this time nondeposition or very slow deposition, periodically interrupted by submarine scour, characterized south-central Kentucky (Conkin and Conkin, 1979).

MISSISSIPPIAN ROCKS

ROCKS OF KINDERHOOKIAN AND EARLY OSAGEAN AGE (EARLY MISSISSIPPIAN)

Earliest Mississippian (Kinderhookian) rocks in Kentucky are widespread, but they are relatively thin and constitute a small part of the total Mississippian rock volume. In eastern Kentucky, the strata which succeed the Bedford-Berea deltaic wedge are terrigenous organic clastics. During Kinderhookian time a thin distinctive green claystone unit was deposited across southern Kentucky, and a thin unit of carbonate rocks with interbedded mudstones was deposited in west-central and western Kentucky. These units are, respectively, the Sunbury Shale, the equivalent of the Maury Formation of Tennessee, and the Rockford Limestone (fig. 7).

SUNBURY SHALE

The Sunbury Shale (Hicks, 1878) provides an easily recognizable horizon and is extensively used as a structural datum; it consists of fissile organic-rich claystone and siltstone similar to that in the older Ohio and Chattanooga Shales. It is 10–25 ft thick in northeastern Kentucky (fig. 14) and as much as 55 ft thick along Pine Mountain, southeastern Kentucky. Both the upper and lower contacts appear to be conformable. The unit is readily distinguishable by its radioactivity profile (Ettensohn, 1979b; Ettensohn and others, 1979). Still farther south and west, beds in the uppermost part of the New Albany and Chattanooga Shales have been recognized as Sunbury equivalents by their contained conodonts and by geophysical log studies (Elam, 1981). The conodonts, principally *Siphonodella* spp., occur in the top few inches of the New Albany Shale in the Berea (Weir, 1967) and Bighill (Weir and others, 1971) quadrangles.

Except for southwestward thinning, the Sunbury Shale exhibits no definitive clues to the transport direction of its sediment. Following progradation of Bedford-Berea sediments under shallow aerobic conditions, the Sunbury accumulated in an anaerobic, probable deep-water environment during a marine transgression, probably from the same general eastern provenance and under conditions similar to those which produced the Devonian-Mississippian black shales. Lineback (1970) considered that the black shales of the eastern midcontinent were deposited in shallow water with circulation restricted by the presence of an algal floatant. Deep-water environments for these black shales were favored by Rich (1951) and by Elam (1981).

MAURY FORMATION EQUIVALENT

South and west from about the vicinity of Berea, a few inches to about a foot of greenish claystone with phosphatic nodules, glauconite, and lag concentrates containing conodonts, unidentified fossil fragments, and fish remains directly overlies the New Albany or Chattanooga Shale (Elam, 1981; fig. 15 of this report). This lithic and positional equivalent of the Maury Formation of Tennessee (Safford and Killebrew, 1900) is also

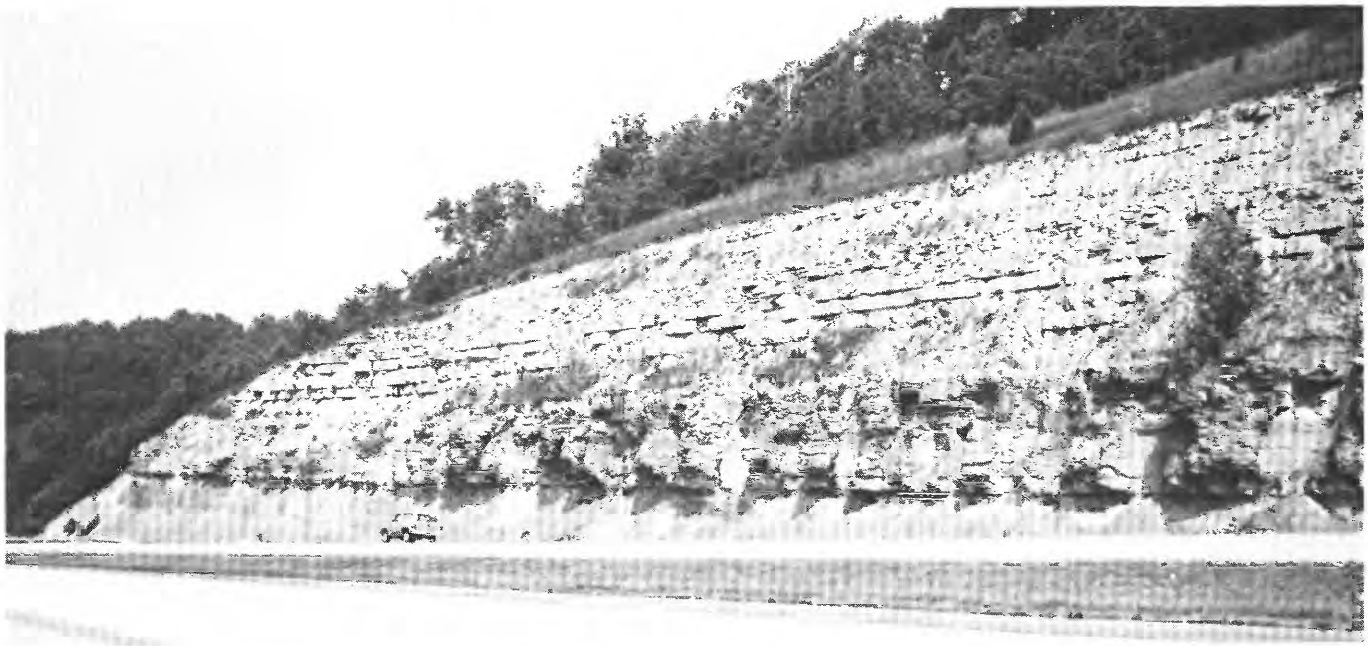


FIGURE 14.—Sunbury Shale (above vehicle) overlying the Bedford Shale (mostly talus-covered slope) and underlying the Farmers Member of the Borden Formation (tabular light-hued beds). Milepost 132.6, Interstate Highway 64, Farmers quadrangle, Rowan County.

reported in basal beds of the New Providence Shale Member of the Borden and Fort Payne Formations in many quadrangles in south-central and central Kentucky. These include Eli, Faubush, Delmer (Thaden and Lewis, 1965a; 1969; Lewis, 1971a) and as far west as Dubre quadrangle (Lewis, 1967) in south-central Kentucky, and Louisville West, Shepherdsville, and Howardstown (Kepferle, 1974; 1968; 1966a) in western central Kentucky. Similar greenish claystone above black shale is reported in many well descriptions in southern and western Kentucky by Freeman (1951, 1953).

Conodonts from several outcrops in southern Kentucky and Tennessee suggest that the Maury is a time-equivalent of most of the Bedford, the Berea, and the Sunbury (Collinson and others, 1962, p. 13), and that it locally contains elements younger than the Sunbury (Hass, 1956, p. 23). In these areas, the Maury may represent generally uninterrupted deposition during most or all of Kinderhookian time (Conant and Swanson, 1961, p. 67). In others, as along the Cincinnati arch in the western part of central Kentucky, Maury lithic equivalents contain a mixed conodont assemblage of Devonian, Kinderhookian, and Osagean ages, and are interpreted as a lag concentrate at an erosional hiatus, which possibly extended through Kinderhookian and early Osagean times (Rexroad and Scott, 1964). This interpretation supports the concept of very slow deposition and essentially starved basin conditions over much of Kentucky and Tennessee during earliest Mississippian time.

The widespread, thin claystone of the Maury Formation and its lithic equivalents in the basal Borden and Fort Payne probably were deposited remote from source areas (Conant and Swanson, 1961, p. 68), at a slow rate, in a low-energy environment favorable to the precipitation of phosphate. The concentration of phosphate nodules in the Maury equivalents appears to represent a lag concentrate from which most of the fine detrital material was winnowed by submarine currents; this environment is also suggested by mixed conodont "lag" assemblages near the Cincinnati arch. South of Kentucky, thin sandstones occur in the Maury along the western margin of the Nashville Dome and suggest local source areas (Conant and Swanson, 1961, p. 53). The normally subjacent Chattanooga Shale is also locally absent there, indicating local uplift or local scour and resultant deposition along the arch. The abundant phosphatic nodules in the Maury Formation equivalent may indicate that southern Kentucky and Tennessee occupied a broad shelf north of a deep basin from which upwelling ocean currents contributed nutrients such as phosphate. Phosphatic nodules have also been reported in the underlying New Albany Shale and in the overlying New Providence Shale Member of the Borden Formation, indicating that conditions for the precipitation of phosphate existed periodically from Late Devonian into Osagean time.

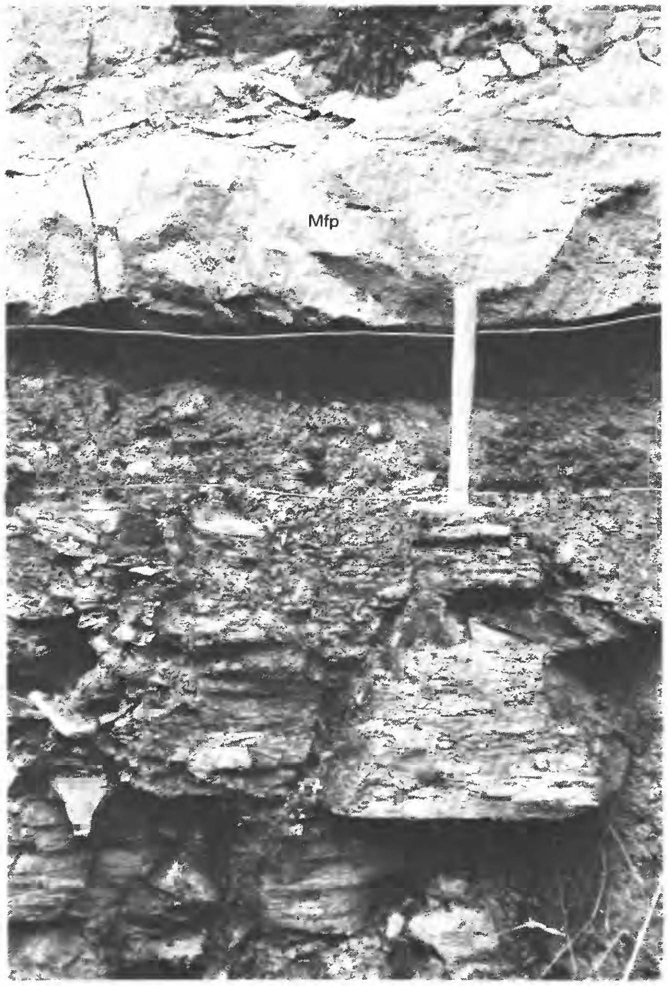


FIGURE 15.—Maury Formation equivalent (Mme), 0.8 ft thick, underlying Fort Payne Formation (Mfp) and overlying Chattanooga Shale (Dc). East side of Kentucky Highway 61, 4.7 mi south of junction of Kentucky Highways 90 and 61, east side of Burkesville, Frogue quadrangle, Cumberland County.

ROCKFORD LIMESTONE

In much of Indiana and adjacent parts of central and west-central Kentucky, earliest Mississippian strata are represented by the thin but widespread Rockford Limestone and thin shale beds which are superjacent to or in the uppermost few feet of the New Albany Shale. The Rockford, first named the Rockford Goniatite bed by Meek and Worthen (1861), was given formational status by Kindle (1899). The Rockford, a gray to greenish-gray, micritic, glauconitic limestone or dolomite, was reported to contain both Kinderhookian and Osagean conodont elements in Indiana (Rexroad and Scott, 1964) but Kinderhookian foraminifera in Indiana and northwestern central Kentucky (Conkin and Conkin, 1979). In northwestern central Kentucky, the Rockford is locally present south of the Ohio River in the Louisville West quadrangle (Kepferle, 1974) and was reported farther south in the Brooks quadrangle (Conkin and Conkin, 1979, p. 57). In this area, it is as much as 3 ft thick and directly overlies New Albany Shale. Southward, the Rockford grades to shale (Conkin and Conkin, 1979, p. 57), and thin carbonate strata in the position of the Rockford are also reported to the southwest in well logs of northern Meade and Breckinridge Counties. In the Louisville West quadrangle, the Rockford apparently is correlative with lithologies of the Maury equivalent.

In western Kentucky, some well records in counties along the Ohio River indicate that the Rockford Limestone (Chouteau Limestone of Illinois usage) is present there. In the Canton quadrangle, Trigg County, a thin limestone within the unit referred by Fox and Seeland (1964) to the New Providence Shale may also represent the Rockford. If this limestone is the Rockford, the 34 ft of shale between it and the older Chattanooga Shale is probably equivalent to the Kinderhookian Hannibal Shale of Illinois.

Carbonate rocks of the Rockford Limestone in Indiana and parts of northern Kentucky were mostly deposited in a notably low energy environment, on a sea floor having little relief. A high iron content and a low proportion of terrigenous detritus in Indiana may indicate a low land area to the east along the Cincinnati arch; dolomitic beds may suggest an intratidal depositional environment, but the enclosing sediments indicate a subtidal marine environment.

The Rockford Limestone in northwestern central Kentucky seems to be coeval with the Maury Formation equivalent farther south. The Maury equivalent may encompass several small-scale disconformities ranging from Late Devonian to Osagean age, expressed by superposition of and mixing of lag concentrates in a starved shelf or basin environment. Landward, such small-scale disconformities might be expressed individually by separate detrital units containing lag concentrates, as suggested by Conkin and Conkin (1979) to be present at the Devonian-Mississippian and Kinderhookian-Osagean boundaries.

KINDERHOOKIAN-OSAGEAN UNIT RELATIONSHIPS

Fine detrital rocks, mostly of the New Providence and Nancy Members (Osagean) of the Borden Formation, overlie Sunbury and New Albany Shales in northeastern, east-central, central, and west-central Kentucky. Judging from the widespread persistence of the thin Sunbury, the Maury equivalent, and the Rockford units, little hiatus preceded deposition of Borden sediments except locally along the western side of the Cincinnati arch. There, an unconformity at the base of the Fort Payne Formation in the Petroleum quadrangle, southern west-central Kentucky, was reported by Myers (1964). The Rockford Limestone is also locally absent in the southern Indiana outcrop belt (Lineback, 1964), and shallow channels filled by Borden strata cut into the New Albany Shale in northwest-central Kentucky (R.C. Kepferle, oral commun., 1967). Scour prior to or during deposition of Borden Formation sediments is therefore indicated in those areas.

In much of the region southwest of the limit of rocks assigned to the Borden, in southern and western Kentucky and western Tennessee, mudstones in the New Providence Shale Member of the Fort Payne Formation rest with apparent conformity on the Maury Formation and its lithic equivalents in places, but abrupt contacts also exist between overlying Fort Payne siliceous rocks and the Maury. These were considered by Conant and Swanson (1961, p. 68) to be due to sudden changes in depositional environments. Conodont faunas collected at scattered localities in southern Kentucky, however, indicate that basal beds of the Fort Payne may vary in age from place to place (J.W. Huddle, written commun., 1967), and an obscure nondepositional or submarine erosional hiatus may therefore be reflected between Maury and Fort Payne strata. Such relations would be expected for a distal, sediment-starved area basinward of deltaic deposits which were subsequently overlain by transgressive carbonate strata of the Fort Payne.

PALEOTECTONIC IMPLICATIONS

Because no known physical evidence points to intersystemic unconformities of much magnitude, structural elements during Kinderhookian time in Kentucky were probably of extremely low amplitude. The region was mildly negative, except for the Cincinnati arch, which may have been a barrier to westward dispersal of Late Devonian and Kinderhookian clastic sediments.

If a shelf-trough depositional and tectonic model is invoked, the widespread thin deposits of the Rockford and Chouteau limestones in Kentucky could have accumulated on the southern part of a broad stable shelf. Maury Formation equivalents accumulated either on the southern extension of this shelf, or in a negative element of larger magnitude which adjoined the shelf to the south. The northward and westward change from these phosphate-bearing Maury equivalent rocks to carbonate rocks of the Rockford Limestone may suggest northward transition from a subsiding oceanic basin, the Ouachita trough. Alternatively, considering a trough model without transition to a shelf, a eustatic rise in sea level could have initiated or extended starved basin conditions. The Rockford Limestone in such a model might represent a deep-water carbonate deposit (R.C. Kepferle, oral commun., 1985).

ROCKS OF MOSTLY OSAGEAN AGE

Rocks of Osagean age are comparatively thicker, lithologically more diverse, and exhibit more complex interrelationships than earlier Mississippian rocks (figs. 7 and 9). They comprise two marine rock assemblages which are dominant in specific areas:

1. Older terrigenous detrital clastics (Borden Formation, New Providence Shale Member, Grainger Formation, and basal clastic parts of Fort Payne Formation) deposited as prograding deltaic wedges. These are mostly confined to the eastern and central parts of Kentucky, but their thinner distal equivalents extend throughout much of the southern and western parts of the State. They are generally bracketed in Kentucky by underlying "black shale" units and Maury Formation lithic equivalents and by overlying dominantly carbonate-rock units.
2. Younger siliceous, argillaceous, dolomitic, and crinoidal carbonate-rock units with local sandy terrigenous clastics (most of the Fort Payne Formation, Muldraugh Member of the Borden Formation and Renfro Member of the Slade Formation), which extend from east-central Kentucky across southern and western Kentucky and Tennessee into southeastern Illinois and southwestern Indiana.

During the 1960–1978 geologic mapping program, the concept of deltaic deposition for Borden and Fort Payne terrigenous clastic rocks in Kentucky (Borden delta) was developed (Peterson and Kepferle, 1970), a concept that has stimulated related research by individuals and groups; see for instance Sedimentation Seminar (1972); Whitehead (1976); Benson (1976); Kepferle (1972a, 1977a); and Kepferle and Lewis (1974).

Thickness and directional transport components of sandstone units of the Borden and Fort Payne are shown in figure 16. Distribution of distinctive lithic units, dark shales, crinoidal limestones, and greenish mudstones, which make up significant rock volumes in some areas, is shown in figure 54 and discussed on pages 51 and 100–101.

BORDEN FORMATION

In eastern and central parts of Kentucky, units of Osagean age are dominated by terrigenously derived detrital rocks in the lower part, overlain by

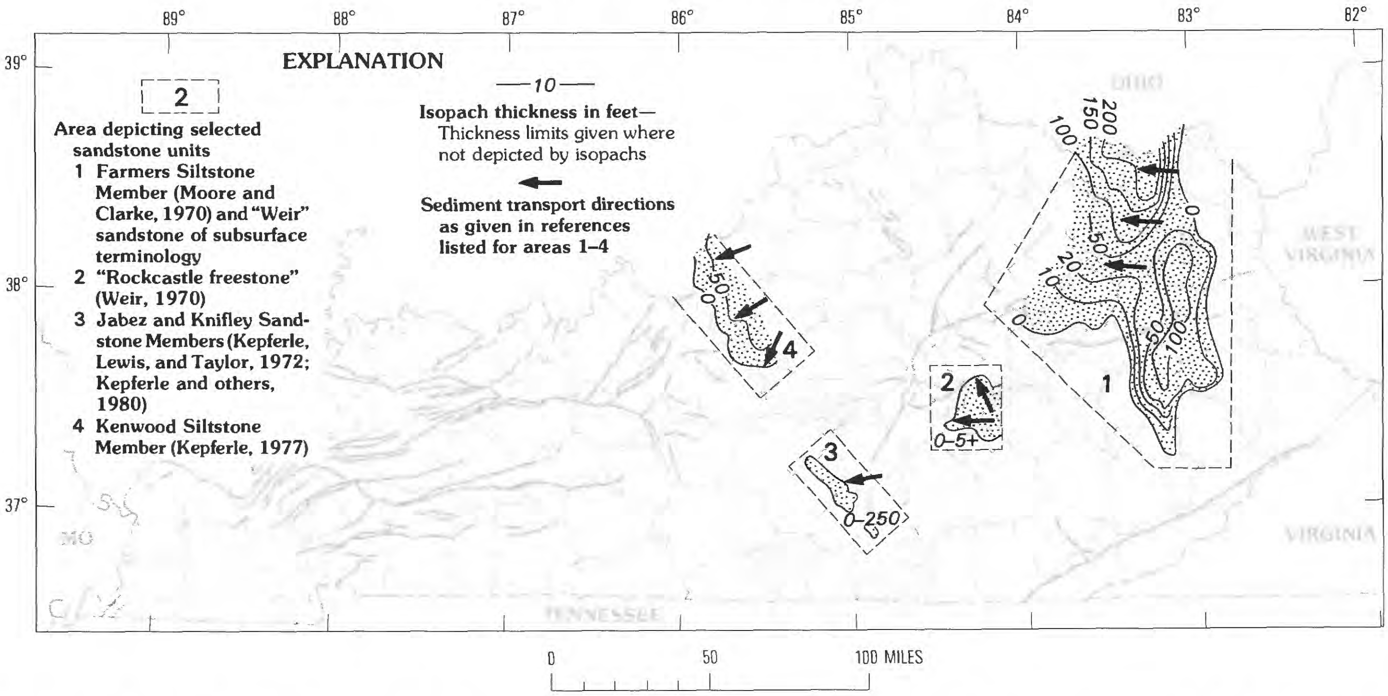


FIGURE 16.—Distribution (stipple pattern), thickness, and sedimentary transport directions of selected sandstone units in the Borden and Fort Payne Formations in Kentucky. Base includes selected faults and fault zones.

carbonate-rich beds in the upper part. The Borden Formation (Weir and others, 1966), in part correlative with the Cuyahoga and Logan Formations of Ohio (Hyde, 1915), the Borden Group of Indiana (Cumings, 1922), and the Pocono Group of West Virginia, makes up all or most of Osagean age-equivalents in northeastern east-central, central, and parts of south-central Kentucky. The Borden Formation consists of 10 members. The terrigenous clastic part of the Borden in Kentucky typically consists of lower units of gray and green mudstone and siltstone (Nancy and New Providence Members) containing planar-bedded sandstone (Farmers and Kenwood Members) and lenses of crinoidal limestone. Sandstones and siltstones are composed largely of subangular to subround quartz and feldspar grains with quartz and calcite cement; they are mostly subgraywackes originating in a provenance of largely felsic plutonic rocks (Kepferle, 1977a). Tongues and lenses of siltstone in the middle part of the Borden in Kentucky grade northward and eastward into thicker and more abundant units of coarser siltstone and sandstone in Ohio and West Virginia. In Kentucky these tongues and lenses include the Cowbell, Halls Gap, and Holtsclaw Members, and thinner, less extensive units such as the Gum Sulphur Bed of the Nancy Member and "Rockcastle freestone" of the Wildie Member. The detrital units form a clastic deltaic wedge which thins southwestward, and in large exposures they exhibit large-scale foreset bedding with westerly dip components (fig. 24). The uppermost units, the Wildie and Nada Members, are composed mostly of shale, including variegated varieties. Contacts of clastic units within the Borden Formation are generally gradational and do not show evidence of significant depositional or erosional breaks, except for thin glauconitic beds that are interpreted to mark a depositional hiatus or an interval of slow sedimentation.

As mapped, the uppermost, dominantly carbonate rock divisions of the Borden included the Renfro Member and the Muldraugh Member. The Renfro Member has been reassigned as the basal member of the Slade Formation by Ettensohn and others (1984). It is, however, discussed here with Borden Formation rocks with which it is in part equivalent. The Renfro includes dolomitic limestone and dolomite in northeastern, east-central, eastern, and south-central Kentucky. The Muldraugh Member, a thicker unit of light-colored cherty and silty dolomite and limestone, crops out in central and south-central Kentucky. The carbonate rock units are commonly separated from underlying clastic strata by thin glauconitic siltstone and limestone beds such as the Floyds Knob Bed of the Muldraugh Member in central Kentucky, and by thin glauconitic siltstone beds in northeastern, east-central, south-central, and west-central Kentucky. The Muldraugh is overlain by the Harrodsburg Limestone or the Salem and Warsaw

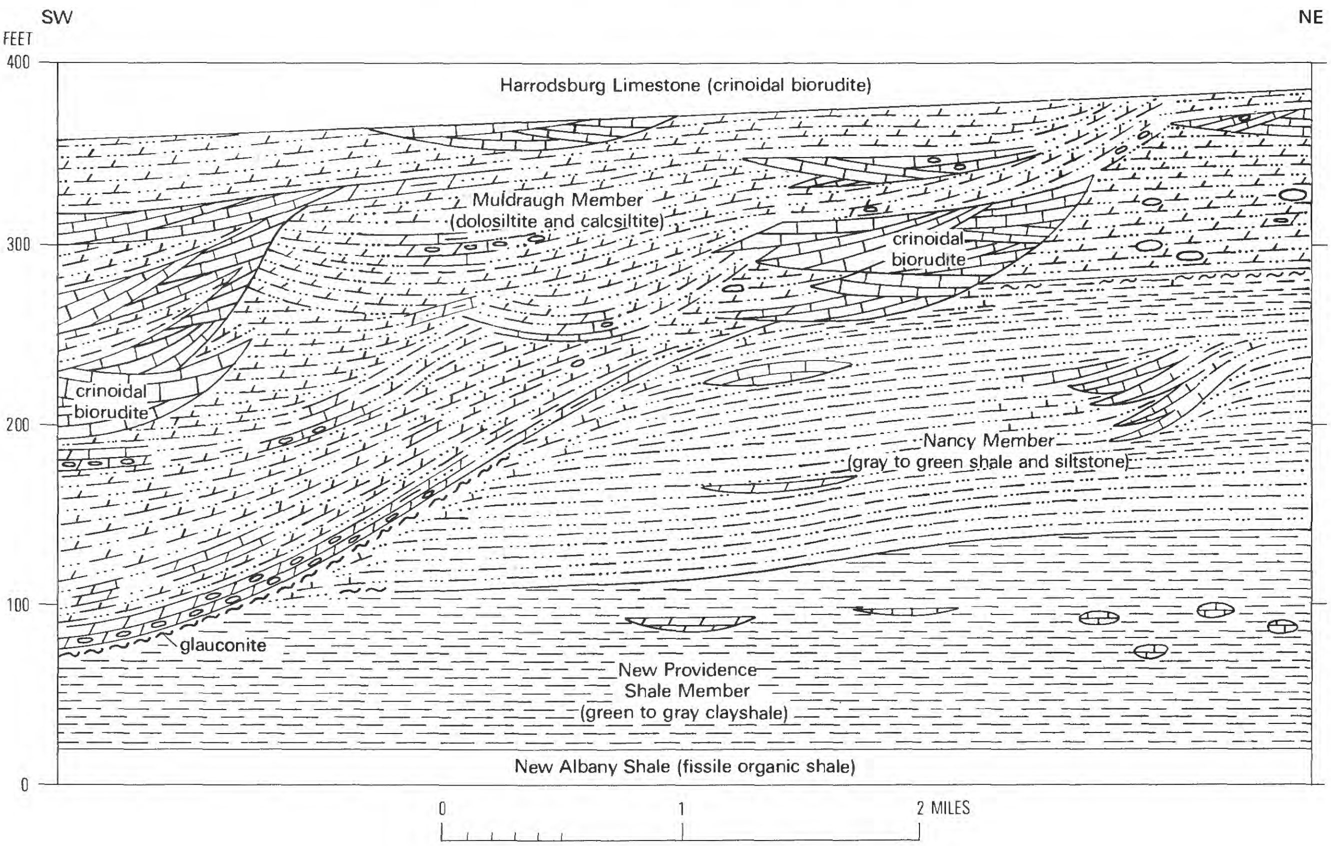


FIGURE 17.—Restored cross section of the Borden Formation delta "front" in Howardstown quadrangle (Kepferle, 1966a), north-central Kentucky, showing relationships of Borden units. Datum, top of New Albany Shale. Modified from Kepferle, 1966a.

Formations unit. Westward thickening of the carbonate rock units and reciprocal thinning of the underlying detrital units are characteristic internal relationships in the Borden. Contacts between these rocks are along generally southwestward-sloping planar surfaces (Peterson and Kepferle, 1970; figs. 9 and 17 of this report).

The southwest-thinning terrigenous clastic wedge of the Borden is an upward-coarsening succession of beds, representing westward progradation of the Borden delta. As indicated in the cross section (fig. 9), two pulses of clastic deposition culminated in deposition of the Farmers Member and the Cowbell Member; shales of the Nancy and New Providence Members represent distal prodelta sediments of the actively prograding deltaic system, followed by cessation of delta encroachment during which time the glauconite-bearing beds in the Nada Member and Floyds Knob Bed were deposited.

FARMERS MEMBER

In northeastern Kentucky, the Farmers Member is the basal unit of the Borden Formation (fig. 14). The Farmers includes the Vanceburg Sandstone Member of Hyde (1915), and was termed the Farmers Siltstone Member of the New Providence Formation by Stockdale (1939). The Farmers in its type area is 60 percent planar-bedded subgraywacke sandstone and 40 percent shale. It is more than 200 ft thick in northeastern Kentucky, thins southward into the Olympia quadrangle (McDowell and Weir, 1977) and extends into the Clay City quadrangle (Simmons, 1967; fig. 18 of this report). It is mapped with the Nancy Member of the Borden Formation in the Preston, Means, and Levee quadrangles (Weir and McDowell, 1976; Weir, 1976; McDowell, 1978), where it consists of the Clay City (sandstone) and underlying Henley (shale) beds.

Directional features, principally sole markings, indicate westward paleocurrent transport directions of the Farmers (Rich and Wilson, 1950; Rich, 1951; Wilson, 1950; fig. 16 of this report). The member is interpreted by Moore and Clarke (1970) to be a turbidite deposit. The "Weir Sand," a driller's term for several subsurface sandstones in eastern Kentucky and adjoining States, is in about the same stratigraphic position as the Farmers (Pepper and others, 1954). Of the two apparent south-trending lobes of sandstone in northeastern

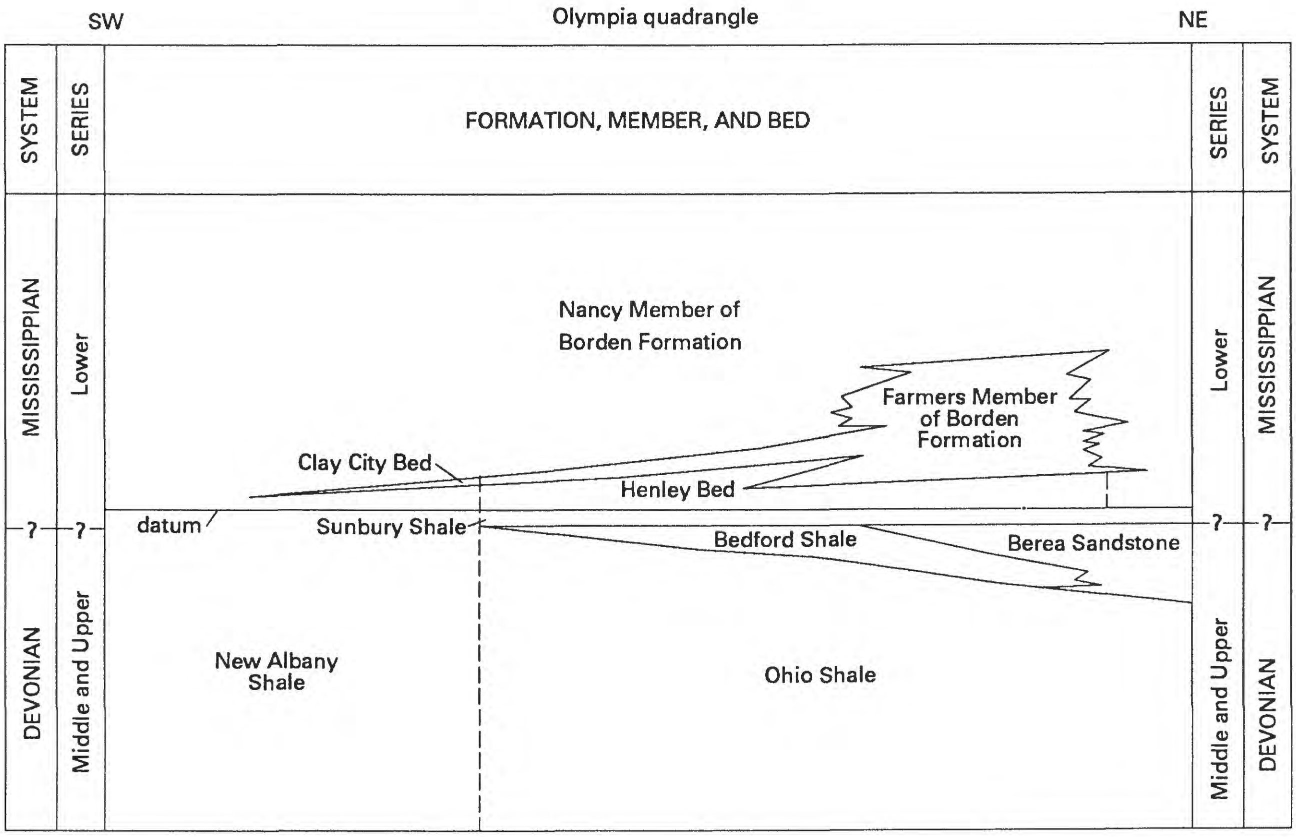


FIGURE 18.—Generalized stratigraphic diagram of lower part of the Borden Formation and underlying units in northeastern Kentucky (from McDowell and others, 1981).

Kentucky shown in figure 16, the western lobe represents the Farmers, strictly speaking, and the eastern lobe, more than 100 ft thick, is a "Weir Sand," which may be a subsurface continuation of the Farmers.

NANCY AND NEW PROVIDENCE MEMBERS

The widespread Nancy Member, from about 150 to 300 ft thick, represents distal foreset and bottomset strata of the Borden delta. For the most part poorly resistant greenish-weathering gray silty shale and siltstone, the Nancy gradationally intertongues with the distal portions of several resistant siltstone-dominant members and beds (Cowbell, Holtsclaw, Roundstone, Conway Cut) (fig. 19). The Nancy Member also contains the Gum Sulphur Bed, a lentil of resistant siltstone in the Nancy shales (fig. 20) that emphasizes the clastic wedge character of the lower Borden. In central Kentucky, beds equivalent to the lower part of the Nancy, mostly greenish-weathering clay shale with sideritic claystone nodules and lenses, are termed the New Providence Shale Member of the Borden Formation (Kepferle, 1971). The New Providence Member in the Louisville West quadrangle (Kepferle, 1974), 120 to 250 ft thick, encompasses the Kenwood Siltstone Member, a unit similar to the Farmers Member but thinner, finer grained, and less extensive. The Kenwood,

FIGURE 19.—Borden Formation; contact of Cowbell Member (resistant unit) and underlying poorly resistant Nancy Member. U.S. Highway 25 at Boone Gap, Berea quadrangle, Rockcastle County.

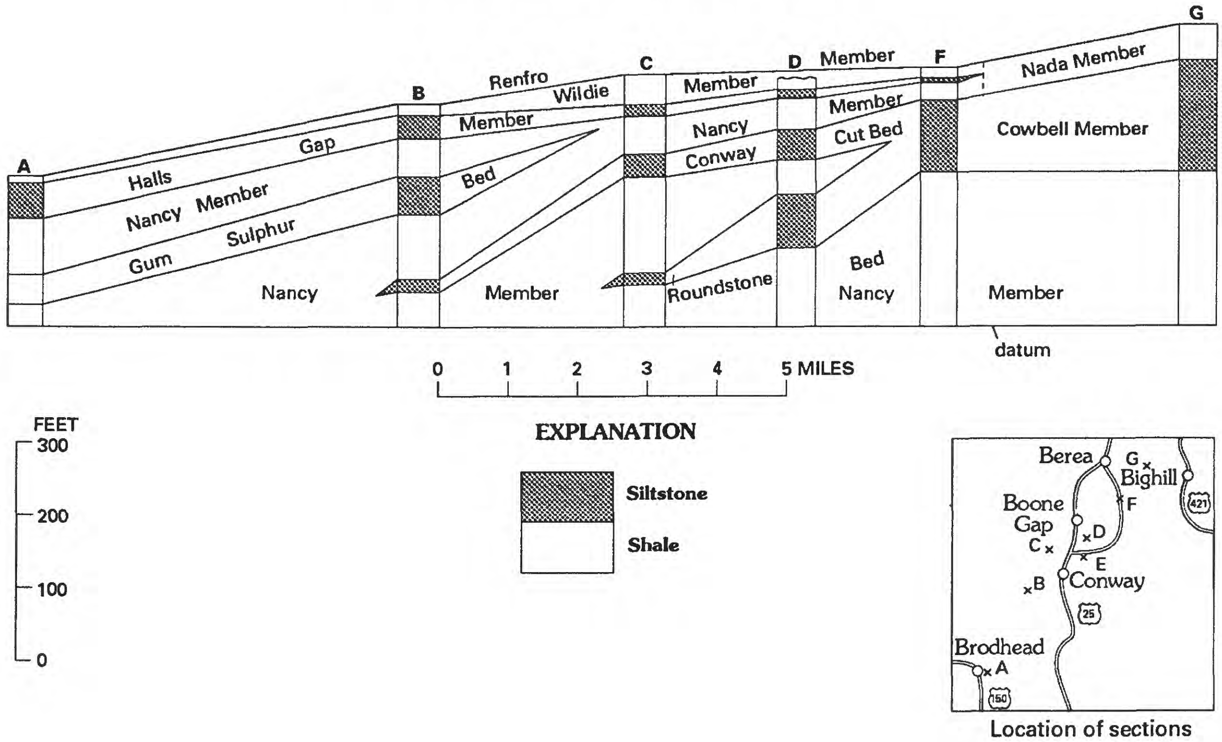


FIGURE 20.—Sections showing relationships of siltstone units in the Borden Formation in the area between Brodhead and Bighill, east-central Kentucky (from Weir and others, 1966).

an illite subarkose to illite-arkose, was studied intensively by Kepferle (1972a, 1977a), who concluded it to be a pro-delta turbidite apron deposit. Directional elements in the Kenwood indicate west-southwest sediment transport directions (fig. 16).

The New Providence and Nancy locally contain crinoidal limestone lenses and concentrations of fossils at many localities, including the classic Button Mould Knob fauna locality of Butts (1917, p. 11–17) and the Coral Ridge fauna, both studied by Conkin (1957), Kammer (1982), and Gordon and Mason (1985). Relationships of these clastic units in the Borden of central to south-central Kentucky are shown in figure 21*A*, *B*.

In western central Kentucky the Nancy and New Providence are overlain abruptly by the Muldraugh Member (fig. 22) or they intertongue with siltstone beds of the Holtsclaw Member. In westernmost Kentucky, the New Providence Shale is given formational rank as a unit between the Fort Payne Formation and the New Albany Shale, as used in the Briensburg quadrangle (Lambert and MacCary, 1964); it is equivalent to the Springville Shale (Savage, 1920) of Illinois, and possibly to the basal fine-grained green shale of the Fort Payne above the Maury Formation equivalent in south-central Kentucky.

COWBELL, HALLS GAP, AND HOLTSCLAW MEMBERS

Resistant siltstone members of the Borden, made up of dominantly gray subgraywacke siltstone, generally with indistinct bedding because of extensive bioturbation, include the Cowbell Member in northeastern and east-central Kentucky (fig. 23), the Halls Gap Member in central, south-central and east-central Kentucky, and the Holtsclaw Siltstone Member in western central Kentucky. These mapped units, generally less than 100 ft but as much as 250 ft thick, include large-scale deltaic foreset bedding; and they intertongue with the Nancy Member. The Halls Gap Member exhibits these foreset beds in exposures such as the railroad cut at Kings Mountain in the Halls Gap quadrangle (Weir, 1972; fig. 24 of this report). These beds dip in westerly and southwesterly directions at angles of generally less than 5°. The Cowbell and Halls Gap Members thin or grade to extinction westward. The Halls Gap extends as far west as the Saloma and Raywick quadrangles (S.L. Moore, 1976; Kepferle, 1973).

NADA AND WILDIE MEMBERS

Two fine-grained clastic units in the upper part of the Borden in east-central and northeastern Kentucky are

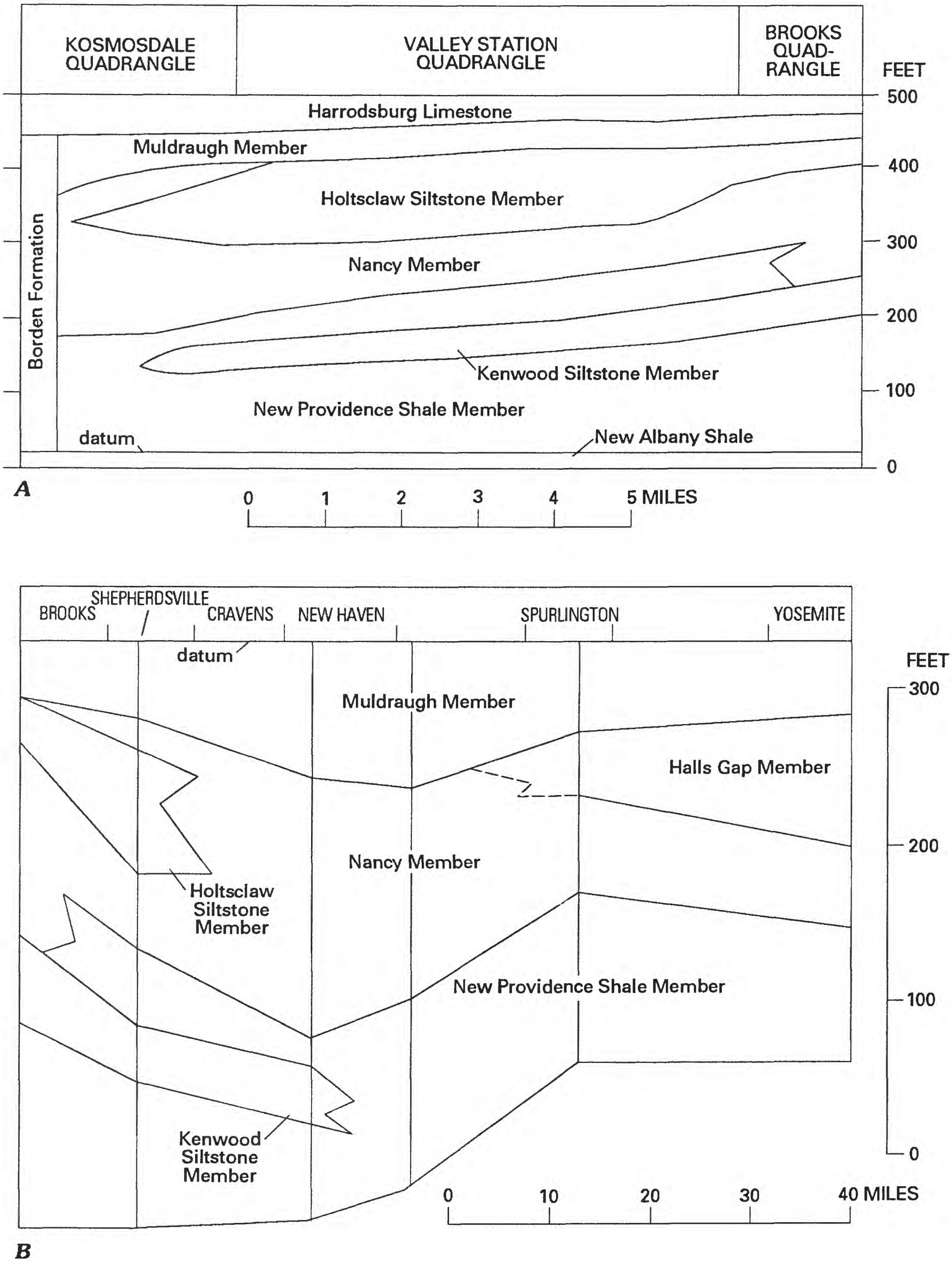


FIGURE 21.—Relationships of the clastic units of the Borden Formation. *A*, As mapped in Kosmosdale, Valley Station, and Brooks quadrangles, central Kentucky (from Kepferle, 1971). *B*, As mapped from southern Jefferson County to Casey County, central and south-central Kentucky (from Kepferle, 1971). Dashed line, relationships uncertain.

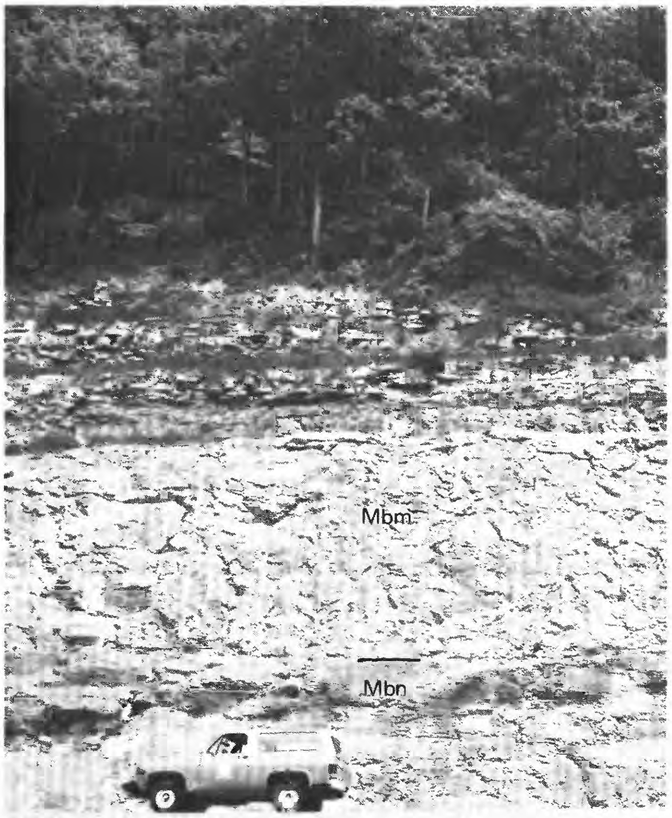


FIGURE 22.—Nancy Member (at vehicle level) and overlying Muldraugh Member of the Borden Formation. Milepost 97.8, Interstate Highway 65, 3.5 mi north of Elizabethtown exit, Colesburg quadrangle, Hardin County.

the Nada and Wildie Members (fig. 9). The Nada (fig. 25), 30–65 ft thick, is predominantly variegated (olive gray, grayish red, grayish purple), clayshale and silt shale with siltstone and glauconitic siltstone; it extends from northeastern Kentucky southeastward through the Berea quadrangle (Weir and others, 1966, p. F15) and the northern part of the Johnetta quadrangle (Gualtieri, 1968b). In northeastern Kentucky the Nada locally contains beds of crinoidal limestone, as in the Cranston quadrangle (Philley and others, 1974). Glauconite-rich layers at the base and top or within the member occur south of the Berea quadrangle (Weir, 1967), and a glauconite layer occurs a few feet below the top of the Nada farther north. The lower part of the Nada is interpreted to grade southwestward into the Nancy Member and the siltstone of the Halls Gap Member, and the upper part into greenish siltstone and shale of the Wildie Member.

The Wildie Member contains very minor amounts of variegated, mostly greenish shale, common beds of glauconitic siltstone, and locally phosphatic nodules at its top, base, or both (Brown and Osolnik, 1974; Gualtieri, 1967a; Schlanger and Weir, 1971). In general, reddish hues in these units diminish southward along the eastern Kentucky outcrop belt.

The Nada and Wildie Members are both overlain by the Renfro Member (fig. 25). The Wildie merges westward with the Halls Gap Member (Weir, 1972) or may thin to become the Floyds Knob Bed (Whitehead, 1976). In earlier mapping, the Nada was considered part of the Muldraugh Member, as in the Haldeman quadrangle (Patterson and Hosterman, 1961). An informal unit of limited extent in the Wildie Member is the "Rockcastle freestone," in which paleocurrent features indicate westward directions of transport (fig. 16), and bedding features suggest that it is a turbidite (Weir, 1970, p. 39).

RENFRO MEMBER

Carbonate rock units named the Renfro and Muldraugh Members (Weir and others, 1966) were placed in the uppermost part of the Borden. These units were considered part of the Borden until 1984, when the Renfro was placed in the basal part of the Slade Formation, overlying the Borden (Ettensohn and others, 1984).

The Renfro Member (Schlanger, 1965) of east-central, northeastern, and south-central Kentucky, with its subsurface and southeastern Kentucky equivalents, is a widespread unit throughout much of the eastern part of the State. It consists dominantly of aphanitic to finely crystalline, argillaceous dolomite and dolomitic limestone with local interbeds of gray micritic limestone. The dolomite in part represents dolomitized calcarenite with few relict grains. At some localities, siliceous carbonate rocks, probably Muldraugh Member equivalents, have been included in the basal Renfro, and St. Louis Limestone micritic lithologies have been included in the upper part of the Renfro. The unit weathers to distinctive yellow and orange hues. Macrofossils are very sparse. Grayish-green shale beds are relatively common, as are arenaceous and glauconitic grains, particularly in east-central Kentucky. In most places the Renfro conformably overlies glauconitic siltstone beds of the Nada or Wildie Members, and in the Woodstock quadrangle where the Wildie pinches out, the Renfro rests on the Halls Gap Member of the Borden Formation (Weir and others, 1966). In northeastern Kentucky, the Renfro is thin, and was included with the Newman Limestone on some geologic quadrangle maps, for example Brushart (Denny, 1964) and Olive Hill (Englund and Windolph, 1975). Renfro-type dolomite lithologies can also be recognized in the basal Newman Limestone ("Greenbrier" or "Big Lime") in many boreholes of eastern and southeastern Kentucky. They also occur

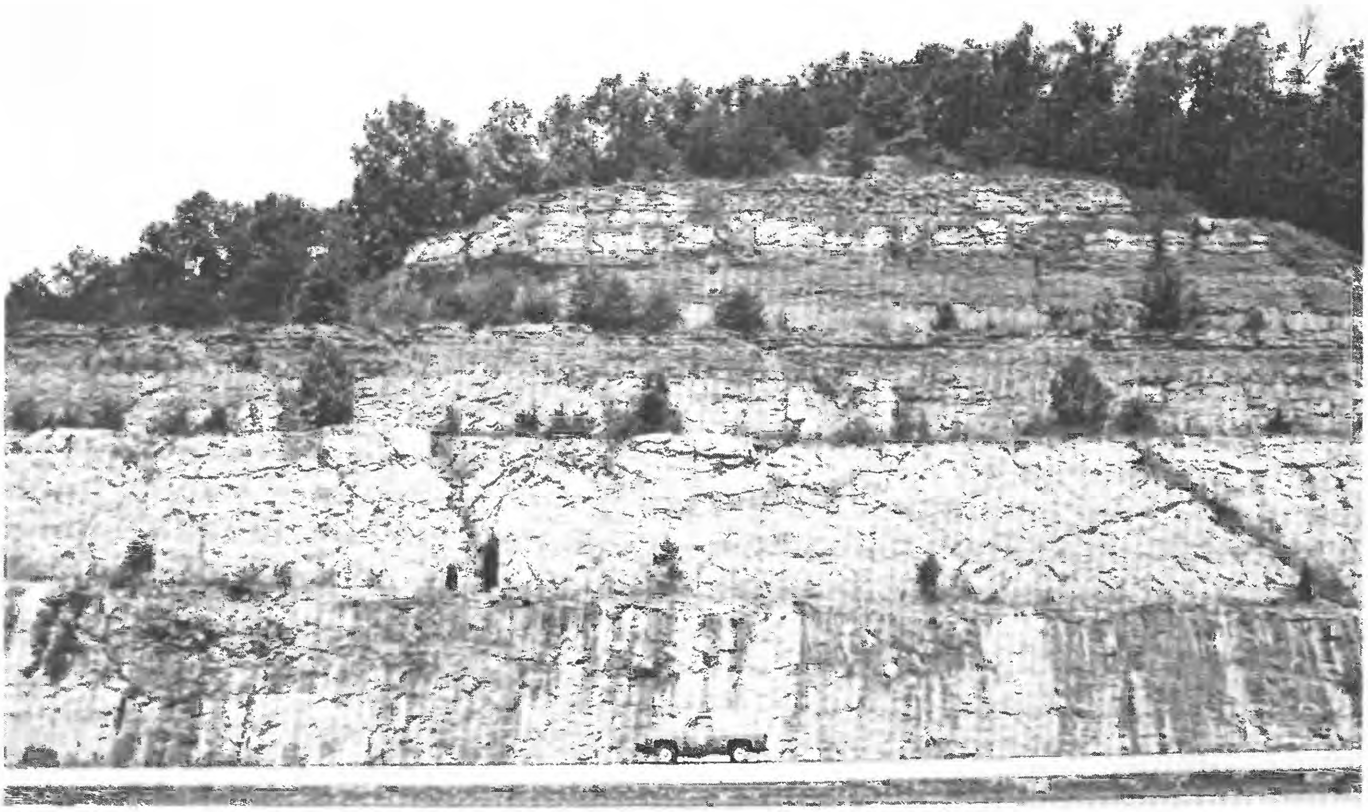


FIGURE 23.—Cowbell Member of Borden Formation (siltstone and shale). Milepost 145, Interstate Highway 64, Cranston quadrangle, Rowan County.

sporadically along the Pine Mountain outcrop belt, southeastern Kentucky, verified by Dever at three sites: the Burdine quarry north of Jenkins, in Hurricane Gap near Cumberland, and in an abandoned quarry at the head of Limestone Branch in Frakes quadrangle. Renfro-type dolomite is also present on Interstate Highway I-75 south of Jellico, Tenn. (Sedimentation Seminar, 1981) and at Cumberland Gap, Va. Subsurface studies of the "Big Lime" (lower and middle Newman Limestone) in eastern Kentucky (Pear, 1980) and southeastern Kentucky (Hetherington, 1981) indicate that dolomite facies possibly equivalent to Renfro dolomite are intermittently present in eastern Kentucky and more persistent in southeastern Kentucky in the basal and lower parts of thick sections of the "Big Lime." These possible Renfro equivalents reach a thickness of more than 30 ft, and contain petroleum and gas reservoir beds.

The upper contact of the Renfro according to Weir and others (1966) is a conspicuous diastem. Intertonguing of Renfro dolomitic strata with the overlying St. Louis dense micritic limestone has been reported in the Wildie (Gualtieri, 1968a) and Brodhead (Gualtieri, 1967b) quadrangles, but subsequent examination of these areas by Dever and others (1979d) suggests that the reported intertonguing may simply reflect the fact that discrete bodies of Renfro-like dolomite occur in the St. Louis Limestone Member of the Newman, and conversely, interbeds of micritic limestone like that in the St. Louis occur in the Renfro. Such occurrences appear to indicate fluctuations in depositional environments during Renfro and subsequent St. Louis time without representing true intertonguing along contemporaneous time boundaries. Subsurface studies in eastern and southeastern Kentucky (Pear, 1980; Hetherington, 1981) suggest that basal dolomitic beds of the "Big Lime" were deposited in submarine channels cut into the underlying Grainger sediments or in other submarine topographic lows. In the east-central Kentucky outcrop belt, the Renfro thins northeastward; the overlying St. Louis Limestone Member maintains a relatively constant thickness. The sharp contact between the Renfro and the St. Louis in east-central Kentucky may represent a hiatus, but observations in recent years suggest that it is a diagenetic contact between dolomitized and undolomitized limestone. Lobate patterns shown by

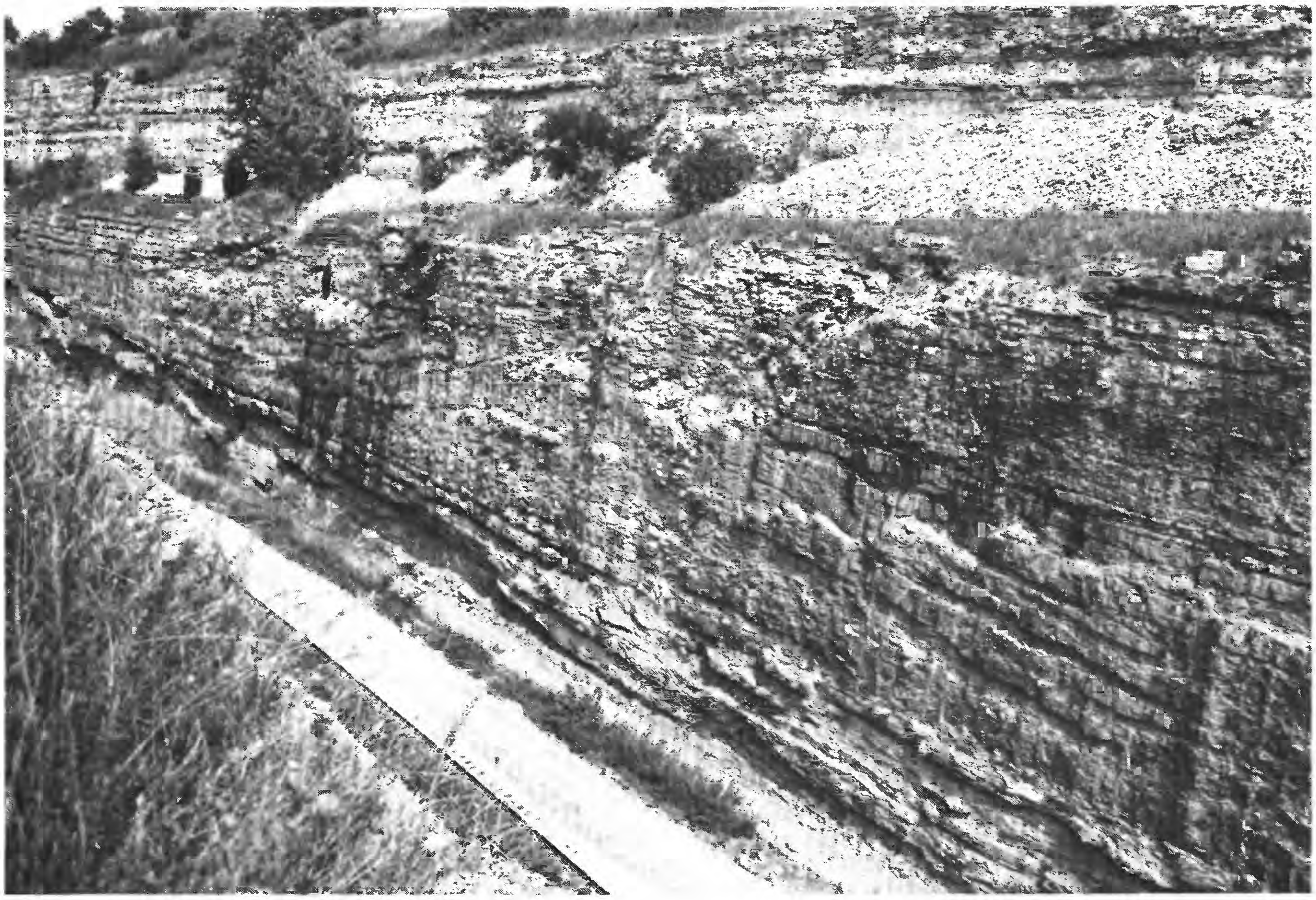


FIGURE 24.—Halls Gap (dark) and Muldraugh (light) Members of Borden Formation, looking west. Inclined bedding along front of Borden deltaic sediments in center of photograph. Railroad cut northwest of Kings Mountain, Halls Gap quadrangle, Lincoln County.

isopach maps of the underlying detrital deposits in east-central and south-central Kentucky suggest that the topography on the top of the Grainger may be mainly depositional rather than the result of erosion.

The major part of the Renfro is reported to merge southwestward with the lower and middle parts of the St. Louis Limestone of south-central Kentucky (Lewis and Taylor, 1979; Dever and Moody, 1979a; Dever, McGrain, and Moody, 1979). Laterally, the lower and middle Renfro merges westward with the Muldraugh Member of the Borden Formation and with the Salem and Warsaw Limestones in the vicinity of the Crab Orchard and Brodhead quadrangles (Gualtieri, 1967a, 1967b); rock types in this interval in the Crab Orchard quadrangle in particular contain lithologies typical of these units and also of the Harrodsburg Limestone. Because Renfro lithologies characterize the unit westward to the Halls Gap quadrangle, an arbitrary west limit of the unit was placed at the Halls Gap-Crab Orchard quadrangle boundary (Weir, 1972).

Fossils in the Renfro are mainly corals, crinoids, and brachiopods. Butts (1922) reported on collections in the present Brodhead quadrangle from Renfro beds which he termed Warsaw Formation, and the fauna was reported by him to have both Osagean and Meramecian affinities. Foraminifera from the middle part of the Renfro in the Bighill quadrangle (Weir and others, 1971), were reported by B.A. Skipp (written commun., 1966) to include endothyrid species generally considered to be of Meramecian age. Conodonts from the Renfro in the Wildie quadrangle (J.W. Huddle, written commun., 1966) indicate that the collections seem to be representative of the *Gnathodus texanus-Apatognathus* zone (early Valmeyeran or Osagean) of Collinson and others (1962) and also of their *Taphrognathus varians-Apatognathus* zone (late Valmeyeran or Meramecian). Thus the Renfro would seem to represent late Osagean to early Meramecian ages, in agreement with Butts' conclusions.

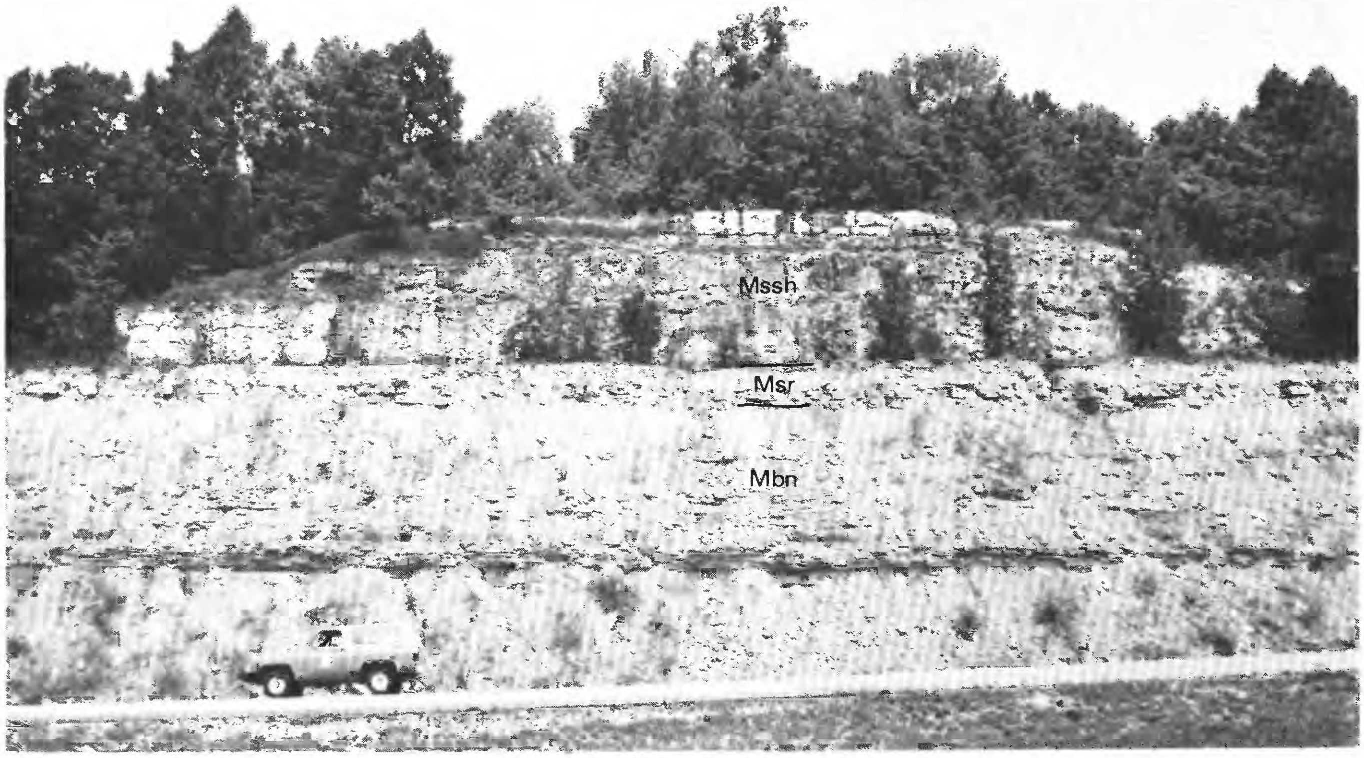


FIGURE 25.—Nada Member of Borden Formation (Mbn) and overlying Slade Formation consisting of Renfro Member (Msr) and limestone and dolomite mostly of the St. Louis and Holly Fork (Ettensohn and others, 1984) Members (Mssh). Milepost 146.2, Interstate Highway 64, Cranston quadrangle, Rowan County.

MULDRAUGH MEMBER

The Muldraugh Member of the Borden Formation (Weir and others, 1966), is 50 to 100 ft thick in southern central and south-central Kentucky and as much as 300 ft thick in the western central Kentucky outcrop; it is the main unit in the uppermost Borden in these areas and in adjoining Indiana. Highly resistant, it is dominantly an olive gray, siliceous dolomitic siltstone (dolosiltite) or silty dolomite (fig. 26). Silica and carbonate (dolomite and calcite) are main matrix minerals and constitute as much as 85 percent of the rock. Quartz-lined geodes and concretions are locally common. Fine-grained components are highly bioturbated. Crinoidal calcirudite lenses and patches of skeletal limestone composed dominantly of crinoid and bryozoan debris (fig. 27) are also common. Large crinoid stem fragments reaching to more than an inch in diameter are similar to those in the Fort Payne Formation and in limy lenses of Borden clastic units. The size and the robust character of brachiopod shells and crinoid columnal fragments are distinctive features of these units in Kentucky, and are not typical of younger Mississippian units.

The lower contact of the Muldraugh Member with the Nancy, Halls Gap, and Holtsclaw Members is commonly abrupt and marked by one or more thin glauconitic beds that have been previously ascribed to the Floyds Knob Formation by Stockdale (1939). These contact features suggest a depositional hiatus, followed by sudden resumption of deposition of mixed clastic and carbonate strata.

FLOYDS KNOB BED

The Floyds Knob Formation of Stockdale (1931, 1939), commonly a thin unit of glauconite or limestone and glauconite, was designated the Floyds Knob Bed of the Muldraugh Member of the Borden Formation in western central Kentucky by Kepferle (1977a). There, it is a widespread unit and an important stratigraphic marker within the Borden. In that area, for example, mapping of the abrupt southwestward stratigraphic drop of the Floyds Knob Bed relative to the base of the Borden enabled Peterson and Kepferle (1970) to recognize a northwest-southeast-trending foreset slope of the deltaic front which marks the southwestern limit of thick Borden detrital deposits of shale and siltstone.

FIGURE 26.—Dolosiltite and calcarenite in Muldraugh Member of the Borden Formation. Milepost 96.8, Interstate Highway 65, 2.5 mi north of Elizabethtown exit, Elizabethtown quadrangle, Hardin County.

To the east, in east-central and northeastern Kentucky, two or more seams of glauconite occur in the upper part of, or at the top of, Borden terrigenous clastic strata. Southward, in south-central Kentucky, glauconite is also common in the uppermost part of the New Providence Member of the Fort Payne Formation. The stratigraphic intervals represented by these occurrences are here considered to be approximately correlative with the Floyds Knob Bed of central Kentucky, in general agreement with the model proposed by Whitehead (1976, 1978b); and they are herein referred to as the Floyds Knob. Rare exposures in the southwestern part of Pine Mountain, southeastern Kentucky, show a glauconite bed, possibly the Floyds Knob, underlying the Fort Payne Chert.

The Floyds Knob Bed of the basal Muldraugh in western central Kentucky consists of a single glauconitic layer or two glauconitic layers separated by 5–25 ft of phosphatic, siliceous silty dolomite, dolosiltite, clayey siltstone, and, locally, oolitic limestone (Kepferle, 1977a, 1979b). The two glauconitic layers converge into one layer along the Borden delta front (Kepferle, 1979b). The Floyds Knob and the overlying lower part of the Muldraugh in northern central Kentucky and southern Indiana have been studied intensively by Whitehead (1976, 1978a). In southwestern central Kentucky, the Floyds Knob is a glauconitic zone, 5–7 ft thick, with the glauconite concentrated in seams and disseminated in the siltstone between seams (Moore, 1977). To the east, where the unit is included in the uppermost Nancy and Halls Gap Members, it is 5–10 ft thick and consists of one to three glauconite seams interbedded with silty shale, glauconitic siltstone, and, locally, crinoidal limestone; it contains chert and geodes (Lewis and Taylor, 1971; Lewis and others, 1973; Weir, 1972).

The Floyds Knob in the uppermost Nancy Member grades eastward and northeastward into the Wildie Member, which consists of as much as 25 ft of shale and siltstone with persistent seams of commonly phosphatic glauconitic siltstone and limestone at the top and base

FIGURE 27.—Upper part of Muldraugh Member of Borden Formation (Mbm) showing westward-thickening calcarenite lenses. Harrodsburg Limestone (Mh) (uppermost light-hued, planar-bedded resistant ledges) at upper left side of photograph. Milepost 3.3, north side of Bluegrass Parkway, Elizabethtown quadrangle, Hardin County.

of the member. Northeast of the Wildie-Nada boundary, the equivalent of the Wildie or Floyds Knob forms the upper part of the Nada Member, with persistent seams of glauconitic siltstone and limestone occurring at the top and near the middle of the Nada in southwestern east-central Kentucky. Discontinuous beds of glauconitic siltstone and limestone also occur in the lower part of the member (Rice, 1972; Weir and others, 1971).

In east-central and northeastern Kentucky, the Floyds Knob Formation as defined by Stockdale (1939) was restricted to the glauconitic seam and associated limestone which occur at the base of the Wildie and extend into the middle part of the Nada. Stockdale identified the Floyds Knob as the most persistent of the several glauconitic seams present in the upper Borden of the eastern outcrop belt. Local occurrences of a glauconitic siltstone near the middle of the Nada were noted during mapping in central and northeastern east-central Kentucky, for example in the Stanton and Olympia quadrangles (Weir, 1974a; McDowell and Weir, 1977). In northeastern Kentucky, a phosphatic, glauconite-rich seam is present at the base of the Nada (Philley and others, 1975) and was considered correlative with the glauconitic siltstone near the middle of the Nada in east-central Kentucky (see Stockdale, 1939, pl. 16). A glauconite-rich shale present about 4 ft below the top of the Nada in exposures along Interstate Highway 64 in eastern Rowan County and western Carter County (Chaplin, 1980) may be correlative with the glauconitic seam at the top of the Nada and Wildie in southwestern east-central Kentucky.

The areal extent of the Floyds Knob on the foreset slope of the Borden delta front and in the basin southwest of the front is not completely known. Peterson and Kepferle (1970) mapped the glauconite zone down the delta front in at least part of western central Kentucky and speculated that its local absence probably resulted from scouring by currents. In Taylor County, southeastward along the front, a core studied by the Sedimentation Seminar (1972) showed that the Floyds Knob extends southwest of the Borden delta front and underlies basinal deposits of the Fort Payne Formation. Farther to the southeast, the distribution of the glauconitic shale in the Delmer quadrangle (Lewis, 1971a), Pulaski County, indicates that the Floyds Knob is present on the upper part of the front, but at least locally absent on the lower part. It appears to merge southwestward with the Maury Formation equivalent at the base of the Fort Payne Formation (R.C. Kepferle, written commun., 1985).

The Floyds Knob Bed and equivalents are fossiliferous, containing pelmatozoans, brachiopods, bryozoans, gastropods, pelecypods, cephalopods, trilobites, conulariids, ostracodes, and fish remains (Kepferle, 1979a; Stockdale, 1939; Weir, 1967; Weir and others, 1971). Foraminifera were studied by Conkin (1954, 1960), and conodont fauna are reported by Weir and others (1971) and by Whitehead (1978a).

Study of Floyds Knob glauconites by the Sedimentation Seminar (1972) showed that the glauconite occurs as dark-green microcrystalline pellets, up to 0.5 mm in diameter, which are concentrated along bedding planes and in burrows. The ovoid pellet shape and close association with intense bioturbation suggest a fecal-pellet origin. Concentration of the Floyds Knob glauconites in a thin, widespread zone suggests accumulation during a period of decreased sedimentation.

GRAINGER FORMATION

The Grainger Formation (Keith, 1895), exposed along Pine Mountain in southeastern Kentucky, is from 200 to 500 ft thick. Lithologies of the Grainger, largely shale and siltstone, are strikingly similar to those parts of the Borden Formation; and the formations probably intergrade or interlense laterally in the subsurface west of the Pine Mountain fault. The Grainger is characteristically gray and greenish-gray shale and siltstone similar to the Nancy and New Providence Members of the Borden, and commonly contains an upper unit of resistant gray, greenish-gray, and reddish-gray siltstone, shale, and sandstone similar to those strata in the Nada Member of east-central Kentucky. Southward the overall grain size of the Grainger strata seems to diminish, and in Tennessee and Virginia, adjoining the southernmost part of the southeastern Kentucky outcrop belt, quadrangle descriptions report variegated shale as the main or only lithic component of the Grainger (Englund, 1964b). Locally, cherty beds which are Fort Payne equivalents are mapped as uppermost Grainger beds (Englund, Landis, and Smith, 1963; Englund, 1964b; Englund and others, 1964). The Grainger is the equivalent of the Nancy Member of south-central Kentucky and the New Providence Shale Member of central Kentucky.

The Grainger is overlain by the Newman Limestone or the Fort Payne Chert. It is separated from the Newman by a relatively sharp diastem. Basal beds of the Newman are mostly micritic limestone characteristic of the St. Louis Limestone Member, but include local dolomitic limestone and dolomite, similar to those in the Renfro Member, and also to the Little Valley Limestone of adjoining Virginia (Wallace de Witt, Jr., oral commun., 1965). The Fort Payne Chert, 0–20 ft thick, in the southwestern part of the Pine Mountain outcrop belt (Rice and Newell, 1975; Newell, 1975; Rice and Maughan, 1978), is considered to be a thin distal eastward extension of the Fort Payne Formation. Exposures are largely of chert residuum; in fresh exposures, chert together with dolomitic limestone is locally interbedded with shale and sandstone (Englund, 1969). Although these beds have been interpreted to intertongue with the Grainger (Englund, 1969), it seems more likely that the Grainger–Fort Payne contact is a discrete interface marked by glauconite much the same as the base of Muldraugh in central Kentucky, as suggested by Whitehead (1976).

In southeastern Kentucky, although glauconitic beds are not reported in the quadrangles mapped along Pine Mountain, glauconite is abundant in beds at the top of the Grainger Formation and in basal beds of the overlying Newman Limestone succession along U.S. Interstate 75 near the Kentucky-Tennessee border in Jellico West quadrangle. A glauconite bed there was identified as the Floyds Knob Bed (Sedimentation Seminar, 1981). Glauconite has also been identified by Dever at two locations in Frakes quadrangle. Hasson (1973) reported a glauconitic zone in the type Grainger area in Tennessee. Whitehead (1976, p. 209–231) considered that this is part of a single glauconite zone which may consist of one or more beds occurring in the Borden (Floyds Knob), Grainger, and Fort Payne, and which extends over a very large region of the eastern and central United States. Whitehead's conclusion was that the glauconitic beds are related to major eustatic sea-level rise in late Osagean time.

FORT PAYNE FORMATION

Rocks of the Fort Payne Formation (Smith, 1890) make up most of the interval between the underlying Chattanooga Shale, Maury Formation equivalent, or New Albany Shale, and the overlying Warsaw or Salem and Warsaw undivided, Harrodsburg Limestone, and Ullin Limestone (Lineback, 1966) in a broad belt encompassing southern and western Kentucky and parts of Tennessee, southern Illinois, and southwestern Indiana. The Fort Payne and Ullin are interpreted to be successively younger units that onlap Borden delta detrital rocks in Illinois and Indiana (Lineback, 1966). In Kentucky, similar relationships indicate that both the Muldraugh Member of the Borden Formation and the Fort Payne are younger than Borden detrital rocks. The Muldraugh is contemporaneous with at least the lower part of the Fort Payne, but beds in the upper part of the Fort Payne in the western part of south-central

Kentucky and in the subsurface of west-central and western Kentucky may be younger than the Muldraugh. Interpretations of Fort Payne and Muldraugh basal relationships in central Kentucky (fig. 28) have ranged from intertonguing to discrete erosional or nondepositional surfaces.

In Kentucky, the Fort Payne Formation is mostly a drab gray siliceous dolostone and dolosiltite, crinoidal limestone and chert, with lesser siltstone and shale, and locally thick sandstone. It is mapped in south-central, southern west-central, and western Kentucky. Four formal members, the New Providence Shale Member (Kepferle and Lewis, 1974), the Cane Valley Limestone and Knifley Sandstone Members (Kepferle and Lewis, 1974), and the Jabez Sandstone Member (Kepferle and others, 1980), and the informal Beaver Creek limestone member (Klein, 1974) are exposed in south-central Kentucky. A thin cherty unit ascribed to the Fort Payne (Rice and Newell, 1975; Newell, 1975; Rice and Maughan, 1978) is recognized in the Pine Mountain area of southeastern Kentucky.

Most of the Fort Payne in south-central Kentucky consists of generally uniform dolosiltites that are olive gray to medium gray, very fine grained, spally, and slightly argillaceous (fig. 29); their silicification ranges from irregular patches to almost complete replacement of patches of crinoidal and bryozoan debris. Evidence of intense bioturbation is common in south-central Kentucky. In a matrix of generally fine dolomite rhombs and clay minerals (illite, chlorite, and kaolinite), the framework is mostly quartz silt and sand grains, and minor glauconite pellets and fossil fragments. Many dolomite rhombs also appear to be detrital. Geodes and blebs are locally common, containing mostly quartz, gypsum, and anhydrite with minor sulfide minerals. Most of the Fort Payne in south-central Kentucky

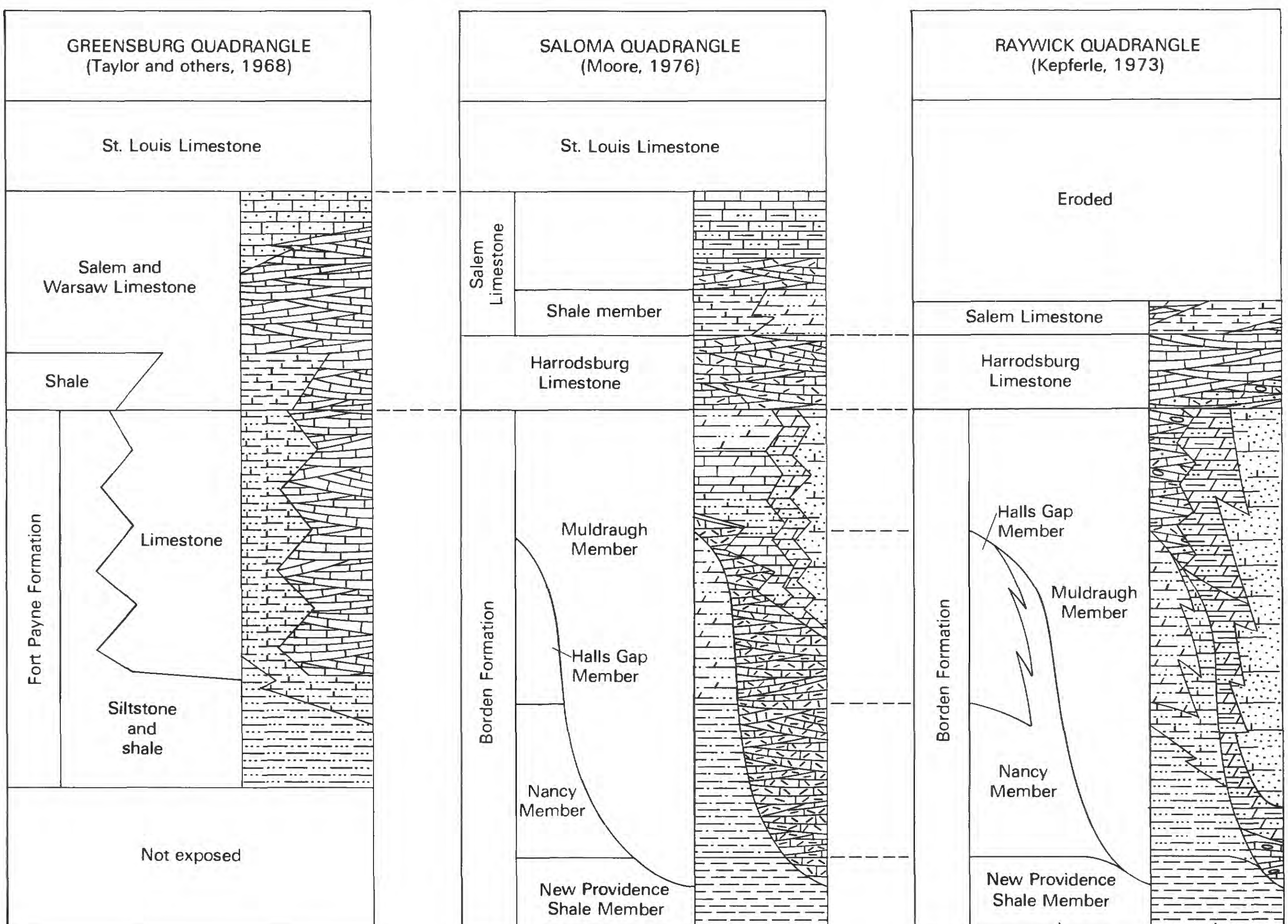


FIGURE 28.—Generalized diagram showing interpretations of relationships of Salem-Warsaw, Salem, Harrodsburg, Borden, and Fort Payne Formations in three quadrangles in central and south-central Kentucky (from S.L. Moore, 1976).

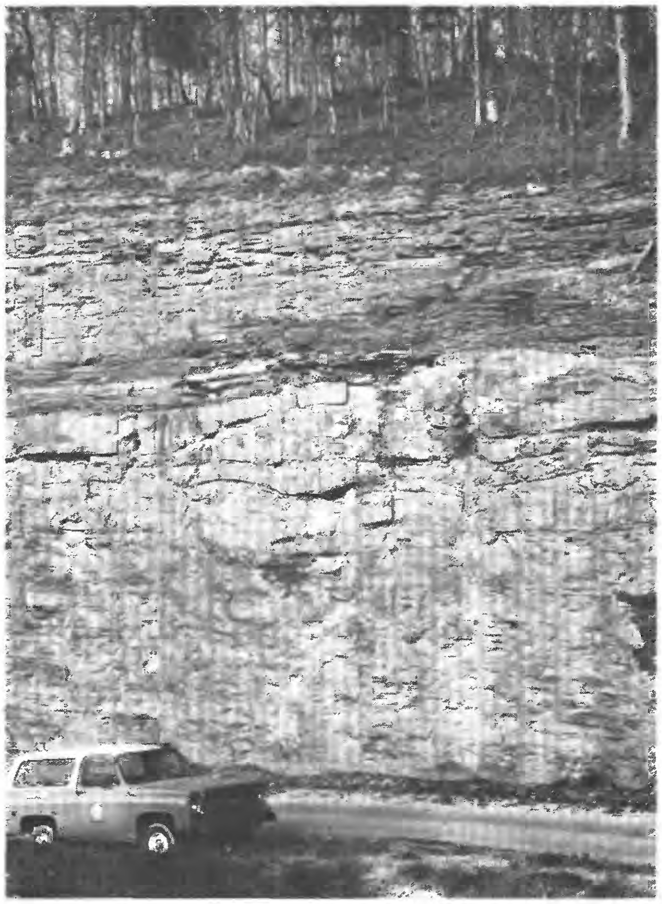


FIGURE 29.—Fort Payne Formation in roadcut along launching ramp road, Lake Cumberland State Park, Jamestown quadrangle, Russell County.

closely resembles the Muldraugh Member of the Borden Formation but is somewhat darker hued. It ranges from about 200 to more than 300 ft thick in south-central Kentucky.

In western and southwestern Kentucky the Fort Payne is thicker (to more than 600 ft), darker, more siliceous and cherty (as much as 40 percent chert), is interbedded with limestone (Fox and Olive, 1966) rather than dolomite, and is generally more planar bedded than the lighter hued, highly bioturbated succession in south-central Kentucky. The westernmost Kentucky Fort Payne is interpreted to represent a basinal facies and the central Kentucky unit to represent platform slope and platform facies, roughly similar to the interpretation of deposition on the Borden platform by Benson (1976).

The lowermost unit of the Fort Payne Formation in south-central Kentucky, the New Providence Shale Member (Kepferle and Lewis, 1974), thins westward from 150 to a few feet thick. Lithologically like the New Providence Member of the Borden Formation and commonly including basal phosphatic claystone identical to the Maury Formation equivalent, it represents the distal foreslope and bottomset beds of the Borden-Grainger deltaic deposits. A glauconite-rich bed, rarely reported in south-central Kentucky geologic quadrangles, at least locally separates the siliceous Fort Payne beds from the underlying New Providence Member. This is correlated with the Floyds Knob Bed of western central Kentucky.

Within the dominant siliceous and dolomitic rock types in the south-central Kentucky outcrop area, the Fort Payne contains elongate lenses of light-hued crinoidal calcirudite limestone with characteristic accompanying green-tinged mudstone. The largest of these lenses, the Cane Valley Limestone Member, is as much as 150 ft thick. It lies west of southeast-trending lenses of sandstone more than 250 ft thick, the Knifley Sandstone Member (Kepferle and Lewis, 1974). The Beaver Creek limestone member of the Fort Payne (Klein, 1974) is another calcirudite unit which is locally a petroleum reservoir. These limestone and sandstone lenses occur parallel to and west of the southeast-trending Borden delta front (fig. 54). They are interpreted to represent two types of carbonate banks, as mud mounds and as skeletal sands (Lewis and Potter, 1978). The Cane Valley and Knifley Members have been intensively studied (Sedimentation Seminar, 1972).

Beds in the Cane Valley Limestone Member interfinger with Fort Payne dolosiltites and locally interfinger eastward with the Knifley Sandstone Member. Limestones are dominantly biorudites, coarse-grained skeletal bryozoan and pelmatozoan limestones with minor quartzose sand grains in a matrix of sparry calcite and minor microcrystalline dolomite. Partial replacement by silica is common. Depositional dips are mostly southwestward but are locally bimodal. Greenish-gray mudstone occurs as conspicuous interbeds and as matrix between fossil fragments. Other largely northwest trending related limestone lenses as much as 100 ft thick exposed in the Fort Payne of south-central Kentucky are composed largely of echinodermal debris and include large crinoid stem segments more than an inch in diameter (Taylor, 1962, 1964; Thaden and others, 1961). The Cane Valley has been interpreted to be a slope edge or platform edge shoal bank deposit into which fossil debris on the deltaic platform to the east was transported, partly winnowed, and concentrated (Sedimentation Seminar, 1972, p. 20; Lewis and Potter, 1978). It is considered mostly younger than the Knifley Sandstone Member, and formed during an interval when coarse clastic terrigenous sedimentation was weak. Cane Valley depositional types, mostly occupying the middle part of the Fort Payne, extend northwestward in the subsurface and may have accumulated as a deeper water submarine bank or fan deposit.

The Beaver Creek limestone member, similar lithologically to the Cane Valley Member, occurs in the lower part of the Fort Payne down-dip from the Cane Valley Limestone Member bodies. It consists of coarsely crinoidal biohermal-type deposits of varying grain size and bedding thicknesses. Klein (1974) interpreted the deposits to be a series of submarine fans deposited by flow mechanisms in approximately 300 ft of water at the toe of a prograding carbonate platform.

Sandstone in the Knifley Member is fine-grained, silty, argillaceous subgraywacke with angular grains, dominantly an illite-sublitharenite (Kepferle, 1977a). Mineral composition is about 30 percent clay and 6 percent dolomite matrix within a framework of 90 percent quartz, 5 percent feldspar and micas, rock fragments, glauconite, and opaque minerals. West to southwest depositional dips are dominant (fig. 16); grain size generally increases upward, but the bedding in the Knifley is poorly defined because of intense bioturbation. The Knifley has been interpreted to be a slope break shoal deposit (Sedimentation Seminar, 1972). The Jabez Sandstone Member of the Fort Payne (Kepferle and others, 1980) is a body similar to and along strike with the Knifley in south-central Kentucky.

Subsurface well logs indicate that a dark shale facies occurs in the Fort Payne–Borden succession along a northwest-trending belt from about 5 to 15 mi wide and 80 mi long in the subsurface of the northern part of western and west-central Kentucky (fig. 54). This belt lies west of the Borden delta front and northeast of the crinoidal limestone–greenish shale facies, along strike of the Knifley Sandstone. West of the dark shale facies are dark siliceous basinal Fort Payne rocks. The shale is generally described (Freeman, 1951, p. 167, 230) as dark-gray to dark-brown limy shale or shaly limestone in contrast to the hard siliceous shale and limestone that are characteristic of the Fort Payne. Because the dark shale facies lies along strike of the Knifley Sandstone Member, the shale may represent fines that were winnowed from Knifley sands or which passed over or around Knifley sand deposits and settled west of and marginal to the Borden delta slope break. Transportation agents may have been northwest-flowing currents along the delta slope.

High carbonate and silica content is characteristic of Fort Payne rocks, but origin of the silica content is uncertain. Analyses of the Fort Payne in south-central Kentucky and Illinois show that quartz of silt and clay size is an important although variable constituent of these rocks (Sedimentation Seminar, 1972, p. 4; Lineback, 1966, p. 23). Silica content in the Fort Payne has also been ascribed to chemical precipitation or replacement during deposition and diagenesis or to secondary causes such as weathering (Bassler, 1932, p. 154–155). Sponge spicules are also abundant constituents of some of these rocks (Gutschik, 1954).

STRATA OVERLYING BORDEN AND FORT PAYNE FORMATIONS

Borden and Fort Payne strata, herein treated as including the Renfro Member, are overlain conformably by units mapped as Warsaw Limestone, Salem and Warsaw Formations undivided, and Harrodsburg Limestone in south-central and western Kentucky. Isolated outliers of the Salem and Warsaw Formations unit above more continuous Borden and Fort Payne strata across the Cumberland saddle in south-central Kentucky permit correlations west of the saddle with those in eastern Kentucky. In eastern Kentucky, the Salem and Warsaw are at least in part continuous with strata of the Renfro Member, exposed along the western margins of the Appalachian basin. In northeastern Kentucky these units are absent because Pennsylvanian rocks unconformably overlie Borden Formation. Fort Payne rocks are locally overlain by Cretaceous and Tertiary beds along the margins of the Mississippi Embayment in western Kentucky (Olive, 1965; Wilshire, 1964).

The Grainger Formation and Fort Payne Chert are overlain abruptly by lowermost beds of the Newman Limestone along parts of the Pine Mountain outcrop belt. In places, the basal beds of the Newman are dolomitic limestones which are like those in the Renfro Member of the Slade Formation in east-central Kentucky; and they are here provisionally correlated with the Renfro.

DEPOSITIONAL HISTORY OF THE BORDEN AND FORT PAYNE FORMATIONS

That the Borden Siltstone of Illinois and the clastic units of the Borden Formation in Kentucky and Indiana were both deposited in a deltaic framework (Frund, 1953; Swann and others, 1965; Lineback, 1966; Weir and others, 1966; Peterson and Kepferle, 1970) is well established. According to Lineback (1966), crinoidal carbonate banks in western Illinois grew to heights of 200–300 ft above the sea floor of a deep-water basin located in central and southern Illinois. As the Borden deltaic complex advanced westward into Illinois, its southward deflection by the carbonate banks on the west determined the direction of growth of the long, tongue-shaped Borden delta there. Lineback (1966) concluded that sediment at the foot of the delta was deposited in water depths exceeding 600 ft, and interpreted several sandstone bodies in Illinois to be turbidites deposited largely on the pro-delta plain (Lineback, 1968b). After active delta growth ceased, dark siliceous carbonate rocks of the Fort Payne were deposited in the adjoining deep-water basin and on foreset slopes of the delta, partly filling depressions adjacent to the delta. Although deltaic structure in the Fort Payne has not been proven, convex-upward profiles of upper surfaces of the unit in Illinois where it is thick (Lineback, 1966, p. 26–27) and some current structures suggest deposition of very fine detritals in environments also favorable to carbonate accumulation. Progradation of the Borden delta into Kentucky, however, probably preceded that of the Borden delta in Illinois, as indicated by the biostratigraphic work of Gordon and Mason (1985).

After deposition of the basinal Fort Payne, according to Lineback (1966, 1969), an irregular submarine topography in part with starved basin conditions was left in southern Illinois. There, deep narrow depressions in the sea floor were filled by Muldraugh-like sediments of the Ullin Limestone, which overlapped the Fort Payne and eventually onlapped terrigenous clastics of the Borden delta. Cross-stratified fossil-fragmental carbonate sediments (Harrodsburg) in the upper part of the Ullin Limestone were deposited on a shallow-water platform on the Borden delta, and filled in the adjoining depressions, resulting in shallow water throughout the area.

Deltaic deposition of Borden terrigenous strata in Kentucky was probably similar to that just described for Illinois, except that the delta in Kentucky advanced as a broad depositional shelf. Evidence includes westerly and southwesterly depositional dips in Borden detrital rocks in south-central and central Kentucky (Weir and others, 1966; Kepferle, 1968), and abrupt reciprocal thickness relationships between westward-thinning Borden siltstone and shale and overlying Muldraugh Member carbonates, which are separated by a discrete depositional delta-front interface (Kepferle, 1966b; Peterson, 1966; Peterson and Kepferle, 1970). The depth of water probably did not exceed 375 ft in northern west-central Kentucky (Kepferle, 1977a, p. 38), and restricting crinoid banks west of the encroaching deltaic sequence were absent or else minor in thickness and extent. Probable turbidite sandstone and siltstone bodies include, in approximate decreasing age order, the Farmers, the Kenwood, and the "Rockcastle freestone." Their emplacement was possibly triggered by seismic shock (Kepferle, 1977a, p. 40). Discontinuous crinoidal biostromal limestones, such as the Cane Valley Limestone Member and Beaver Creek limestone member, and the elongate bar-like sandstone bodies such as the Knifley Sandstone Member, lie parallel and marginal to the main mass of Borden detrital rocks in west-central and south-central Kentucky. Carbonate skeletal material was washed from platform areas of the delta into deeper water where it accumulated in bar-like and fan deposits along the delta front, possibly on a shelf-break on the delta slope and on the delta toe adjoining the basin.

According to Hannan (1975), Fort Payne rocks in south-central Kentucky represent deposits by gravity flow mechanisms along the southwest-facing clinoform slope of a carbonate platform edge. The deposits include toe, slope, shallow water, and evaporite facies of a southwestward-prograding carbonate platform which succeeded the more actively prograding Borden delta.

The Cincinnati arch area, "Cincinnatia" of Pepper and others (1954), was probably submergent during most or all of Early Mississippian time. Thicknesses of Borden strata and their depositional vector directions do not show evidence that such a barrier was present during Borden–Fort Payne deposition (Whitehead, 1976, p. 269–270). It has been suggested that the Cincinnati arch was slightly emergent during earliest Mississippian time and even contributed minor amounts of fine-grained sediment initially to the basal Borden (Sable, 1970). That phosphatic nodule accumulations likely caused by upwelling along a single shelf were present both east and west of the arch (R.C. Kepferle, written commun., 1985) argues against the presence of an extensive emergent arch during any part of Early Mississippian time.

The protoquartzites or subgraywackes prevalent in detrital Borden units (Potter and Pryor, 1961) contrast strongly with the clean orthoquartzite characteristic of Upper Mississippian sandstones; Borden rocks are relatively immature, and their mineralogy reflects a source terrane of metamorphic and felsic plutonic rocks. Major source areas for Borden sandstones have been interpreted as being east and north of the Appalachian basin (Potter and Pryor, 1961; Walker, 1962), in the Canadian Shield (Potter and Pryor, 1961), and possibly in northernmost Canada (Swann and others, 1965, p. 15). Whitehead (1976, p. 267) presented evidence for an easterly source area, and rejected distant northern Canada sources. The volume and thickness trends of detrital sediments transported into the Eastern Interior and Appalachian basins indicative of transport directions also suggest to us that eastern rather than northern Canada sources were dominant, perhaps located in or east of the present Piedmont belt or the New England Acadian mountain systems, and that the Canadian Shield was not an important source area. Sources east and northeast of the Appalachian basin contributed a large quantity of sediment to the eastern United States, but only the distal portions of this large volume of detritus reached Kentucky.

Location of source areas for the fine detrital components of the Fort Payne of southern and western Kentucky is uncertain; if the silica contained in the Fort Payne is largely clastic detritus, this might indicate distant topographically low eastern or southern sources. Perhaps supporting the possibility of southern source areas is the presence of relatively thick mudstones in the basal Fort Payne in some places in southwestern Kentucky and in Tennessee (fig. 9). Paleogeographic reconstruction for late Borden–Fort Payne time (Sable, 1979a) indicates that shallow marine waters covered most of the areas, but westward-deepening troughs existed in western Kentucky (figs. 54, 55, 56; Lineback, 1969, p. 123), later to be filled with the Fort Payne Formation, the Harrodsburg Limestone, and the Warsaw Limestone of Butts (1917).

AGE

In the type Mississippian Mississippi Valley succession, the Meppen Limestone (Collinson, 1969) and Fern Glen Limestone are considered to be of earliest Osagean (Valmeyeran of Illinois) age, the Burlington Limestone to be of middle Osagean, and the Keokuk Limestone to represent late Osagean time.

Beds representative of earliest Osagean or Valmeyeran time (Meppen in the Mississippi Valley (Collinson, 1969)) have not been recognized in Kentucky. Megafauna in the lower part of the Borden of northeastern and east-central Kentucky (New Providence group of Butts, 1922) were assigned to Fern Glen and possibly Burlington ages by Butts (1922, p. 50). In central Kentucky, however, megafauna, foraminifera, and conodonts in the basal part of the Borden (New Providence Shale of Butts) are reported as Burlington in age (Butts, 1917, p. 17; Conkin, 1957; Collinson and Scott, 1958; Rexroad and Scott, 1964). Thus a considerable hiatus representing early and part of middle Osagean time seems to be indicated at the base of the Borden Formation in some Kentucky areas. Such a time gap would represent the time taken for the Borden delta front, encroaching from the east or northeast, to reach central and south-central Kentucky, time during which starved-basin conditions existed west of the delta front. During this time, only thin red and green mudstones in Kentucky, central Indiana, and Ohio were interpreted to have been shed from Cincinnati arch areas (Sable, 1970), but even these may represent distal sediments from sources farther east or northeast.

Fossils in the Muldraugh Member include crinoids, brachiopods, and bryozoans. Identifications by Mackenzie Gordon, Jr. (written communs., 1965, 1971) indicate a late Early Mississippian (late Osagean) age.

Conodonts from the Floyds Knob in south-central and east-central Kentucky (Science Hill, Delmer, Bighill, Wildie, Mt. Vernon, Maretburg, Halls Gap, and Yosemite quadrangles) and from the type Floyds Knob Bed at Floyds Knob, Indiana, were identified by J.W. Huddle (written communs., 1964, 1965; see tables 3–6). *Gnathodus texanus* Roundy is relatively abundant in those samples, and is representative of the *Gnathodus texanus-Taphrognathus* zone (lower Valmeyeran or Osagean) of Collinson and others (1962, fig. 66). Paleontologic identifications by Whitehead (1976, p. 71–141) of conodonts from the Muldraugh of Indiana and Kentucky, including the Floyds Knob, confirmed Huddle's interpretation of the age of the Floyds Knob in central Kentucky and Indiana as the *Gnathodus texanus-Taphrognathus* zone. Whitehead placed overlying beds of the Muldraugh in the *Taphrognathus varians-Apatognathus* zone of Collinson and others (1962), which ranges through the Warsaw Limestone and Salem Limestone in Illinois and according to Nicoll (1971) into the St. Louis Limestone in Indiana. The *Gnathodus texanus-Taphrognathus* zone according to Nicoll and Rexroad (1975, p. 16) ranges through the Edwardsville Formation, Ramp Creek Formation (Stockdale, 1929), and part of the Harrodsburg Limestone in Indiana; and the *Taphrognathus varians-Apatognathus* zone extends from the upper part of the Ramp Creek and Muldraugh Formations (Muldraugh Member of Kentucky) through the Harrodsburg and most of the Salem, becoming rare in the St. Louis Limestone. Thus this evidence suggests that the Floyds Knob Bed and glauconitic zones of Kentucky are of late Osagean (Keokuk) age and that the Muldraugh Member of the Borden Formation is of late Osagean and early Meramecian age. This is not reflected in the correlation chart (fig. 7), which indicates this boundary to lie above the Muldraugh Member, pending further verification of the interpretation discussed herein.

Megafauna in the Fort Payne of south-central, central, and west-central Kentucky was reported by Butts (1922, p. 76–88) to be of late Osagean (Keokuk) age. Butts obviously included strata now considered to be in the Muldraugh. Few recent collections have been made, and none shed more light on specific ages of the Fort Payne within Kentucky.

PALEOTECTONIC IMPLICATIONS

Parts of the Ozark region, northeastern Missouri, and western Illinois were uplifted during early Borden time. Farther east, in Illinois, Indiana, and western Kentucky, a differentially subsiding basin existed. Still farther east, a stable, submerged shelf was present in eastern Kentucky.

The Cincinnati arch, including the Nashville dome, was a stable to slightly positive structure that separated somewhat more rapidly sinking basins. The LaSalle anticlinal belt of Illinois including its southeastward extensions in Kentucky was stable to slightly positive. After possible slight uplift early in Osagean time, the Ozarks and their marginal areas in western Illinois and Missouri became a slowly subsiding platform. North of the area, the Transcontinental and Wisconsin arches, probably emergent in early Osagean time, were also slightly negative later in the interval.

A major negative feature in Early Mississippian (early Osagean) time was a southward-deepening trough that extended from the Michigan Basin southwestward across central and southern Illinois and southward under the present Mississippi Embayment (Pryor and Sable, 1974, p. 293). This trough may have continued into the deep Ouachita geosyncline of Arkansas and Oklahoma.

OSAGEAN-MERAMECIAN SERIES BOUNDARY

The Osagean-Meramecian Series boundary has been extremely difficult to recognize in the Eastern Interior basin. Uncertainties of correlation result from disagreements regarding specific ages of megafaunal assemblages at or near the boundary, and from imperfect understanding of the complex depositional relations. Although many published reports on the western part of Kentucky and on Indiana, Tennessee, and Missouri refer to the Osagean and Meramecian Series designations, the Illinois State Geological Survey has combined these into a single series, the Valmeyeran. Most geologists agree that no regional hiatus marks the series boundary in the Eastern Interior basin, and that deposition was generally uninterrupted, although in some areas such as east-central Kentucky, depositional environments changed markedly.

Osagean-Meramecian Series boundary problems have been mostly related to the age assignments and correlations of the Warsaw Formation (or Warsaw Shale) near its type area in western Illinois and in its eastward subsurface extension; of rocks termed Warsaw in Kentucky and Tennessee; and of the Harrodsburg and Salem Limestones in Indiana and adjoining Kentucky. Shales and limestones of the Warsaw in western Illinois have been variously assigned to the Osagean or Meramecian or both (S. Weller, 1909; Butts, 1922; Moore, 1928; Van Tuyl, 1925; Laudon, 1948; Wanless, 1957; Weller and Sutton, 1940; J.M. Weller and others, 1948; Sando and others, 1969). Subsurface work by Lineback (1966) indicated that shale in the type Warsaw merges eastward into the Borden Siltstone, thereby suggesting that the shale is of Osagean age. However, Lineback's cross sections indicate that part of the Warsaw may descend into the Borden and part maintain a high position within the upper Borden. As a discrete unit, the Warsaw is recognizable only in western Illinois and a short distance eastward into the Borden of the Illinois subsurface; thus far, it has not been possible to establish conclusive physical continuity or contemporaneity with the Kentucky Mississippian succession.

Butts (1922) first used the name Warsaw in western Kentucky for rocks overlying the Fort Payne chert or Holtsclaw Sandstone of Butts (1915), currently the uppermost Borden detrital rock units in Jefferson County, Ky. The name Warsaw remains in current use in parts of Kentucky and throughout Tennessee. In Kentucky, in addition to this usage, Warsaw has been used in a restricted sense for rocks corresponding to the "Upper" Harrodsburg of Indiana (McFarlan, 1943, p. 75). Because the type Warsaw in Illinois is neither directly traceable into nor lithologically identical with the Warsaw of Kentucky and Tennessee, both usages of Warsaw in Kentucky and Tennessee, in the opinion of the present authors, should be abandoned. The 1960–68 mapping in Kentucky confirmed Stockdale's (1939) opinion that Butts' Warsaw unit includes lithologic and age equivalents of the Salem (Meramecian), Harrodsburg (Meramecian and Osagean?), and Muldraugh (Osagean). Examples of varied interpretations in this stratigraphic interval in central and south-central Kentucky are shown in figure 28. Rocks called Warsaw in Tennessee, even farther from the type Warsaw in Illinois, are probably also correlative with part of the Salem, the Harrodsburg, and the Muldraugh.

In much of east-central and northeastern Kentucky, the Renfro Member of the Borden and Slade Formations and Renfro equivalents in the basal part of the Newman Limestone, as well as younger beds, directly overlie Borden detrital rocks. In outcrop, the Renfro lies between Borden detrital rocks and upper St. Louis equivalents in the Slade Formation, and is relatively thin. In northeastern south-central and southwestern east-central Kentucky, thin Harrodsburg-like crinoid- and bryozoan-bearing, light-gray limestone lenses and beds appear in the middle part of the Renfro and thicken westward, as the lower and middle parts of the Renfro grade respectively into the Muldraugh and the Salem (Weir and others, 1966); the upper part of the Renfro is absent in this crucial area because of Quaternary erosion. The upper Renfro, however, has been demonstrated to be equivalent to the lower and middle parts of the St. Louis Limestone of south-central Kentucky (Dever and Moody, 1979a).

Nicoll and Rexroad (1975) indicated that the Harrodsburg Limestone and part of the Salem Limestone in

Indiana contain conodont elements similar to those of the Warsaw Shale and overlying Salem Limestone of Illinois. These data suggest that the Harrodsburg-Salem boundary of Indiana and Kentucky is only slightly younger than the Warsaw-Salem boundary of Illinois. Lineback's (1966, p. 14) correlation equating the western Illinois Warsaw with part of the Borden Siltstone may relate only to Illinois stratigraphy. On the basis of conodont evidence, the Warsaw Shale equates with the upper part of the Muldraugh and lower part of the Harrodsburg in Indiana because of *Taphrognathus varians-Apatognathus* zone forms in these units (Nicoll and Rexroad, 1975, p. 16).

In the Cincinnati arch area erosion has removed most of the rocks spanning the Osagean-Meramecian boundary, so that all except the lower units in south-central Kentucky are separated by at least 80 mi from their western counterparts. Lithologic and faunal evidence, however, indicates that all major units were once continuous at least across the Cumberland saddle in south-central Kentucky. The extensive yellowish-weathering carbonate rocks of the Renfro Member of the Slade Formation and its lithic equivalents in the basal Newman Limestone span the Osagean-Meramecian boundary in east-central Kentucky but appear to be a St. Louis equivalent, and thus are entirely Meramecian in northeastern Kentucky (Dever, McGrain, and Moody, 1979, fig. 5.4). The Renfro grades westward into the Salem, Harrodsburg, and Muldraugh, as well as into the Salem and Warsaw Formations undivided unit in south-central and central Kentucky (Weir and others, 1966).

Nomenclatural history of the Harrodsburg Limestone in Indiana is complex (Hopkins and Siebenthal, 1897; Cumings, 1922, p. 493–499; Smith, 1965), and ages of its faunal elements, which were compared to those in the Illinois Warsaw and the underlying Keokuk Limestone, have been strongly debated (Laudon, 1948). In the Indiana outcrop, the Harrodsburg overlies the Ramp Creek and Muldraugh Formations (usage of Nicoll and Rexroad, 1975), these latter two being equivalent to the Muldraugh Member of the Borden Formation in Kentucky; the Harrodsburg underlies the Salem Limestone. Currently, the siliceous and dolomitic carbonate rocks of the lower Ramp Creek Member of the Harrodsburg of Stockdale (1929) are included in the Muldraugh or Ramp Creek Formations, formerly units of the Borden Group in Indiana. The younger Leesville and Guthrie Creek Members (Stockdale, 1929) and an uppermost unnamed division, the "Upper" Harrodsburg, dominantly pelmatozoan crinoid- and bryozoan-bearing skeletal limestone, have been retained in the Harrodsburg by Nicoll and Rexroad (1975). The base of the "Upper" Harrodsburg has been considered to be the Osagean-Meramecian Series boundary in Indiana Geological Survey reports since 1954, although the entire unit had been assigned to the Osagean by others (Stockdale, 1931, 1939). Nicoll and Rexroad (1975) indicated that the conodont assemblage in the Harrodsburg Limestone of Indiana and adjacent Kentucky equates approximately with that of the Warsaw Shale of Illinois. The Kentucky Harrodsburg is a close lithologic and time equivalent of the Indiana Harrodsburg (Sable and others, 1966). The Kentucky Harrodsburg as such is the practical mapping unit used in geologic maps of western central Kentucky such as in the Fort Knox (Kepferle and Sable, 1977), Colesburg (Kepferle, 1967), and Rock Haven (Withington and Sable, 1969) quadrangles.

ROCKS OF LATE OSAGEAN AND MERAMECIAN AGE

Rocks of late Osagean and Meramecian age in Kentucky are predominantly limestone, dolomite, and siltstone that accumulated on intracratonic platforms and in shallow basins. Sandstone and mudstone, which form relatively minor constituents in the succession, mainly occur in south-central and western Kentucky. Bedded evaporites in west-central Kentucky indicate a period of shallow restricted seas and aridity during part of Meramecian time. No regional hiatus is recognized within the succession.

Principal lithologies in the stratigraphic succession characteristic of Early to Late Mississippian (mostly Meramecian) time are, in ascending order, fossil-fragmental limestones deposited under moderately high-energy subtidal conditions (Harrodsburg, Warsaw, Salem, and the Salem and Warsaw Formations unit (fig. 30)); very fine grained chemically or organically precipitated dolomitic carbonates and evaporites deposited in quiet-water, subtidal to probable supratidal environments (Renfro, St. Louis), and oolitic and bioclastic limestones deposited in shallow-water, moderately high energy subtidal environments (Ste. Genevieve). Generalized relationships of these units are shown in the cross section (fig. 9).

Besides the above units, two additional formational units of predominantly carbonate rocks are the Monteagle Limestone and the Slade Formation. These represent equivalents to part of the Meramecian succession west of the Cincinnati arch as well as Chesterian equivalents. The Monteagle Limestone, of Tennessee derivation (Vail, 1959; Stearns, 1963), is restricted to south-central Kentucky and includes units between the St. Louis Limestone and the Hartselle Sandstone; it comprises the Ste. Genevieve and Kidder Limestone

FIGURE 30.—Salem and Warsaw Formations undivided and lower part of St. Louis Limestone. Base of St. Louis shown by arrow. Uppermost part of Muldraugh Member of Borden Formation (dark beds) at extreme lower left. Milepost 85.6, north side of Cumberland Parkway, Delmer quadrangle, Pulaski County.

Members (Lewis, 1971b). The Slade Formation (Ettensohn, Rice, and others, 1984) in east-central and northeastern Kentucky includes the Renfro, St. Louis, and Ste. Genevieve Members, 10 additional younger members, and one named bed.

HARRODSBURG LIMESTONE

In Kentucky, the Harrodsburg Limestone (Sable and others, 1966) consists of light-gray, crossbedded to planar-bedded, pelmatozoan-bryozoan, relatively pure biocalcirudite and biocalcarenite. It extends northwestward from central Kentucky through Indiana to central and southwestern Illinois. It is equivalent to the "Upper" Harrodsburg unit of Indiana. Harrodsburg equivalents are present in the Ullin Limestone of Illinois and in the Warsaw and subsurface "Big Light" (drillers' term) of western Kentucky. The Harrodsburg of central Kentucky pinches out eastward and southward in south-central and east-central Kentucky into the Salem and Warsaw Formations unit, the upper part of the Muldraugh Member of the Borden Formation (Weir, 1972; Lewis and others, 1973), and laterally correlative rocks of the Renfro Member (Gualtieri, 1967a; Weir and Schlanger, 1969). The Harrodsburg averages about 30 ft thick in its outcrop belt in central Kentucky and thickens westward in the subsurface to form part of the more than 500 ft of "Big Light" or Warsaw Limestone strata in western Kentucky.

WARSAW LIMESTONE

The name Warsaw Limestone is used in western Kentucky for a 250 to 500 ft-thick unit of light- to medium-gray biocalcirudite, biocalcarenite, and dolomitic limestone which overlies the darker, siliceous beds of the Fort Payne Formation. It is the "Big Light" of western Kentucky drillers' terms. Much of the Warsaw comprises crossbedded relatively pure limestone like that in the Harrodsburg Limestone. The lower part consists of, in part, dolomitic and siliceous limestone, similar lithologically to the Muldraugh Member of the Borden Formation. The Warsaw, as mapped in western Kentucky (Fox and Seeland, 1964), is considered to be equivalent to the Ramp Creek, Muldraugh, and Harrodsburg of Indiana, the Ullin and Harrodsburg of Illinois, and the Warsaw of western Tennessee. A detailed treatment of the Warsaw in western Kentucky is given by Trace and Amos (1984).

SALEM LIMESTONE AND SALEM AND WARSAW FORMATIONS UNIT

The Salem Limestone, named for Salem, Washington County, Indiana (Cumings, 1901), in Kentucky consists of conspicuously crossbedded, medium- to coarse-grained biocalcarenite composed of fossil-fragmental, pelletal, and minor oolitic limestone interbedded with micritic dolomitic limestone, calcareous mudstone, and minor sandstone. Biocalcarenite units range up to several tens of feet thick and are dominantly biosparites with varying amounts of argillaceous matrix. In a few places they contain units of the well-sorted, winnowed high-calcium biosparites like that of the Salem building stone facies in Indiana; in Kentucky this lithology is limited to very thin beds of endothyrid and pelmatozoan-bryozoan biocalcarenite. For the most part, dark argillaceous biocalcarenite and calcareous mudstone typify the Salem in western central and south-central areas of Kentucky; dark biocalcarenite consisting of fossil fragments, endothyrid tests, and oolitic and pelletal fragments is characteristic of the Salem map unit in western Kentucky.

The Salem thickens irregularly from generally less than 100 ft in its Indiana outcrop belt to more than 350 ft in southern Illinois. Strata in the Indiana outcrop belt, except for the exposureless break across the Ohio River, are directly traceable into Kentucky (Withington and Sable, 1969; Kepferle and Sable, 1977).

In central and south-central Kentucky, the Salem Limestone and Salem and Warsaw Formations unit range from about 50 to 170 ft thick. In general, the unit thickens westward, and the areas of greatest thickness are in northwestern central and southwestern south-central Kentucky. Meaningful correlation of the Salem in these areas with strata in western Kentucky, however, is equivocal, because reliable subsurface information across much of west-central and western Kentucky is widely spaced. Based on a lithologic succession roughly comparable to that in central and west-central Kentucky, the Salem interval in western Kentucky, as mapped in the Fredonia, Crider, and Princeton East quadrangles, is only 120–130 ft thick. However, if the Salem is expanded to include strata mapped as the lower member of the St. Louis Limestone (upper part of the Illinois Salem) which overlies this interval, the total Salem thickness in western Kentucky is about 350 ft.

In south-central Kentucky, most of the rocks between the Fort Payne Formation and the St. Louis Limestone were mapped in the early stages of the mapping program as Warsaw Limestone, for example, in the Austin quadrangle (S.L. Moore, 1961). Later, as it became apparent that beds equivalent to and lithologically like the Salem Limestone of central Kentucky and southern Indiana were present in part of this unit, it was designated the Salem and Warsaw Formations (or Limestones) undivided map unit, as in the Holland quadrangle (Nelson, 1962). This compound name does not indicate that Salem and Warsaw beds are "lumped" for ease of mapping; it designates one mappable unit which is not practically divisible. The name Warsaw is retained herein for areas in south-central and western Kentucky because of its long history of usage. As previously stated, however, the type Warsaw cannot be directly traced from its type area in western Illinois into Kentucky, and the lithologies in the widely separated areas are not closely similar. We therefore believe that the use of the name "Warsaw" in Kentucky is inappropriate.

Biocalcarenite, calcareous mudstone, and argillaceous limestone (Somerset Shale of Butts, 1922; Lewis and others, 1973) are dominant lithologies in the Salem and Warsaw Formations unit, but dolomitic limestone and lesser amounts of sandstone (Garrett Mill Sandstone of Butts, 1922, p. 107; Science Hill Member of the Warsaw, Lewis and Taylor, 1979) constitute appreciable parts in south-central Kentucky. Argillaceous rocks in the unit there, such as in the Science Hill quadrangle (Taylor and Lewis, 1973) and in the Salem farther north (S.L. Moore, 1976; Withington and Sable, 1969), are also common in western central Kentucky and southern Indiana. The Garrett Mill Sandstone Member in the upper part of the Salem and Warsaw Formations unit, and the Science Hill Sandstone Member in the basal part are each less than 50 ft thick. Their distribution (fig. 31) in the Cumberland saddle area is similar and also in part overlaps the distribution of the older Jabez and Knifley Sandstone Members of the Fort Payne Formation. They show two directional distribution components, north-northwest, parallel to the Jabez-Knifley sandstone trend, and normal to that, east-northeast. Apparent age-equivalent strata to the east, west, and northwest are fine-grained terrigenous clastics with limy admixture, ranging from calcareous mudstones to calcareous siltstones. Pebbles occur in the upper part of the Science Hill Member throughout its outcrop area. Directional data for the upper part of the Science Hill (Lewis and Taylor, 1979) indicate that the member was a shallow subtidal deltaic sand body derived from an eastern source. More detailed study of these sandstone units and related fine clastics both in Kentucky and Tennessee is needed to better understand the period of transition from delta-dominated clastic deposition to shelf-controlled carbonate sedimentation phases of middle Mississippian time.

The basal strata of the Salem and the Salem and Warsaw Formations unit in Kentucky—biocalcarenite, argillaceous limestone, or sandstone—in some places contrast strongly with the lithologies of the underlying units, the Harrodsburg, Borden, and Fort Payne; but the contacts do not seem to indicate a major depositional hiatus. In western central Kentucky, the Salem-Harrodsburg contact is generally abrupt, from relatively pure calcarenite upwards to calcareous mudstone or shale, but as much as a few feet of argillaceous Salem calcarenite are transitional in some

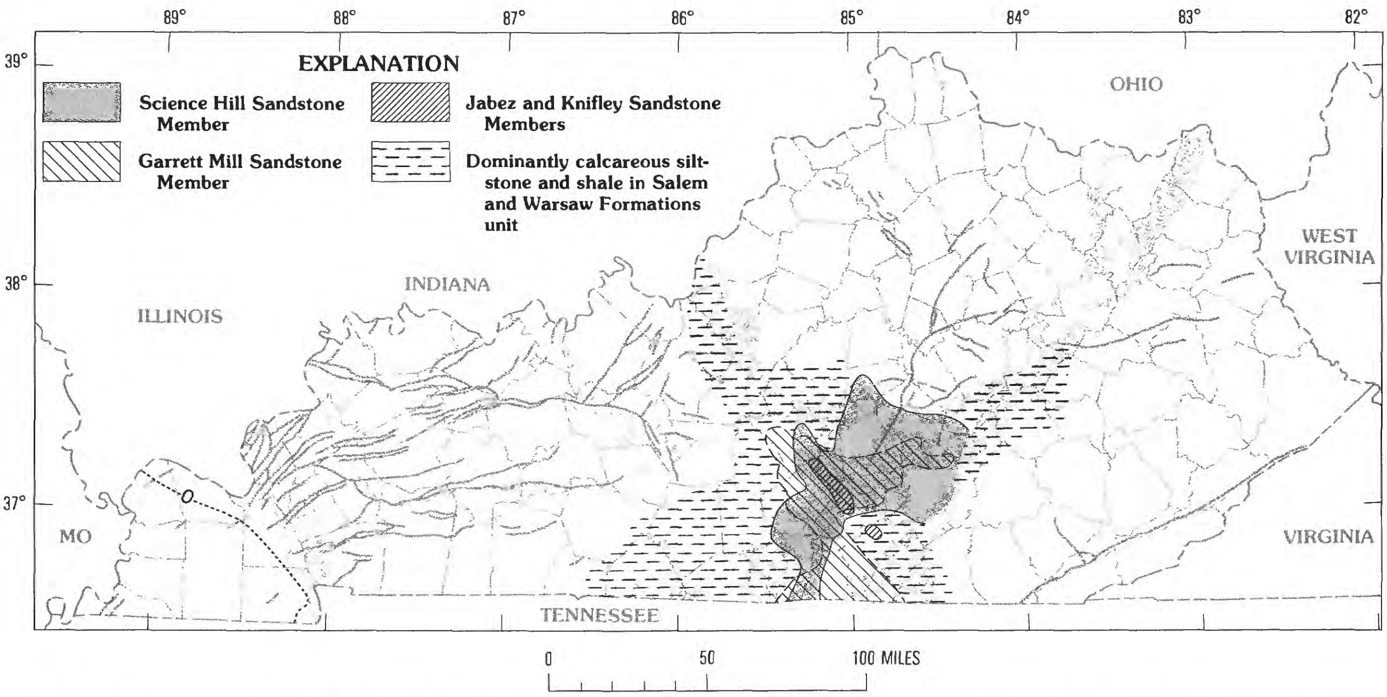


FIGURE 31.—Approximate distribution of Science Hill Sandstone and Garrett Mill Sandstone Members of Warsaw Formation and Jabez and Knifley Sandstone Members of Fort Payne Formation in south-central Kentucky.

exposures. In certain south-central Kentucky quadrangles, the Salem-Warsaw unit, dominantly argillaceous to sandy biocalcarenite, locally contains beds that are lithologically similar to the Harrodsburg.

As mapped in western and southwestern Kentucky, the Salem is commonly restricted to strata containing coarsely crystalline biocalcarenite with oolitic overgrowths, and pelletal calcarenite with the abundant foraminifer *Globoendothyra* (*Endothyra*) *baileyi* (Trace, 1974). This definition of the Salem is more restricted than that used by the Illinois Geological Survey (Baxter and others, 1963, p. 7). According to Trace and Amos (1984) the basal Salem contact corresponds to the base of the middle unit of the Illinois Salem as used by Baxter and others (1967, p. 9) in the Fluorspar district adjacent to Kentucky. In Illinois, the Salem includes younger argillaceous limestone beds bearing "endothyrids" and "lithostrotionoid"[1] colonial corals, which in western Kentucky are placed in the lower member of the St. Louis Limestone. In addition, rocks in the basal unit of the Illinois Salem have been assigned to the Warsaw Limestone in western Kentucky. Lineback (1972), after subsurface study of the Salem and St. Louis, indicated that the Salem and St. Louis lithologies in Illinois and Indiana, based on relative abundance of biocalcarenite versus dolomitic and evaporitic strata in the Salem and St. Louis, respectively, are intergradational and intertonguing. The formational boundary, therefore, has no regional time-stratigraphic significance. (See section "St. Louis and older unit relationships," p. 66.)

Both the upper part of the Salem (Kepferle, 1967) and the basal St. Louis (Kepferle and Sable, 1977) in western central Kentucky contain thick beds of micritic to calcarenitic, dolomitic limestone and dolomite similar to the "finely granular argillaceous dolomitic limestone" of the Salem in Indiana (Pinsak, 1957, p. 37 and pl. 5). This development of dolomitic lithologies is considered by Sable (1979b) to signal a precursor of the evaporite environments in the succeeding St. Louis Limestone. It is interpreted to represent a regressive trend which resulted in intertidal and supratidal environments encroaching over a large area of previously subtidal deposition.

ST. LOUIS LIMESTONE

The St. Louis Limestone (Engelman, 1847) overlies the Salem and the Salem and Warsaw Formations unit in western, west-central, central, and south-central

[1]"Lithostrotionoid" coral species used as biostratigraphic indicators of Mississippian strata in Kentucky have been referred to as *Lithostrotion castelnaui* Hayasaka, 1936; *Lithostrotion canadense* Milne-Edwards and Haime, 1851; and *Lithostrotion* [Lithostrotionella] *proliferum* Hall, all from the St. Louis and Salem Limestones, and to *Lithostrotion harmodites* Milne-Edwards and Haime from the Ste. Genevieve Limestone. The first three above have been reassigned to the genus *Acrocyathus* by Sando (1983). Sando (written commun., July 1985) has referred specimens of *Lithostrotion harmodites* to *Schoenophyllum aggregatum* Simpson, 1900.

Kentucky. That geologic mapping was difficult because clearly delineated contacts could scarcely be discerned suggests that in many areas the contact is gradational and intertonguing.

During the mapping program, rocks originally equated with the St. Louis of central and western Kentucky were assigned in east-central and northeastern Kentucky to two formations (Dever and Moody, 1979a; Dever, McGrain, and Moody, 1979). The dolomite and interbedded limestone of the lower part of the St. Louis were included in the Renfro Member of the Borden Formation (Weir and others, 1966) together with older rocks correlative with the Salem-Warsaw unit and Muldraugh; limestone of the upper St. Louis was designated as the St. Louis Limestone Member of the Newman Limestone (Hatch, 1964).

Most of the St. Louis Limestone in Kentucky is similar to that in adjoining States, and consists of very fine grained micritic to lutitic carbonate rock with lesser terrigenous material as dark carbonaceous shale and grayish-green shale in the lower and middle parts of the formation. Abundantly fossiliferous beds associated with biocalcarenites and biorudites are common in the upper St. Louis of eastern and south-central Kentucky. Chert is a common to abundant accessory and occurs as irregularly shaped masses, spherical nodules, discontinuous beds, and replacement layers ("scraggy" or "scraggly" chert) of limestone and dolomite (fig. 32). In some areas chert occurs in fairly discrete widespread "zones."

In west-central and central Kentucky, subsurface beds of gypsum and anhydrite as much as 15 ft thick, with associated dolomite, occur within a stratigraphic interval of as much as 200 ft in the lower part of the St. Louis; these are related to similar occurrences extending from west-central Illinois and south-central Indiana into Kentucky (Saxby and Lamar, 1957; McGregor, 1954; McGrain and Helton, 1964). The lower and middle St. Louis of south-central and east-central Kentucky contains multiple zones of brecciated dolomite associated with quartz nodules, celestite, and pyrite, which are considered to have formed during

FIGURE 32.—Cherty dolomite in upper part of St. Louis Limestone. J.F. Pace Construction Company quarry, Glasgow North quadrangle, Barren County. Hammer for scale.

dissolution and replacement of evaporites (Dever and others, 1978; this report, fig. 33). Beds of carbonaceous shale containing marine fossils and plant debris, reported in the lower part of the St. Louis in west-central Kentucky (R.C. Kepferle, oral commun., 1966; Withington and Sable, 1969), are in about the same stratigraphic position as the evaporite beds. Carbonate strata in this part of the section include laminated limestone, very probably of stromatolitic origin, and fine-grained limestone breccia beds.

The St. Louis as mapped shows a general eastward thinning across the State. On the west side of the Cincinnati arch, average thicknesses range from 475 ft in western Kentucky, through 300 ft in west-central Kentucky, to 230 ft in western central and south-central Kentucky. The thinning seems to occur largely in the interval assigned to the upper member of the St. Louis north and west of the Caledonia and Johnson Hollow quadrangles. The "Lithostrotionoid" coral-bearing lower member averages about 250 ft in thickness in western, west-central, central, and south-central Kentucky. In western Kentucky where the St. Louis map unit is 450–525 ft thick, it includes rocks assigned to the lower part of the overlying Ste. Genevieve Limestone in the outcrop belt east of Trigg County (fig. 34). On the east side of the Cincinnati arch, average thicknesses of the St. Louis range from 125 ft in south-central Kentucky to 25 ft in northeastern Kentucky. Northeastward thinning along the outcrop belt is noticeable principally in the sequence of dolomite and interbedded limestone of the lower and middle St. Louis and their equivalents included in the Renfro of east-central and northeastern Kentucky. This dolomitic sequence ranges in thickness from 75 ft in Pulaski County to 2 ft in Greenup County. The distinctive, cherty upper limestone of the St. Louis maintains a relatively uniform thickness of 15–25 ft across the outcrop belt.

The St. Louis is absent in parts of northeastern, east-central, and eastern Kentucky, the result of erosion associated with Late Mississippian tectonic activity along the Kentucky River fault system and Waverly arch (Dever, 1973, 1977, 1980b). Subtidal St. Louis sediments originally were deposited across the entire area. Deposition was interrupted by uplift along the Waverly arch, resulting in subaerial exposure and vadose diagenesis of the subtidal limestone, but without large-scale, extensive erosion. Diagenetic fabrics indicative of exposure and vadose diagenesis are present

FIGURE 33.—Dolomite in middle part of St. Louis Limestone. Young man pointing to zone of nodular quartz and brecciated dolomite which represents dissolved evaporite beds. Burnside Island State Park, Burnside quadrangle, Pulaski County.

AREAS WEST AND NORTH OF CALEDONIA QUADRANGLE			CHARACTERISTIC FEATURES	CALEDONIA QUADRANGLE AND AREAS TO EAST AND SOUTH
Ste. Genevieve Limestone	Levias Limestone Member	Ste. Genevieve Limestone and upper member of St. Louis Limestone	Light-gray limestone, some oolitic, clastic, and very fine grained	Ste. Genevieve Limestone
	Rosiclare Sandstone Member		Sandstone, siltstone, and limestone	
	Fredonia Limestone Member		Thick oolitic limestone	
St. Louis Limestone	Upper member		Top of zone of abundant chert — Chert occurs locally Limestone, in part oolitic	
			Top of zone of abundant nodular chert Cherty limestone, in part oolitic	
	Lower member	Lower member of St. Louis Limestone	Top of abundant "lithostrotionoid" corals Limestone and dolomite, chert common	St. Louis Limestone

FIGURE 34.—Generalized relationships between Ste. Genevieve and St. Louis Limestones as mapped in and near Caledonia quadrangle, western Kentucky (from Ulrich and Klemic, 1966).

at the top of the St. Louis in the eastern outcrop belt as far southwestward as northern Rockcastle County. Erosional removal of the St. Louis and part of the underlying Borden Formation followed recurrent movement of the Kentucky River fault system during or immediately after Ste. Genevieve time. Eroded areas are mainly on the north (upthrown) side of the fault system.

The upper limestone unit of the St. Louis, mapped as St. Louis Limestone Member of the Newman but currently in the Slade Formation, also is absent to the south in parts of Estill and Jackson Counties (Rice, 1972; Haney and Rice, 1978); but the dolomite and interbedded limestone representing the lower and middle St. Louis are present. In adjacent areas, limestone of the upper unit locally has convolute bedding, exhibiting ball-and-pillow structure, and projects several feet into the underlying dolomite.

On the Pine Mountain overthrust block, southeastern Kentucky, an interval of cherty limestone and dolomite in the basal Newman Limestone was identified on the basis of lithology as St. Louis by Butts (1922) and Hauser and others (1957), and as the Hillsdale Member of the Greenbrier Limestone of Appalachian basin terminology by Wilpolt and Marden (1959). The dominant lithologies, micrograined limestone, very finely crystalline dolomite and chert, are typical of the St. Louis; and the interval commonly is overlain by Ste. Genevieve-type calcarenite, although distinctive St. Louis megafossils, such as "lithostrotionoid" corals, have not been reported. The interval commonly is about 40 ft thick, but in the Pineville area, Hauser and others (1957) and Butts (1922) assigned 80 and 115 ft, respectively, of basal Newman to the St. Louis.

STE. GENEVIEVE LIMESTONE

The Ste. Genevieve Limestone (Shumard, 1860, p. 406), the youngest Meramecian formation in Kentucky, is composed principally of carbonate rocks: light-colored, medium- to coarse-grained, oolitic and bioclastic calcarenite; light-colored to gray, bioclastic calcirudite; gray calcilutite; and gray, very finely crystalline dolomite. The oolitic and bioclastic calcarenites are commonly considered to be important lithologic criteria for recognizing the Ste. Genevieve. Principal constituents in the bioclastic calcarenite and calcirudite are pelmatozoans, brachiopods, and bryozoans. Clay shale and sandstone are relatively minor constituents of the formation, but they are more common in western Kentucky, where they form named stratigraphic units. Chert is a relatively minor accessory, occurring as nodules, irregular masses, and siliceous replacements of fossiliferous beds such as the Lost River Chert Bed of Elrod (1899).

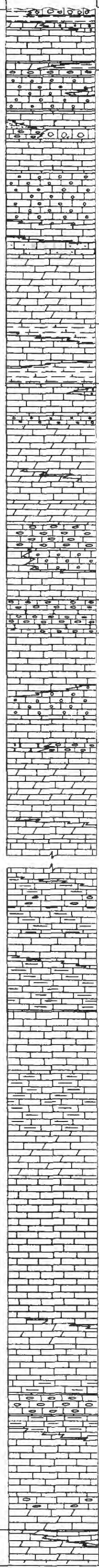
The Ste. Genevieve Limestone is a roughly tabular unit from western central and south-central Kentucky across west-central and western Kentucky. It averages from about 180 to 240 ft thick in a distance of about 140 mi, thus suggesting that the rates of deposition and subsidence were essentially in equilibrium west of the Cincinnati arch.

In western Kentucky, the Ste. Genevieve averages about 240 ft thick and ranges to more than 300 ft. There it is divided into three members, in ascending order, the Fredonia Limestone Member (Ulrich and Smith, 1905); Rosiclare Sandstone Member (Ulrich and Smith, 1905); and Levias Limestone Member (Sutton and Weller, 1932). The Fredonia Limestone Member is characterized by oolitic limestone including the drillers' unit, "McClosky oolite," an important oil reservoir in some areas. The Fredonia ranges from 170 to 260 ft and averages 205 ft thick. In western Kentucky, 20–30 ft below the top of the Fredonia, a possible shale and sandstone equivalent of the Spar Mountain Sandstone of Illinois (Tippie, 1945) was noted by Amos (1967, 1974) and Amos and Hays (1974). The Rosiclare Sandstone Member, sandstone and green shale with local sandy limestone, is 5–25 ft thick, averaging about 10 ft, in western Kentucky. The overlying Levias Limestone Member, finely crystalline to micritic to oolitic limestone, ranges from 10 to 35 ft thick and averages 25 ft.

The three members are not mapped in the major part of the Ste. Genevieve outcrop west of the Cincinnati arch because the Rosiclare Sandstone Member separating the Fredonia and Levias Limestone Members grades into limestone southeast of Caldwell County and thus does not remain a mappable unit. However, a number of useful stratigraphic units are recognizable within the Ste. Genevieve west of the arch, in ascending order, the Lost River Chert Bed (Shaver and others, 1970); silicified oolitic limestone unit; *Schoenophyllum aggregatum* (formerly *Lithostrotion* (*Siphonodendron*) *genevievensis*) zone; Rosiclare Sandstone equivalent; and Bryantsville Breccia Bed (Shaver and others, 1970).

The Lost River Chert Bed (Elrod, 1899), whose type area lies in southern Indiana, is a distinctive unit of one or more commonly silicified highly fossiliferous limestone beds that ranges from 1 to about 10 ft thick. In its type area it lies 20 or more feet above the Ste. Genevieve's base, as defined by oolitic limestone beds (Malott, 1952, p. 8). When weathered this limestone is a porous, siliceous coquinoid rock having a chalky matrix in which the fossil fragments (relatively large fenestellid bryozoan fronds, and large orthotetid, productid, and spiriferoid brachiopod whole shells and fragments) are outlined or filled with stain from bright-red clay. In Kentucky this lithology is described in western central Kentucky in the Howe Valley and Rock Haven quadrangles (Kepferle, 1963a; Withington and Sable, 1969), and in west-central Kentucky (fig. 35). Similar rocks are described in several western Kentucky quadrangles (Sample, 1965; Amos, 1974; Amos and Hays, 1974). McGrain (1969) also recognized this chert bed east of the Cincinnati arch in Wayne and Pulaski Counties (fig. 59), where it serves as a useful stratigraphic marker as much as 20 ft above the horizon that separates Ste. Genevieve calcarenitic and oolitic limestone lithology from the underlying lithostrotionoid coral-bearing micritic limestone of the St. Louis (fig. 36). In south-central Kentucky it is the uppermost part of the Horse Cave Member of the St. Louis Limestone of Pohl (1970). Such a siliceous layer is a valuable mapping tool in areas of low relief, poor exposure, and thick residual soil. It is also recognizable in cuttings and cores of bore holes (Kepferle and Peterson, 1964). Other cherty limestone beds which weather to residuum somewhat similar to that of the Lost River Chert Bed occur both above (Withington and Sable, 1969) and at (fig. 37) the Ste. Genevieve–St. Louis contact in central and south-central Kentucky. The Lost River Chert Bed is also locally absent in parts of south-central Kentucky, and thus the other cherty units could be confused with it during geologic mapping.

The Rosiclare Sandstone Member of the Ste. Genevieve, as mapped in western Kentucky, grades southeastward from Caldwell County into a silty to sandy, peloidal and intraclastic calcarenite. This calcarenite, although not a mappable unit, has been found to form a distinct bed, 1–10 ft thick, which can be traced, through quarry and roadcut sections, across the Ste. Genevieve outcrop belt from western Kentucky into west-central, south-central, and central Kentucky where it is considered to be the Rosiclare equivalent (Dever, McGrain, Ellsworth, and Moody, 1979; Dever, 1980). Both the calcarenite bed and the Rosiclare are within the upper interval of the formation bracketed by the *Schoenophyllum aggregatum* (formerly *Lithostrotion* (*Siphonodendron*) *genevievensis*) zone and Bryantsville Breccia Bed. Commonly associated with the calcarenite are micritic crusts and stringers developed during vadose diagenesis; identical diagenetic features occur in the Bryantsville Breccia Bed at the top of the Ste. Genevieve.



SYSTEM	SERIES	FORMATION AND MEMBER	THICKNESS, IN FEET		DESCRIPTION
MISSISSIPPIAN	Meramec	St. Louis and Ste. Genevieve Limestones	15-25		Limestone, shale, and chert breccia: Limestone, light- to medium-gray, finely to medium crystalline; few beds are sublithographic; medium to thick bedded; oolitic beds local in upper part; some beds locally dolomitic. Shale, light-greenish-gray, in part calcareous; thin interbeds. Chert breccia, medium- to light-gray very fine grained chert fragments in sparse to abundant matrix of light-gray sublithographic limestone; large chert fragments as much as 1 foot in diameter consist of well-cemented small angular chert fragments of various shades of gray; at top of unit, locally absent; bed is the Bryantsville Breccia of Malott (1952, p. 9).
			60-80	135-195	Limestone and sandstone: Limestone, very light gray to medium-gray, finely to coarsely crystalline, excellent abundant and well-developed white to light-gray oolites common in upper half of unit in zones as thick as 15 feet; medium to thick bedded, less commonly thin bedded; crossbedding in coarsely crystalline beds; scattered gray fine-grained chert nodules that weather chalky white at and near top of unit; few slightly sandy beds about middle, dolomitic beds near top and base; limestone breccia or intraformational conglomerate locally in upper part; *Platycrinites penicillus* Meek and Worthen common. Sandstone, gray, very calcareous, medium- to thick-bedded, in upper part; locally absent. Unit generally well exposed throughout map area.
			15-20		Shale and limestone: Shale, dark-green to greenish-gray, slighty calcareous. Limestone, medium-gray, finely crystalline, medium- to thick-bedded.
			50-70		Limestone and dolomite: Limestone, very light gray to medium-gray, sublithographic to medium-crystalline; oolitic beds in upper and lower thirds; medium to thick bedded, less commonly thin bedded and laminated; light-gray, fine-grained nodules of chert 15 to 25 feet above bese; much of upper half of unit is dolomitic. Dolomite, gray, finely crystalline, medium- to thick-bedded, near middle of unit.
		Lost River(?) Chert of Elrod (1899)	5-14		Limestone and chert: Limestone, very light tan to light-yellowish-gray, medium- to finely crystalline, medium- to thick-bedded; abundant fenestellid bryozoans and brachiopods (especially *Orthotetes* sp.) on bedding plane surfaces. Chert, light- to medium-gray, commonly gray mottled, very fine grained, medium beds to thin elongated lenses, wavy bedding plane surfaces. On upland surfaces unit weathers to angular residual slabs and blocks with limonite-stained irregular surfaces. Well exposed in bluffs along Ohio River.
			20-35		Limestone, light- to medium-gray, medium-crystalline to oolitic, thick- to medium-bedded, few thin beds. Contact between Ste. Genevieve and St. Louis Limestones has been defined by other workers as approximately at the bottom of this unit 20 to 35 feet below the base of the Lost River(?) Chert (Ray and others, 1946; Malott, 1952).
			180-200		Limestone, dolomite, and chert. Limestone, brownish- to medium-gray, medium- to finely crystalline, commonly dolomitic in upper half; lower half commonly argillaceous, scattered beds have light-gray to light-brown chert nodules; thick to medium bedded, few thin beds. Dolomite, medium- to dark-gray, finely crystalline, thick- to medium-bedded, few beds argillaceous; in upper part. Chert, light-gray to light-tannish-gray, very fine grained, medium-bedded, wavy bedding plane surfaces; grades laterally to lenses; at top of unit.
			60-70	340-375	Limestone and gypsum(?): Limestone, medium- to dark- to brownish-gray, fine-grained to sublithographic, thick- to medium-bedded; some thin to shaly bedded to laminated argillaceous limestone near middle; in part dolomitic; *"Lithostrotion"* spp. and *Syringopora* sp. present; petroliferous odor common when broken. Gypsum not present at surface in map area but penetrated by core drill hole in the adjacent Guston quadrangle (Kepferle and Peterson, 1962); large springs in bluff about 0.8 mile east of Brandenburg (Gallaher, 1964) are at the same stratigraphic positions as bedded gypsum encountered in the drill hole.
			65-80		Limestone, medium- to dark- to brownish-gray; some light olive gray in lower part; fine grained to sublithographic; few beds in lower half medium grained organic detrital; thick to medium bedded, few thin to laminated beds near middle; dolomitic at base and near top; commonly argillaceous near middle, scattered gray chert nodules about middle and near base; few small spiriferid brachiopods; strong petroliferous odor when broken.
		Salem Limestone	10+		Limestone, light-brownish-gray to brownish-gray, medium- to coarse-grained, medium- to thick-bedded, slightly crossbedded; some dolomitic. Only upper few feet exposed in extreme southeast corner of map area.

FIGURE 35.—Stratigraphic section and description showing lithologies of St. Louis and Ste. Genevieve Limestones and Lost River Chert Bed in New Amsterdam quadrangle, west-central Kentucky (from Amos, 1972).

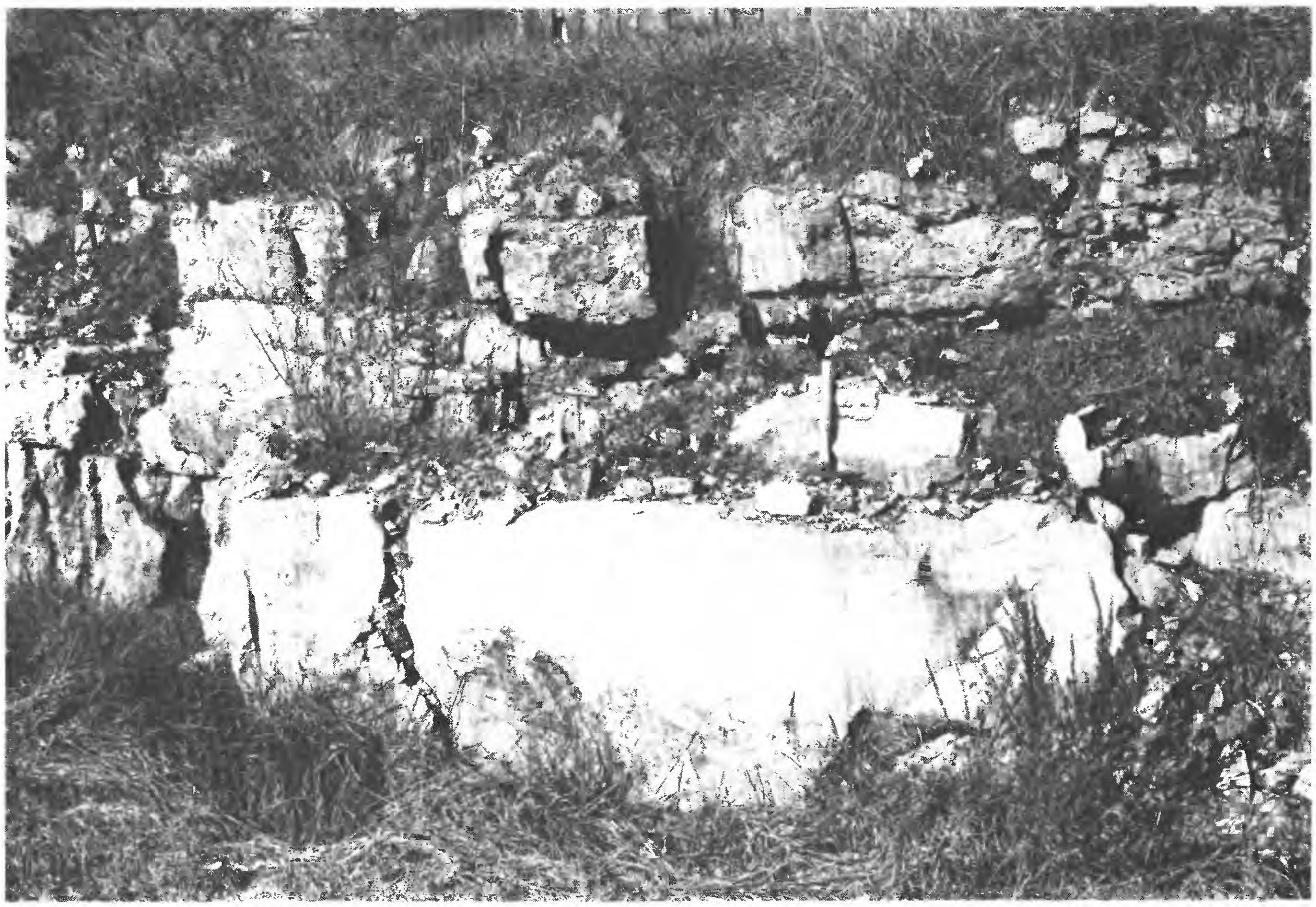


FIGURE 36.—Lost River Chert Bed (above hammer handle) about 2.5 ft thick. Roadcut on north side of Kentucky Highway 96 at Touristville, Mill Springs quadrangle, Wayne County.

The distinctive colonial coral *Schoenophyllum aggregatum* Simpson 1900 (*Lithostrotion* (*Siphonodendron*) *genevievensis* and *Lithostrotion harmodites* of earlier reports) has long been recognized as a useful guide fossil for the Ste. Genevieve (for example, Ulrich and Smith, 1905; Ulrich, 1917; Butts, 1917, 1922). The coral has a narrow stratigraphic but widespread geographic range across the Ste. Genevieve outcrop belt west of the Cincinnati arch (Dever and others, 1980). Its occurrence is restricted to a zone 1–10 ft thick (more commonly, 1–2 ft thick) in the upper part of the formation. The zone commonly is about 20 ft below the top of the Ste. Genevieve in northern west-central, central, and south-central Kentucky, and about 40–50 ft below the top in southern west-central and western Kentucky. The coral also occurs in the Ste. Genevieve in parts of south-central Kentucky (Butts, 1922; Lewis, 1971b) where it is locally abundant, but generally rare (for example, Lewis and Taylor, 1976; Taylor, 1977). Some zonation in this area was also noted by Lewis (1971b), but the stratigraphic range of the coral within the unit has not been well defined.

The top of the Ste. Genevieve in the outcrop west of the Cincinnati arch is marked by a widespread zone of altered limestone, 1–5 ft thick, which has been correlated with the Bryantsville Breccia Bed of Indiana (Patton, 1949; Malott, 1952). Diagenetic features in the limestone indicate that alteration resulted from subaerial exposure and vadose diagenesis. The exposure zone, mostly darker colored than the underlying limestone, has a variety of lithologic expressions in the outcrop belt, displaying various combinations of carbonate lithotypes and diagenetic fabrics, ranging from rubbly to massive, highly brecciated calcilutite and calcisiltite to unbrecciated calcarenite containing micritic crusts and stringers. Cherty silicification of the diagenetic crusts and stringers is common.

The Ste. Genevieve crops out east of the Cincinnati arch in the northeast-southwestward-trending belt of Mississippian rocks along the western border of the

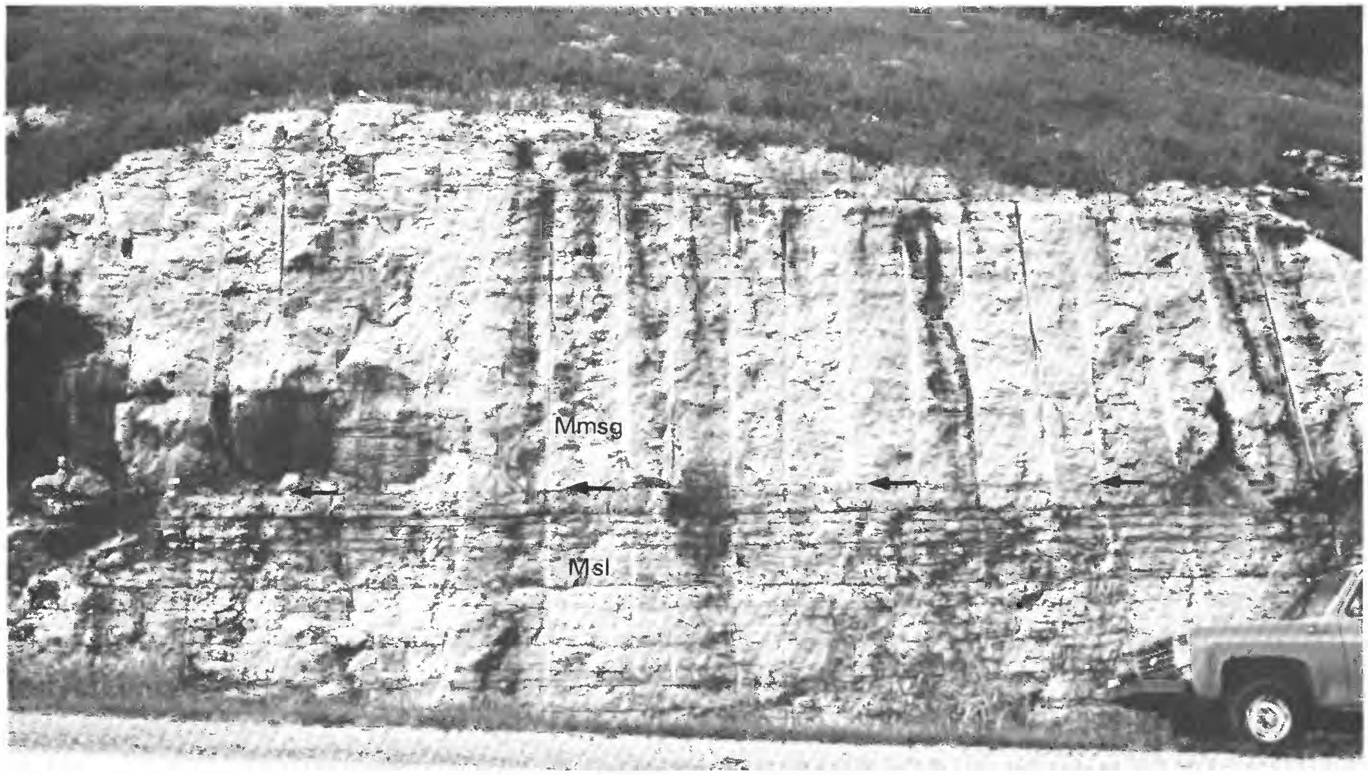


FIGURE 37.—Ste. Genevieve Limestone Member of Monteagle Limestone (Mmsg) and St. Louis Limestone (Msl). Arrows indicate contact between members at top of 1-ft cherty limestone bed. Kentucky Highway 80, Pulaski County.

Eastern Kentucky coal field; it is absent along the axis of the arch. During the geologic mapping program, the Ste. Genevieve in this eastern outcrop belt was reduced in stratigraphic rank and mapped in south-central Kentucky as the Ste. Genevieve Limestone Member of the Monteagle Limestone (Lewis and Thaden, 1965; Lewis, 1971b); in northeastern, east-central, and northeast-south-central Kentucky, it was mapped as the Ste. Genevieve Limestone Member of the Newman Limestone (Hatch, 1964; Cohee and West, 1965). In 1984, the Ste. Genevieve in east-central and northeastern Kentucky was assigned to the Slade Formation (Ettensohn and others, 1984) after a more comprehensive understanding of the stratigraphic relations of Upper Mississippian strata was reached.

Lithologies in the Ste. Genevieve are virtually the same on both sides of the Cincinnati arch; some included stratigraphic markers occurring on the west side have been recognized east of the arch. The Lost River Chert Bed is present 15–20 ft above the base on the east in parts of south-central Kentucky, but it commonly is unfossiliferous (McGrain, 1969). Northeast of Somerset, a bed of cherty limestone is at the top of the mapped St. Louis; it weathers to a chert similar in appearance to the Lost River Chert.

A zone of altered limestone, with features indicative of subaerial exposure and vadose diagenesis, caps the Ste. Genevieve east of the Cincinnati arch and has been correlated with the Bryantsville Breccia Bed at the top of the unit west of the arch (McFarlan and Walker, 1956). In south-central Kentucky as in central Kentucky, the breccia bed is bracketed by diagnostic crinoid fauna, Meramecian *Platycrinites penicillus* in the Ste. Genevieve, and Chesterian genus *Talarocrinus*. In south-central Kentucky, the unit containing *Talarocrinus* is named the Kidder Limestone Member of the Monteagle Limestone (Lewis, 1971b). Northeastward along the outcrop belt, identification of the Bryantsville Breccia Bed and top of the Ste. Genevieve is complicated by (1) the presence of multiple exposure zones, lithologically similar to the Bryantsville, in both the Ste. Genevieve and overlying limestones, (2) absence or sparse presence of diagnostic crinoid fauna, and (3) northeastward thinning of the carbonate units (Dever, Hester, and others, 1979).

Rocks in east-central and northeastern Kentucky assigned to the Ste. Genevieve Limestone by Butts (1922) and McFarlan and Walker (1956), and designated as the Ste. Genevieve Limestone Member of the Newman Limestone during the mapping program, for example in the Tygarts Valley (Sheppard, 1964) and Bangor (Hylbert and Philley, 1971) quadrangles, consist of two distinct limestone units, separated by an erosional unconformity (Dever, 1973, 1980b). The older *Platycrinites*-bearing Ste. Genevieve, composed mainly of bioclastic and oolitic calcarenite and capped by the Bryantsville Breccia Bed, extends along the outcrop belt from south-central into northern east-central Kentucky (fig. 59) where the unit was erosionally truncated following Late Mississippian movement along the Kentucky River fault system. In addition to being truncated on the north, the Ste. Genevieve in the east-central area pinches out eastward toward the axis of the Waverly arch, which remained a positive feature following the earlier uplift that interrupted St. Louis deposition.

The younger limestone unit included in the Ste. Genevieve was deposited after the period of uplift and erosion associated with recurrent movement along the Kentucky River fault system. Extensive erosion, mainly on the upthrown (north) side of the fault system, resulted in erosional thinning and truncation of the *Platycrinites*-bearing Ste. Genevieve and erosional thinning and removal of the St. Louis and upper Borden (Renfro, Nada, and upper Cowbell) in parts of northeastern and east-central Kentucky. The younger limestone, named the Warix Run Limestone Member of the Newman (Dever, 1977) and later of the Slade Formation (Ettensohn and others, 1984) was deposited on the erosional surface developed on the uplifted northern block, where it rests unconformably upon the Borden (mainly on the Cowbell Member) and only locally upon the older Ste. Genevieve and St. Louis. South of the fault system, it rests unconformably upon the Ste. Genevieve and St. Louis.

The Warix Run Member, as much as 100 ft thick, consists mainly of crossbedded quartzose calcarenite, with lesser amounts of calcilutite. The calcarenite is composed of peloids, with sparse to locally abundant micrite-enveloped grains, ooliths, and bioclastic grains. The unit contains abundant quartz silt and sand, and, locally, grades into calcareous sandstone (Klekamp, 1971). Material derived from eroded members of the Borden and Newman is present in the basal part; grains and granules of St. Louis chert and limestone are common constituents in much of the unit.

Rocks assigned to the Warix Run Member of the Slade Formation accumulated in erosional lows on the uplifted northern block of the Kentucky River fault system, partly filling them. The member commonly reaches its maximum thickness, as much as 100 ft (Englund, 1976), near the middle of these lows, and it thins and pinches out along the margins of each area. Thus, the member forms a series of isolated deposits in the present outcrop of northeastern and northern east-central Kentucky (Dever, 1977; Ettensohn and others, 1984). South of the Kentucky River fault system where the unit is more widespread, it is thinner; here it forms a blanketlike deposit of calcarenite which has been traced as far south as central Rockcastle County (fig. 59).

In northeastern and northern east-central Kentucky, Warix Run calcarenite is overlain by calcilutite of the upper member of the Newman or Slade. The lithologies of these two units form a transgressive-regressive sequence; the contact between them appears conformable, in part sharp and in part intertonguing. Diagenetic features indicative of exposure and vadose diagenesis occur at the top of the Warix Run in parts of the area, but their meager development and the absence of extensive alteration in the limestone suggest formation during relatively brief periods of exposure.

On the Pine Mountain overthrust block in southeastern Kentucky, an interval in the lower Newman Limestone, composed mainly of oolitic and bioclastic calcarenite, was identified as Ste. Genevieve by Butts (1922) and Hauser and others (1957). The calcarenitic interval, as much as 100 ft thick, overlies the zone of cherty limestone and dolomite in the basal Newman which was identified as St. Louis. Above the calcarenitic interval are beds correlated by de Witt and McGrew (1979) with the Taggard Red Member of the Greenbrier Limestone of Wilpolt and Marden (1959), a West Virginia unit characterized by the presence of variegated limestone, mudstone, and shale. Butts (1922) reported the occurrence of *Lithostrotion* (*Siphonodendron*) *genevievensis*, now *Schoenophyllum aggregatum* Simpson 1900, in the Ste. Genevieve at Pineville. *Platycrinites penicillus* has been found in the interval below the Taggard at localities in Letcher and Whitley Counties, Ky. In West Virginia, the Taggard has been placed at the Meramecian-Chesterian boundary (Wells, 1950) and in the basal Chesterian (de Witt and McGrew, 1979).

STRATIGRAPHIC RELATIONSHIPS

ST. LOUIS AND OLDER UNIT RELATIONSHIPS

West of the Cincinnati arch in Kentucky, field relationships between the St. Louis Limestone and the underlying Salem Limestone or the Salem and Warsaw Formations unit appear conformable, but lithologic units at the mapped boundary vary (Withington and Sable, 1969). On a 7½-minute quadrangle scale, boundary units commonly interlayer strata characteristic of each unit, or else the lithologic contact can be sharp and unequivocal. In larger areas, the relationships are conformable and probably gradational or intertonguing, so that inconsistencies arise when regional correlations are attempted.

Lineback (1972), in an attempt to reconcile differences in the Salem and St. Louis boundary, traced contacts in the subsurface eastward from the St. Louis, Mo., type area of the St. Louis and westward from the Salem, Ind., type area of the Salem into areas of Illinois, and concluded that the two formations partly intergrade and reciprocally thicken and thin in Madison and Bond Counties, Ill. Lineback virtually restricted the Salem to strata containing biocalcarenitic and oolitic limestone ("biocalcarenite facies"). His criteria for this usage are similar to those used in western Kentucky. Both the older (Baxter, 1960; Baxter and others, 1963, 1967) and newer (Lineback, 1972) usages are shown on the cross section (fig. 9).

Contact criteria between the Salem and St. Louis Limestones in central Kentucky generally follow those used in adjacent Indiana, but according to Pohl (1970, p. 3), the criteria are inconsistent. The contact in central Kentucky is placed between underlying biocalcarenite, argillaceous shaly limestone, or saccharoidal dolomitic limestone and overlying even-bedded cherty, dense, micrograined or micritic, in part laminated limestone and dolomitic limestone. The contact is based on gross lithologic differences, but it is generally sharp to gradational over a few feet (or at the most, 10–20 ft) in central, west-central, and south-central Kentucky, where the combined thickness of the St. Louis and Salem ranges from about 100 to 400 ft. In western Kentucky, however, the combined thickness increases from about 400 to more than 700 ft; here a unit of dark, partly argillaceous limestone as much as 170 ft thick intervenes between biocalcarenite beds typical of the Salem, and the dense micritic limestones considered typical of the St. Louis (Trace, 1974). In some quadrangles the Salem and St. Louis have been mapped as an undivided unit (Fox, 1965; Rogers, 1963); in more recent maps the units were differentiated (Trace, 1974; Rogers and Hays, 1967). In western Kentucky, the uppermost boundary of the Salem is placed at the top of the highest biocalcarenite or oolitic limestone bed. This corresponds to the boundary of Lineback (1972) in Illinois. Elsewhere in Kentucky, the current lithologic boundaries of the Salem also appear to generally correspond to those in Illinois.

To early workers concerned with the relative age of the St. Louis, faunal and lithologic differences indicated that a hiatus or disconformity separated the St. Louis from older rocks in the Mississippi River Valley (S. Weller, 1909; Van Tuyl, 1925). More recent studies indicate that conodont faunas are transitional upwards into basal St. Louis beds, but that a sharp widespread break in the conodont succession exists within the lower part of the St. Louis and is associated with limestone breccias in some places (Collinson and others, 1971, p. 382). This break, between the *Taphrognathus varians-Apatognathus* zone and the *Apatognathus scalenus-Cavusgnathus* zone, may mark a widespread hiatus. Similar positions of this zonal boundary are reported by Nicoll and Rexroad (1975) in Indiana adjacent to north-central Kentucky, and in general the break may correspond with occurrence of evaporite beds and breccia beds in Illinois, which have been considered to represent remnants of fractured carbonate beds associated with dissolved evaporite strata (Collinson, 1964, p. 9).

The Renfro Member of the Borden and Slade Formations apparently spans the Osagean-Meramecian boundary; its conformable stratigraphic relationships with underlying Borden clastic units and with the overlying St. Louis have previously been discussed. In some areas, however, glauconite in and underlying the basal Renfro suggests a depositional hiatus there.

Reciprocal thicknesses of the Renfro Member and the overlying St. Louis Limestone Member of the Slade Formation in east-central Kentucky are indicated by Weir and others (1966, p. F20), although the Renfro includes equivalents of Muldraugh, Salem and Warsaw Formations unit, and about the lower two-thirds of the St. Louis. Thickness reciprocity is inferred by probable intertonguing of the Salem and St. Louis in areas west of the Cincinnati arch. Thus, the thicknesses of the combined Warsaw-Salem-Renfro and St. Louis thicknesses (fig. 57) are considered to represent a more generally correct gross chronostratigraphic unit than do isopach maps of the separate units.

ST. LOUIS-STE. GENEVIEVE RELATIONSHIPS

The contact between the St. Louis and Ste. Genevieve Limestones and their equivalents in Kentucky east of the Cincinnati arch is based on general lithologic and faunal differences. It has been considered to be regionally inconsistent in Illinois (Swann, 1963, p. 27). Likewise, in western Kentucky, some abrupt vertical offsets of this contact (fig. 34) have resulted from differences in contact criteria used by geologists who mapped adjacent quadrangles (Pohl, 1970, p. 6), considerations of different criteria used by adjoining States, the lack of detailed faunal studies, and the characteristically poor exposures of rocks associated with this contact.

The Lost River Chert Bed of Elrod, discussed previously, has been used in west-central, central, and south-central Kentucky (McGrain, 1969) to approximate the St. Louis–Ste. Genevieve contact, which occurs in areas of characteristically poor exposures. This zone or its identical lithologies have been reported in many quadrangle section descriptions from south-central to western Kentucky. Identical lithologies have been observed at least as far west as near Anna, southern Illinois, by Sable, and may extend into Missouri and to northwestern Illinois (F.J. Woodson, written commun., 1983). In western and west-central Kentucky these rocks have been mapped as part of the St. Louis Limestone (Rogers and Hays, 1967). The Lost River Chert Bed is considered by Sable to mark a widespread virtually time-equivalent unit which lent itself by its porosity and permeability to relative ease of silicification.

Criteria for discerning the base of the Ste. Genevieve Limestone vary considerably throughout Kentucky, as they have in adjoining States. In Kentucky, the basal contact has been mapped at the following successively lower horizons and approximations of horizons:

1. The base of abundant oolitic limestone beds; this contact corresponds to the base of the Fredonia Limestone Member, and approximates the contact as mapped in Illinois. It has been used commonly in western Kentucky, particularly in the Fluorspar district (Trace and Amos, 1984). There it coincides with the base of a laminated dolomitic limestone and the top of a zone of nodular light-gray chert, the "upper" or "first" cherty zone of mapping geologists in western Kentucky (Trace, 1962). This is the contact currently recognized in that area.

2. The base of all oolitic or biocalcarenitic limestone beds in the St. Louis–Ste. Genevieve interval, at the top of a "lower" or "second" cherty zone. This contact was used in earlier mapping of the western Kentucky and Illinois fluorspar district (Weller and Sutton, 1951), and has generally been considered to be the boundary between the two formations in Indiana (Malott, 1932; McGrain, 1943) and in central to west-central Kentucky.

3. The uppermost occurrence of "lithostrotionoid" corals which are commonly silicified and are conspicuous in deeply weathered areas. This involves only minor lithologic differences but has been used in both west-central and western south-central Kentucky (Haynes, 1966).

4. At or as much as 20–50 ft below the Lost River Chert Bed (Kepferle, 1963b; Taylor, 1976). The uppermost "lithostrotionoid" corals occur within 10–25 ft or less below the Lost River Chert Bed in south-central and southern east-central Kentucky, but the interval between the corals and the chert bed increases westward and may be as much as 110 ft below the top of the Lost River Chert lithologic equivalent in western Kentucky. As previously mentioned, the lithologic equivalents of the Lost River Chert Bed have been observed in several western Kentucky quadrangles (for example, Rogers and Hays, 1967). A possible candidate for the Lost River Chert Bed equivalent in western and west-central Kentucky is a chalky-weathering chert containing abundant fenestellid bryozoans and brachiopods below an interval of abundant nodular chert. This would correspond to the lower, or second, chert of the upper member of the St. Louis Limestone (Klemic, 1966a, 1966b; Klemic and Ulrich, 1967; Ulrich, 1966; Ulrich and Klemic, 1966). Geologists mapping in that area, however, interpreted this lithology either to occur sporadically throughout a thick stratigraphic interval of as much as 250 ft in the upper member of the St. Louis, or to represent secondary vadose or other exposure silicification after deposition in keeping with a new tectonic regime, possibly post-Paleozoic or post-Mesozoic. They therefore did not relate this lithology to a specific stratigraphic position. Nevertheless, the unique abundance and association of fossil fauna are very distinctive. The chert may be a diagenetic feature or a replacement product of a widespread subtidal deposit which preceded minor uplift or sea-level withdrawal enough to expose the beds to supratidal conditions, initiating silicification by vadose circulation. It is quite certain that only one such zone containing one or more cherty beds exists in Indiana and west-central, central, and south-central Kentucky. It is difficult to explain more than one such zone in western Kentucky, which lies basinward of the above area, and where repeated exposure seems more unlikely than in shelf areas.

In addition to the mapped contacts described above, other St. Louis–Ste. Genevieve boundary positions have been proposed. Pohl (1970) placed the boundary several feet above the Lost River Chert Bed and proposed a new subdivision, the Horse Cave Member of the St. Louis Limestone, to include the transitional lithologies between the lowest prominent oolitic limestone in the St. Genevieve and the highest occurrence of spheroidal ("ball") chert and amoeboid to lensatic chert in the St. Louis dolomitic micritic lithologies. The approximate upper limit of the Horse Cave, according to Pohl, marks a "viable extinction" of a foraminifer genus and a dasyclad algal genus. Macrofossils historically considered to be the guide fossils of the Ste. Genevieve (*Platycrinites penicillus* [Meek and Worthen] and *Pugnoides ottumwa* [White]), however, extend as much as 65 ft below the Lost River Chert Bed in western south-central Kentucky according to Pohl. An even higher St. Louis–Ste. Genevieve boundary in southern Illinois, the base of the Spar Mountain Sandstone Member of the Ste. Genevieve, is based on conodont zonation (Rexroad and Collinson, 1963; Burger, Rexroad, and others, 1966). In south-central Kentucky, conodont studies suggest to Rexroad that the upper limit of the St. Louis lies roughly 2 to 10 ft or more above the Lost River Chert Bed (F.J. Woodson, written commun., January 1983). These contacts, although they combine both lithologic and faunal criteria, do not lend themselves to mapping definition in that the lithologic criteria are subtle, rarely observable, and extremely difficult to map in the poorly exposed areas in which they occur.

As mapped, the relationships between the St. Louis and Ste. Genevieve west of the Cincinnati arch are apparently conformable and gradational. In south-central Kentucky, east of the arch, the contact between the cherty limestone and dolomite of the upper St. Louis and the basal Ste. Genevieve calcarenite also appears conformable. However, in the northeastern part of south-central Kentucky, a conglomerate as much as 10 ft thick, composed of abundant clasts of St. Louis-type chert in an oolitic matrix, has been reported at the base of the Ste. Genevieve (Butts, 1922; Lewis, 1971b). In parts of the area around Somerset, roadcut exposures show that from 4 to 18 ft of Ste. Genevieve-type calcarenite is present between the base of the chert-bearing conglomerate and the top of the cherty calcilutite and calcisiltite of the St. Louis. Across most of east-central Kentucky, the Ste. Genevieve rests unconformably upon an exposure zone at the top of the St. Louis and commonly contains a thin, basal conglomerate of St. Louis chert and limestone clasts. The St. Louis was removed from parts of northeastern Kentucky by intra-Mississippian erosion; where present, it is unconformably overlain by limestone and shale of the upper part of the Slade Formation (formerly Newman Limestone), which is considered to be a Chesterian equivalent.

SOURCES OF SEDIMENTS AND DEPOSITIONAL ENVIRONMENTS

Although all preserved rocks of Meramecian age were deposited in marine or marginal marine environments, the distribution of terrigenous detrital material indicates transport from source areas mostly east and northeast of the Appalachian basin. Lesser sources of sediment may have been east of the present-day southern Appalachians, and small amounts of sediment may have been shed from areas of low relief along the Cincinnati arch and Ozark uplift. Williams (1957, p. 315–316) suggested three source areas for detritals in Warsaw and Salem rocks for the midcontinent region—Wisconsin, Ozarkia, and Appalachia. Rubey (1952, p. 50) reported sand grains derived from igneous and metamorphic rocks in the St. Louis of eastern Missouri, and suggested the presence of newly exposed land areas in the Ozark region.

Directional data for the Garret Mill Sandstone Member are reported by Lewis and Taylor (1979). They interpreted the Science Hill Member of the Warsaw to be a shallow deltaic sand body derived from an eastern source area. Thus the Science Hill, at least, appears to represent a late southwestward spillover along the southern part of the Borden delta front after clastic deposition had generally ceased in more northern areas such as in central Indiana.

Source areas and transport directions are not known for the conspicuous mudstones of the Salem and Warsaw Formations unit ("Somerset Shale") in the Cumberland saddle area of south-central Kentucky and adjacent Tennessee and those of the Salem in central Kentucky. These mudstones are interpreted to be genetically related to the sandstones in those units. Their general distribution and thickness suggest westward and northward transport. They, along with the sandstones of the Garret Mill and Science Hill Members, may have been swept westward from sources east of the southern Appalachians possibly through the Cumberland saddle, with the fine clastic muds carried farther westward and northward along the west flank of the Cincinnati arch. These latter two possibilities seem likely because eroded pre-Mississippian units on the Jessamine or Nashville domes probably did not contain sufficient sand to be the source for the sandstones.

A northeastward-increasing sand content and thickening of the Warix Run Member of the Slade (Newman), in northeastern Kentucky and correlatives in southern Ohio, northern West Virginia, and western Pennsylvania suggest a northeastern source area for that member (de Witt and McGrew, 1979). Southwestward- and westward-dipping regional paleoslopes are indicated during Borden and, presumably, ensuing Mississippian deposition (Potter and Pryor, 1961). In contrast, sediment transport to the northeast is indicated by paleocurrent measurements in the calcarenites of the Warix Run in western Carter County (Klekamp, 1971). The calcarenites, interpreted as tidal-channel deposits, were transported in migrating large-scale sand waves. Klekamp suggested that northeastward transport in the area did not necessarily reflect regional paleocurrent directions, but may have resulted from coastline configuration, wind direction, or flood- and ebb-dominated tidal currents. The Warix Run of northeastern Kentucky was deposited on the irregular topography of an intra-Mississippian erosional surface cut down as deeply as into the Borden. In western Carter County, the Warix Run also was studied by Ferm and others (1971) and Horne and others (1974), who considered it to represent tidal-bar belt deposits and, around topographic highs, a complex of beach, bar, and tidal-channel deposits.

The Spar Mountain Sandstone Member (Tippie, 1945) of the Ste. Genevieve Limestone in Illinois and the younger Rosiclare (Aux Vases Sandstone) in Illinois and western Kentucky are two detrital tongues in the uppermost part of the otherwise carbonate-dominated Meramecian sequence. Sand in both units was considered by Swann (1963) to have been transported from northeastern source areas by a southwest-flowing river system, the Michigan river, which was active also during Chesterian time. No studies of current directional criteria in these units are known to have been made in Kentucky.

Depositional environments for Meramecian-age sediments were largely very shallow marine except for the darker and finer grained rocks of the Salem and St. Louis in westernmost Kentucky and southernmost Illinois, where the water may have been moderately deep (more than 500 ft?) during Salem and early St. Louis time. The textures of the shallow-marine carbonate rocks reflect a wide variety of depositional conditions including oolite shoals, lagoons, reefoid or bank detritus areas, and bars. Waters ranged from clear to turbid, and from agitated to quiet. High-energy environments produced by wind-driven and (or) tidal currents combined with shallow water (less than 100 ft) over most of Kentucky are indicated by fossil fragmental, crossbedded, and interlensing beds in the Harrodsburg, Salem and Warsaw Formations unit, Ste. Genevieve, and Rosiclare (Aux Vases) strata, whereas quiet water of probable bay and lagoon intertidal-supratidal environments is inferred for the St. Louis evaporites and other fine-grained carbonate rocks.

The Harrodsburg's relatively pure carbonate composition, abundant disarticulated fossil remains, and crossbedding indicate a striking change from turbid water, in which the underlying Borden was deposited, to widespread clear water. Fossil-debris beds, biorudites, that fill depressions marginal to Borden delta platforms (fig. 17) probably are the disarticulated hard parts of fauna indigenous to the platforms, swept by currents into adjacent depressions on the sea floor (Peterson and Kepferle, 1970).

Pinsak (1957) concluded that near-shore, shallow-water offshore (shelf), and deep-water offshore (basin) environments are represented in limestones of the Salem Limestone of northern, central, and southwestern Indiana. The shallow-water offshore environment of Pinsak has been compared to the environment on the present-day Bahama Banks (Sedimentation Seminar, 1966). Clear-water conditions are shown by the Salem in Indiana, but markedly turbid water is indicated by the argillaceous content of the Salem and the Salem and Warsaw Formations unit in Kentucky and by associated sandstone strata in the Cumberland saddle area.

A distinct change to very low energy conditions is reflected by rocks of the St. Louis Limestone. Evaporites in the St. Louis Limestone in Illinois, Indiana, and western Kentucky are indicators of a probable sabkha shelf environment along the Cincinnati arch trend (Jorgensen and Carr, 1973). A seaway opening to the south and intermittently connected with the Michigan basin, where evaporite deposition also occurred, is inferred to have been the source of waters for the evaporite deposits in the St. Louis (Sable, 1979b). The widespread limestone and dolomite breccias in the St. Louis Limestone west, south, and east of known evaporites are interpreted to result from dissolution of contiguous evaporite beds which occurred over a much wider area than present evaporite occurrences (Collinson, 1964, p. 7; Dever and others, 1978). Carbonaceous mudstones and limestones in lower St. Louis beds of west-central Kentucky (Kepferle, 1966b; Withington and Sable, 1969), probable time equivalents of the evaporites, may indicate that land along the Cincinnati arch acted as a barrier to free circulation.

Rocks in the upper St. Louis largely represent a general transition to clear, freely circulating but quiet water without terrigenous clastic influence, perhaps restricted by conditions similar to those of the Florida Bay, in which organically precipitated carbonates from organisms such as calcareous algae could accumulate. A slow but major transgression during this time probably inundated all or much of the Cincinnati and Waverly arches. Fine grain size, tabular beds, and general scarcity of terrigenous clastic debris indicate that wave and current activity was weak over a large area and that source areas were low or remote. Dolomitic beds, the relative scarcity of fossil remains, and scattered occurrences of gypsum also suggest that a hypersaline environment existed in some areas throughout much of later St. Louis time.

During deposition of the Ste. Genevieve, clear, very shallow oxygenated seas with normal open circulation prevailed. A general vertical transition to shallow agitated water occurred from St. Louis to Ste. Genevieve time throughout the basin, as indicated by an upward increase of oolitic limestones, current structures, and prolific shallow-water faunas and sedimentary limestone breccias of probable supratidal and subaerial exposure origin. Low-energy protected lagoon or bay conditions in which lime mud was dominant were supplanted by subtidal shelf and oolitic shoal and bank environments as general marine transgression occurred. Terrigenous clastics of the Spar Mountain, Aux Vases, and less widespread units in the central and southern part of the Eastern Interior basin are generally sheetlike deposits in lobes that accumulated in this shallow marine environment. These clastics and more subtle examples of cyclicity in carbonate depositional environments, as in the Ste. Genevieve of south-central Kentucky (Sandberg and Bowles, 1965), represent the onset of cyclical deposition which characterizes the marine and continental environments displayed by Chesterian deposits still to come.

Paleogeographic interpretation indicates that during most of Meramecian time, Kentucky was inundated by a fluctuating shallow sea. Seaway connections existed mainly to the south, and connections with the Appalachian basin may have been through the Cumberland saddle. The Cincinnati and Waverly arches were intermittently emergent. There, in northern east-central and northeastern Kentucky, after uplift resulted in cessation of St. Louis deposition, the Waverly arch remained partly emergent during the remainder of Meramecian time and early Chesterian time.

Paleogeographic reconstruction for Meramecian time would show topographically low peninsulas along the Cincinnati and Waverly arches southward into Kentucky. During an early St. Louis marine regression (evaporite interval), low-lying land may have extended northwestward along the Kankakee arch (Sable, 1979b). In Ste. Genevieve time, source areas south or east of Kentucky may have shed a small amount of sandy sediment northward.

Evidence for a Michigan river system (p. 85) lies in the youngest Meramecian units in western Kentucky. Prior to these, the river may have had little sediment-carrying capacity due to widespread aridity, or because it headed in lowlands. Most likely, the point where the river debouched into the sea was too far distant for much sediment to reach the Eastern Interior basin region. In eastern Kentucky, however, either in late Meramecian or early Chesterian time, northeast-trending bars composed of carbonate and silica-sand admixture were prominent along the Waverly arch.

PALEOTECTONIC IMPLICATIONS

Trends and positions of major tectonic elements inherited from Osagean time stabilized considerably during ensuing Meramecian time, and infilling of irregular depositional topography continued. The Eastern Interior basin in western Kentucky was a major negative feature, as shown by accumulation of more than 1,100 ft of sediments in western Kentucky, and thinning towards such positive features as the Cincinnati and Kankakee arches. Maximum subsidence of the basin in western Kentucky occurred during Salem and early St. Louis time. This major differential downwarping ceased in late St. Louis time, and wide areas subsided gently and evenly, the exceptions being eastern, northeastern, and east-central Kentucky, where the Waverly arch and Kentucky River fault system were rejuvenated.

The Cincinnati arch and Ozark uplift restricted seaways during St. Louis evaporite deposition, although they contributed little detrital sediment.

In northeastern, east-central, and eastern Kentucky, discontinuous deposits of sediments imply a broad, unstable platform, the Waverly arch (Woodward, 1961), between the Cincinnati arch and the Appalachian basin trough. The platform was modified by a shallow basin in southeastern Kentucky and emergent areas in northeastern Kentucky during part of Meramecian time.

MERAMECIAN-CHESTERIAN SERIES BOUNDARY

The Ste. Genevieve Limestone is the youngest formation of the Meramecian Series in Kentucky. In adjoining Illinois, the youngest Meramecian (Valmeyeran) rocks are assigned to different formations (Swann, 1963). The top of the Ste. Genevieve in eastern Illinois is correlative with the top of the Fredonia Limestone Member of the Ste. Genevieve in western Kentucky. The Rosiclare Sandstone and Levias Limestone Members of the Ste. Genevieve in Kentucky correlate with the Aux Vases Sandstone and Levias Limestone Member of the Renault Limestone, respectively, in Illinois.

The Ste. Genevieve is overlain by the Renault Limestone in western Kentucky, the Girkin Formation in southern west-central and south-central Kentucky, and the Paoli Limestone in central and northern west-central Kentucky. In the northern west-central area, a sandy limestone or calcareous sandstone, mapped in the basal Paoli, represents the Popcorn Sandstone Bed of Swann (1963). It was identified as the Aux Vases Sandstone of Malott (1952) on geologic quadrangle maps of the area, for example in the New Amsterdam quadrangle (Amos, 1972). East of the Cincinnati arch, the Ste. Genevieve Limestone Member of the Monteagle Limestone, as mapped, is overlain by the Kidder Limestone Member of the Monteagle Limestone in south-central Kentucky and by the upper member of the Newman Limestone (Mill Knob through Poppin Rock Members of the Slade Formation of Ettensohn and others, 1984) in east-central and northeastern Kentucky.

The boundary between the Chesterian and Meramecian Series in Kentucky is marked by both a change in crinoid fauna and a break in deposition. J.M. Weller and Sutton (1940) considered the unconformity at the Chesterian-Meramecian boundary to be the most important stratigraphic break within the Mississippian System in the Eastern Interior basin, citing variations in thickness and absence of upper members or all of the Ste. Genevieve within comparatively short distances, overlap of Chesterian units on older beds, and thickness variations and conglomerates in basal Chesterian formations. Swann (1963), however, considered that no important "time break" occurred between Ste. Genevieve and Chesterian deposition.

Late Meramecian rocks are characterized by the common presence of *Platycrinites penicillus* and early Chesterian rocks by species of *Talarocrinus* (other than *T. simplex*) (Swann, 1963). The abundance of crinoid-bearing limestones in this part of the Mississippian section in much of Kentucky makes the presence of these forms a useful field criterion. In conjunction with the crinoid "break," the Bryantsville Breccia Bed exposure zone at the top of the Ste. Genevieve has been traced across western, west-central, central, south-central, and east-central Kentucky, indicating widespread interruption of deposition at or near the end of Meramecian time.

The change in crinoid fauna and the Bryantsville exposure zone are the most reliable field criteria for identifying the top of the Ste. Genevieve. However, additional exposure zones with identical or similar diagenetic features are present below the Bryantsville in the Ste. Genevieve and above the Ste. Genevieve in the Girkin Formation, Kidder Limestone Member of the Monteagle, and upper member of the Slade (Newman) Formation (Dever, Hester, and others, 1979; Dever, McGrain, and Ellsworth, 1979; Dever, McGrain, and others, 1979). In the outcrop west of the Cincinnati arch and in south-central Kentucky east of the arch, vertical distribution of the diagnostic crinoid fauna can be used to distinguish the Bryantsville from older and younger exposure zones. Criteria used for identifying the Bryantsville in east-central Kentucky where diagnostic fauna are absent or sparse are outlined by Dever, Hester, and others (1979).

In the subsurface of eastern Kentucky, the top of the Ste. Genevieve is even more difficult to determine. There, it is largely delineated on the basis of projected regional trends and, in a few wells, by the presence of red shale and limestone. These latter lithologies are considered correlative with the Taggard Formation (Reger, 1926) of the Appalachian basin, which was placed in the basal Chesterian by de Witt and McGrew (1979).

The Warix Run Member of the Slade Formation was formerly identified as Ste. Genevieve (Butts, 1922; McFarlan and Walker, 1956; Sheppard, 1964; McGrain and Dever, 1967; Hylbert and Philley, 1971). The Warix Run, separated from the *Platycrinites*-bearing Ste. Genevieve by an erosional unconformity (Dever, 1973, 1980b), was deposited on a post-Ste. Genevieve erosional surface. In northeastern Kentucky and northern east-central Kentucky, the Warix Run rests unconformably upon the Borden and, locally, St. Louis; and in east-central Kentucky, from Menifee County southwestward into Rockcastle County, it rests on the Bryantsville Breccia Bed at the top of the *Platycrinites*-bearing Ste. Genevieve.

The question of a Meramecian or Chesterian age for the Warix Run has not been resolved. Microfaunal studies have been inconclusive (Pohl and Philley, 1971; Horowitz and Rexroad, 1972). Warix Run calcarenite in northeastern and northern east-central Kentucky is overlain by a calcilutitic unit, forming a transgressive-regressive, fining-upward sequence. The calcilutite, which locally intertongues with Warix Run calcarenite, contains *Endothyranella*, indicating a late Genevievian or later age (Pohl and Philley, 1971); it has been correlated with *Talarocrinus*-bearing limestones to the southwest and Chesterian equivalents in east-central and south-central Kentucky (McFarlan and Walker, 1956). Determination of a Chesterian age for the Warix Run would suggest possible correlation with the Popcorn Sandstone Bed (Swann, 1963), the basal Chesterian unit in Lawrence County, Ind., equivalents of which may be present in northern west-central Kentucky.

In northeastern and northern east-central Kentucky, erosional thinning and, in parts of the area, complete removal of Meramecian rocks followed post-Ste. Genevieve movement along the Kentucky River fault system (Dever, 1977, 1980b). The Ste. Genevieve is preserved on the uplifted side of the fault system only in limited parts of Bath and Menifee Counties. Elsewhere, the youngest preserved Meramecian unit is the St. Louis, which generally is unconformably overlain by limestone and shale of the upper member of the Newman (Slade), units considered by McFarlan and Walker (1956) to be Chesterian equivalents.

ROCKS OF CHESTERIAN AGE

Rocks of Chesterian age (figs. 7, 8) are characterized by distinct cyclical alternation of detrital and carbonate strata in western Kentucky, and less obvious, but recognizable cyclicity in eastern Kentucky. Whether cyclicity is truly synchronous between western and eastern Kentucky has not been determined. The strata are preserved in three separate areas: west of the Cincinnati arch from south-central Kentucky into Indiana, Illinois and southeastern Missouri; east of the arch in northeastern, east-central, and south-central Kentucky and in the eastern Kentucky subsurface; and in the Pine Mountain and Cumberland Mountain belts of southeastern Kentucky. Detailed correlations among the somewhat different sequences in the three areas are uncertain. The succession is the Chesterian Series in the Eastern Interior basin and its age equivalent in the other areas.

A voluminous literature covers many aspects of Chesterian Series rocks in the Eastern Interior basin. The synthesis by Swann (1963) discusses Illinois, western Kentucky, and Indiana; it reviews nomenclatural history of units; discusses time and rock stratigraphy, biostratigraphy, and depositional framework; and it includes an exhaustive, pertinent bibliography. Petrographic and environmental studies of Chesterian Series sandstone-dominated units include papers by Potter and others (1958), and Potter (1962, 1963). Conodont studies include those from the type Chesterian area in southwestern Illinois (Rexroad, 1957). Rocks of Chesterian age in Indiana which are directly pertinent to Kentucky stratigraphy were discussed by Malott (1952) and those in western Kentucky by Ulrich (1917), Butts (1917), and McFarlan and others (1955). Literature on Chesterian equivalents in eastern Kentucky includes papers by Butts (1922), McFarlan and Walker (1956), Vail (1959), Weir (1970), Dever and others (1977), Ettensohn (1980), Ettensohn and Dever (1979), and Ettensohn and Peppers (1979).

Because of the many units in the Chesterian Series, the formations are not described individually here and the reader is referred to the geologic quadrangle series maps of 1961–1979 and reports such as Sedimentation Seminar (1969); Calvert (1968); Englund and Windolph (1971); Vincent (1975); McFarlan and others (1955); McFarlan and Walker (1956); Ferm and others (1971); Stouder (1938, 1941). Trace and Amos (1984) gave excellent descriptions and discussions of relationships of Chesterian units in the Fluorspar district of western Kentucky.

ROCKS WEST OF THE CINCINNATI ARCH

Rhythmically deposited units of limestone and minor dolomite, and clay- to sand-size terrigenous clastics characterize the Chesterian Series in the Eastern Interior basin. Subdivision into more than 20 formations is shown on the correlation chart (fig. 8). Formations have been defined in outcrops in the Chester district in southwestern Illinois; in southern Illinois; in western, west-central, and south-central Kentucky; and in south-central Indiana. Correlations of nomenclatural units are generally consistent across State boundaries, although some units which are not divisible in some areas are readily divided in others. Physical criteria for some formational boundaries are different in adjoining States, and variations in terminology and groupings of units occur from State to State.

Chesterian strata in the Eastern Interior basin comprise five formal groups in Illinois and three in Indiana. Groupings are based on lithologic similarity. Facies changes were produced by shifting loci of terrigenous clastic accumulations (Swann, 1963, p. 21–22). Time-stratigraphic divisions include the post-Genevievan, successively younger Gasperian, Hombergian, and Elviran Stages in Illinois (Swann, 1963, p. 21–23); the stage boundaries are considered to closely correspond to rock-stratigraphic boundaries.

CARBONATE-DOMINATED UNITS

Widespread units that are mostly limestone west of the Cincinnati arch in Kentucky include parts or all of the Renault Formation, the Paint Creek, Paoli, Beaver Bend, and Reelsville Limestones, the Girkin Formation, the Beech Creek and Haney Limestone Members of the Golconda Formation, and the Glen Dean, Vienna, Menard, Clore, and Kinkaid Limestones. They range from a few feet to 200 ft thick and generally consist of relatively pure limestones with micritic microcrystalline to sparry calcite matrix. Oolitic and pelletal limestones occur locally in nearly all Chesterian carbonate-dominated units. Argillaceous and limonitic material is locally common. Framework grains identified in the field and under the microscope consist of foraminifers, corals, bryozoans, brachiopods, echinoderms, mollusks (gastropods and pelecypods), and arthropods (trilobites and ostracodes), as well as ooids, pellets, detrital quartz, and carbonate rock fragments. Chert and silicified limestone are relatively rare, although they locally characterize some units such as the Haney Member of the Golconda Formation and the Vienna Limestone—and thus are valuable mapping criteria. Dolomitic limestone beds are not abundant, but some form marker "zones" such as those with calcite concretions in the Beaver Bend Limestone. Interbedded mudstone is generally more abundant in the middle and upper Chesterian units such as the Glen Dean, Menard, and Clore than in the lower ones. Thin and discontinuous shale beds in the Girkin Formation of west-central and south-central Kentucky are distal facies of thicker, dominantly sandstone and shale formations—Bethel (Mooretown), Sample, Elwren (Cypress) to the north and west (see Sandberg and Bowles, 1965). The lower surfaces of limestone units are commonly more planar than those of detrital units (fig. 38), but some gradational and interfingering relationships between limestone and underlying mudstone and sandstone, such as the Sample and Reelsville in west-central Kentucky (Sable, 1964), and local thickening of limestone units at the expense of underlying clastic units have been recognized. Several limestone units within the Leitchfield and Buffalo Wallow Formations in west-central Kentucky are correlated with the Vienna, Menard, and Kinkaid of western Kentucky areas (Stouder, 1938; Clark and Crittenden, 1965; Gildersleeve, 1971; Johnson, 1977).

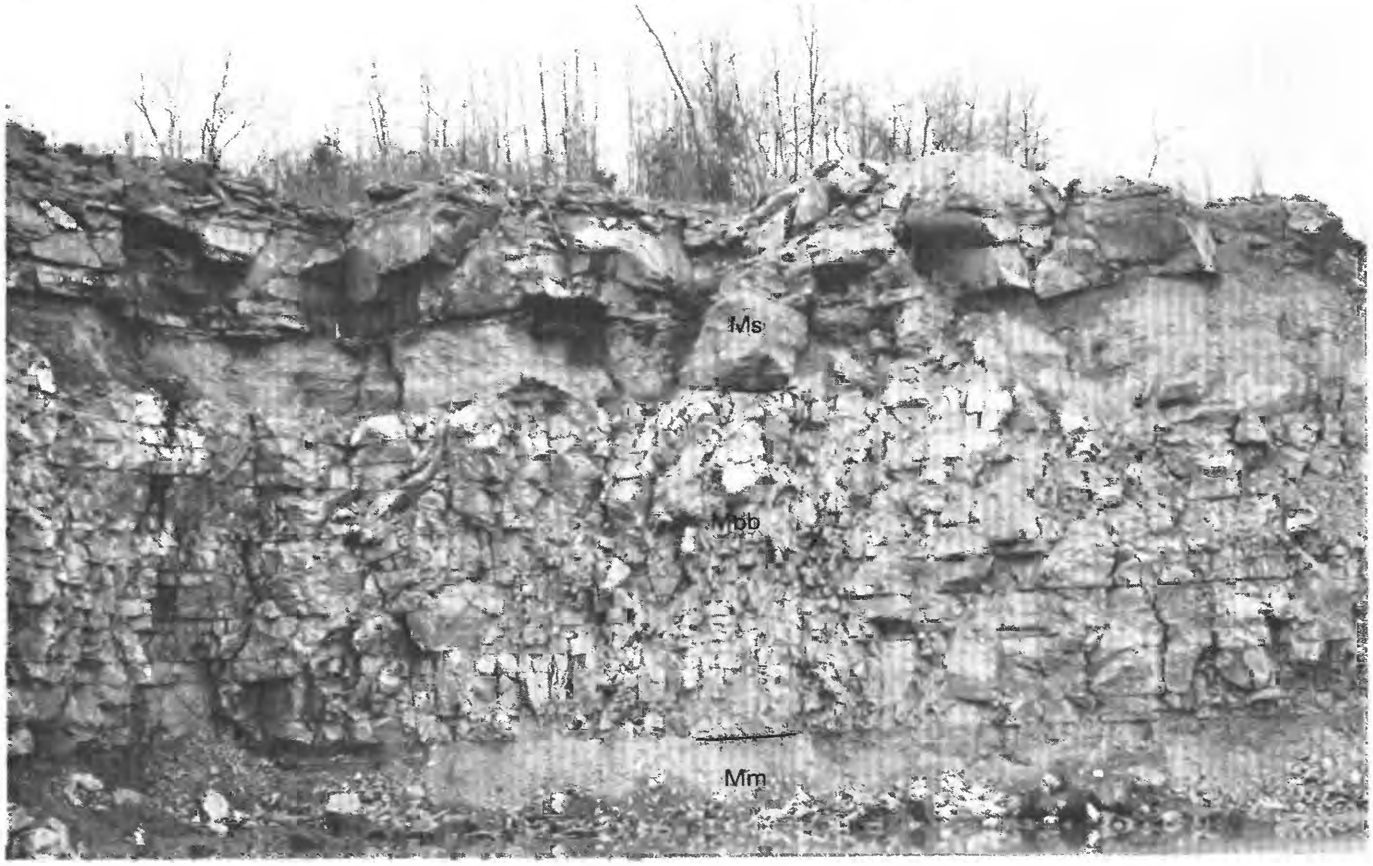


FIGURE 38.—Upper part of Mooretown Formation (Mm) underlying 18.5 ft of Beaver Bend Limestone (Mbb) overlain in turn by shale and sandstone of the Sample Sandstone (Ms). Kentucky Stone Company Upton Quarry, Upton quadrangle, Hardin County.

Fairly persistent detrital units within carbonate rock units are reported in the Paoli Limestone in central and west-central Kentucky (Kepferle, 1963a), where prominently crossbedded quartzose calcarenite and oolitic limestone occur, and in the Renault Formation of western Kentucky, where green shale occurs (Amos, 1965; Sample, 1965). The Paoli clastic beds may correspond to the middle shale break of the Paoli in Indiana (Perry and Smith, 1958). The Renault clastic beds are equivalent to the Yankeetown Shale in southern Illinois (Baxter and others, 1963, 1967).

Chesterian limestone units west of the Cincinnati arch which are most widespread and therefore of great value for long distance correlation are the Beech Creek (subsurface "Barlow Lime"), the Glen Dean ("Little Lime"), the Vienna ("Brown Lime"), the Menard, and the Kinkaid.

Chert is particularly useful in correlation of the Haney Limestone in the outcrop belt of central, west-central, and south-central Kentucky. This is characteristically a whitish-weathering replacement of oolitic and fossil fragmental limestone and is conspicuous in weathering residuum. Similar chert has been observed above the Hartselle Formation in the Albany quadrangle, in south-central Kentucky (Preston McGrain, written commun., 1964, verified by Sable); but chert is also common below the Hartselle equivalent in east-central and northeastern Kentucky. Chert also is a valuable widespread correlation tool in the Vienna Limestone of west-central, south-central and western Kentucky. This latter is also a replacement chert but weathers to brown-tinged, darker hues than does chert in the Haney.

TERRIGENOUS CLASTIC UNITS

Dominantly detrital units in western, west-central and western central Kentucky include, in general ascending order, the Bethel Sandstone or Mooretown Formation, Sample Sandstone, Paint Creek Shale, Cypress Sandstone or Elwren Formation equivalent (Malott, 1919), Big Clifty Sandstone Member of the Golconda Formation, Hardinsburg, Tar Springs, Waltersburg, Palestine, and Degonia Sandstones. The Grove Church Shale (Swann, 1963), the youngest known

Chesterian formation of Illinois, is documented only in the subsurface of Webster County, western Kentucky (Hansen, 1975). The Leitchfield Formation of west-central Kentucky includes largely mudstone equivalents of the Tar Springs and younger clastic and minor limestone units; the adjacent Buffalo Wallow Formation is similar lithologically but excludes Tar Springs beds (fig. 8).

Mudstone and sandstone regionally constitute roughly 50 and 25 percent respectively of Chesterian rocks in Kentucky. The proportions and thicknesses of mudstone and sandstone show great lateral variation. In many places thick sandstones such as the Big Clifty (fig. 39) make up most or all of a formation. Their lower boundaries are commonly erosional, and truncation of underlying beds can be intraformational or can involve removal of one or more underlying formations. The morphology and internal features of the sandstones established some of them as bar-fingers and channel-fill or tidal current deposits (Calvert, 1968); some, such as the Big Clifty, may be regressive shoreline sheet sands. Where the basal parts of clastic units are fine-grained sedimentary rocks, perhaps bay-fill or overbank deposits, their basal contacts are generally planar and apparently conformable with underlying carbonate units (fig. 40). However, splay(?) channel fills of mudstone or of mudstone and sandstone admixtures are also present (Sable and Peterson, 1966, p. 25) although rarely seen. Marine fossils occur in the lower parts of many sandstones. Thin coaly beds and unfossiliferous red shales are locally present in the upper parts of some units such as the Mooretown and Big Clifty (Sable, 1964; Amos, 1972). Suggesting alternating shoreline regression and transgression, the depositional regime was that of lower delta plain and delta front environments.

Most Chesterian sandstones are dominantly fine- to coarse-grained orthoquartzites as compared to the subgraywackes of Kinderhookian and Osagean ages. Some sandstones in the upper Chesterian strata, such

FIGURE 39.—Big Clifty Sandstone Member of the Golconda Formation showing tabular beds, gently cross-laminated beds, and minor channel fills. Note asphaltic exudation as drip and flow features. Milepost 120.7, Western Kentucky Parkway, Big Clifty quadrangle, Hardin County.

FIGURE 40.—Hardinsburg Sandstone (Mh) conformably overlying Haney Limestone Member of the Golconda Formation (Mgh). Milepost 114.8, Western Kentucky Parkway, Summit quadrangle, Grayson County.

as in the Pennington Formation of eastern Kentucky, are subgraywacke types, however. Framework is predominantly quartz and minor alkali and sodic feldspars, chert, fossil fragments, rock fragments, and heavy minerals. Locally, pyrite grains are common. Sideritic nodules are also locally common. Matrix consists of common quartz overgrowths, sparry calcite, micrite, clay minerals (reported as illite and kaolinite in several reports), and iron oxides. Other constituents are clay pellets, carbonized plant impressions, sideritic and limonitic nodules, carbonized wood fragments, and tree trunks, with a few in growth positions. Conglomeratic sandstone is rare; the Mooretown (Bethel) Formation contains scattered granules and pebbles of white quartz in a thick channel fill in western central Kentucky, and the Cypress Sandstone contains sandstone clasts in western Kentucky.

A striking example of a thick channel-fill deposit is the Bethel (Mooretown) Sandstone in central, west-central and western Kentucky. This deposit extends for more than 150 mi, and the channel has cut through more than 250 ft of previously beveled pre-Bethel strata as old as the St. Louis (Sable and Peterson, 1966; Reynolds and Vincent, 1967) (fig. 41). This deposit is interpreted to have been a submarine shelf channel fill (Sedimentation Seminar, 1969). Other elongate channel sandstone bodies have integrated distribution patterns suggesting delta plain stream channels, some of which are repeated as stacked channel deposits (Potter, 1962, 1963) in the north-central part of the western Kentucky fluorspar district (Trace and Amos, 1984).

Another thick, southerly-trending unit is the Tar Springs Sandstone in northern west-central Kentucky (Clark and Crittenden, 1965; fig. 42, this report), considered by Calvert (1968) to have been a tidal current sand.

Siltstone, mudstone, and claystone in strata of Chesterian age are commonly medium dark gray to greenish gray. Reddish-gray varieties occur in several clastic units, including the upper part of the Big Clifty Sandstone Member of the Golconda Formation and units within the Leitchfield and Buffalo Wallow Formations; they are common in the Hardinsburg and Palestine Sandstones of western Kentucky. Dark-gray

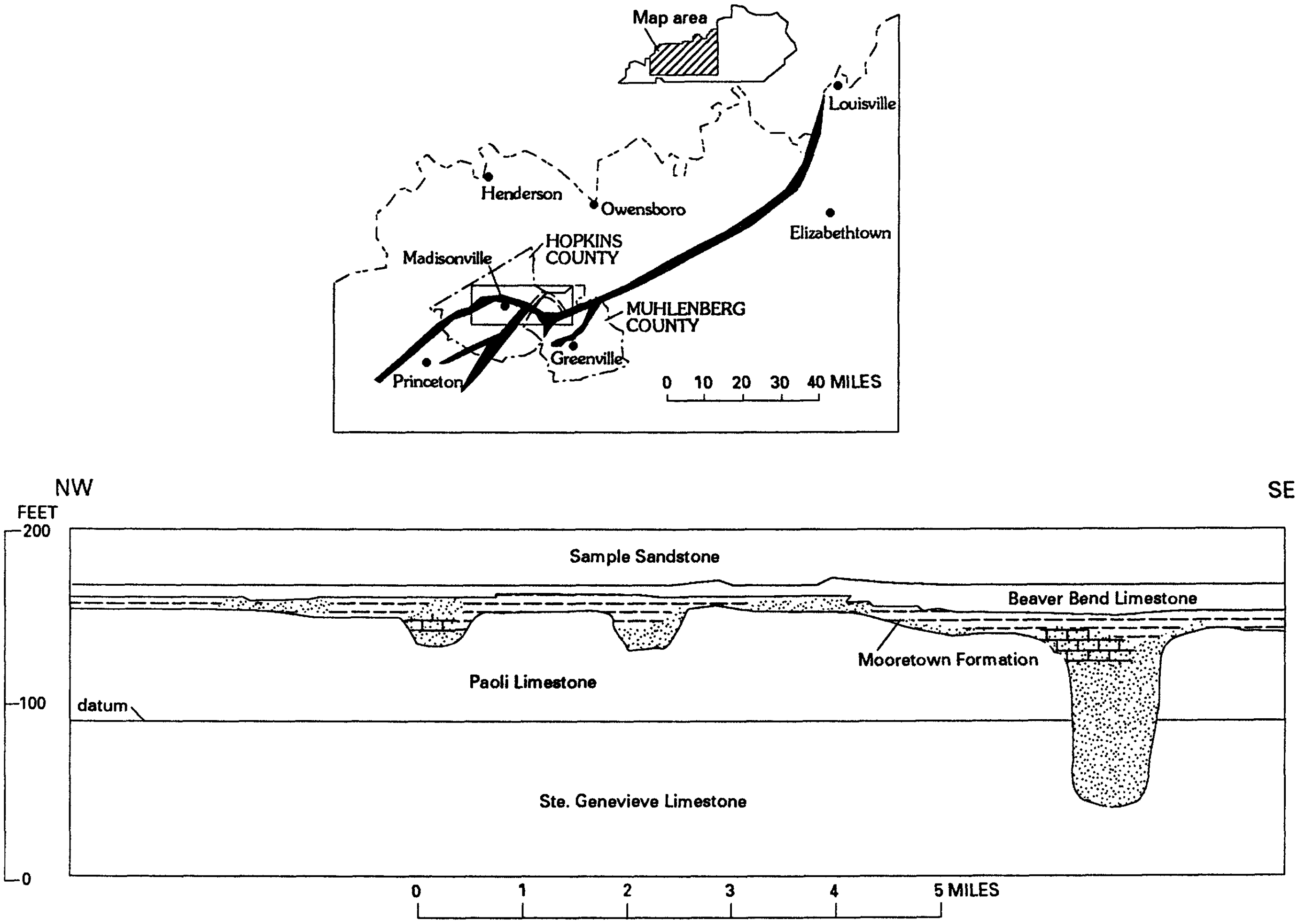


FIGURE 41.—Generalized map showing distribution of Mooretown Formation–Bethel Sandstone channel fill in central to western Kentucky and cross section showing relationships of channel fill to other rock units. (Map modified from Reynolds and Vincent, 1967; cross section northwest of Elizabethtown from Peterson, 1964.)

to black carbonaceous shale with siderite nodules is associated with thin and discontinuous coal beds in the upper part of the Big Clifty and the Mooretown (Bethel) in west-central Kentucky and in the Cypress, Hardinsburg, and Tar Springs Sandstones of western Kentucky. Perhaps the thickest is a 1-ft bed reported in the Cub Run quadrangle (Sandberg and Bowles, 1965) of south-central Kentucky.

ROCKS EAST OF THE CINCINNATI ARCH

East of the Cincinnati arch, Chesterian age equivalents crop out along the western border of the Eastern Kentucky coal field in a belt extending across south-central, east-central, and northeastern Kentucky; they also are exposed along Pine and Cumberland Mountains in southeastern Kentucky. Carbonate rocks are dominant in the lower part of the succession of Chesterian correlatives; the upper part mainly consists of terrigenous clastic rocks.

During the 1960–1978 geologic mapping in south-central Kentucky, the interval dominated by carbonate rocks was assigned, in ascending order, to the Kidder Limestone Member (Lewis, 1971b) of the Monteagle Limestone (Vail, 1959; Stearns, 1963), Hartselle Formation (Smith, 1894) (a relatively thin unit of sandstone and shale), and Bangor Limestone (Smith, 1890). In east-central, eastern, and northeastern Kentucky, correlatives of the Kidder, Hartselle, and Bangor generally were mapped together as the upper member of the Newman Limestone (Campbell, 1893). The overlying interval dominated by terrigenous clastics was designated as the Pennington Formation (Campbell, 1893), but in northeastern Kentucky, following the usage of Englund and Windolph (1971), these rocks generally were mapped in the Newman Limestone. The Carter

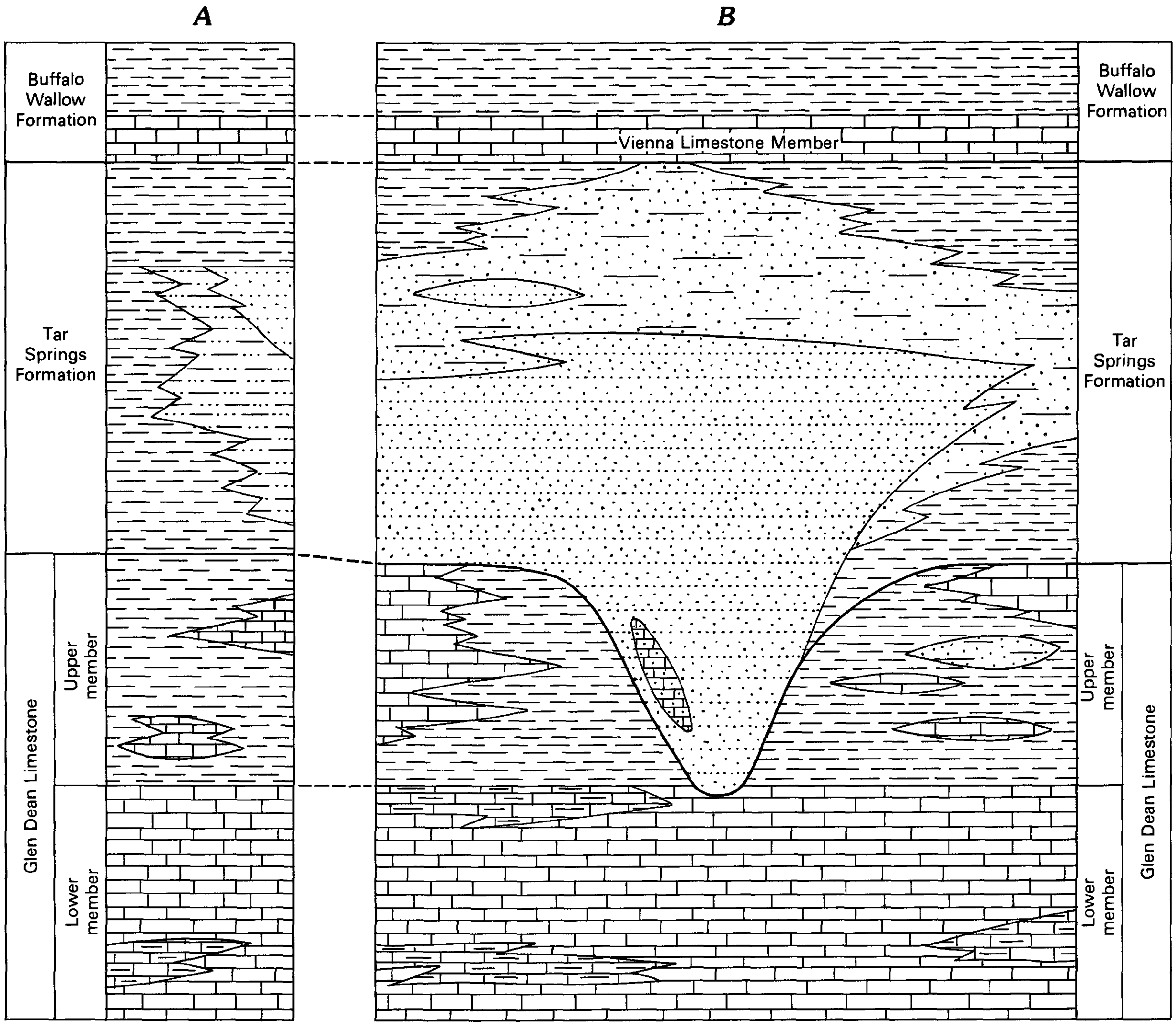


FIGURE 42.—Diagram showing relationships of the Glen Dean Limestone, Tar Springs Formation, and lower part of Buffalo Wallow Formation in Mattingly quadrangle, west-central Kentucky. *A*, local section at Bull Creek; *B*, typical of remainder of quadrangle (from Clark and Crittenden, 1965).

Caves Sandstone (Englund and Windolph, 1971) is a linear body of sandstone occurring within the terrigenous-clastic sequence of northeastern and northwest eastern Kentucky. It commonly rests disconformably upon limestones of the Newman.

In east-central and northeastern Kentucky, as previously mentioned, the names Slade and Paragon Formations have replaced the Newman Limestone and Pennington Formation used during the mapping program (Ettensohn and others, 1984). The Slade Formation (fig. 43) includes 9, possibly 10 (Warix Run) members of Chesterian age, including the unit formerly identified with the Glen Dean and Bangor Limestones to the west and south, and the Cave Branch Bed. The overlying Paragon Formation, mostly fine grained clastic rocks (fig. 44), is divided into four informal members of contrasting shale and carbonate rock. Because the gross units, Slade and Paragon, closely approximate the stratigraphic limits of the previously used Newman and Pennington terminology, which is well entrenched in the literature, these terms are used interchangeably in the discussion here, with Newman and Pennington generally first mentioned because they are the terms used on the geologic maps. Changes from the older names are based on a rationale which considers the older Appalachian basin terms inappropriate because of correlation difficulties. The various members of the Slade and Paragon are significant subdivisions of these units in that they allow study of detailed depositional environments and authigenic processes.

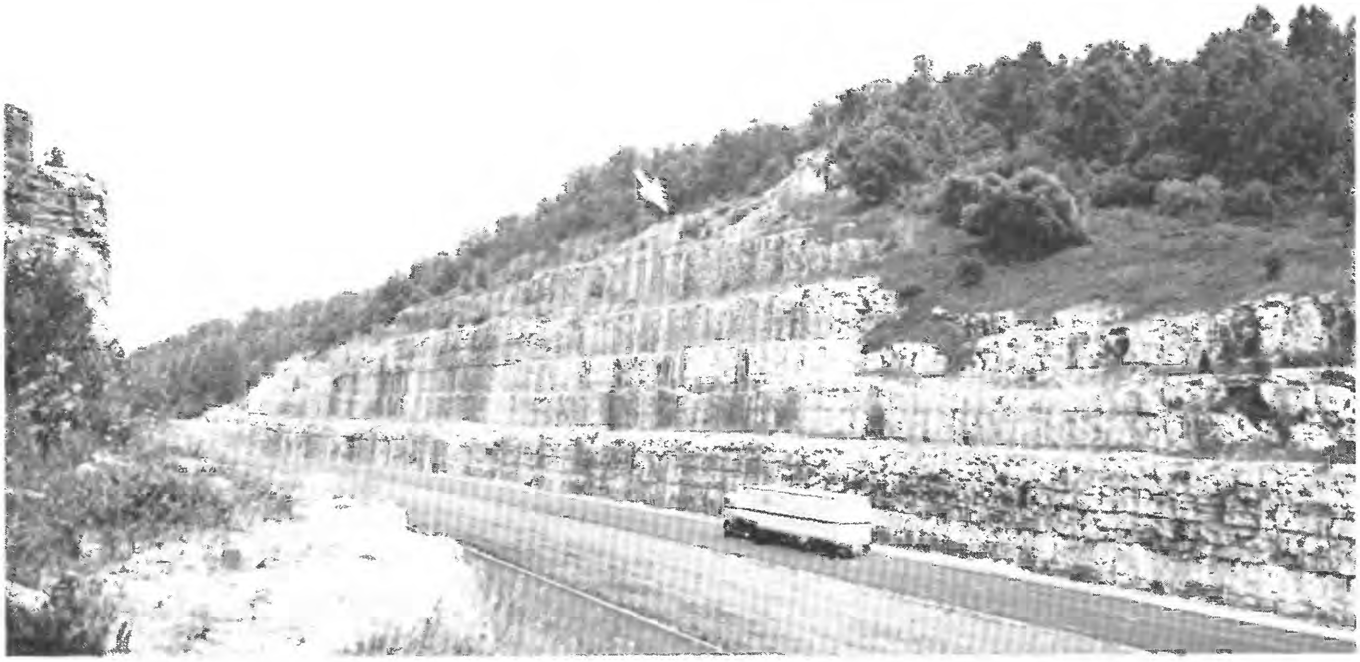


FIGURE 43.—Roadcut mostly in Slade (Newman) Formation. Bench above truck is top of Mill Knob Member. Lower tongue of Breathitt Formation (arrow) (Pennsylvanian) above topmost vertical face of Slade limestone. Milepost 60.7, Interstate Highway 75, Mount Vernon quadrangle, Rockcastle County.

The limestone, dolomite, shale, and sandstone of the Kidder, Hartselle, Bangor, and the equivalent upper member of the Newman (Slade) form a relatively uniform succession of lithologic subunits which can be traced along the outcrop belt bordering the Eastern Kentucky coal field (Butts, 1922; McFarlan and Walker, 1956). Carbonate rocks in the lower part of both the Kidder and upper member of the Newman (Slade) consist of bioclastic and oolitic calcarenite alternating with calcilutite and dolomite. To the northeast, the lower interval is dominantly calcilutite. The calcarenites and calcilutites form multiple fining-upward sequences, commonly capped by exposure zones which, in part, are altered by secondary silicification and dolomitization. A prominent exposure zone which can be traced the length of the outcrop belt caps the interval of fining-upward cycles. It is overlain by the Cave Branch Bed (Dever, 1980a), a thin but widespread shale that forms a useful marker within the carbonate section.

Overlying the Cave Branch Bed in the middle part of the Kidder and upper Newman (Slade) are oolitic and bioclastic calcarenite and thick-bedded, crinoidal calcirudite, characterized by an association of *Agassizocrinus*, *Pentremites*, and a distinctive, large, unidentified crinoid columnal (McFarlan and Walker, 1956). In northeastern Kentucky, deposits of calcilutite and dolomite underlie this subunit. The crinoidal calcirudite is overlain by a complex sequence of bioclastic and oolitic calcarenite, calcilutite, dolomite, and shale. The presence of nodular chert is a distinctive feature of these upper calcarenites, particularly in east-central and northeastern Kentucky.

The Hartselle Sandstone in south-central Kentucky and along the Kentucky-Tennessee State line consists of very fine to medium-grained quartzose sandstone and shale. Northeastward along the outcrop belt, the sandstone pinches out and the Hartselle and its equivalent in the upper Newman (Slade) are composed of shale characterized by thin, discontinuous beds and lenses of calcilutite. The Bangor and correlative limestone of the upper Newman (Slade) are mainly bioclastic calcarenite containing zones of dolomitic limestone and locally, oolitic calcarenite. The limestones are commonly argillaceous, in part silty and sandy, and locally cherty; they generally are darker colored than limestones of the Kidder and underlying Newman (Slade). The unit is thick bedded in the lower part and grades upward into thinner beds with shale partings, forming a gradational contact with the Pennington (Paragon) Formation. The upper, thinner bedded interval is very fossiliferous.

The Pennington (Paragon) and correlative rocks of northeastern Kentucky are composed of shale, sandstone, siltstone, limestone, and dolomite. The sequence of lithologies, in ascending order, consists of (1) gray

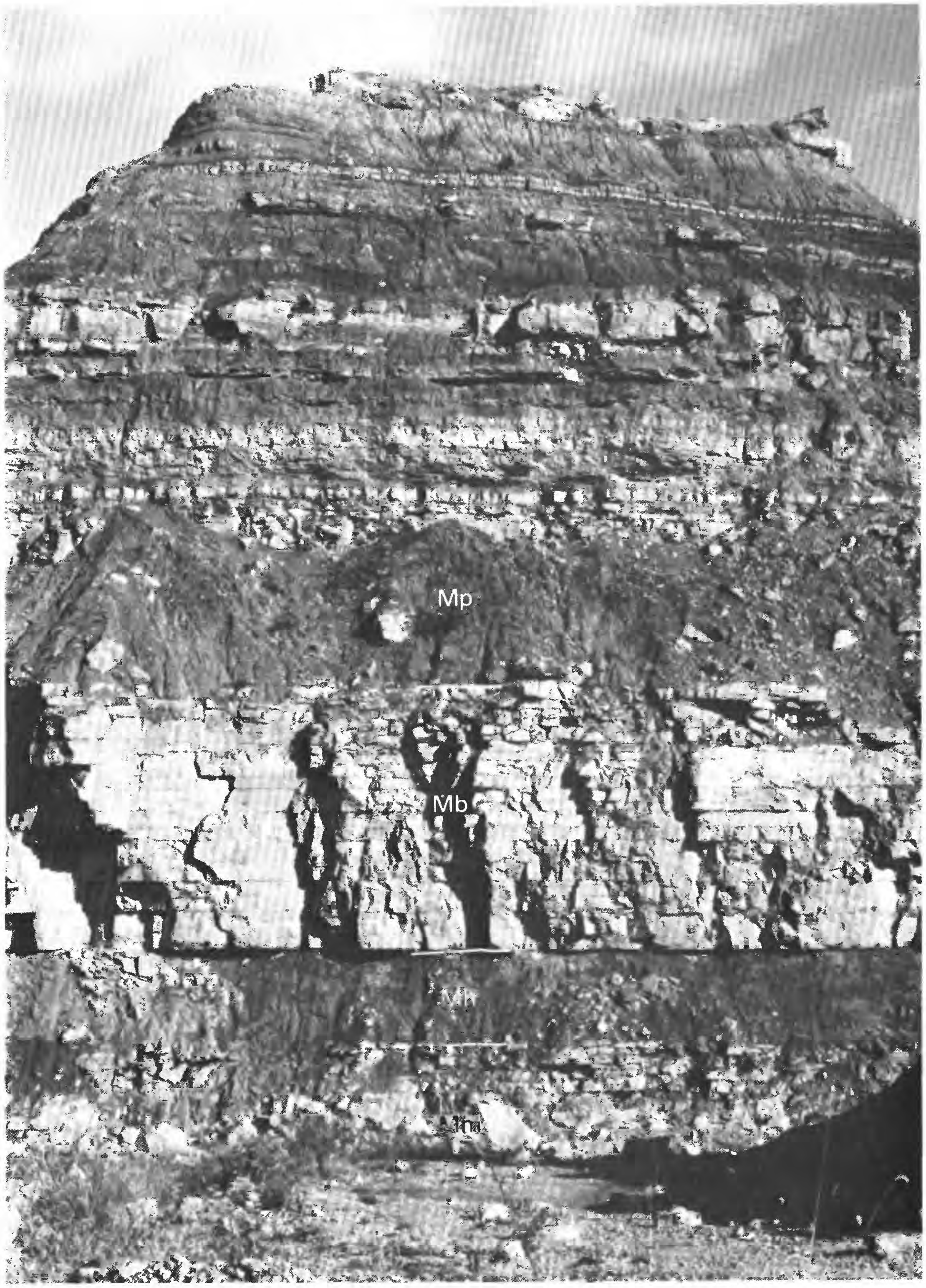


FIGURE 44.—Section at Strunk Crushed Stone Company quarry, Tateville, Burnside quadrangle, Pulaski County. Monteagle Limestone (Mm); Hartselle Formation (Mh); Bangor Limestone (Mb), and Paragon (formerly Pennington) Formation (Mp).

shale, (2) interbedded dolomite and limestone (south) or sandstone (north), and (3) gray shale grading upward into red and green shales with interbeds of dolomite and siltstone. In south-central Kentucky, carbonate rocks are important constituents of this dominantly terrigenous-clastic sequence. Fossiliferous limestone is interbedded with the basal gray shale, which is overlain by an interval of interbedded dolomite and limestone; a thin but widespread limestone occurs near the middle of the formation, and dolomites are associated with the upper red and green shales (Ettensohn and Chesnut, 1979a, 1979b). Northeastward along the outcrop belt, carbonate-rock deposits are restricted mainly to the middle limestone unit and upper dolomites. Sandstones occur in the middle and upper Pennington (Paragon) of south-central Kentucky and in the middle and lower parts of the unit in east-central and northeastern Kentucky. They commonly are slightly argillaceous and micaceous; but orthoquartzitic sandstones, similar to those of the Mississippian and Pennsylvanian Lee Formation, are present within the sequence and include the Carter Caves Sandstone of northeastern Kentucky and a sandstone in the upper Pennington (Paragon) of south-central Kentucky (Smith, 1978). Thin coals have been found locally in the Pennington (Paragon) in east-central Kentucky (Ettensohn, 1977; Ettensohn and Peppers, 1979; Rice, 1972).

In southeastern Kentucky, rocks of Chesterian age are present along Pine Mountain in the Newman Limestone (upper member and part of lower member), Pennington Formation, and tongues of Lee Formation (Campbell, 1893) occurring within the Pennington. Chesterian correlatives exposed on Cumberland Mountain along the Kentucky-Virginia and Kentucky-Tennessee State lines are the upper member of the Newman Limestone, Pennington Formation, Pinnacle Overlook Member (Englund, 1964a), and Chadwell Member (Englund, 1964a; Englund and others, 1963) of the Lee Formation. The White Rocks Sandstone Member of the Lee Formation, formerly listed as Mississippian in age, is now assigned to the Pennsylvanian (Englund and others, 1985).

The Newman on the Pine Mountain overthrust block has been divided into two informal members. The lower member is composed of limestone and minor dolomite; the upper member is mainly shale, with lesser amounts of limestone, dolomite, siltstone, and sandstone. The approximate boundary between Meramecian and Chesterian equivalents is within the lower member, about 250 ft below the top, based on the position of the Taggard Red Member of the Greenbrier Formation (Wilpolt and Marden, 1959). The Taggard is a distinctive unit, commonly from 5 to 20 ft thick, consisting of grayish-red to grayish-red-purple and greenish-gray calcarenite, calcilutite, mudstone, and shale. It is a useful marker in the central and northeastern parts of the Pine Mountain belt; in the northeast, however, distinct units with similar coloration and lithology also occur at several positions in the lower half of the lower member of the Newman.

Limestones of the Newman lower member above the Taggard are principally bioclastic calcarenites. Immediately above the Taggard, they are partly oolitic and interbedded with calcilutite and dolomite. The calcarenites are increasingly argillaceous and darker colored upward within the member and, in the upper part, interbedded with argillaceous limestone and thin shales. Fossil content also increases upward within the member. Chesterian crinoid genera, *Talarocrinus* and *Agassizocrinus*, have been found in the lower member in Harlan and Letcher Counties (Greenfield, 1957).

The calcarenite, argillaceous limestone, and shale of the lower member grade upward into the upper member of the Newman, which is mainly medium gray to dark-gray and greenish-gray shale, with lesser amounts of siltstone. Limestone is interbedded with calcareous shale in the lower part; sandstone, in discontinuous lenses, occurs in the middle and upper parts. At the northeastern end of Pine Mountain, a zone of grayish-red and greenish-gray shale with lenses of dolomite is present at the top of the Newman (Alvord and Miller, 1972).

Along Pine Mountain the Newman is overlain by the Pennington Formation, which consists mainly of siltstone, sandstone, and shale. Rocks assigned to the Pennington principally are of Late Mississippian age, but the presence of Pennsylvanian rocks locally in the upper part of the formation is indicated by the occurrence of the spore, *Laevigatosporites* (mostly *L. ovalis*) (Maughan, 1976). Average thickness of the formation is about 450 ft in the southwestern part of Pine Mountain, 900 ft in the central part, and 750 ft in the northeast. At Pineville, the Pennington thickens abruptly, from 500 ft on the west side to 1,100 ft on the east side of the Rocky Face fault, a north-south-trending fault with strike-slip displacement (Froelich and Tazelaar, 1974).

The Newman-Pennington contact in the northeastern part of Pine Mountain is placed at the base of the Stony Gap Sandstone Member (Reger, 1926) of the Pennington, which was mapped along the outcrop belt in Pike County and part of Letcher County (Elkhorn City through Whitesburg quadrangles). To the southwest, correlative rocks were mapped as part of the lower member of the Pennington. The Stony Gap is dominantly crossbedded, quartzose sandstone, with tongues and interbeds of variegated shale and siltstone. Southwestward from central Letcher County, sandstone in the lower Pennington commonly is less quartzose, ripple-bedded, and interbedded and interlaminated with shale and siltstone. In the southwestern part of the outcrop belt, siltstone and shale are dominant lithologies in the lower member (Newell, 1975; Rice and Newell, 1975).

The upper Pennington above the Stony Gap in the northeastern part of Pine Mountain consists mainly of siltstone and shale, with lenticular bodies of sandstone. The siltstone and shale range from variegated grayish red and greenish gray to dark gray and carbonaceous. Lithologic descriptions on the geologic quadrangle maps indicate that the sandstone content of the upper Pennington is greater to the southwest. Tonguelike bodies of conglomeratic, quartzose sandstone, similar to that of the overlying Lee Formation, occur in at least two positions within the Pennington (Maughan, 1976). These have been mapped as the "lower tongue of Lee Formation" (Englund and others, 1964), "sandstone tongue(?) of Lee Formation" (Csejtey, 1970; Froelich, 1973; Froelich and Tazelaar, 1974), and "sandstone tongue of Lee(?) Formation" (Rice and Maughan, 1978). The sandstone or lower tongue of Lee occurring in the upper member of the Pennington in the Pineville area (Englund and others, 1964; Froelich and Tazelaar, 1974; Rice and Maughan, 1978) is considered to be correlative with the Pinnacle Overlook Member of the Lee on Cumberland Mountain (Rice, 1984).

The Little Stone Gap Member (Miller, 1964) of the Pennington, composed of marine fossiliferous shale, siltstone, and limestone, was mapped in Pike County and part of Letcher County. There, it occurs near the middle of the Pennington section above the Stony Gap Member. To the southwest, discontinuous deposits of fossiliferous, calcareous shale and siltstone, and limestone near the middle of the formation may be correlative with the Little Stone Gap. Marine fossil-bearing beds also occur locally at various positions in the upper and lower parts of the Pennington.

Coal beds are fairly common in the upper Pennington of Letcher and Harlan Counties, and one bed has been reported at the base (Maughan, 1976). The coals generally are thin, but locally are as much as 3 ft thick (Froelich, 1973). Plant remains occur in sandstones of the Pennington, including the Stony Gap Member.

The youngest Mississippian unit in southeastern Kentucky is the Chadwell Member of the Lee Formation, which crops out along Cumberland Mountain. During the mapping program, the Chadwell (previously designated as "sandstone member A") and the generally overlying White Rocks Member were considered to be of probable Pennsylvanian age, but they were assigned a Late Mississippian age by Englund (1979). Englund and others (1985) later reassigned the White Rocks back to the Pennsylvanian designation. The older Pinnacle Overlook Member of the Lee (previously designated as "lower tongue of Lee Formation"), which also crops out on Cumberland Mountain, occurs mainly as a tongue of Lee sandstone within the Pennington. All three members consist of very light gray to white, fine- to coarse-grained, quartzose sandstone which is partly conglomeratic, with well-rounded quartz pebbles ½ to 1 in. in diameter. They are thick bedded to massive, and crossbedded. The presence of an unusual abundance of quartz pebbles is the main distinguishing characteristic of the White Rocks Member (Englund, 1964a).

The Chadwell Member overlies the Pennington. Basal sandstone of the Chadwell intertongues with upper Pennington shale and laterally grades into argillaceous sandstone of the Pennington (Englund, 1964a). South of Cumberland Gap, the upper member of the Pennington pinches out and the Chadwell rests on the Pinnacle Overlook Member (Englund, 1964b). The White Rocks Member (Pennsylvanian) locally overlies the Chadwell. The White Rocks thins southwestward from its type locality on the crest of Cumberland Mountain, near Ewing, Va., and pinches out southwestward about 5 mi northeast of Cumberland Gap. Thicknesses of the Lee members are varied; they reach a maximum of about 350 ft for each member. In southwestern Virginia, northeast of the Kentucky outcrop, the Chadwell and Pinnacle Overlook intertongue with rocks of the Bluestone Formation (equivalent to upper Pennington) and pinch out to the northeast (Englund, 1979).

A Chadwell correlative may be present on Pine Mountain in southwestern Harlan County, where the Pennington is overlain, in ascending order, by conglomeratic sandstone and marine shale (C.L. Rice, U.S. Geological Survey, oral commun., 1981). The sandstone and shale were mapped as the basal part of the Middlesboro(?) Member of the Lee (Froelich, 1972).

LITHOLOGIC TRENDS AND INTERBASIN CORRELATIONS

A lithofacies depiction of the total Chesterian succession in the Eastern Interior basin (Sable, 1979a) results from combining the many rhythmic alternations of detrital and carbonate units, which are modified by irregular amounts of erosion in the upper part of the interval. In the most complete Chesterian rock sections in the southern part of the basin, sandstones are most abundant in southern and southeastern Illinois, and are common in western Kentucky. Lobate sandstone tongues converge towards the center of the basin in southern Illinois as shown by Swann and Bell (1958). Increase of carbonate rocks along the southernmost limits of Chesterian strata in west-central and south-central Kentucky results mostly from the southward thinning and disappearance of pre-Big Clifty detrital units into the Girkin Formation (fig. 45). A westward increase in mudstone in Chesterian units such as in the Big Clifty is reported by Swann (1963, p. 15; 1964, p. 649) and is shown by comparison of Kentucky GQ maps (for example, Big Clifty quadrangle versus Olney quadrangle); a southeastward increase in the mudstone: sandstone ratio also occurs in post-Glen Dean rocks of west-central Kentucky.

Relationships between Chesterian units of the Eastern Interior basin and presumed equivalents in the Appalachian basin are critical for understanding the Mississippian System in Kentucky. These rocks have been removed by erosion along the axis of the Cincinnati arch; outcrops in the two basins are about 50 mi apart at their nearest point in the Cumberland saddle area of south-central Kentucky. Two major lithologic trends indicate a continuity of deposition between the two basins. The southeastward decrease in detrital input in the Eastern Interior basin during early Chesterian time extended into the western part of the Appalachian basin, as reflected by the dominance of carbonate rocks in both the Girkin Limestone, west of the Cincinnati arch, and the Kidder Member of the Monteagle Limestone, east of the arch. Chesterian rocks in most of the Eastern Interior basin, as noted previously, consist of a cyclic sequence of limestones alternating with sandstones and shales. In contrast, the upper part of the Chesterian succession in both the eastern part of the Eastern Interior basin (Buffalo Wallow and Leitchfield Formations) and the western part of the Appalachian basin (Paragon and Pennington Formations) mainly consists of shale with lesser amounts of sandstone and relatively minor amounts of limestone and dolomite.

Specific correlations between Chesterian-age units of the Eastern Interior and Appalachian basins, based on megafaunal elements and the similarity and sequence of lithologic units, were proposed by Butts (1922), Stokley and McFarlan (1952), and McFarlan and Walker (1956). The stratigraphic units and nomenclature of McFarlan and Walker (1956) have been utilized in reports of the Kentucky Geological Survey and in papers and theses of other Kentucky workers, but were not considered applicable by the U.S. Geological Survey during the geologic mapping project because of lack of mappable continuity and specific paleontologic and lithologic correlations of many units east and west of the Cincinnati arch.

The Hartselle Formation, as mapped in eastern south-central Kentucky (Lewis and Thaden, 1965), the only

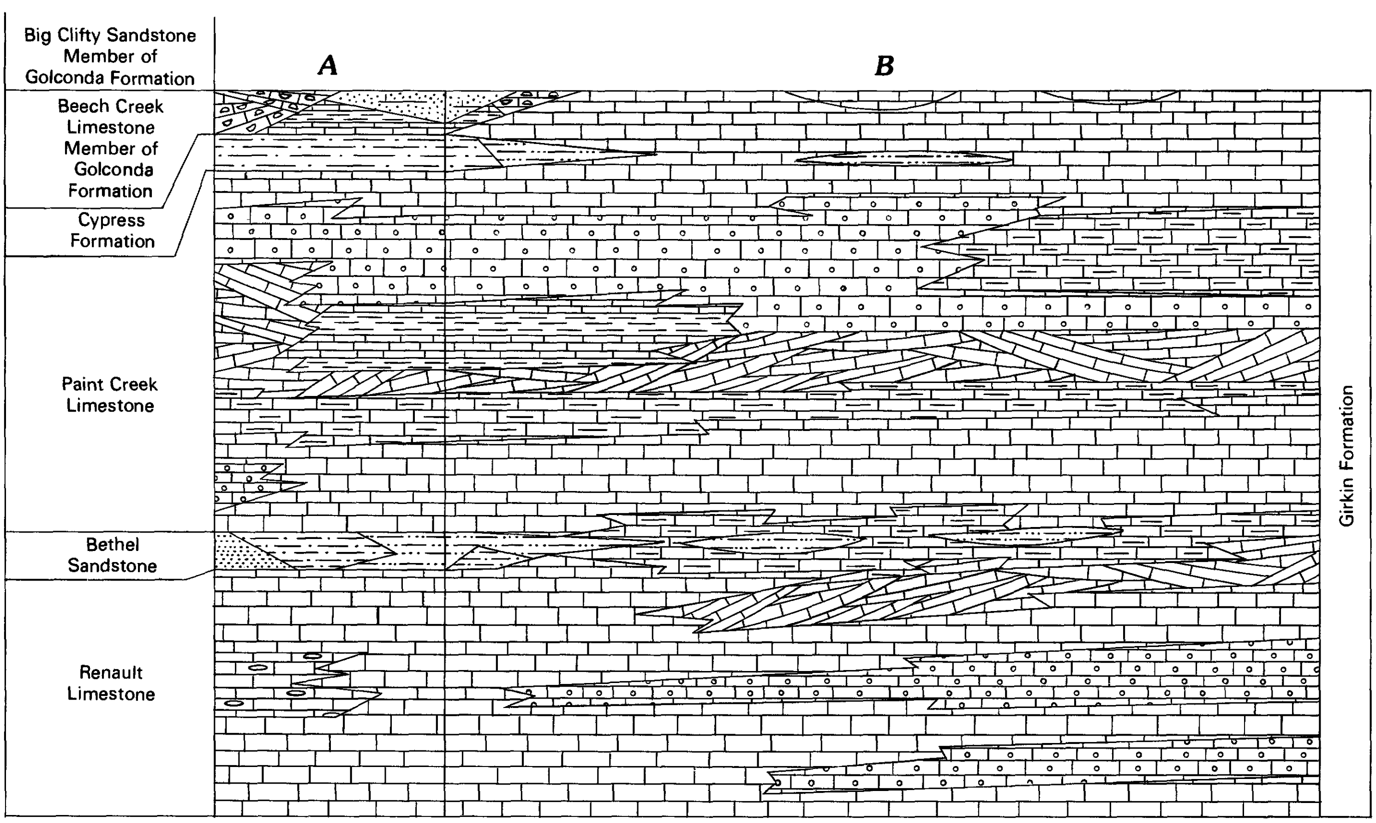


FIGURE 45.—Relationships of Girkin Formation with coeval units of Chesterian age as mapped in the Homer quadrangle, west-central Kentucky. *A*, typical of the western part of the quadrangle; *B*, typical of central and eastern parts (modified from Gildersleeve, 1966).

sandstone occurring in the carbonate-dominated section between the Ste. Genevieve and Pennington (Paragon), may be a key to understanding relationships between Chesterian-age units in the two basins. Correlation with two different sandstone-bearing units west of the Cincinnati arch has been suggested: Hardinsburg Sandstone (Stokley and McFarlan, 1952; McFarlan and Walker, 1956; Lewis and Thaden, 1965; Ettensohn, 1980) and Big Clifty Sandstone Member of the Golconda Formation (Butts, 1922; Peterson, 1956; Vail, 1959; Horowitz and Strimple, 1974; Sable, 1979a; Horowitz and others, 1979). It should be noted that the widespread shale facies in the Hartselle was correlated with the Golconda by Butts (1922) because in northern Tennessee, the shale lies above the sandstone facies which was correlated with the "Cypress" (Big Clifty).

Correlation of the Hartselle with the Hardinsburg is based in part on characteristics of the enclosing limestones. The Hartselle is overlain by limestone similar to the Glen Dean of west-central Kentucky, and is underlain by limestone similar to the Haney Limestone Member of the Golconda Formation, and at some places containing chert like that in the Haney. However, Haney-type chert in limestone overlying the Hartselle has been reported in the vicinity of Albany, Clinton County (see section, "Carbonate-dominated units," p. 73).

Microfaunal elements from a core taken in northern Tennessee, just south of the Kentucky-Tennessee State line, show that the Hartselle is overlain and underlain by beds of Golconda age, the basal Bangor and uppermost Monteagle respectively. This indicates that the Hartselle is correlative with the Big Clifty, the middle member of the Golconda in the Eastern Interior basin (Horowitz and others, 1979). Massive sandstones are well developed in the Hardinsburg Sandstone in the northern part of west-central Kentucky, but the sand:shale ratio of the Hardinsburg decreases southward (compare Mattingly and Homer geologic quadrangle maps). The Hartselle in south-central Kentucky and north-central Tennessee contains considerable sandstone. It thus appears that the Hardinsburg clastic ratios do not correspond with those of the Hartselle. The Big Clifty, on the other hand, is largely massive thick-bedded sandstone to its erosional limits in western south-central Kentucky; and its lithofacies pattern can, with a fair degree of assurance, be compared favorably to that of the Hartselle. Directional depositional components (crossbedding and lobes of sandstone lithofacies (fig. 46)) of the Big Clifty in west- and south-central Kentucky (Potter and others, 1958), if they represent primary sand input, suggest westward and northwestward transport through the Cumberland saddle (unlike most Michigan river southwestward transport features). This may further suggest that the thick Big Clifty sandstones may be related to the Hartselle in Kentucky.

In addition to possible correlation of the Hartselle with units west of the Cincinnati arch, a southwestern source for the type Hartselle Sandstone of Alabama was suggested by Thomas and Mack (1982). The body of sandstone in northern Alabama pinches out to the northeast (Thomas, 1972, 1974). Its exact relationship with the sandstone in the Hartselle of northern Tennessee and south-central Kentucky, about 100 mi north, is uncertain because detailed studies along the outcrop belt in Tennessee have not yet been done. Thus, the Hartselle Sandstone of Alabama may or may not equate with that in Kentucky.

During the mapping program, rocks in the unit that Butts (1922) had identified as Glen Dean in south-central and east-central Kentucky were assigned to two formations. The thick- to medium-bedded bioclastic limestone forming the main part of the Glen Dean of Butts (1922) was designated as the Bangor Limestone in south-central Kentucky; it was included in the upper Newman Limestone (Slade Formation) in east-central and northeastern Kentucky. The shale and interbedded limestone at the top of the Glen Dean of Butts (1922) were included in the Pennington Formation; these uppermost beds are the principal source of Glen Dean–age megafauna (Butts, 1922; Horowitz, 1965; Weir and others, 1971; Ettensohn and Chesnut, 1979b; Chesnut, 1980). The Bangor in the northern Tennessee core studied by Horowitz and others (1979) contains foraminifera and conodonts which indicate a Glen Dean age for at least part of the formation; the older Golconda age, as noted above, was determined for the basal Bangor.

On Pine Mountain in southeastern Kentucky, limestone similar to the Bangor is present in the upper part of the lower member of the Newman. The overlying upper member of the Newman is correlated with the Bluefield Formation of southern West Virginia and southwestern Virginia (Wilpolt and Marden, 1959), which generally is considered to be of Glen Dean age (Butts, 1940; Cooper, 1944).

Age determinations for the unit designated as Paragon Formation of Ettensohn and others (1984) (formerly Pennington Formation), along the western border of the Appalachian basin, and reported correlations with Upper Mississippian units of the eastern Appalachian basin and Eastern Interior basin are not entirely compatible. Paleontological data indicate the presence of younger rocks in the Paragon than are suggested by lithostratigraphic correlations. Recent studies of the palynology and microfauna indicate a Glen Dean to Grove Church age for the Paragon in and near the

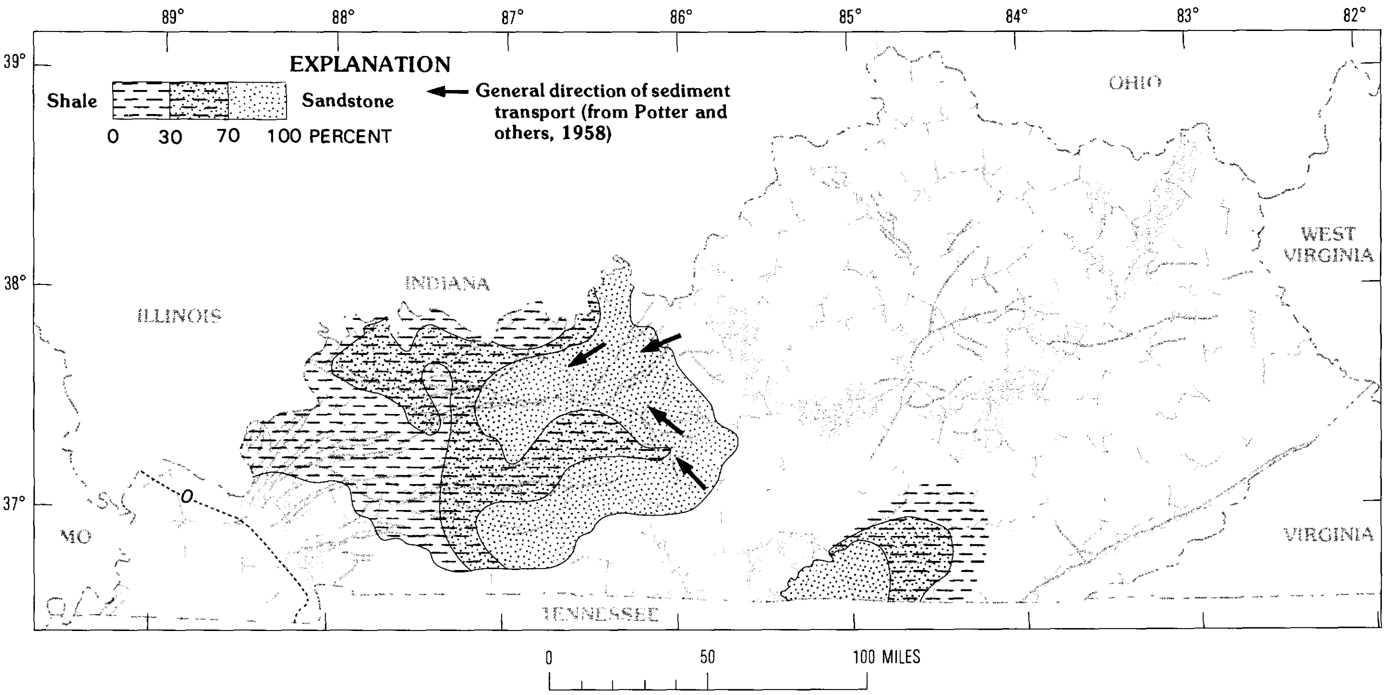


FIGURE 46.—Distribution of sandstone and shale in Big Clifty Sandstone Member of Golconda Formation in west-central, central, and western Kentucky, and Hartselle Formation in south-central Kentucky, showing sediment transport directions. Kentucky fault patterns shown on base.

outcrop belt along the western border of the Eastern Kentucky coal field (Ettensohn and Peppers, 1979; Horowitz and others, 1979). Rocks designated as Paragon in this outcrop belt have been correlated with the upper member of the Newman, or Bluefield, on the Pine Mountain overthrust block (Englund and Windolph, 1971; Englund and Randall, 1981). The Bluefield, as noted previously, is considered to be Glen Dean in age.

Englund and Henry (1979) and Englund and Randall (1981) indicated that as a result of progressive westward, post-Mississippian truncation of Upper Mississippian units, the equivalents of the Pennington Formation on the Pine Mountain overthrust block are not present in the Paragon outcrop belt along the western border of the Eastern Kentucky coal field. The Pennington on Pine Mountain is approximately correlative with the Hinton Formation, Princeton Sandstone, and Bluestone Formation of West Virginia and Virginia (Wilpolt and Marden, 1959), which range in age from Menard to Grove Church or younger (Gordon and Henry, 1981).

SOURCES OF SEDIMENTS AND DEPOSITIONAL ENVIRONMENTS

An ancient southward-flowing river system, first envisioned by Stuart Weller (1927, p. 26) and later named the Michigan river (Swann, 1963, p. 12), is interpreted to have transported detrital Chesterian sediments into and across the Eastern Interior basin. Evidence for the Michigan river consists of regional thickness and facies distribution of Chesterian units (Swann and Bell, 1958), southward-dipping crossbeds in generally southward trending sandstone bodies (Potter and others, 1958; Potter, 1963), and channel-fill morphology of sandstone bodies (Potter, 1962, p. 28–29; 1963; Reynolds and Vincent, 1967; Sedimentation Seminar, 1969). The main sediment source was in eastern Canada, either in the Canadian shield or east of the northern Appalachian fold belt. The possibility that the uplifted Franklinian geosyncline in northern Canada may have been a major source was also suggested by Swann (1964). According to Swann, the Michigan river flowed southwestward across Michigan and northern Indiana into a shallow sea, where detrital sediments accumulated as a birdsfoot delta projecting southward beyond a N. 65° W.-trending shoreline. Lateral northwest or southeast shifts in the course of the Michigan river of as much as 200 mi produced belts of sand and mud in different parts of the region at different times. Major northeast and southwest oscillations of the shoreline, perhaps as much as 600 to 1,000 mi, produced numerous marine transgressions during which carbonates were deposited in the basin and surrounding areas and the amount of clastic detritus was relatively low. The resulting highly variable but rhythmic depositional complex of sediments includes shallow-marine detrital and carbonate facies, littoral detrital facies, and continental detrital and coaly facies. Superimposed on the system of shifting shorelines and positions of the river system, Swann (1963, p. 14–15) postulated a northwest-flowing sea current or drift which carried muds northwestward, leaving relatively clear water in the southeastern (south-central Kentucky) part of the basin where limestone accumulated. Sea depths in the Eastern Interior basin during Chesterian time have been estimated on the basis of water depths near modern deltas, increased by the estimated amount of compaction of the sediments deposited. These estimates place the depth of water at 50–75 ft, with a range of from 30 to 100 ft (Swann, 1964, p. 652–653).

A low dip of the paleoslope, low relief of the sea floor, and a widespread shallow-marine environment are indicated by (1) the distribution of tabular carbonate units which individually cover thousands of square miles and indicate similar depositional environments across these large areas, (2) the presence of oolitic limestones and current-bedding features, and (3) numerous shallow-water fossils. Likewise, the widespread sheets of terrigenous clastics also indicate generally uniform shallow-marine, shoreline and lower delta plain environments, in contrast to environments of the earlier Borden deltaic beds, which prograded into deep water and were onlapped by deep-water carbonates deposited along the delta front.

The major sources for terrigenous clastic sediment of the Pennington Formation were highlands of sedimentary and metamorphic rocks lying generally east of the Appalachian basin (de Witt and McGrew, 1979). Whether detrital material from Appalachian basin source areas contributed to Chesterian rocks west of the Cincinnati arch in the Eastern Interior basin as may be suggested by Big Clifty–Hartselle distribution (p. 84) is uncertain. Some contribution in late Chesterian time may also be suggested by lithologic similarity of the Pennington and Paragon Formations of eastern Kentucky and the Leitchfield and Buffalo Wallow Formations of west-central Kentucky. Carbonate-dominated units of earlier Chesterian and Meramecian age were deposited across the Cumberland saddle area as shown by their lithic and faunal similarities, and their thickness trends indicate that the saddle was then a negative element athwart the Cincinnati arch. In southeastern and eastern Kentucky, sandstones in the Pennington and Paragon, which thin to extinction westward and southward, have been interpreted to have been transported southwestward along the Appalachian basin from a northeastern source area (Vail, 1959, p. 59), but in view of the proposed Paragon-Bluefield correlations discussed previously (p. 84–85), this conclusion may be invalid. The northwest sea-current drift proposed by Swann, which moved muds discharged by the Michigan river westward, explains the mudstone in the western part of the Eastern Interior basin. A connection across the Cumberland saddle area (Cumberland strait) also could provide a passage for late Chesterian (Pennington-Paragon) fine-grained sediments from Appalachian sources carried by westward-flowing marine currents to form Leitchfield–Buffalo Wallow clastic strata in the Eastern Interior basin. Mixing of Appalachian sediments with those from the Michigan river would thus have taken place in west-central Kentucky.

Depositional environments of the rocks of Chesterian age in the upper member of the Newman (Slade), the Kidder-Hartselle-Bangor sequence, and Pennington (Paragon) along the western border of the Eastern Kentucky coal field have been studied extensively in recent years. Carbonate rocks in the lower part of both the Kidder and the upper member of the Newman (Slade), below the Cave Branch Bed, form multiple fining-upward sequences. These sequences indicate transgressive-regressive cycles, with shallow, subtidal carbonate sands grading upward into prograding tidal-flat and supratidal deposits of lime mud and silt (Dever, 1973, 1977). Individual sets of supratidal and tidal-flat deposits commonly are capped by exposure zones. The entire interval of fining-upward sequences is capped by a prominent exposure zone which can be traced the length of the outcrop belt of these units.

Limestone, shale, and sandstone of the upper Newman (Slade) overlying the widespread exposure zone, and sediments of the younger Pennington (Paragon) Formation were deposited in a major transgressive-regressive sequence (Ettensohn, 1975, 1977, 1980; Ettensohn and Chesnut, 1979b). The transgressive sequence consists of intertidal mud flats (Cave Branch Bed), lagoonal lime mud (calcilutite), carbonate sand belt (calcarenite and calcirudite), shallow open-marine deposits (fossiliferous calcarenite, calcilutite, and shale), and deeper open-marine deposits (shale and calcilutite). The change from transgression to regression is considered to have occurred during deposition of this open-marine shale, an equivalent of the Hartselle. Succeeding regressive deposits consist of carbonate sand belt (calcarenite; Bangor equivalent), lagoonal deposits (fossiliferous shale and limestone of basal Pennington (Paragon)), and carbonate and detrital tidal flats with local coal-forming swamps (dolomite and sandstone; see Ettensohn and Peppers, 1979). The regressive sequence was temporarily interrupted by a marine advance with deposition of a thin but widespread limestone. Succeeding the limestone are prodelta deposits of prograding shoal-water deltas or tidal flat sediments (shale, siltstone, and dolomite of uppermost Pennington-Paragon). As each of the depositional environments migrated with transgression or regression across the region, its lithologic expression assumed a sheetlike geometry forming a stack of widespread, tabular lithologic units (Ettensohn, 1977).

The linear body of the Carter Caves Sandstone in northeastern Kentucky has been described variously as an offshore bar (Englund and Windolph, 1971), a beach-barrier island system (Horne and others, 1974), a tidal-channel deposit paralleling the Waverly arch (Ettensohn, 1977), and a distributary-channel deposit of a Pennington (Paragon) delta system (Short, 1978). Deposition of Chesterian-age rocks in northeastern and east-central Kentucky was influenced by the Waverly arch, which was a positive feature, and by recurrent movement along the Kentucky River fault system, as described in Dever and others (1977), Ettensohn and Dever (1979), and Ettensohn and Peppers (1979).

Depositional environments of the Newman and Pennington in southeastern Kentucky on the Pine Mountain overthrust block have not yet been studied extensively, but the environments of deposition for correlative units in southwestern Virginia and southern West Virginia have been discussed by Englund (1979), Englund and others (1981), and Miller (1974). Rocks of Chesterian age show a general upward transition from shallow-marine shelf and nearshore-marine deposits to nearshore tidal-flat, beach, lagoon, and marsh deposits. The Pennington, in particular, is characterized by deposition in alternating near-coastal terrestrial and nearshore marine environments.

PALEOGEOGRAPHY AND PALEOTECTONIC IMPLICATIONS

In general, stream and shoreline positions lay in western Kentucky through much of Chesterian time. The Michigan river system was the dominant transporting agent. A delta-complex at its mouth included both sheet sands and linear sand bodies such as channel fills, point bars, and distributary mouth bars. Sediment discharged by the Michigan river may have been deposited as far south as northwestern Alabama and northeastern Mississippi. Only minor coaly beds formed in interdistributary swamps on the delta plain, suggesting that rates of clastic deposition were high, with rapid shifts of distributaries and splay channels. Highlands east of the Appalachian basin contributed detrital sediments, some of which in late Chesterian time were probably carried through the Cumberland saddle and intermingled with Michigan river sediments in western Kentucky. The northern part of the Cincinnati arch in Ohio and possibly Kentucky was a low-lying peninsula or shoal area which contributed little sediment but may have acted as a partial barrier between the Eastern Interior and Appalachian basins.

Abundant marine faunas and oolitic limestones indicate subtropical or tropical conditions during Chesterian time. Scattered coaly beds and fairly abundant fossil plant remains in sandstones and siltstones suggest humid terrestrial conditions. Red shales are common in some detrital units such as the Big Clifty, Pennington, and Leitchfield Formations; they may indicate the presence of deep residual soils in source areas (Vail, 1959, p. 52).

Mild but persistent subsidence characterized broad areas of western Kentucky, and sediment thicknesses indicate that the greatest subsidence was in the Fairfield basin in Illinois and Moorman syncline in Kentucky. The lateral persistence of individual formations and their small thickness variations show that subsidence was relatively even. Minor differential movements probably occurred along the La Salle anticlinal belt, folds in Illinois and Indiana (Siever, 1951, p. 569), and the Rough Creek and Pennyrile fault systems. A regional southwestward-dipping paleoslope and a mildly negative trough across Michigan, Indiana, Illinois, and western Kentucky controlled the trend of the Michigan river system. The area of the Cumberland saddle is presumed to have been a mildly downwarped element between the Jessamine and Nashville domes that connected eastern and western basins in Kentucky.

In eastern Kentucky, the area between the present Cincinnati arch and the Appalachian basin, the Waverly arch, was a relatively high and unstable platform during Chesterian age deposition. Minor differential movement occurred along the Kentucky River fault system.

MISSISSIPPIAN-PENNSYLVANIAN-YOUNGER ROCK RELATIONSHIPS

Detrital rocks of terrigenous origin of Pennsylvanian and Cretaceous age unconformably overlie rocks of all Mississippian series in Kentucky. Only in the southeastern part of Kentucky has it been described that Mississippian and Pennsylvanian strata are conformable. Recent literature on systemic relationships includes a comprehensive synthesis by Rice and others (1979).

Pennsylvanian rocks overlying Mississippian strata are dominantly lower delta plain deposits of sandstone, mudstone, conglomerate, clay, and coal with very minor marine beds including limestone and mudstone. These basal strata of Morrowan and Atokan ages are the lower part of the Lee and Breathitt Formations in the eastern part of Kentucky, and the Caseyville Formation in the west. About 100 mi separates the two main belts of exposures.

A major erosional hiatus between Mississippian and Pennsylvanian rocks is well documented in much of Kentucky; it is marked by progressively deeper beveling of pre-Pennsylvanian strata north of Kentucky in northern Illinois and Indiana, where as much as 1,500 ft of Mississippian section may have been removed (Sable, 1979a). Channels superimposed on a gently rolling surface are as much as 450 ft deep in southeastern Illinois (Siever, 1951). In western Kentucky, as much as 900 ft of Mississippian strata is believed to have been removed, with channels incised as much as 250 ft into the Mississippian surface (Bristol and Howard, 1971). In northeastern and east-central Kentucky pre-Pennsylvanian erosion is evinced by a southward- or south-southeastward-sloping beveled surface locally marked by paleokarst topography developed on Mississippian limestones (Dever, 1971; Weir, 1974b; Hoge, 1977). The beveling appears to have been controlled by growth of the Cincinnati and Waverly arches (Englund, 1972). In west-central Kentucky, pre-Caseyville Formation beveling has truncated progressively older Chesterian units in general eastward or southeastward directions, toward the Cincinnati arch, as shown in figures 47, 48, and 49; the illustrated localities lie along an 18-mi line of section and show the Caseyville Formation lying on post-Kinkaid Limestone beds, on post-Menard Limestone beds, and on the Vienna Limestone, respectively, from northwest to southeast. Channeling into this surface is locally pronounced, and relief along the borders of the deeper channels is commonly about 60–80 ft. Reconstruction of Mississippian strata prior to Pennsylvanian erosion indicates that 160 ft of Borden and Newman and an undetermined amount of Pennington may have been removed in the vicinity of the Bell Branch channel in Pomeroyton quadrangle (Weir and Richards, 1974). On the west side of Indian Fort Mountain in the Bighill quadrangle (Weir and others, 1971), as much as 240 ft of upper Newman (Slade) and Pennington (Paragon) strata may have been present prior to erosion.

Several southwest-trending sub-Pennsylvanian channels in central, west-central, and western south-central

FIGURE 47.—Sandstone of Caseyville Formation (ℙc) with basal thin coal bed (c) overlying limestone equivalent of Kinkaid Limestone in Buffalo Wallow Formation (Mbwk). Intervening shale probably of Mississippian age. Caneyville Crushed Stone Company quarry, Caneyville quadrangle, Grayson County.

FIGURE 48.—Caseyville Formation (ℙc) disconformably overlying Buffalo Wallow Formation (Mbw). Exposed Buffalo Wallow units are (descending) unnamed gray shale; 6-ft thick Menard Limestone equivalent (Mbwm), unnamed greenish and reddish shale and dolomite (Mbwd). Milepost 101.0, Western Kentucky Parkway, Caneyville quadrangle, Grayson County.

Kentucky are incised as much as 250 ft in the Mississippian surface, following truncation which may have removed as much as 1,000 ft of Mississippian strata (Rice and others, 1979). East of and colinear with the southernmost channel, isolated hilltop outliers of sandstone, shale, and conglomerate, interpreted to be remnants of basal Pennsylvanian channel fill, extend along a west-southwest linear trend across parts of Edmonson, Hart, and Larue Counties, west-central and south-central Kentucky (Burroughs, 1923; McFarlan, 1943, p. 96). These outliers mapped in Hibernia (F.B. Moore, 1976) and other quadrangles overlie strata of the Ste. Genevieve and upper part of the St. Louis Limestones. Growth of the Cincinnati arch prior to channel cutting is suggested by these relationships. The main channel continues southwestward across the southern part of the western Kentucky coal field as part of the channel complex overlying Chesterian units, described by Shawe and Gildersleeve (1969) and Sedimentation Seminar (1978), and termed the Brownsville channel by Bristol and Howard (1971, p. 9). Rice and Weir (1984) interpreted the Brownsville paleochannel to be the distal part of the much larger southeast-gradient Sharon-Brownsville paleovalley system which headed north of Pennsylvania.

In general, Pennsylvanian sandstones are compositionally and texturally similar to Mississippian sandstones, and in many places unfossiliferous mudstone, shale, and siltstone constitute the strata between unmistakable Mississippian and unmistakable Pennsylvanian rocks so that recognition of the systemic boundary is difficult. Two-group discriminant functional analysis of geochemical data of Pennsylvanian and Chesterian sandstones was reported by Connor (1969) and Connor and Trace (1970) to be of potential use in future discrimination of similar rocks of the two systems.

In southeastern Kentucky, the Mississippian-Pennsylvanian systemic boundary occurs within rock sequences that generally were considered to be conformable. Along Pine Mountain, the boundary locally is in shale and siltstone sequences of the Pennington Formation. The Pennington rocks are mostly of Late Mississippian age, but the occurrence of the spore, *Laevigatosporites* (mostly *L. ovalis*), in the upper part of the formation indicates the presence of rocks of Pennsylvanian age (Maughan, 1976). On Cumberland

FIGURE 49.—Sandstone of Caseyville Formation (Pc) overlying 8-ft thick Vienna Limestone (Mv). Basal Caseyville consists of 6 ft of quartz-pebble conglomerate. Section below Vienna is 26 ft of Tar Springs Formation (Mts) shale, sandstone, and limestone overlying Glen Dean Limestone (Mgd). Cardinal Stone Company Quarry, Bee Spring quadrangle, Edmonson County.

Mountain, Englund and Smith (1960), Englund (1964a), and Englund and Delaney (1966) reported intertonguing and lateral gradation between rocks of the Lee and Pennington Formations which, at that time, generally were considered to be of Pennsylvanian and Mississippian age, respectively. Lower members of the Lee, the Pinnacle Overlook, Chadwell (previously designated as "sandstone member A"), and White Rocks Members, which intertongue with the Pennington, later were assigned a Late Mississippian age by Englund (1979). The oldest Pennsylvanian unit on Cumberland Mountain, according to Englund (1979), was the Dark Ridge Member (previously designated as "sandstone and shale member B") of the Lee Formation, which apparently was conformable with Mississippian rocks of the Lee and Bluestone Formations. The Dark Ridge was described as gradational and intertonguing with the Chadwell and White Rocks (Englund, 1964a, 1964b; Englund, Landis, and Smith, 1963). Rice (1984), however, suggested that the systemic boundary may be an unrecognized paraconformity within the Dark Ridge. More recently, Englund and others (1985) reassigned the White Rocks to the Pennsylvanian System and showed the White Rocks and Dark Ridge Members of the Lee Formation to unconformably overlie Mississippian rocks of the Bluestone Formation and Chadwell Member of the Lee Formation.

The conclusion that an unconformity between the Mississippian and Pennsylvanian Systems extends throughout eastern Kentucky is supported by a subsurface study that, in southeastern Kentucky and southwestern Virginia, identifies a 350-ft-deep, southwest-trending valley fill at the base of the Pennsylvanian called the "Middlesboro paleovalley" (Rice, 1985). The reassignment of the White Rocks Sandstone Member of the Lee Formation from Mississippian to Pennsylvanian age by Englund and others (1985) has suggested to Rice (in Shepherd and others, 1986) that sediments of the White Rocks filled the Middlesboro paleovalley where that valley intersects Cumberland Mountain.

An intra-Pennsylvanian unconformity originating within the lower part of the New River Formation of West Virginia and Virginia was considered by Englund (1974, 1979) and Englund and Henry (1979) to be coextensive with an unconformity at the base of the Middlesboro Member of the Lee in southeastern Kentucky and with an unconformity occurring between Mississippian and Pennsylvanian rocks along the western border of the Eastern Kentucky coal field. More recently the unconformity beneath the Pineville Member of the New River Formation in West Virginia and Virginia was extended southwestward beneath the White Rocks, Dark Ridge, and Middlesboro Members of the Lee Formation along the Kentucky-Virginia State line where it is coextensive with the Mississippian-Pennsylvanian systemic boundary (Englund and others, 1985). Where the Middlesboro Member of the Lee overlies the Pride Shale, its base marks the unconformity at the systemic boundary according to C.L. Rice (written commun., 1987).

The presence of an unconformity at the Pennsylvanian-Mississippian systemic boundary in northeastern Kentucky has been challenged by several workers. Deposition of the Carboniferous rocks of northeastern Kentucky as part of a gradational sequence of westward-prograding fluvial, deltaic, lagoonal, shoreline, and marine sediments was proposed by Horne and Ferm (1970), Swinchatt (1970), Ferm and others (1971), Horne and others (1971), Ferm (1974), and Horne and others (1974). Their depositional model involved rocks of the Borden, Newman (Slade), Pennington (Paragon), Carter Caves, Lee, and Breathitt; intra- and post-Mississippian unconformities, identified by earlier workers, were considered to be facies or depositional boundaries. In the model, orthoquartzites (Carter Caves, Lee) were interpreted as beach-barrier deposits which grade landward into lagoonal-bay and deltaic-fluvial shales, subgraywackes, and coals (Breathitt). The beach-barrier sandstones grade seaward into marine shales (Borden and Pennington) which surround limestones (Newman) deposited as carbonate barriers, bars, and tidal-flat-island complexes. The model was developed incorporating the exposures of Carboniferous rocks along Interstate Highway 64 in Carter and Rowan Counties.

Study of the rock units along the interstate highway and in adjacent areas has shown that the field relationships do not support the proposed model (Dever, 1973; Ettensohn, 1975, 1979a, 1980, 1981; Rice and others, 1979). For example, a large body of marine shale which is shown in the model as occurring between and gradational with isolated limestone bodies and with orthoquartzites does not exist at that stratigraphic position (fig. 50, upper cross section). The area of northeastern Kentucky used for the depositional model is on the upthrown block of the Kentucky River fault system and astride the axis of the Waverly arch, but these tectonic elements were not recognized during the model's development. Uplift and movement along these features during the Carboniferous resulted in extensive intra- and post-Mississippian erosion in the area and partly controlled deposition of Mississippian and Pennsylvanian units (Dever, 1973; Dever and others, 1977; Englund, 1972; Ettensohn, 1975, 1980, 1981; Ettensohn and Dever, 1979; Ettensohn and Peppers, 1979; Haney, 1976; Haney and others, 1975; Horne and Ferm, 1978; Sergeant and Haney, 1980; Short, 1978).

Short (1978) also proposed that the Mississippian-Pennsylvanian systemic boundary in northeastern Kentucky is within a gradational sequence, with continuous deposition from deltaic and marine sediments of the Pennington into deltaic and fluvial sediments of the Lee and Breathitt. He recognized that local disconformities occur in the sequence at the base of channel-fill sandstones, but suggested that the extensive intra-Mississippian unconformity in the area commonly is misidentified as a post-Mississippian unconformity. Both Short (1978) and Ettensohn and Peppers (1979) suggested a Late Mississippian age for the Olive Hill Clay Bed of Crider (1913) which traditionally has been assigned to the Pennsylvanian. Their suggested age is based on the occurrence of palynomorphs that may include pollen from an eroded Mississippian upland, according to C.L. Rice (written commun., 1987).

On the other hand, Haney (1979, 1980) reported that the systemic boundary is coincident with an unconformity in areas that were tectonically active during the Carboniferous, such as northeastern Kentucky, but that in areas distant from active tectonic features, such as south-central Kentucky, the systemic boundary commonly is within a gradational sequence. In the latter areas, occurrences of an erosional surface between Pennsylvanian and Mississippian rocks are considered to be related to downcutting during intra-Pennsylvanian erosion. Rice (1980), in rebuttal, contended that regional relationships indicate the presence of a widespread unconformity coincident with the systemic boundary, and he reported the development of an extensive consequent drainage system after emergence of the region in Late Mississippian time. Subsurface analysis of oil and gas logs by C.L. Rice and others (written commun., 1987) indicates that Lower Pennsylvanian strata thin and onlap onto older Mississippian rocks northward in eastern Kentucky. This suggests that some localities in northeastern Kentucky were emergent during Early Pennsylvanian time—no strata were deposited there. In parts of south-central Kentucky where no obvious

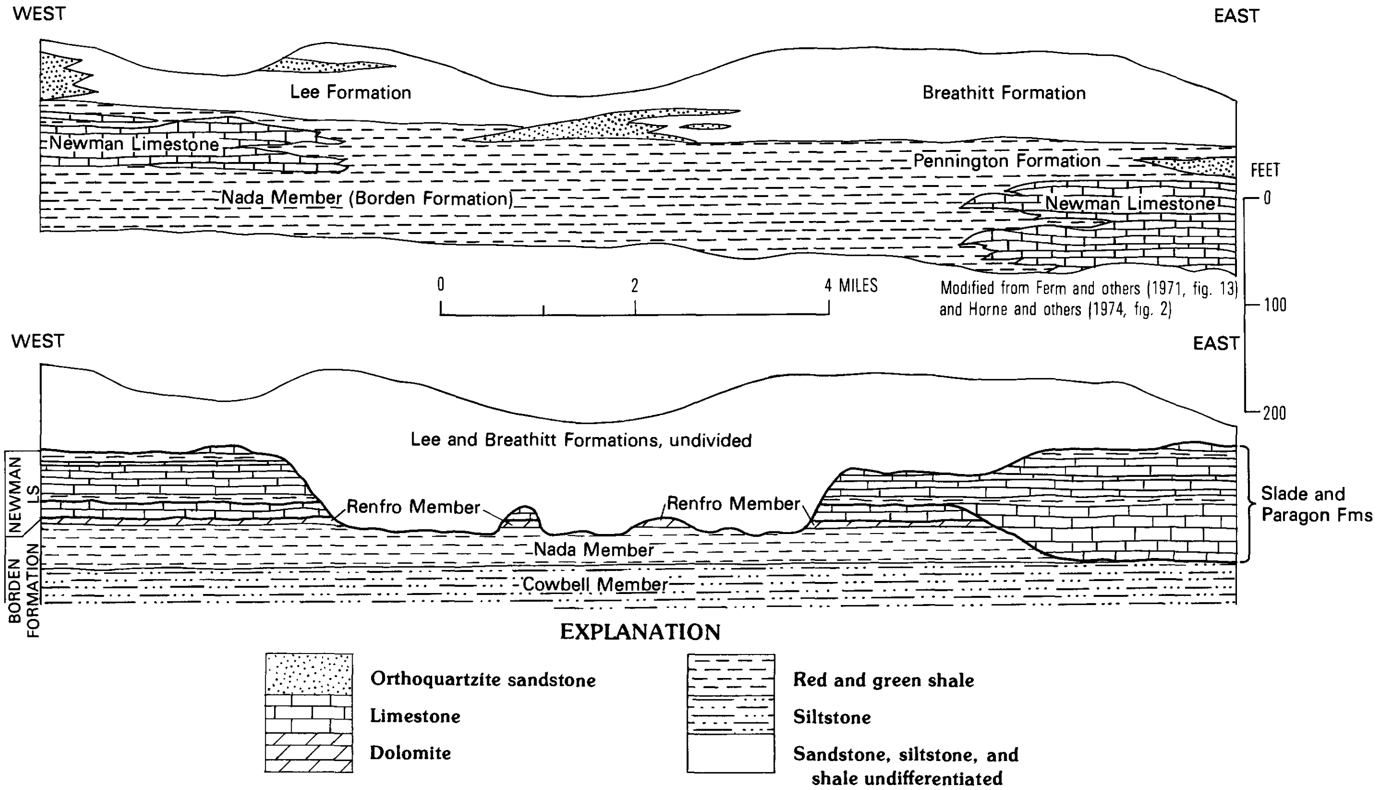


FIGURE 50.—Generalized cross sections showing two interpretations of Pennsylvanian and Mississippian unit relationships along Interstate Highway 64, northeastern Kentucky (from Rice and others, 1979, modified from Dever, 1973).

erosional surface is recognized between Mississippian and Pennsylvanian rocks, the systemic boundary is considered to be a paraconformity which may be misinterpreted as a normal bedding plane or facies-related boundary (Rice, 1980).

Detrital rocks of the Tuscaloosa and McNairy Formations of Late Cretaceous (Gulfian) age lie on an erosional surface of Mississippian and older rocks in the Mississippi Embayment area of southern Illinois, westernmost Kentucky, Tennessee, and southeastern Missouri. More than 3,000 ft of Mississippian strata were removed by pre-Cretaceous erosion in westernmost Kentucky and southern Illinois, the result of the growth of the Pascola arch and its denudation (Schwalb, 1969). There is little indication of growth of the Pascola arch in western Kentucky during Mississippian time; only the isopach pattern of latest Chesterian sediments (fig. 64), may suggest influence of a positive feature such as the Pascola arch to the south and west of western Kentucky. Through much of Mississippian time, however, a south-southwest-trending depositional trough or basin in which more than 3,300 ft of Mississippian rocks accumulated is evidenced by the record of Mississippian strata. Thickening of most Mississippian stratigraphic intervals shown in figures 54–63 is towards the Pascola arch.

SUMMARY OF THICKNESSES AND LITHOLOGIC TRENDS

The generalized isopach maps (figs. 51–64) portray thicknesses of single or multiple units of Mississippian strata and are based largely on data from geologic quadrangle maps of Kentucky and individual measured surface sections; they also rely upon subsurface data from published reports and from files of the Kentucky Geological Survey. Isopach intervals are variable between maps and also within some individual maps. Thicknesses shown reflect in-place depositional thicknesses modified by subsequent burial and induration. The isopachs give only general unit thicknesses for two reasons: (1) Considerable range in unit thicknesses is given in columnar sections of mapped quadrangles so that an accurate representative average thickness figure for a unit in any given quadrangle is difficult to obtain. The average thicknesses used in thickness calculations were therefore based on average thicknesses shown in the columnar sections and augmented by map inspection. (2) Some unit thicknesses given in well descriptions are highly subjective because of varying interpretations by different geologists who described the subsurface rocks

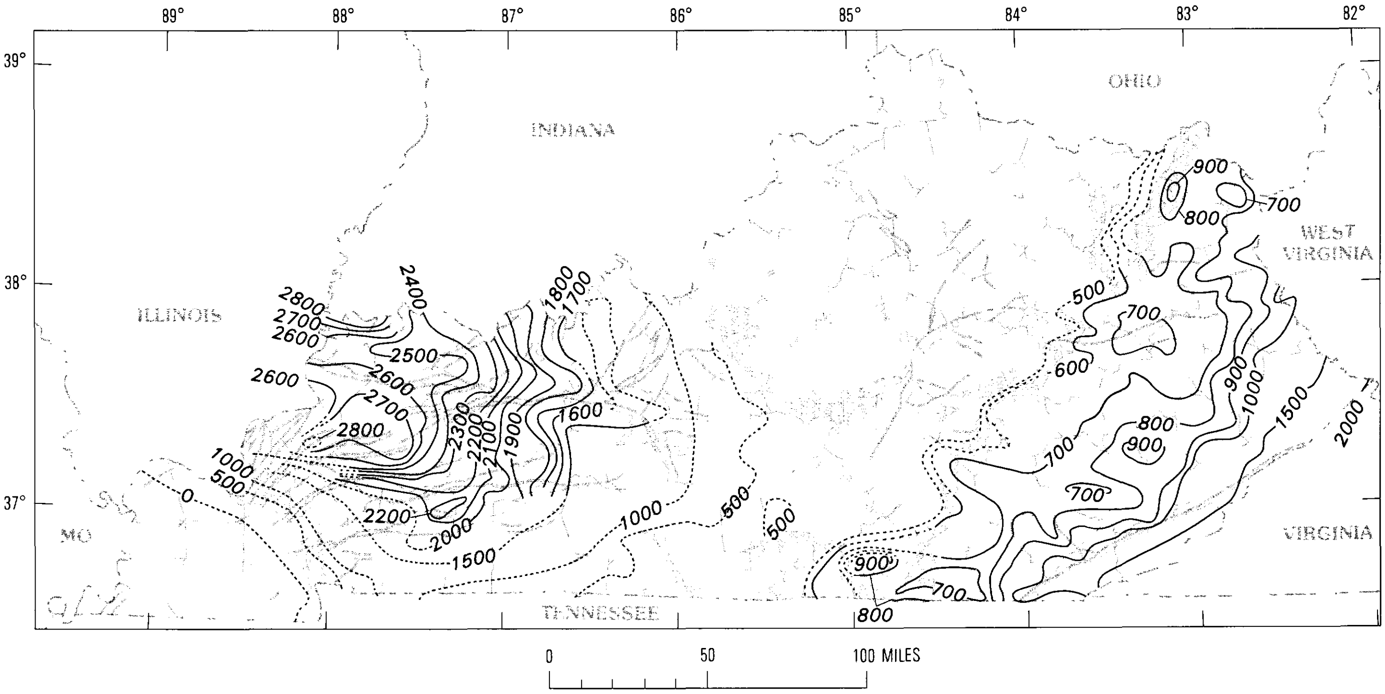


FIGURE 51.—Total thickness (in feet) of Mississippian rocks in Kentucky. Solid isopachs show thicknesses of strata underlying Pennsylvanian rocks; dotted lines where overlain by Cretaceous and Tertiary rocks or in exposure areas of Mississippian rocks. See figure 2 for distribution of units. Selected faults and fault zones shown on Kentucky base.

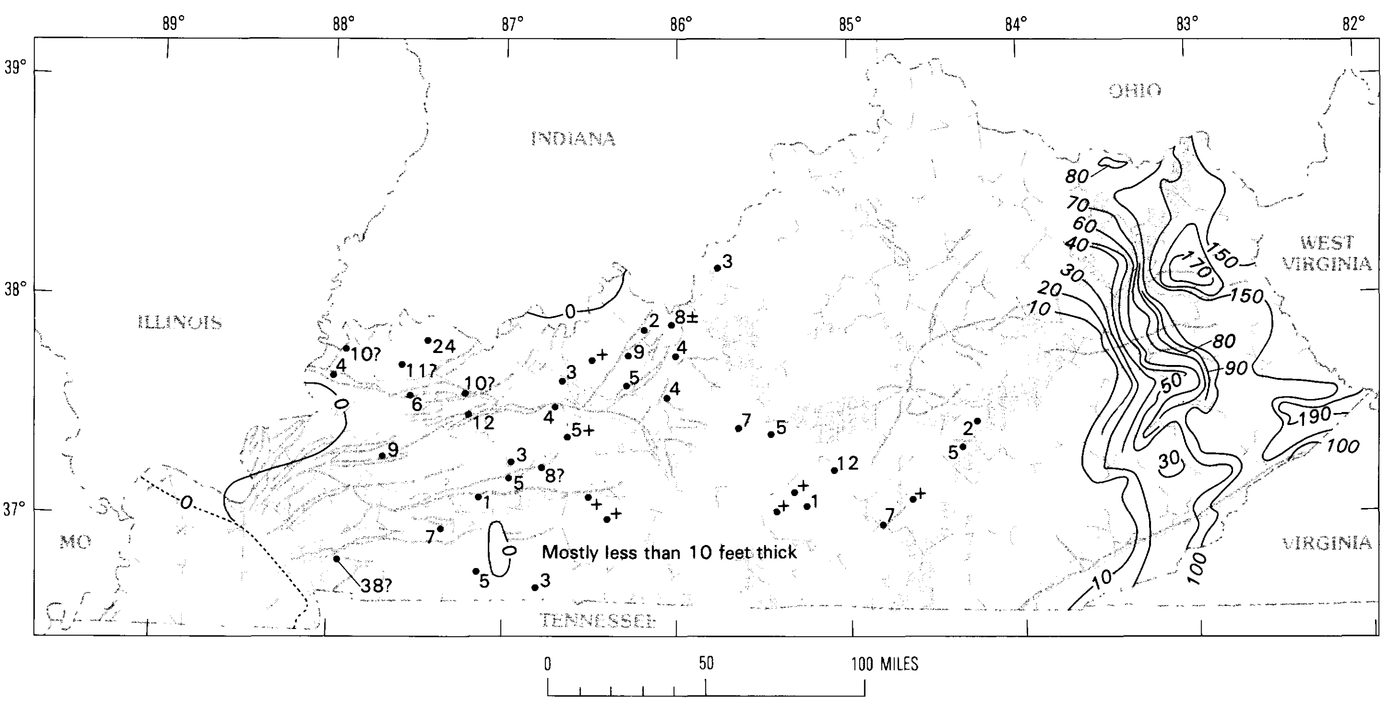


FIGURE 52.—Cumulative thickness (in feet) of Bedford Shale, Berea Sandstone, and Sunbury Shale in eastern part of Kentucky, and thickness of approximate age-equivalent strata (Maury Formation, Rockford Limestone, and Hannibal Shale equivalents) in other parts of Kentucky. +, thickness uncertain, less than 10 ft.

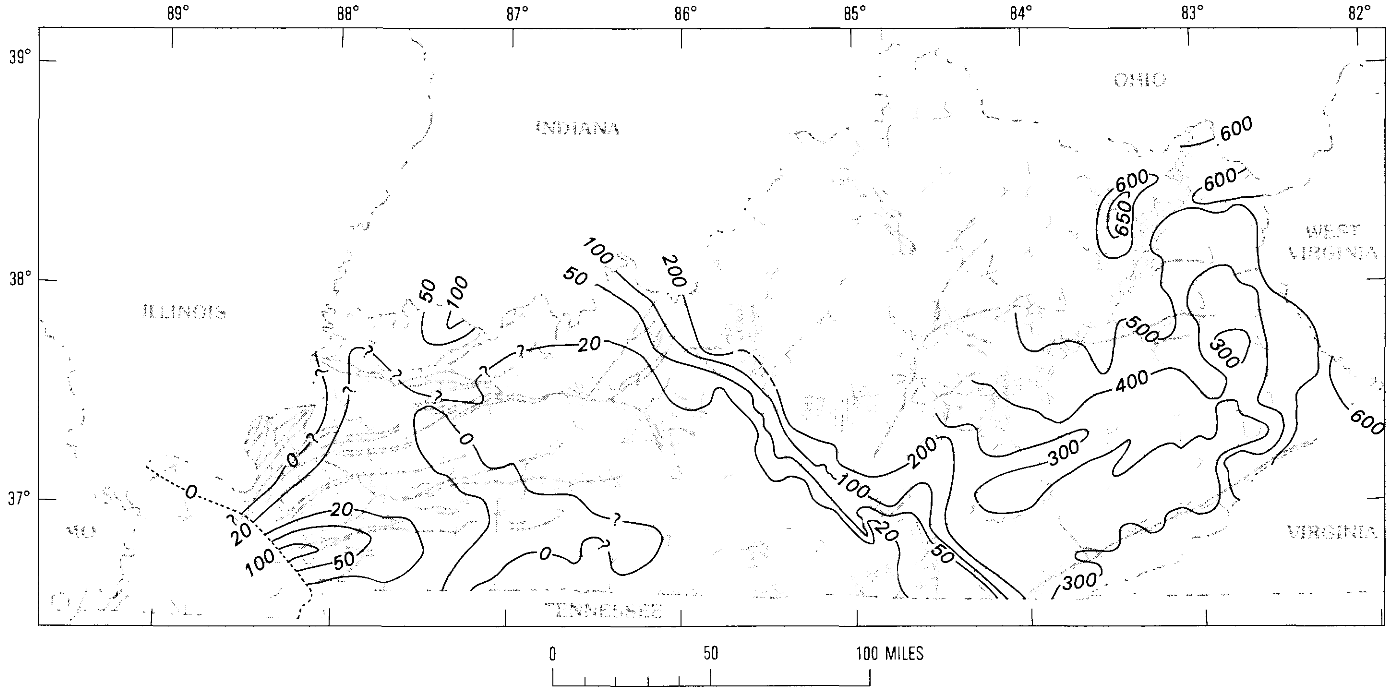


FIGURE 53.—Thickness (in feet) of terrigenous clastic units of the Borden Formation (New Providence, Nancy, Cowbell, Halls Gap, Wildie, Nada, Holtsclaw, Farmers, Kenwood), New Providence and Grainger Formations, and basal shale beds (New Providence Member) in the Fort Payne Formation.

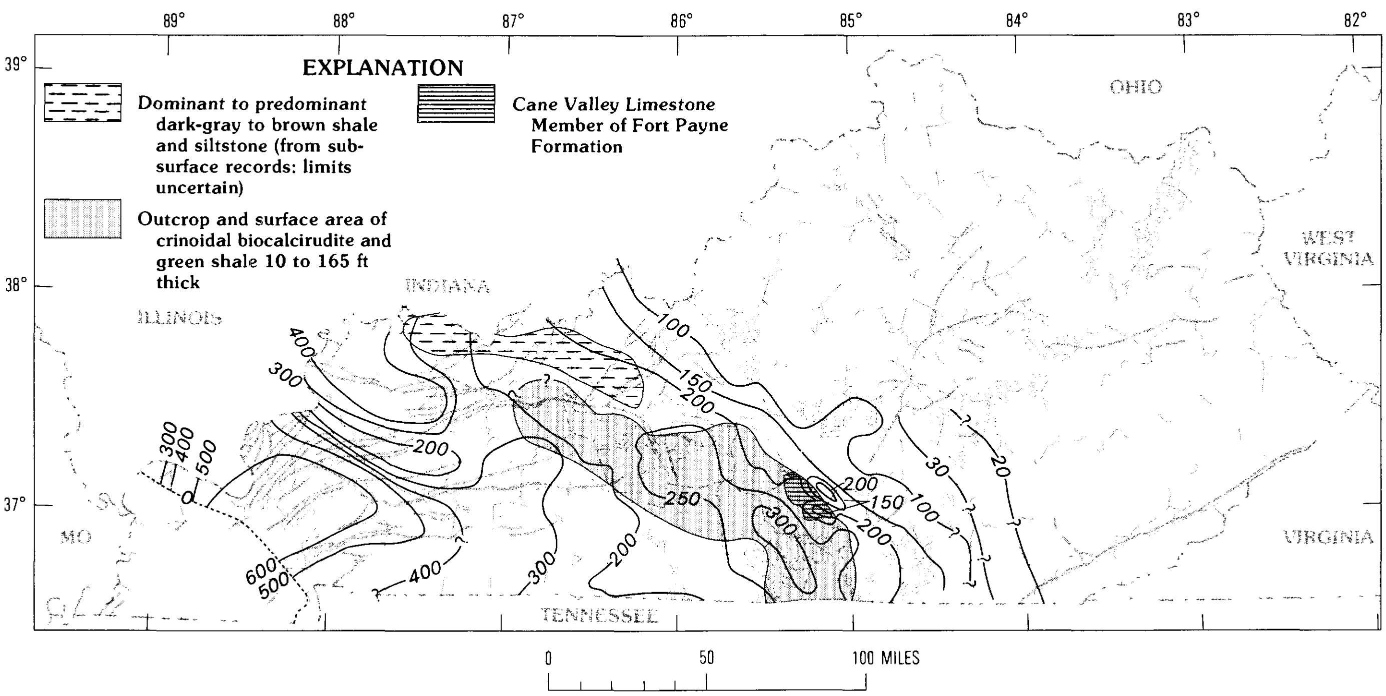


FIGURE 54.—Thickness (in feet) of Muldraugh Member of Borden Formation and of Fort Payne Formation exclusive of basal shale units, and showing distribution of unusual lithic components.

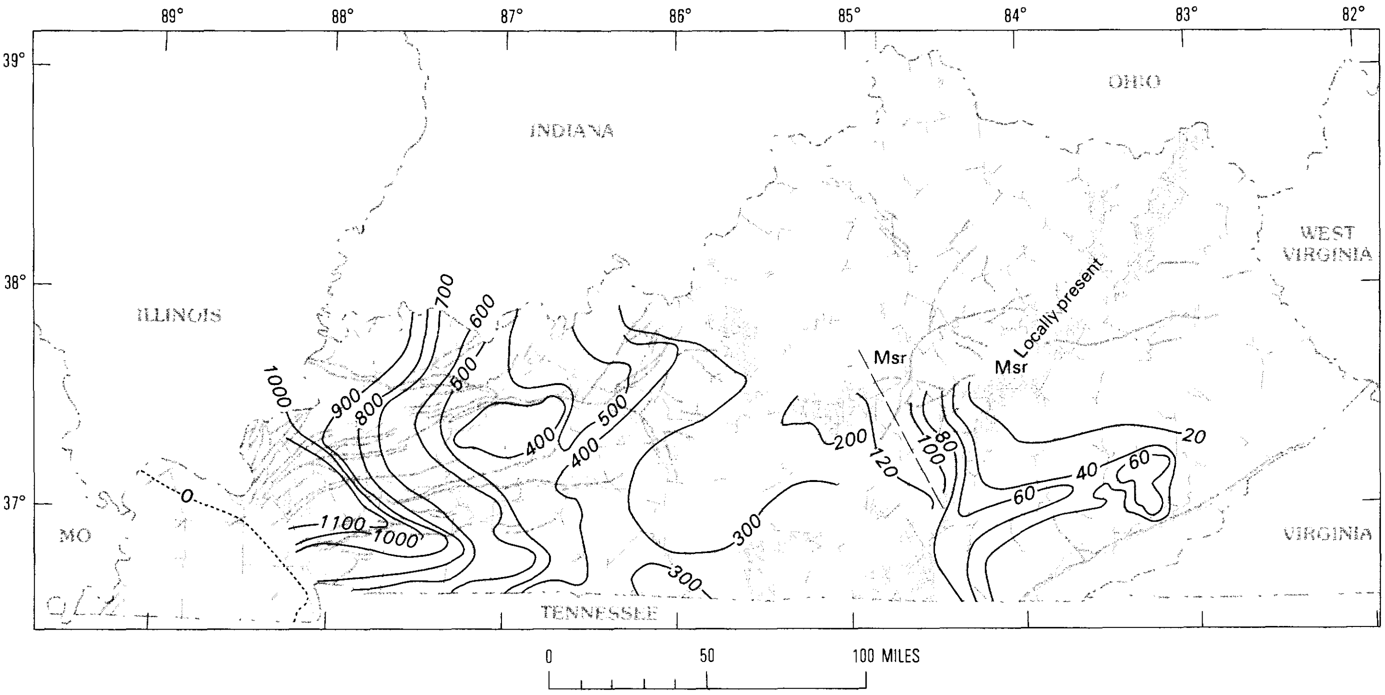


FIGURE 55.—Combined thickness (in feet) of Muldraugh-Fort Payne-Salem-Warsaw-Harrodsburg units in central to western Kentucky, and probable equivalent Renfro Member of Slade Formation (Msr) (previously of Borden Formation) in east-central and southeastern Kentucky. Dashed line is arbitrary cut-off of Renfro Member isopachs.

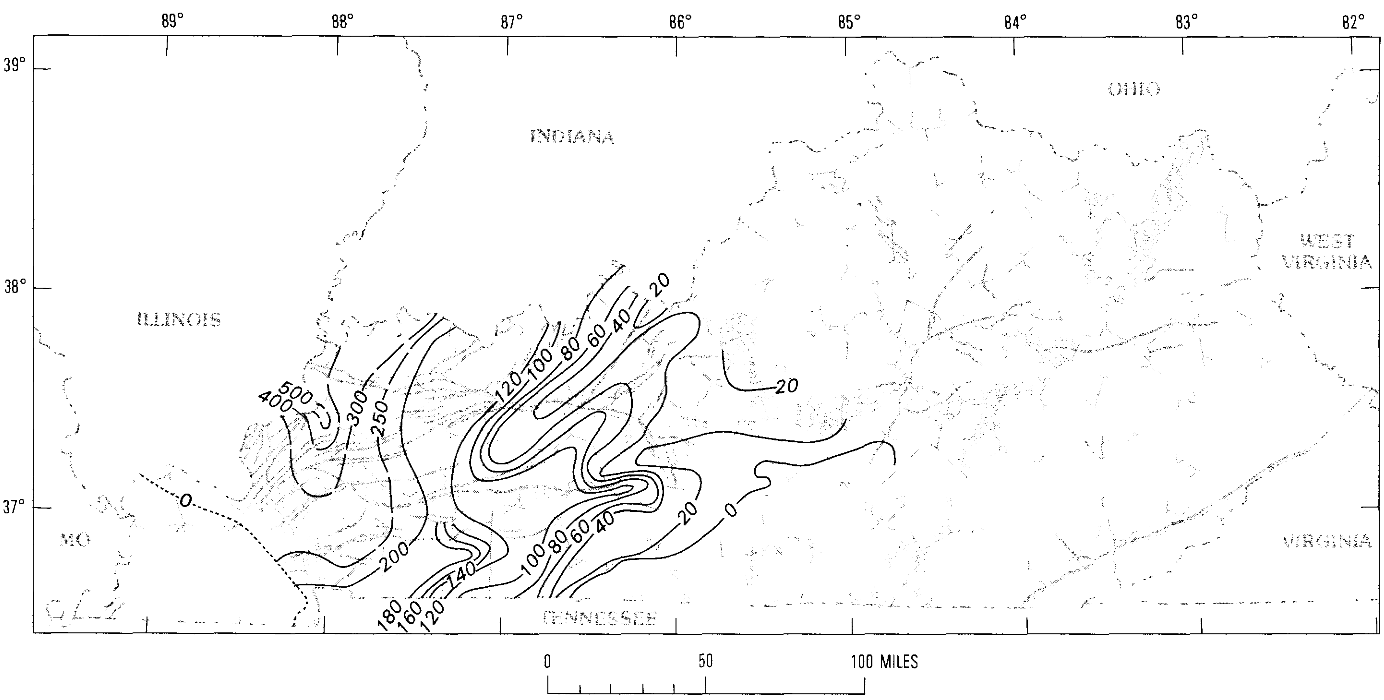


FIGURE 56.—Thickness (in feet) of Harrodsburg Limestone in central, south-central, west-central, and western Kentucky. Dashed isopachs in areas of little control.

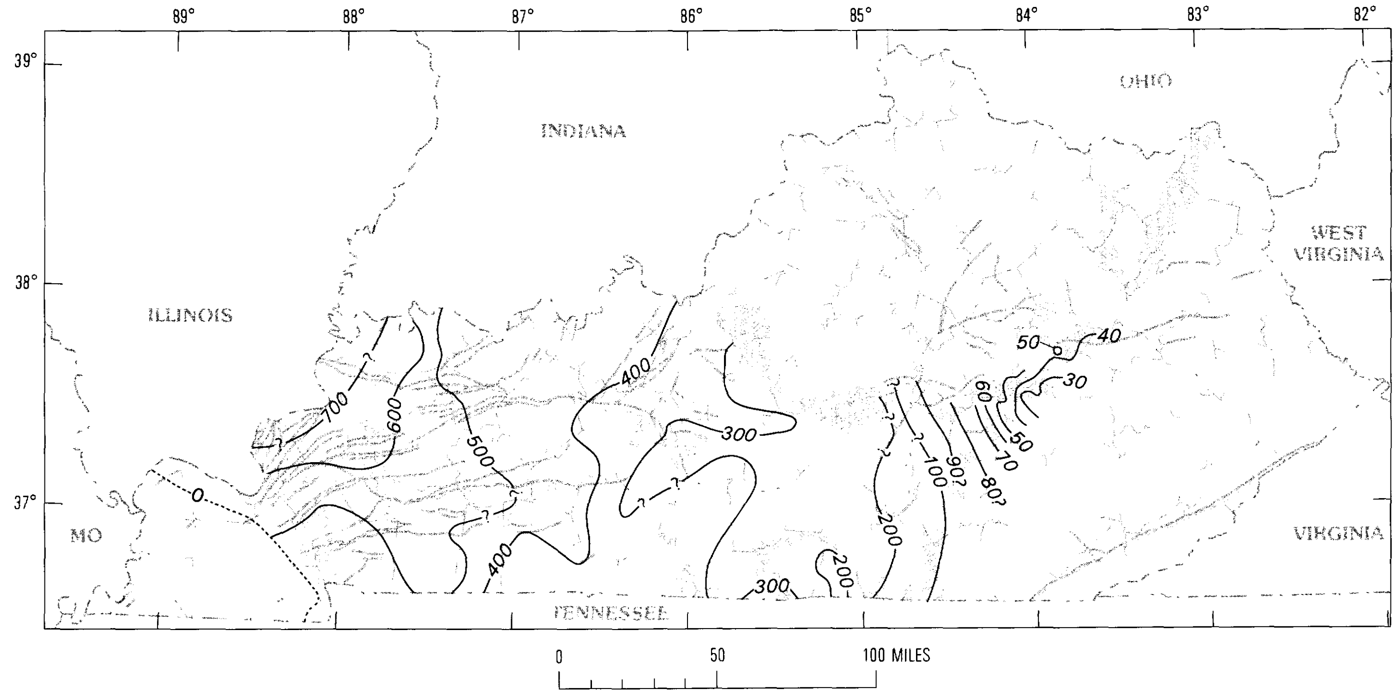


FIGURE 57.—Cumulative thickness (in feet) of Salem, Salem-Warsaw, St. Louis, and Renfro (excluding Muldraugh equivalents) units in Kentucky.

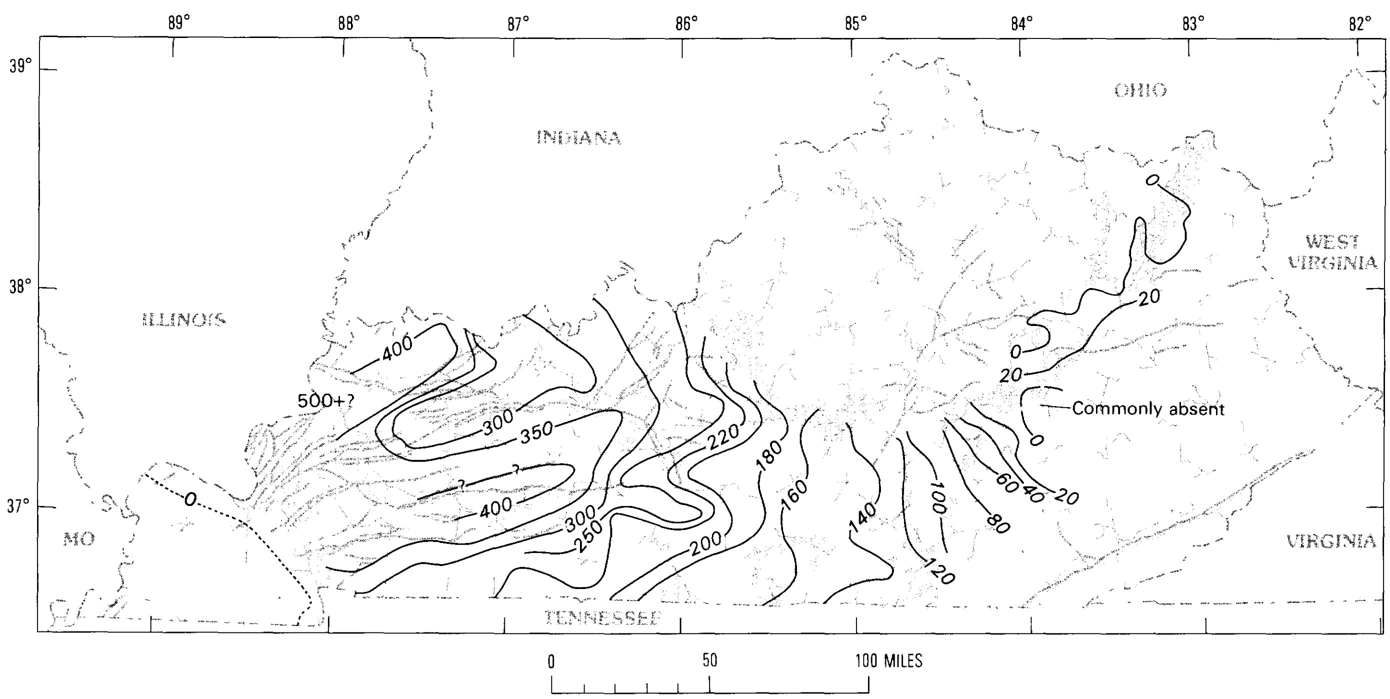


FIGURE 58.—Thickness (in feet) of St. Louis Limestone and St. Louis Member of Newman Limestone and Slade Formation. Top of unit placed at top of Lost River Chert Bed of Elrod (1899) in south-central and west-central Kentucky and inferred equivalent in western Kentucky.

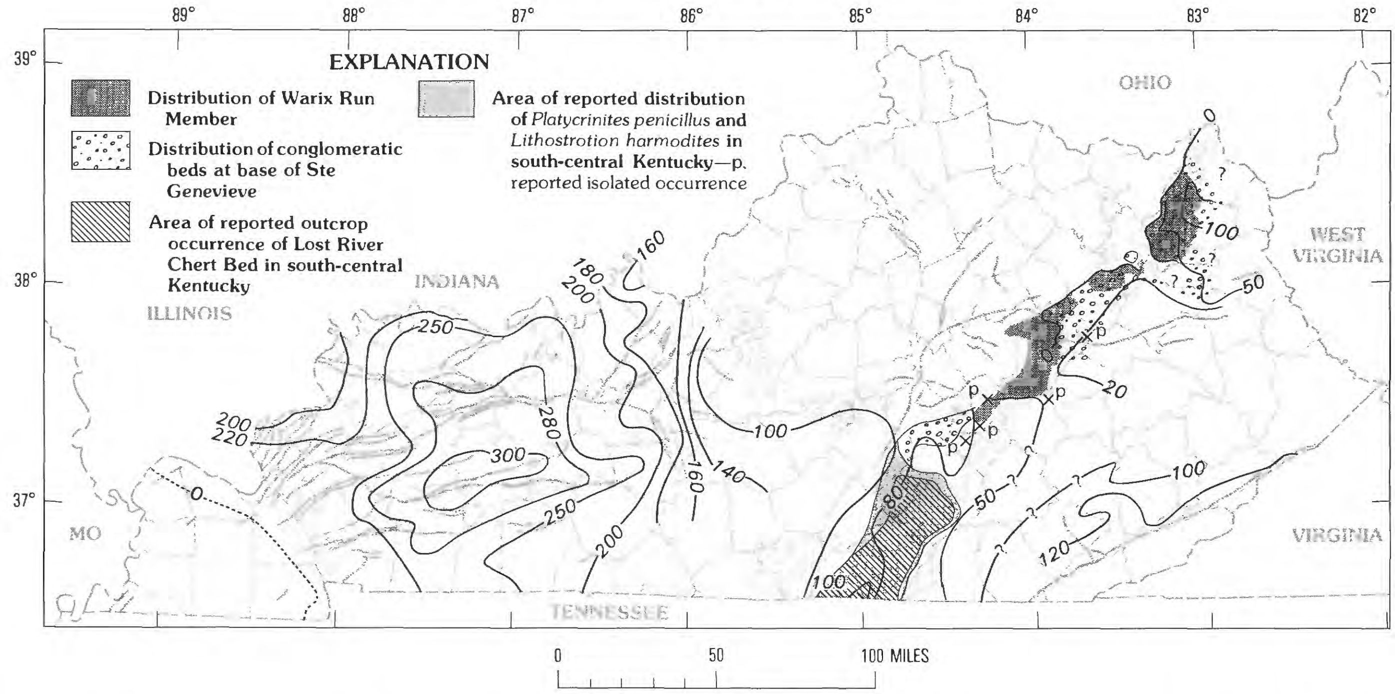


FIGURE 59.—Thickness (in feet) of Ste. Genevieve Limestone and probable and inferred equivalents (Warix Run and Ste. Genevieve Members of Slade Formation and Newman Limestone, and Ste. Genevieve Limestone Member of Monteagle Limestone). Base of Ste. Genevieve in west-central and western Kentucky placed at top of Lost River Chert Bed of Elrod (1899) or inferred equivalent.

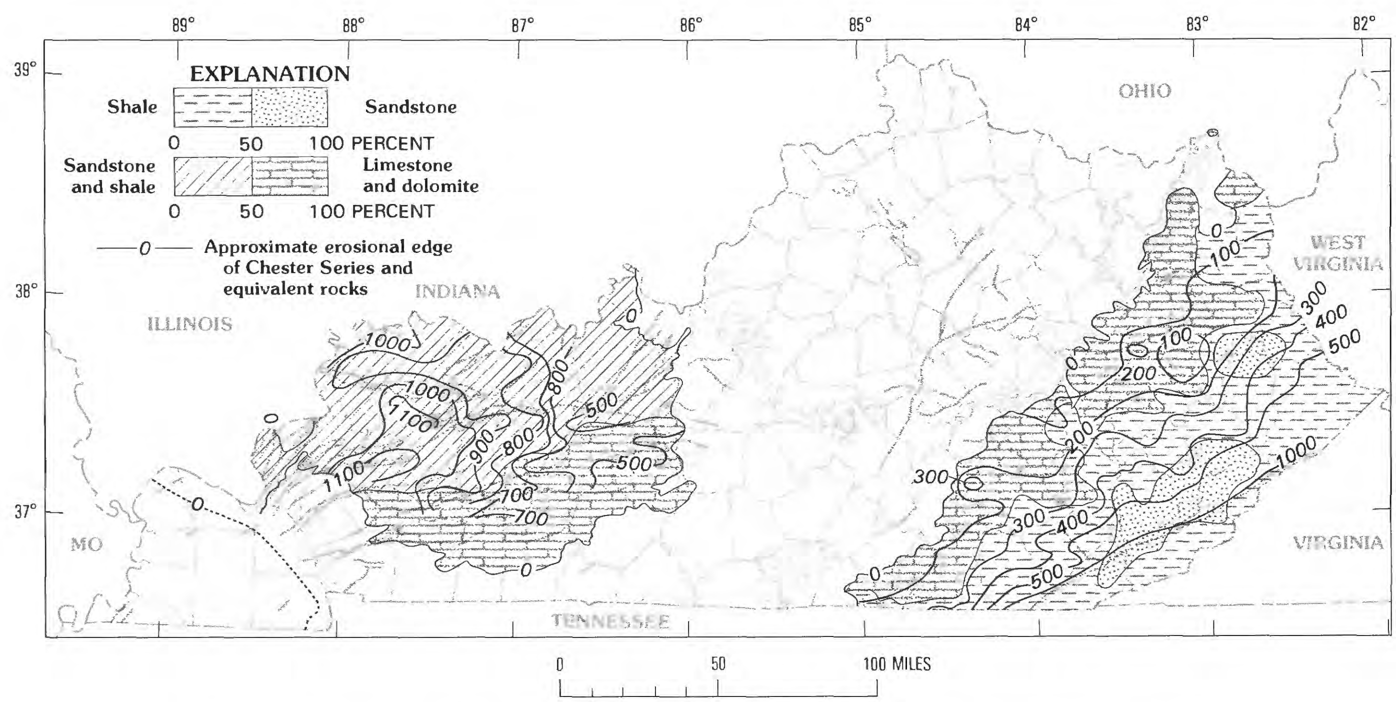


FIGURE 60.—Thickness (in feet) and generalized lithofacies of Chesterian rocks and equivalents in Kentucky.

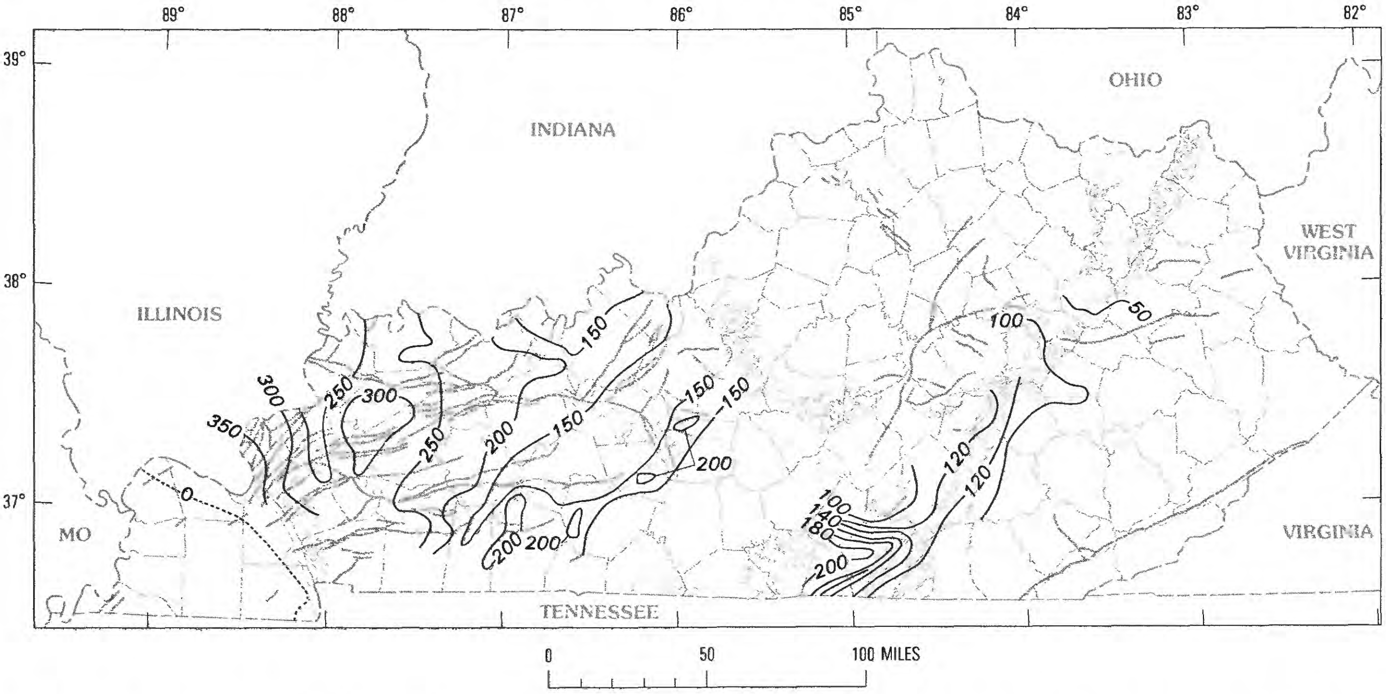


FIGURE 61.—Thickness (in feet) of Kidder Limestone Member of Monteagle Limestone and equivalents in eastern to south-central Kentucky, and cumulative thickness of Paoli Limestone through Elwren Sandstone, and Renault Limestone through Cypress Sandstone in west-central and western Kentucky.

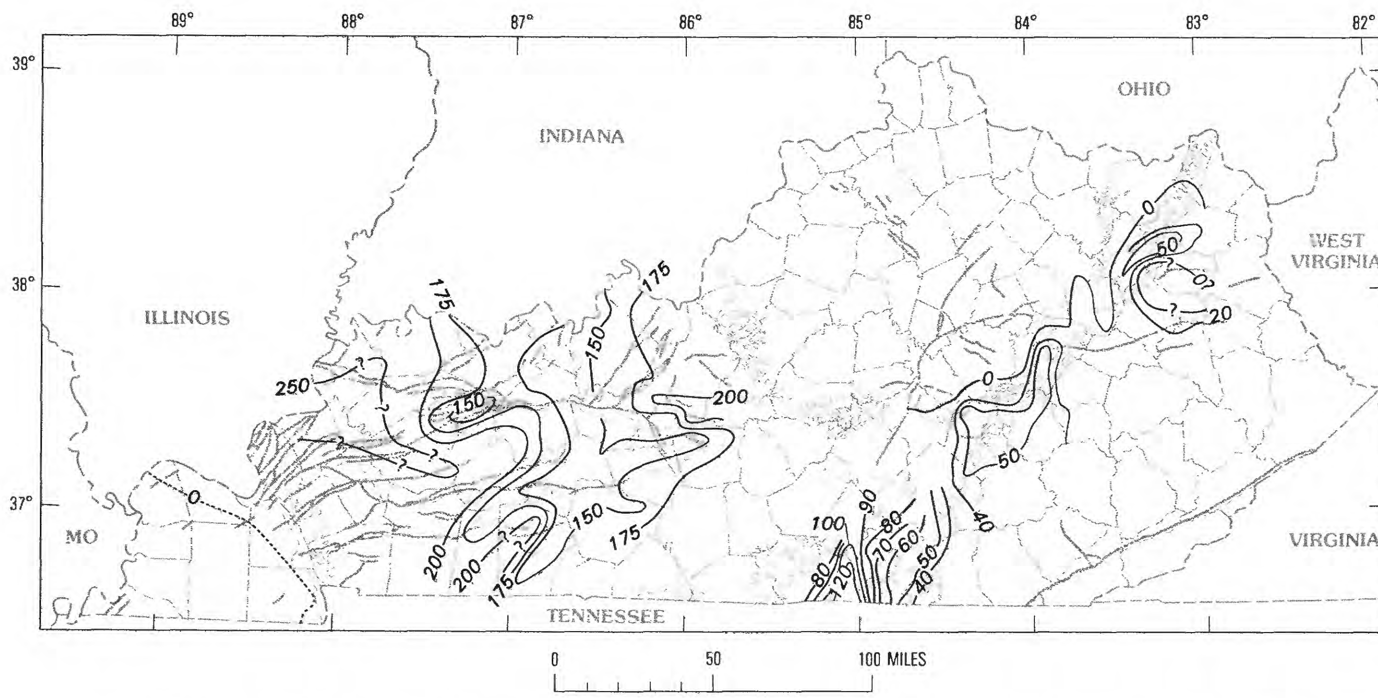


FIGURE 62.—Thickness (in feet) of combined Hartselle Formation and Bangor Limestone in eastern to south-central Kentucky and thickness of Golconda Formation in west-central and western Kentucky.

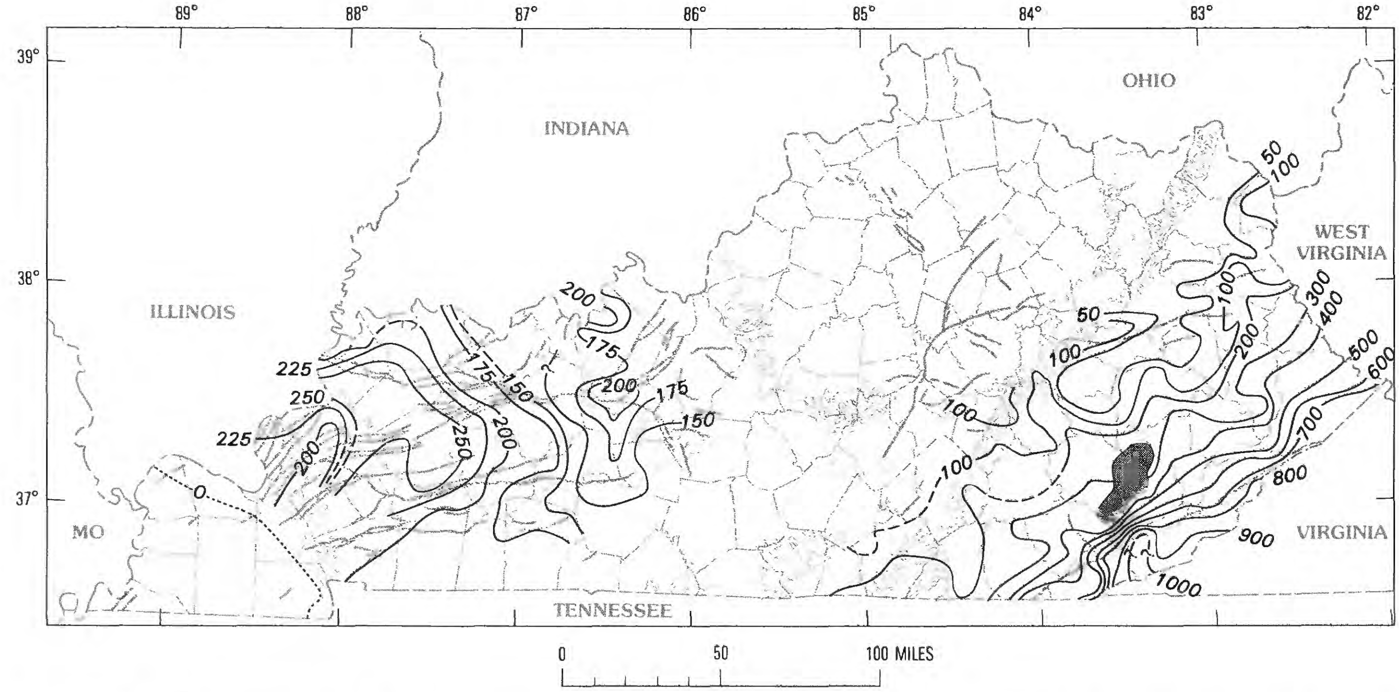


FIGURE 63.—Thickness (in feet) of Paragon and Pennington Formations in eastern to south-central Kentucky and combined thickness of Glen Dean–Tar Springs–Vienna–Waltersburg formational units in west-central and western Kentucky. Dashed isopach lines indicate approximate or inferred thickness. Area of anomalous thickness patterned.

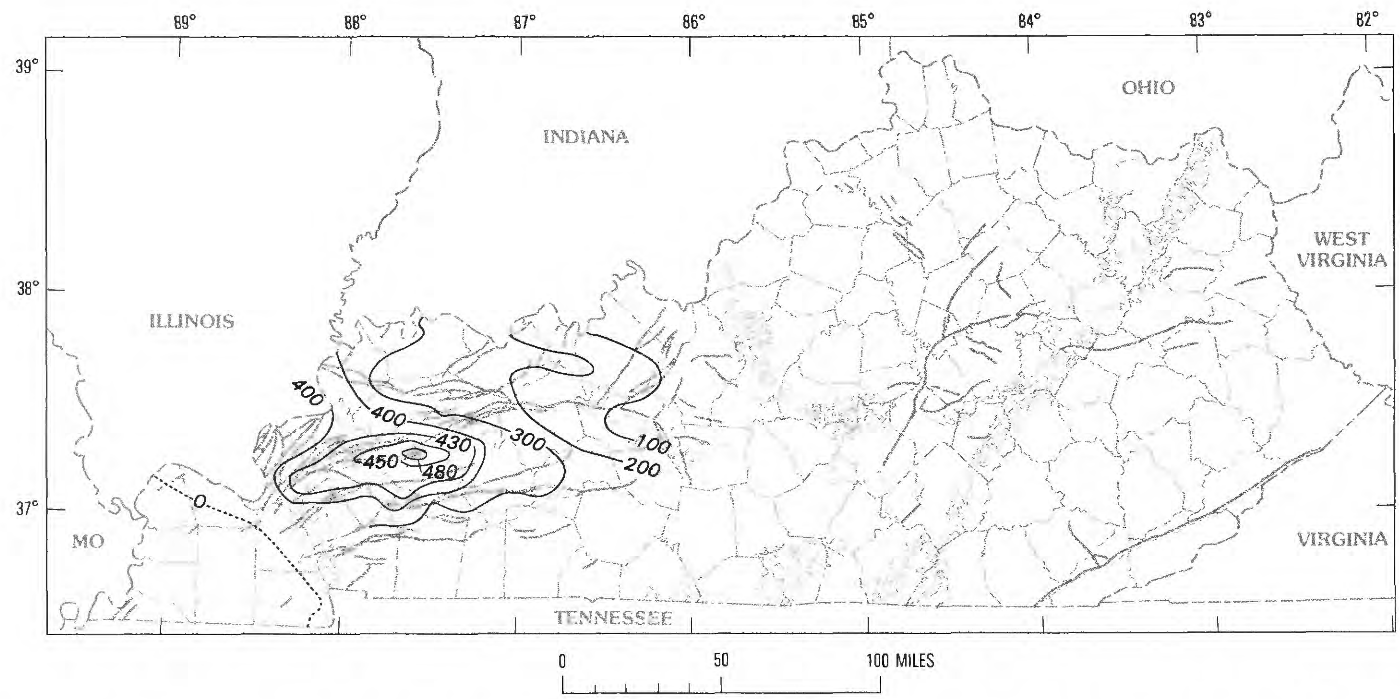


FIGURE 64.—Generalized thickness (in feet) of interval from base of Menard Limestone and equivalent units in Leitchfield and Buffalo Wallow Formations to base of Caseyville Formation (Pennsylvanian).

at different times in their nomenclatural history. These isopach maps were compiled by Sable, who has attempted to use criteria consistent with surface interpretation where possible. Because of the above factors, general thickness trends shown on the maps are considered to be valid, but positions of isopachs should not be considered to be exact. For instance, the known linear trend in the thick, narrow Bethel (Mooretown) sandstone-filled channel (see section, "Terrigenous clastic units," p. 74), is not adequately shown in the corresponding thickness map (fig. 60), which portrays the early Chesterian interval within which the Mooretown occurs (recall fig. 8). In the following discussion relating to figures 51–64, some reiteration of material previously discussed is included for the sake of emphasis.

Factors affecting the total thickness of Mississippian rocks (fig. 51) in Kentucky are post-Mississippian erosion, variations in Mississippian sediment volume distribution, and Mississippian tectonic movements. Erosional effects include regional beveling after deposition of Chesterian rocks but prior to deposition of Pennsylvanian strata, and Mesozoic and Cenozoic erosion that has stripped Mississippian rocks from the Pascola arch in westernmost Kentucky and the Cincinnati arch in central Kentucky. Thickness variations of Mississippian deltaic deposits in parts of the region, shifts in loci of detrital deposition, and filling of troughs peripheral to deltaic platforms by carbonate and detrital rock sediments appear to be less important factors than late- or post-Mississippian erosion in portrayal of present total thicknesses.

In western Kentucky, Mississippian strata thicken towards the Fairfield basin in Illinois to more than 2,800 ft in Crittenden County, western Kentucky. Deviations in general trend directions suggest control by warping along the Rough Creek–Shawneetown and Pennyrile fault zones. In eastern Kentucky, a broad, irregular northeast-trending platform area is represented by 700–900 ft of Mississippian strata, east of which the rocks thicken rapidly into the Appalachian basin. The thickest strata east of the Cincinnati arch trend are on the east side of the Cumberland saddle area in south-central and southeastern Kentucky, and locally in northeastern Kentucky east of the Waverly arch.

The clastic wedge of latest Devonian and earliest Mississippian rocks in Kentucky, comprising the Bedford-Berea-Sunbury units, is less than 200 ft thick. Isopachs of these units (fig. 52) indicate the distal parts of major deltaic deposits (Pepper and others, 1954), with minor depocenters in northeastern Kentucky, and southwest-trending lobes which are interpreted to reflect deltaic lobes originating east of Kentucky. The Pine Mountain fault does not appear to affect isopach trends.

In south-central and western Kentucky, clastic rocks of Kinderhookian age (Maury Formation and Hannibal Shale equivalents) are for the most part extremely thin (fig. 52), and their constitutents appear to represent lag deposits resulting from winnowing of distal deltaic deposits by bottom currents. Some areas in which Fort Payne or New Providence strata rest directly on the Chattanooga Shale, mostly in western Kentucky (see section, "Kinderhookian-Osagean unit relationships," p. 35), may indicate areas of mild uplift scoured by strong current action and swept clean of distal deltaic fines.

Isopachs of the terrigenous clastic units in the Borden, basal Fort Payne, New Providence and Grainger Formations (fig. 53) indicate an irregular depositional platform area in eastern Kentucky in which axes of the thicker clastic lobes trend southwestward, normal to the conspicuous northwest-trending Borden delta front slope deposits that extend in an almost straight-line trend from west-central through south-central Kentucky. The Borden delta front and the mildly irregular delta platform topography in eastern Kentucky represent the last phase and finally cessation of active Early Mississippian deltaic deposition in Kentucky. Southwestward paleoslopes were dominant, and eastern source areas were probably the important contributors to the sediment wedge as shown by distribution and transport indicators of some sandstones (fig. 16).

West of the Borden delta front, thin distal green shales are generally less than 20 ft thick, and locally absent in western Kentucky (fig. 53). A northwest-trending belt in which the carbonate and siliceous rocks of the Fort Payne Formation strata directly overlie the Chattanooga Shale occurs in the southern part of western Kentucky subparallel to the Borden front, and may indicate that a low submarine platform occupied this area during deltaic deposition. Another area in which basal clastics are absent is part of the fluorspar district of western Kentucky, which may have been a dome before collapse and mineralization. Southwest of this, however, a thickening of greenish shales interpreted here to be Osagean in age suggests the upper end of a westward-deepening mud-filled trough. Possibly the area in the fluorspar district was a low platform that acted as a barrier to sediments from the Borden delta of Illinois (Willman and others, 1975, p. 137) and the Borden delta deposits in Kentucky.

Carbonate-dominated units, which form the Muldraugh Member of the Borden Formation and the bulk of the Fort Payne Formation (fig. 54), thicken southwestward parallel to the Borden delta front across west-central and south-central Kentucky, and, farther west, thicken westward and southwestward to more than

400 ft towards the Fairfield basin of Illinois and to more than 600 ft into the Mississippi Embayment. Lithologies are mostly dark siliceous silty dolostones and silty limestones except for two northwest-trending belts of strikingly different strata recorded in subsurface sections: (1) a belt of crinoidal biocalcirudite with associated green shale which extends northwestward from the outcrop area of Cane Valley Limestone Member of south-central Kentucky, and (2) a dominantly dark gray to brown shale and siltstone, in places more than 200 ft thick, occupying most of the interval which is commonly siliceous carbonate rocks. The shale belt is parallel to the biocalcirudite–green shale belt, and on strike with the Knifley Sandstone Member of the Fort Payne Formation of south-central Kentucky. (See section, "Fort Payne Formation," p. 48.)

The biocalcirudite–green shale interval in the Fort Payne Formation largely coincides with a northwest-trending belt of thicker Fort Payne strata. The greater thickness is inferred to be the result of uneven depositional bottom topography rather than filling of a tectonically controlled depression. Spatial relationships and directional trends of the crinoidal biocalcirudite and green shale and the related Cane Valley Limestone Member, the dark shale unit, the Knifley Sandstone Member, and the Borden delta front indicate genetic relationships of these features. The biocalcirudites and green shale formed southwest of and adjoining the Knifley Sandstone Member and the dark shale unit. The dark shale unit may be equivalent to the Knifley, a distal fine sediment winnowed from the Knifley sands by longshore currents and deposited to the northwest by them. The crinoidal limestones and the green mudstones, rather than being a slope edge deposit derived from an area of delta platform origin as interpreted by Sedimentation Seminar (1972), may have been submarine bank deposits growing in a peridelta belt proximal to the deltaic bottom slope deposits and swept by currents that maintained a nutrient supply, but from which muds were trapped by the in-place crinoid organisms. Green coloration of the muds may indicate accumulation in a mildly reducing, open circulation environment. Basinwards, darker sediments accumulated more slowly perhaps in a deeper anoxic environment, as indicated by the tabular bedding and fine-grained to aphanitic character of much of the Fort Payne strata.

In figure 55, cumulative thicknesses are shown for all pre-St. Louis carbonate-dominated units of Osagean and Early Meramecian age, including the Harrodsburg, Salem, and Warsaw Limestones. In this and in the Harrodsburg Limestone thickness map (fig. 56), westward-thickening strata culminate in a west- to northwest-trending trough trending toward Fairfield basin of Illinois. The 300-ft isopach on figure 55 encompasses a broad area in west-central and south-central Kentucky, roughly reciprocal with the thickness trends shown for the Muldraugh–Fort Payne carbonate rock thicknesses in figure 54.

Thicknesses of the Renfro Member in southeastern Kentucky (fig. 55) are derived mostly from subsurface information, and correspond reciprocally with the thicknesses of the underlying Borden Formation clastic strata of figure 53. This type of relationship is considered to result from filling of underlying irregular depositional topography by the overlying carbonates. However, the degree of thickening into the trough in western Kentucky is not related to such causes, but indicates filling of a structural trough which either predated carbonate deposition, existing under starved basin conditions, or, more likely, which developed in late Osagean and early Meramecian time during carbonate sediment deposition.

Rocks of mostly Meramecian age (figs. 56–59) are best developed in parts of eastern and western Kentucky. Pre-Pennsylvanian and intra-Mississippian erosion has removed much strata from former areas of deposition in parts of northeastern Kentucky. Pre-Cretaceous erosion has removed very thick sections of rocks in westernmost Kentucky and southernmost Illinois. Thicknesses of Meramecian rocks (Sable, 1979a) range from 400 to more than 1,100 ft. The thickest accumulation of sediment was in western Kentucky, southern Illinois, and southwestern Indiana. Marginal to the Cincinnati arch in eastern Kentucky, thicknesses are generally less than 200 ft.

Strata of Meramecian age are predominantly carbonate rocks throughout the State. The bordering areas in which terrigenous detrital components are concentrated are those in which the upper, dominantly limestone units, such as the St. Louis and Ste. Genevieve, have been eroded; in south-central Kentucky (Cumberland saddle area) and western central Kentucky, fine detritals in the lower units such as the Salem and Warsaw make up a significant proportion of the strata that remain. Mudstone is also present in these units on the west side of the Cincinnati arch from southern Indiana to the Nashville dome in Tennessee. Quartz sand grains are present in the Ste. Genevieve Member of the Newman (Slade) and Warix Run Member of the Slade in northeastern Kentucky and their equivalents in southern Ohio and West Virginia, and farther south in eastern Kentucky.

The thicknesses of the Harrodsburg–Warsaw Limestone interval in western Kentucky, more than 300–500 ft in Trigg and Crittenden Counties (fig. 56), are interpreted to reflect filling of troughs peripheral to banks formed on earlier Fort Payne deposits. (See Dever and McGrain, 1969, fig. 6.) Westerly transport directions of carbonate debris and westward thickening into the Fairfield basin in Illinois are indicated. Of interest is the considerable volume of clean, winnowed and sorted bryozoan- and crinoid-bearing debris interpreted to originate from shoals on the surface of the older Borden delta and Fort Payne accumulations. The regional strike of the Harrodsburg Limestone in Kentucky is nearly at right angles to strike of the earlier Borden delta and to the strike of the Borden and Fort Payne carbonate units of figure 54. This seems to reflect general filling of peridelta areas and the basin in southern Illinois.

In Illinois, the St. Louis and the Salem Limestones have generally been considered to be intertonguing units so that their boundary cannot be considered to approximate a regional time rock boundary (Lineback, 1972). The field relationships and reciprocal thicknesses of the St. Louis and Renfro indicated by comparisons of quadrangle maps do not reflect the intergrading and interlensing of the two units as much as they do inconsistent mapping of the contact. In figure 57, the upper limit of the St. Louis is arbitrarily placed at the top of the Lost River Chert Bed in south-central, central, and west-central Kentucky and at the top of inferred equivalents in western Kentucky. The resulting thickness map shows a gradual thickness increase towards the Fairfield basin of Illinois; the regional strike of the isopachs swings from north-northwest east of the Cincinnati arch to northeast and east-northeast in western Kentucky, reflecting rather even basin filling and indicating that the irregular bottom topography which characterized the region during Borden deposition had disappeared probably by Salem or early St. Louis time.

Thickness of the St. Louis Limestone alone in Kentucky (fig. 58), shows a rather even basinward thickening similar to that discussed above. Difficulties of tracing both the base and top of this unit in western Kentucky, however, make thickness interpretations there uncertain.

The Ste. Genevieve Limestone and its equivalents represent largely shoal water deposition over a wide area. Isopachs of this unit and its presumed equivalents in eastern and southeastern Kentucky, the Ste. Genevieve Member of the Monteagle and Newman Limestones and Slade Formation (fig. 59), show an apparent westward-thickening trend across the Cincinnati arch and development of a distinct basin in western Kentucky south of the Moorman syncline. There thicknesses exceed 300 ft. Thicknesses in southeastern Kentucky are uncertain but appear to be generally about 50–75 ft, except for a few estimates along Pine Mountain, where strata in the Newman Limestone which are lithologically like the Ste. Genvevieve and contain *Platycrinites penicillus* are as much as about 100 ft thick.

All originally deposited thicknesses of Chesterian age rocks (fig. 60) in Kentucky have been modified by post-Mississippian erosion. The youngest known Mississippian units, the Kinkaid Limestone and Grove Church Shale, occur in the southern part of the basin in western Kentucky. There, nearly 1,200 ft of Chesterian Series rocks are recorded, but the original upper surface of the Mississippian deposits cannot be confidently restored. Within Chesterian units that are most widespread, however, the Glen Dean Limestone and older Chesterian strata thin towards the margins of the Eastern Interior basin; this thinning is considered to be depositional thinning towards uplifted belts.

Strata of the Chesterian Series and equivalents are more than 1,100 ft thick in both eastern and western Kentucky. The strata are thin or absent, however, in northeastern Kentucky in the Waverly arch area and along the margins of the Cincinnati arch. Irregular thicknesses along the east side of the Cincinnati arch are largely the result of irregular original thickness differences as affected by positive tectonic and irregular topographic features. The latter feature resulted from earlier intra-Mississippian erosion and to a lesser extent, from Late Mississippian or pre-Pennsylvanian erosion prior to deposition of the Lee and Breathitt Formations. In western Kentucky, basinal outlines are shown along the Moorman syncline and subparallel to the faults of the Pennyrile fault system.

Thicknesses of intra-Chesterian intervals (figs. 61–64) show the continuing basinal character of western Kentucky, but do not definitively show the Cincinnati arch trend. A depocenter in or near the Cumberland saddle area is indicated in figures 61 and 62, as is the influence of the Waverly arch either during or following deposition of the Paragon Formation (fig. 63). Thickening of sediments towards the present Pascola arch in early and middle Chesterian time (figs. 61–63) indicates that the arch area was still negative, but isopachs of latest Chesterian strata (fig. 64) show an east-west-trending basin along the Pennyrile fault system, suggesting that the arch began to grow before the Mississippian-Pennsylvanian erosional interval began. In the eastern part of Kentucky, isopachs of rocks show a northeast-trending belt of variable sediment thickness ranging from 150 to more than 200 ft which, taken with the dominant carbonate lithofacies, seems to reflect a trend of carbonate banks fringing the Appalachian basin (fig. 60).

In summary, the selected thickness maps of the Mississippian and maps showing lithologic trends (Craig and Connor, 1979) reflect the onset of deltaic deposition in eastern Kentucky during Late Devonian and Early Mississippian time followed by the main southwestward progradation of the Borden delta. A trough or depocenter was maintained in extreme southwestern Kentucky during Kinderhookian(?) and early Osagean time. This shifted northward in late Osagean and early Meramecian time, and concurrently a southwest-dipping paleoslope developed. Depositional infilling west of the present Cincinnati arch appears to have slowed by middle Meramecian (middle and upper St. Louis) time. In western Kentucky a shallow depositional basin developed, the depocenters of which appear to have shifted throughout Chesterian time. This shifting may have been in part due to tectonic causes such as sags along the Pennyrile fault system, and in part to depositional deltaic depocenters, depending on whether tectonism or sediment load was a more important factor.

In eastern Kentucky, history of downsinking of the northeast-trending Appalachian basin is not well documented in this report because reliable subsurface information is scarce. Early Mississippian strata of the Borden show little indication of strong northeast linear trough development. Rocks considered equivalent to the St. Louis, Ste. Genevieve, and Chesterian strata below the Paragon and Pennington likewise show no appreciable basinal thickening in Kentucky, but Pennington strata do show a decided southeastward thickening, which may reflect both tectonic downsinking and loading response to Pennington sediments.

The role of the Cincinnati arch in Kentucky during the Mississippian is not clear. Judging from the isopach thicknesses and trends, the arch seems to have been rather quiescent or only mildly active until late Chesterian time. The Waverly arch also does not seem to have exerted control of sediment thicknesses until post-St. Louis time. Between Osagean and Chesterian time, the area of the Cincinnati arch in Kentucky may have been a broad, irregular platform downwarped to the west, with vague northeast- to north-trending hingelines west of the present arch axis. Subsequent growth of the arch is shown by the apparent increased rates of thinning of St. Louis, Ste. Genevieve, and Chesterian age strata towards the arch in south-central Kentucky. The average thicknesses of St. Louis beds west and east of the present Cincinnati arch are about 229 and 166 ft respectively, with a thickness ratio west:east of 1.4. Beds of the Ste. Genevieve average about 166 and 68 ft thick respectively, with a ratio west:east of 2.4. Depositional rates thus appear to have increased from St. Louis through Ste. Genevieve time within Kentucky, with areas to the west demonstrating a greater relative amount of downsinking during this interval. During Chesterian time and the post-Mississippian–pre-Pennsylvanian interval, the arch seems to have been well developed, as indicated by the Bethel (Mooretown) channel remnants which cut progressively older Mississippian strata northeastward, and by the basal Pennsylvanian channel remnants in central Kentucky, which also cut progressively older Mississippian strata eastward.

CYCLIC DEPOSITION

Two major pulses of terrigenous detrital sediments during Mississippian time followed deposition of the Sunbury Shale, which overlies the shallow- to deep-water deltaic Bedford-Berea units. These terrigenous pulses resulted in the Borden-Grainger offshore delta units and the rhythmic Chesterian lower delta plain deposits. The two pulses were separated by a widespread shallow-water marine transgression in which extensive carbonate rocks as well as minor evaporites were deposited. Transitional units between the earlier deltaic deposits and the carbonate-dominated succession are the Muldraugh and Renfro Members of the Borden Formation and siliceous carbonate rocks of the Fort Payne Formation.

The Devonian-Mississippian Bedford-Berea-Sunbury units become finer grained upwards, but in the eastern United States, including most of Kentucky, conditions favorable to carbonate sedimentation did not occur until after the pulse of clastics of the Borden-Grainger succession. However, the organic, low-energy Sunbury Shale is probably the eastern time equivalent of extensive carbonate rocks in Indiana, Illinois, Missouri, and Iowa, and thus may represent the late stage of a regional broad cycle of deposition. Cessation of Borden deltaic deposition and subsequent infilling by the upward-fining carbonate succession culminating in the St. Louis carbonate and evaporite strata may represent a second broad cycle. The Ste. Genevieve does not in itself seem to fit neatly into a cyclic framework, but thinner rhythmic upward-fining units are reported within the Ste. Genevieve (Sandberg and Bowles, 1965) and are discussed herein.

St. Louis lithologies reflect very low energy environments and probably represent protected lagoonal and shallow bay conditions over a large area. Internal cyclicity is reflected by upward-fining successions generally beginning by a pulse of fine terrigenous debris, green shales such as those reported in quadrangles in west-central Kentucky (Kepferle, 1963b; Withington and Sable, 1969), and associated fine-grained calcarenites and calcsiltites with scattered fossils which grade upward into calcilutite limestone. Because the St. Louis is very poorly exposed, little evidence for cyclical repetitions is recorded from surface exposures. However, in exploratory well cores, Kepferle and Peterson (1964) recorded upward alternations of oolitic crossbedded limestone to fine-grained dolomitic limestone and dolomite to fine-grained micritic limestone capped by cherty micritic limestone. (Also see Fox and Seeland, 1964; Seeland, 1968.)

Examples of cyclicity in Ste. Genevieve strata prior to the rhythmic repetition of Chesterian carbonate and clastic strata are discrete units of widespread sandstone and green shale in the upper part of this otherwise carbonate-dominated unit. Shales which may be Spar Mountain Sandstone equivalents and units referred to the Aux Vases Sandstone (Amos, 1971, 1972) and Rosiclare Sandstone Member (Amos, 1965) are examples of periodic interruption of the dominantly carbonate depositional regime. These shales in themselves do not necessarily support a hypothesis of cyclicity, because they may simply be the results of lateral migration of deltaic channels and channel splays in a general downsinking region. However, in south-central and the southern part of west-central Kentucky, the Ste. Genevieve Limestone and the overlying Girkin Limestone display rhythmic alternations of carbonate rocks. Units of crossbedded sandy or oolitic limestone are overlain by fossil fragmental and micritic limestone and capped by cherty limestone (Sandberg and Bowles, 1965). Upward-coarsening cycles are also recognized in the Girkin (Dever and Moody, 1979b). Columnar sections in other quadrangles (Sable, 1964; Ulrich, 1966) suggest similar cyclicity in which crossbedded oolitic or sandy limestone and green shale represent repetitive breaks in otherwise similar-appearing sections. In the lower part of the Ste. Genevieve, a succession of alternating dolomite and oolitic limestone 30 ft thick has been recognized in Breckinridge, Hardin, Hart, and Warren Counties. As more detailed information becomes available, intraformational cyclic successions such as the preceding may become valuable correlation indicators.

In east-central and northeastern Kentucky, columnar sections of considerable detail (Delaney and Englund, 1973; Gualtieri, 1967b; McFarlan and Walker, 1956, pl. 2) show lithologic repetition which has been ascribed to relatively local tectonic movements of the Waverly arch and along the Kentucky River fault system (Dever and others, 1977). In these sections, thin units of subtidal oolitic and sandy limestone, irregularly bedded micritic limestone, dolomitic limestone, cherty limestone and green shale, or a part of this succession are broken by breccias with dark micritic matrix interpreted to represent subaerial exposure or vadose zones (Dever and others, 1977). Associated structures include birdseye texture and contorted piercement "tepee" structures that attest to repeated submergence and emergence during Chesterian and late Meramecian time. Interpreted from a tectonic viewpoint, the above evidence might indicate repeated oscillations of the source area as well as tectonic- or otherwise-induced sea-level movements within the depositional area.

Causes for the apparent cyclical sedimentation in the Chesterian are unresolved. J.M. Weller (1956) suggested that tectonism was chiefly responsible for late Paleozoic cyclicity. Swann (1964, p. 656–657) considered climatic fluctuations, primarily changes in rainfall in the source region of the Michigan river combined with even basin subsidence, to be the chief factor. He (Swann, 1964, p. 654) also cited eustatic sea-level changes as possible factors in some cycles in the upper Chesterian series, and suggested that alternation between pluvial and interpluvial stages corresponded to fluctuations of the margins of continental glaciers in the southern hemisphere. About 13 world-wide synchronous depositional sequences of Kinderhookian through Chesterian ages resulting from eustatic sea-level changes were postulated by Ross and Ross (1985). Major regressions include those in early Kinderhookian, early and middle Meramecian (St. Louis evaporites), and latest Chesterian times. They cited possible mechanisms for the eustatic changes to include oceanic crust volume changes, ocean trench activity, and orogenic activity along continental margins. "Jostling" of continental plates during a mid-Paleozoic collision of northeastern North America and Europe (Craig and Varnes, 1979) may have periodically uplifted source areas and may be a realistic tectonic concept to account for apparent cyclicity.

PALEONTOLOGY

During the geologic mapping program, fossils were used as practical mapping aids during quadrangle mapping. Paleontologists of the U.S. Geological Survey assisted in field identifications of genera and species of macrofossils, and in some instances laboratory determinations of fauna and flora. An excellent summary of the paleontological zonation of Mississippian rocks in the United States (Dutro and others, 1979) included discussions of foraminiferal, brachiopod, ammonoid, and conodont zonation.

MACROFOSSILS

Taxonomy and zonation of macrofossils in Mississippian rocks stem from extensive early studies in Kentucky and adjacent States by S. Weller (1920, 1926), J.M. Weller (1931), Butts (1915, 1917, 1922), and E.O. Ulrich (1917), and others, reviewed and updated by Weller and Sutton (1940). Crinoids, brachiopods, blastoids, bryozoans, solitary and colonial corals, and echinoids are dominant forms in the Mississippian assemblage; pelecypods, gastropods, and trilobites are locally abundant. Crinoid studies by Horowitz (1965), and biofacies studies of a Chesterian rock unit (Vincent, 1975) are two examples of the many selective studies done in recent years.

One significant break in the crinoid fauna marks the Meramecian-Chesterian Series boundary in western, west-central, central and south-central Kentucky—that between strata containing *Platycrinites penicillus* Meek and Worthen, a Meramecian form, and strata containing Chesterian forms of *Talarocrinus* spp. The faunal change corresponds to the time of formation of a widespread zone of altered limestone and breccia (Bryantsville Breccia Bed) interpreted to have developed during subaerial exposure and diagenesis. Other series boundaries, with the possible exception of the Kinderhookian-Osagean boundary, appear to occur within intervals of continuously deposited strata, and faunal criteria for specific boundary demarcation are not conclusive. However, many specific and generic forms have proved valuable aids in practical recognition and mapping of stratigraphic units. Figure 65 shows general stratigraphic occurrences of selected fossil faunal elements which have been helpful in discriminating Mississippian rock units in Kentucky.

Macrofossils of Late Devonian and Kinderhookian ages are scarce in Kentucky. Sparse brachiopod and molluscan faunas in the New Albany, Chattanooga, Ohio, Bedford, and Sunbury Shales present difficulties in determining the systemic boundary (Campbell, 1946). Studies of macrofloras by Cross and Hoskins (1951, 1952) in regard to the Devonian-Mississippian systemic boundary were also generally indeterminate and in some cases contradictory to age determinations of macrofossil assemblages. Savage and Sutton (1931) concluded that the lower part of the black shale (New Albany (Chattanooga)) in Allen County, Ky., is Devonian and the upper part Mississippian.

Macrofossils in units of mostly Osagean age, the Borden, Fort Payne, Grainger and lower part of the Harrodsburg, are generally uncommon and scattered in terrigenously derived clastic strata. Fossil remains consist largely of scattered crinoid columnal fragments and brachiopod shells, with minor bryozoan fragments. Locally, concentrations of a more varied, well-preserved fauna occur in thin limestone lenses in clay shale of the New Providence Member of the Borden, such as the localities at Buttonmold Knob, Bullitt County, and Kenwood Hill, Jefferson County (Butts, 1915, 1917; Conkin, 1957). The New Providence fauna has most recently been studied by Kammer (1982). In northeastern Kentucky, in Stricklett and Head of Grassy quadrangles, large spiriferoid brachiopods, crinoids, and bryozoans are locally abundant in the Cowbell Member of the Borden (Morris, 1965b, 1966a). Chaplin (1980) reported on fossil concentrations in the Nancy, Cowbell, and Nada Members of the Borden. Mason (1979) and Mason and Chaplin (1979) also described cephalopod faunas in the Farmers, Nancy, and Cowbell Members; and ammonoid faunas indicating westward progradation of the Borden in Kentucky are discussed by Gordon and Mason (1985). In the Borden, Fort Payne, and lower part of the Harrodsburg, biostromal accumulations of crinoid and bryozoan debris occur at various horizons. They include the Cane Valley Limestone Member and Beaver Creek limestone member which are thick and areally extensive in south-central Kentucky (Thaden and others, 1961; Sedimentation Seminar, 1972; Kepferle and Lewis, 1974). Biostromal lenses in which crinoid and other echinoderm fragments are common are also reported in the Fort Payne in western Kentucky (Rogers, 1963; Hays, 1964; Fox and Olive, 1966).

Macrofossils of Meramecian age, compared to the earlier Mississippian occurrences, are abundant and varied, particularly in the Salem, the Warsaw, the Salem and Warsaw map unit, and the Harrodsburg Limestone. Brachythyrid, spiriferoid, and productid brachiopods, solitary corals, echinoid spine and test fragments, fenestrate bryozoans, and ubiquitous crinoid columnals form calcarenitic, calciruditic, and coquinoid beds. Fossils are best preserved in limy shales (Lewis, 1971a; Kepferle, 1967) and are generally more fragmental in the coquinoid and marly fine-grained limestones and dolomitic limestones. Fewer forms are found in the St. Louis Limestone, which is largely micritic, containing scattered colonial corals, brachiopods, and echinoids; fenestrate bryozoans are locally common, as are crinoidal calcarenite and calcirudite. Faunal elements in the Ste. Genevieve are more abundant and varied than those in the St. Louis, and shelly coquinoid beds occur particularly in the upper part of the unit. Many of these are crinoidal biorudites and biocalcarenites in which stem segments and calyx bases of the crinoid *Platycrinites* are abundant.

Formations of Chesterian age in western to south-central Kentucky, consisting of rhythmically alternating units of limestones and detrital rocks, have abundant macrofossils in the carbonate rocks, and scattered remains in the clastic strata. Some carbonate units can be identified with a good degree of assurance by recognition of species of brachiopods, crinoids, and bryozoans and to a lesser extent of corals and pelecypods. Limy shales are locally very fossiliferous;

WESTERN

SERIES	Unit	Fossils
CHESTERIAN	Kinkaid, Menard, and Clore Limestones	*Spirifer increbescens* Hall *Composita subquadrata* Hall *Sulcatopinna missouriensis*
CHESTERIAN	Glen Dean Limestone	*Pterotocrinus* spp.* *Archimedes* spp.*
CHESTERIAN	Golconda Formation	
CHESTERIAN	Paint Creek and Renault Limestones	*Talarocrinus* spp.
MERAMECIAN	Ste. Genevieve Limestone	*Schoenophyllum aggregatum* "*Lithostrotion*" (*Siphonodendron*) *genevievensis* *Platycrinites penicillus* Meek and Worthen
MERAMECIAN	St Louis Limestone	*Acrocyathus proliferum* "*Lithostrotion*" *proliferum* Hall* *Acrocyathus floriformis floriformis* *Lithostrotionella castelnaui* Hayasaka* *Melonechinus* sp. *Syringopora* sp.
MERAMECIAN	Salem Limestone	*Endothyra baileyi* Hall *Hapsiphyllum* sp. *Brachythyris subcardiiformis* (Hall)
MERAMECIAN	Warsaw Limestone	*Echinocrinus* sp.* *Spirifer lateralis* *Pentremites conoideus* *Talarocrinus* sp.
?		
OSAGEAN	Fort Payne Formation	
OSAGEAN	New Providence Shale	

WEST-CENTRAL

Unit	Fossils
Buffalo Wallow and Leitchfield Formations	*Spirifer increbescens* Hall *Composita subquadrata* Hall
Glen Dean Limestone	*Pterotocrinus* spp.* *Prismopora serrulata* Ulrich *Archimedes* spp.*
Beech Creek and Haney Limestones	*Archimedes* spp.* *Inflatia inflata* (McChesney)*
Paoli, Beaver Bend, and Reelsville Limestones	*Agassizocrinus* spp. *Lithodromus veryi* (Greene) *Talarocrinus* spp.
Ste. Genevieve Limestone	*Schoenophyllum aggregatum* "*Lithostrotion*" (*Siphonodendron*) *genevievensis* *Platycrinites penicillus* Meek and Worthen
St. Louis Limestone	*Acrocyathus proliferum* "*Lithostrotion*" *proliferum* Hall* *Acrocyathus floriformis floriformis* *Lithostrotionella castelnaui* Hayasaka* *Melonechinus* sp. *Archeocidaris* sp. *Syringopora* sp.
Salem Limestone	*Endothyra baileyi* Hall *Brachythyris subcardiiformis* (Hall) *Hapsiphyllum* sp.
Harrodsburg Limestone	*Marginirugus magnus*
Borden Formation	*Orthotetes keokuk* (Hall) *Syringothyris textus* (Hall) Very large crinoid stem segments*

SOUTH-CENTRAL AND EAST-CENTRAL

Unit		Fossils
Pennington Formation		*Pterotocrinus* spp.
Bangor Limestone	Newman Limestone	*Archimedes* spp.*
Monteagle Limestone	Newman Limestone	Large crinoid stem segments* *Pentremites* spp.* *Agassizocrinus* spp. *Talarocrinus* spp. *Platycrinites penicillus* Meek and Worthen
St. Louis Limestone	Newman Limestone	"*Lithostrotion*" *proliferum* Hall *Lithostrotionella castelnaui* Hayasaka *Syringopora* sp.
Salem and Warsaw Limestones		*Hapsiphyllum* sp.
?		*Spirifer lateralis*
Fort Payne Formation		Very large crinoid stem segments*

FIGURE 65.—Stratigraphic occurrences of Mississippian fossil fauna, selected on basis of abundance and ease of identification, that are helpful in recognition of map units in Kentucky. Asterisk following name denotes very abundant forms. Lined areas denote intervals of largely terrigenous detrital strata.

shales in the Glen Dean Limestone and younger units are notable examples. Brachiopods in sandstones are locally common but mostly rare and scattered in such units as the Big Clifty and Bethel (Mooretown).

In east-central and northeastern Kentucky and along Pine Mountain, the lower Chesterian equivalents below the Cave Branch Bed are generally less fossiliferous than their western counterparts. Units in the upper parts of the section such as the Bangor Limestone and its equivalents and limy lenses in the Pennington Formation contain a more abundant macrofossil fauna. On Pine Mountain, Chesterian equivalents are considerably more fossiliferous than Meramecian units. In general, probable supratidal conditions and hypersalinity contributed to the dearth of fossil remains in the lower part of the Chesterian equivalent section; rapid clastic deposition and high turbidity probably inhibited the growth and abundance of forms now found in most of the Pennington Formation rocks.

MICROFOSSILS

The microfossils in Mississippian rocks of Kentucky include conodonts, endothyrid and paleotextulariid foraminifers, and ostracodes. Although no systematic studies of the entire system have been done in Kentucky, foraminiferal studies include those by Browne and Pohl (1973), Browne and others (1977), Conkin (1954, 1956, 1960, 1961), Pohl and others (1968), Pohl (1970), and Pohl and Philley (1971). Conodont studies, following zonation used in the Mississippi valley (Collinson and others, 1962, 1971), include those by Rexroad (1958, 1969), Nicoll and Rexroad (1975), Rexroad and Liebe (1962), Horowitz and Rexroad (1972), and Chaplin and Mason (1979).

Conodonts currently seem to be the most reliable faunal elements used in separating Devonian and Mississippian marine rocks (see section "Devonian-Mississippian systemic boundary," p. 32) and for zonation of Mississippian marine strata. Zones and ranges of conodont assemblages have been established in the upper Mississippi River valley (Collinson and others, 1962; Rexroad and Scott, 1964, reviewed in Collinson and others, 1971) (fig. 66). Their use in delineating the Devonian-Mississippian system boundary in the Eastern Interior basin has also been discussed by Sable (1979a) and in the Appalachian basin by de Witt and McGrew (1979) and Sandberg (1981). Locations of conodont collections from Upper Devonian and Lower Mississippian rocks in Kentucky are shown in figure 67; the collections are discussed below and in tables 3–6.

CONODONT IDENTIFICATIONS

Samples of Late Devonian and Early Mississippian ages were collected at scattered localities in east-central, south-central, and central Kentucky during the geologic mapping program. They were identified and commented on by J.W. Huddle. His identifications and comments are included in tables 3–6, arranged on the basis of stratigraphic position and geographic area of the samples collected.

Huddle (written commun.) commented in 1967:

> The interpretation of these collections [Samples USGS 22787-PC through 22794-PC] and those in KG-65-43 is not certain***. Most of the forms that were starred as possibly reworked are heavy forms that could stand transportation or remain in lag concentrates. It seems certain that the deposition in late New Albany and early New Providence time was very slow and gaps may be present, but the presence of phosphate nodules, fish remains and conodonts representing several zones suggests that the area was under water and the gaps are due to non-deposition and submarine erosion. The absence of the conodont zones in the lower part of the New Providence in southern Indiana and north-central Kentucky [central Kentucky of this report] was determined by Rexroad and Scott (1964).*** The sequence [uppermost New Albany Shale and lowermost Borden Formation] seems to be most complete to the southeast, in a diagonal tier of quadrangles from Burkesville to Panola. The *Bactrognathus-Taphrognathus* zone is at or near the base of the New Providence in the Lebanon Junction, Howardstown and New Haven quadrangles and the *Bactrognathus-Polygnathus communi* zone is present in the Shepherdsville quadrangle. The older Mississippian zones in these quadrangles in north-central Kentucky are thin or absent.

FLORA

Fossil plant remains occur as replacements by iron and manganese oxides and silica, and as carbonized woody fragments, tree trunks (some in growth attitudes) in sandstones such as the Big Clifty, and macerated plant remains in carbonaceous shale and thin coaly beds in the Bethel (Mooretown), Big Clifty, and younger units. Spores occur in the coaly parts of these Chesterian units and in the Pennington Formation (Ettensohn and Peppers, 1979). The zonation of plant microfossils in western Kentucky and in adjacent States Eastern Interior basin strata has established criteria for distinguishing Mississippian terrigenously derived clastics from lithologically similar Pennsylvanian strata (Jennings, 1977).

Rare lycopod occurrences in the basal part of the St. Louis Limestone of central Kentucky were reported by Browne and Bryant (1970) and from the Salem and Warsaw unit in south-central Kentucky by Dever and Moody (1979b). Concentrations of plant debris are reported in this part of the Mississippian succession in the Elizabethtown quadrangle (R.C. Kepferle, oral commun., 1965) and in the Rock Haven quadrangle (Sable, oral commun., 1968).

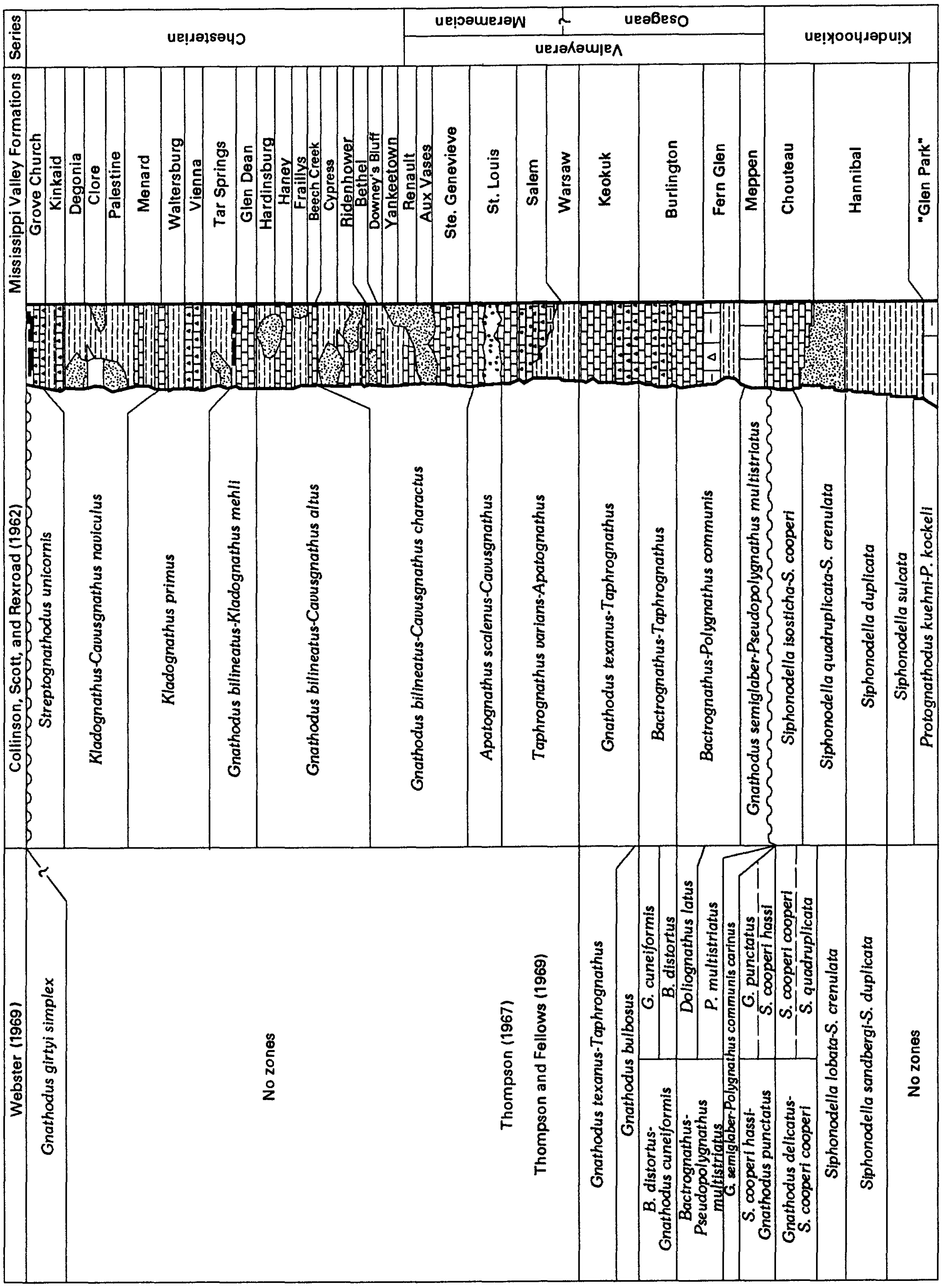


FIGURE 66.—Comparison of major conodont zonal classifications for the Mississippian System in North America (modified from Collinson and others, 1971).

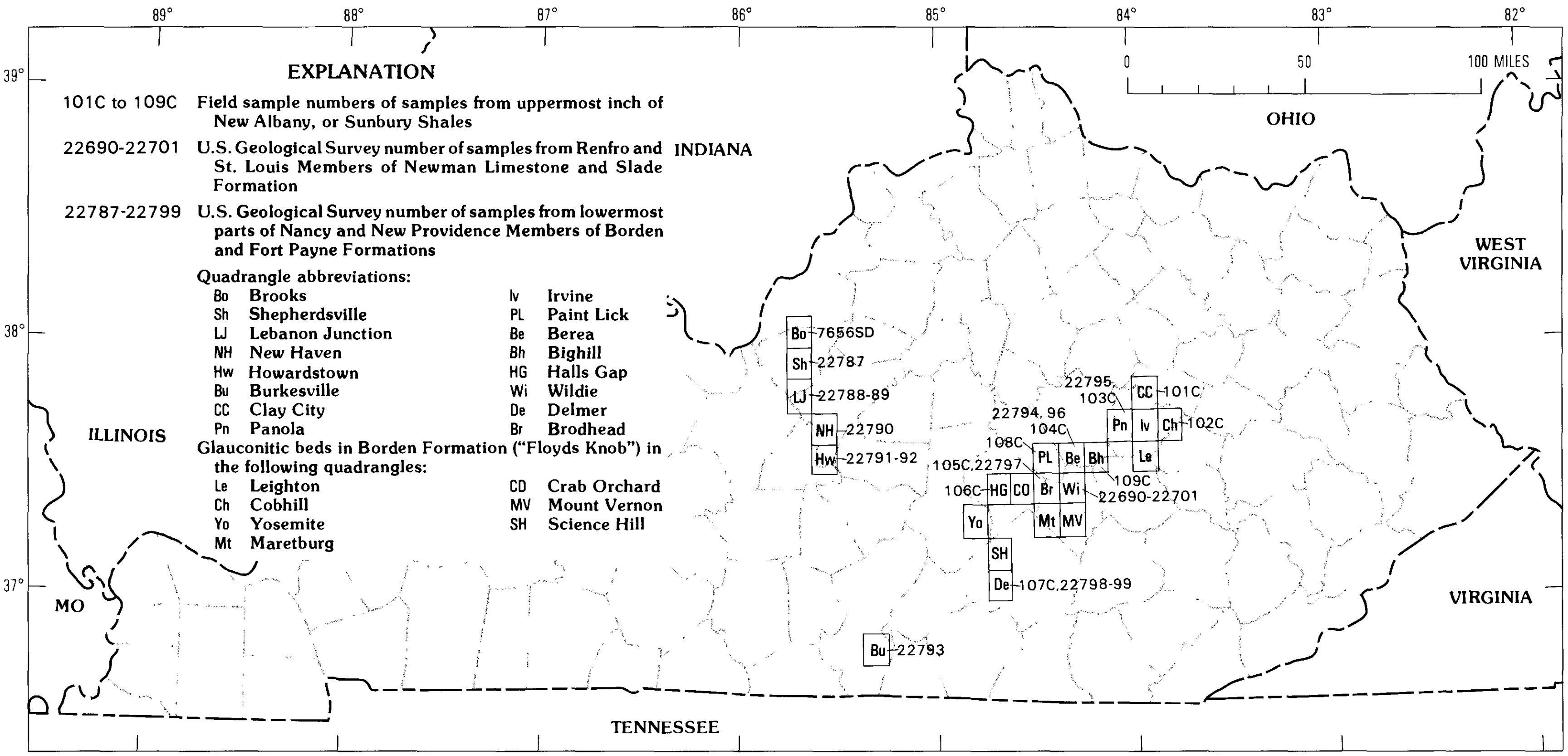


FIGURE 67.—Map showing quadrangles of Mississippian and Devonian conodont-bearing samples in central, east-central, and south-central Kentucky.

TABLE 3.—*Conodonts from top one inch of New Albany and Sunbury Shales in east-central, eastern central, and south-central Kentucky*

[Locations shown in fig. 67; identifications by J.W. Huddle, 1964; number of specimens shown in parentheses]

Samples 101C-109C collected from uppermost 1 in. of New Albany or Sunbury Shales.

Samples 101C: State Hwy. 15, about 3 mi east of Clay City and 1/3 mi northeast of where Hwy. 15 crosses Hatton Creek, Clay City quadrangle, Kentucky.
- *Hindeodella* sp. (7)
- *Eupnoniodina* sp. (6)
- *Spathognathodus* sp. (1)
- Scolecodont (1)
- Fish scales, conical fish teeth, plant trash, linguloid and orbiculoid brachiopods

Sample 102C: about 1,000 ft south of southernmost part of Ravenna, Ky., city limits, on the left bank of Cow Creek above L&N Railroad, Irvine quadrangle, Kentucky.
- *Hindeodella* sp. (6)
- Polygnathids indeterminate (4)
- *Bryantodus* sp. (1)
- *Siphonodella* sp. (4)
- *Elictognathus* sp. (1)
- *Euprioniodella* sp. (1)
- *Ligonodina* sp. (1)
- Conical fish tooth (1)

Sample 103C: About 2 mi south of Panola, Ky. on dirt road about 600 ft southwest of Knob Lick School and about 1,300 ft northeast of Knob Lick Cemetery, Panola quadrangle, Kentucky.
- *Euprioniodina* sp. (9)
- *Hindeodella* sp. (51)
- *Spathognathodus* sp. (3)
- *Ozarkodina* sp. (8)
- *Gnathodus*? sp. (2)
- *Lonchodina* sp. (1)
- Polygnathids indeterminate (16)
- Linguloid and orbiculoid brachiopods

Sample 104C: U.S. Hwy. 25, about 2½ mi south of L&N Railroad tunnel in Berea, Ky., and about ¾ mi north of Boone Gap, Berea quadrangle, Kentucky.
- *Siphonodella* sp. (17)
- *Siphonodella duplicata* Branson and Mehl (2)
- *Hindeodella* sp. (33)
- *Ligonodina* sp. (2)
- *Bryantodus* sp. (2)
- *Euprioniodina* sp. (4)
- *Spathognathodus* sp. (9)
- *Prioniodina* sp. (2)
- *Ozarkodina* sp. (2)
- *Diplododella* sp. (1)
- *Falcodus* sp. (1)
- Polygnathids indeterminate (6)
- Linguloid brachiopod

Sample 105C: About 2¾ mi east of Crab Orchard on U.S. Hwy. 150, about 900 ft east of Slate Creek and about 800 ft west of Lincoln-Rockcastle County line, Brodhead quadrangle, Kentucky.
- *Hindeodella* sp. (14)
- *Ozarkodina* sp. (1)
- *Lonchodina*? sp. (1)
- *Euprioniodina* sp. (1)
- *Hibbardella* sp. (1)
- Polygnathid indeterminate (3)
- Orbiculoid brachiopods

Sample 106C: On edge of reservoir near road from old U.S. Hwy. 27 to Mayfield, Ky., about ½ mi northeast of Halls Gap, Ky., Halls Gap quadrangle, Kentucky.
- *Hindeodella* sp. (14)
- *Hibbardella* sp. (2)
- *Spathognathodus* sp. (3)
- *Pinacodus*? sp. (1)
- *Euprioniodina* sp. (1)
- *Lonchodina* sp. (1)
- *Ligonodina*? sp. (1)
- Spores abundant

Sample 107C: State Hwy. 1248 about 3¼ mi southwest of West Somerset on the east side of Lake Cumberland near bottom of hill, Delmer quadrangle, Kentucky.
- *Euprioniodina* sp. (1)
- *Hindeodella* sp. (1)
- *Spathognathodus* sp. (2)
- Abundant spores and linguloid brachiopods

Sample 108C: About 3½ mi southwest of Cartersville, Ky. along road about 3/5 mi southwest of Pine Grove Church and about 3/5 mi southeast of Bottom Lick Knob, Paint Lick quadrangle, Kentucky.
- *Hindeodella* sp. (1)
- *Spathognathodus* sp. (1)
- Shark's tooth
- Linguloid and orbiculoid brachiopods

Sample 109C: About 1½ mi southeast of Bighill, Ky. along road and about 800 ft east of point where the road crosses Owsley Fork of Red Lick Creek, Bighill quadrangle, Kentucky.
- *Hindeodella* sp. (5)
- *Siphonodella* sp. (1)
- *Spathognathodus* sp. (1)
- Polygnathids indeterminate (2)
- "Worm trails"

"All of the above samples were collected from the top inch of the black fissile shale (New Albany or Sunbury Shale). Nearly all of the samples are more or less weathered and most of the conodonts are altered. The conodonts characteristic of the Sunbury fauna are *Siphonodella, Elictognathus, Pinacodus* and *Gnathodus* and these genera are also found in the Maury Formation. Samples 102C, 104C, and 109C are definitely Mississippian, Kinderhookian in age. Samples 103C and 106C are probably Mississippian in age. The age is based on the questionably identified *Gnathodus* and *Pinacodus*. There are no diagnostic conodonts in the other samples, and they could be either Devonian or Mississippian. Hass (Prof. Paper 286, p. 24) reports a *Siphonodella* fauna in the basal New Providence Shale at his locality 6 (1956, p. 27), near Sample 107C in Pulaski Co. *** this same *Siphonodella* fauna also occurs in the top of New Albany Shale throughout southern Indiana ***"

TABLE 4.—*Conodonts from basal part of Nancy (New Providence) Member of the Borden Formation and from basal beds of the Fort Payne Formation in east-central and south-central Kentucky*

[Locations shown in fig. 67; identifications by J.W. Huddle, 1967; number of specimens shown in parentheses; starred forms may be reworked]

Samples 22795-PC–22799-PC from lowermost beds of Nancy Member, Borden Formation.

USGS 22795-PC, field No. 103A, lowest bed in the Nancy Member, Borden Formation (New Providence Shale), about 2 mi south of Panola, Ky., 600 ft southwest of Knob Lick School and about 1,300 ft northeast of Knob Lick Cemetery, Panola quadrangle, Kentucky.

Diplododella sp. (5)
Gnathodus antetexanus Rexroad and Scott (19)
Hindeodella sp. (137)
Ozarkodina roundyi Hass (18)
Polygnathus communis Branson and Mehl (81)
Polygnathus sp. (10)
**Pseudopolygnathus dentilineata* Branson (29)
**Siphonodella quadruplicata*? (Branson and Mehl) (3)
**Spathognathodus crassidentatus* (Branson and Mehl) (11)
**S. stabilis* (Branson and Mehl) (8)
Synprioniodina sp. (3)

The presence of *Gnathodus antetexanus* suggests that this may be as young as Cu II beta (*G. semiglaber–Polygnathus communis* zone). *Spathognathodus crassidentatus* suggests that Cu II alpha (*Siphonodella cooperi–S. isosticha* zone) may be represented and *Pseudopolygnathus dentilineata* is characteristic of Cu I strata. Very slow deposition or a lag concentrate is suggested. This seems more likely than reworking, another possible explanation.

USGS 22796-PC, field No. 104A, lowermost Nancy Member, Borden Formation (New Providence Shale Member), U.S. Hwy. 25, about 2½ mi south of Berea, Ky., and about ¾ mi north of Boone Gap, Berea quadrangle, Kentucky.

Polygnathus communis Branson and Mehl (1)
Pseudopolygnathus prima Branson and Mehl (6)
Siphonodella duplicata (Branson and Mehl) (1)
Siphonodella quadruplicata (Branson and Mehl) (32 fragments)
Spathognathodus stabilis (Branson and Mehl) (1)
Spathognathodus sp. (3)

This collection probably belongs in the *Siphonodella duplicata* zone of Collinson and others (1962).

USGS 2297-PC, field No. 105A, lowermost Nancy Member, Borden Formation (New Providence Shale Member), about 2¾ mi east of Crab Orchard, Ky., on U.S. Hwy. 150, about 900 ft east of Slate Creek and about 800 ft west of the Lincoln and Rockcastle County line, Brodhead quadrangle, Kentucky.

Bactrognathus? sp. (1)
Hindeodella sp. (5)
Polygnathus communis Branson and Mehl (1)
Prioniodina sp. (1)
Pseudopolygnathus prima Branson and Mehl (8)
Siphonodella duplicata (Branson and Mehl) (3)
Siphonodella sp. (29 fragments)
**Spathognathodus aculeatus* (Branson and Mehl) (4)
Spathognathodus sp. (4)

The presence of *Siphonodella duplicata* and *P. prima* suggests that this collection also represents the *S. duplicata* assemblage zone. The specimens of *Spathognathodus aculeatus* are interpreted as reworked. *Bactrognathus* has never been reported below the "Sedalia" Limestone. Its presence in this sample may be explained by contamination, misidentification, stratigraphic leak, or as an extension of its range.

USGS 22798-PC, field No. 107A, lowermost Nancy Member, Borden Formation (New Providence Shale Member), State Hwy. 1248 about 3½ mi southwest of West Somerset on the east side of Lake Cumberland near bottom of hill, Delmer quadrangle, Kentucky.

Gnathodus commutatus Branson and Mehl (2)
Hindeodella sp. (14)
Ozarkodina roundyi Hass (2)
Polygnathus symmetrica Branson (8)
Polygnathus sp. (2)
**Spathognathodus aculeatus* (Branson and Mehl) (10)
S. anteposicornis Scott (7)
S. linguliferus? (Branson) (3)
S. praelongus Cooper (45)
S. stabilis (Branson and Mehl) (4)

This collection is placed in the upper part of the *Spathognathodus costatus* zone (equivalent to the Louisiana Limestone) bcause of the presence of *Spathognathodus anteposicornis* and *Gnathodus commutatus*.

USGS 22799-PC, field No. 107B, same locality as 107A, from rock less than 1 in. thick transitional between the New Albany Shale and New Providence Shale Member.

Hindeodella sp. (2)
Spathognathodus praelongus Cooper (4)
S. stabilis (Branson and Mehl) (3)
Synprioniodina sp. (1)

Spathognathodus praelongus has previously been reported from the *S. costatus* zone in Montana.

TABLE 5.—*Conodonts from basal (New Providence) part of Nancy Member of the Borden Formation in east-central and south-central Kentucky*

[Locations shown in fig. 67; identifications by J.W. Huddle, 1967; number of specimens shown in parentheses; starred forms may be reworked]

Samples 22793-PC and 22794-PC from lowermost Fort Payne Formation and basal beds of Nancy Member, Borden Formation.

USGS 22793-PC, field No. 2 of 5/7/65 Huddle, Branson, and Lewis. Limestone lens about 1 ft above the Chattanooga Shale in the Fort Payne Formation, in a small west-flowing tributary of Bear Creek, 1.23 mi west of Seminary School, Burkesville quadrangle, Kentucky.

Bryantodus sp. (1)
Gnathodus antetexanus Rexroad and Scott (79)
Hindeodella sp. (14)
Polygnathus communis Branson and Mehl (13)
Prioniodina pulcher Branson (2)
Pseudopolygnathus multistriata Mehl and Thomas (6)
**Siphonodella duplicata* (Branson and Mehl) (4)
**S. quadruplicata* (Branson and Mehl) (24)
**S. obsoleta*? Hass (2)
**Spathognathodus aculeatus* (Branson and Mehl) (9)
Synprioniodina sp. (2)

The presence of *Gnathodus antetexanus* and *Pseudopolygnathus multistriata* in this collection suggests that the lower part of the Fort Payne Chert is equivalent to the upper part of the Rockford Limestone of Indiana (Rexroad and Scott, 1964) and the "Sedalia" Limestone. The assemblage probably represents the *Gnathodus semiglaber–Pseudopolygnathus multistriata* zone of Collinson and others (1962).

USGS 22794-PC, field No. 1 of 5/5/65 Huddle, Branson, and Weir (same locality as USGS 22796-PC and USGS 7652-SD). 0.0–0.8 ft above base Nancy Member of the Borden Formation (New Providence Shale Member), U.S. Hwy. 25 about 2½ mi south of Berea and ¾ mi north of Boones Gap, Berea quadrangle, Kentucky.

Hindeodella sp. (2)
Polygnathus communis Branson and Mehl (2)
P. inornata Branson (1)
P. permarginata Branson (1)
P. scorbiformis Branson (1)
Pseudopolygnathus prima Branson and Mehl (1)
Siphonodella duplicata (Branson and Mehl) (10)
S. cooperi? Hass (7 fragments)

This collection is assigned to the *Siphonodella duplicata* zone of Collinson and others, 1962.

TABLE 6.—*Conodonts from basal part of New Providence Shale Member of the Borden Formation in central Kentucky*

[Locations shown in fig. 67; identifications by J.W. Huddle, 1967; number of specimens shown in parentheses; starred forms may be reworked]

Samples 22787-PC–22792-PC from lowermost beds of New Providence Shale member, Borden Formation.

USGS 22787-PC, field No. 5 of 5/12/65 Huddle and Branson. 0–1.2 ft above base of New Providence Shale Member, on knob south of road to Bernheim Forest opposite the County Farm near Kentucky Turnpike, Ky. State coord. 1,584,600 E. by 158,100 N., Shepherdsville quadrangle, Kentucky.

Bactrognathus hamata Branson and Mehl (7)
Hindeodella sp. (18)
Neoprioniodus sp. (2)
Ozarkodina sp. (1)
Polygnathus communis Branson and Mehl (7)
**Polygnathus inornata* Branson (6)
**P. longiposita* Branson (6)
**P. symmetrica* Branson (5)
**Pseudopolygnathus prima* Branson and Mehl (18)
**P.* sp. (1)
**Siphonodella cooperi* Hass (13)
**Siphonodella duplicata* (Branson and Mehl) (14)
**S. quadruplicata* (Branson and Mehl) (4)
**Spathognathodus aculeatus* (Branson and Mehl) (23)

The specimens in this collection do not look reworked and the abundance of *S. aculeatus* suggests the presence of the Lower or Middle *Spathognathodus costatus* zone (to VI). The youngest zone present, the *Bactrognathus–Polygnathus communis* zone, is indicated by *Bactrognathus hamata* and *P. communis*.

USGS 22788-PC, field No. 1 of 5/12/65 Huddle and Branson. 0.6–1.8 ft above the base of the New Providence Shale Member, roadcut on north side of U.S. Hwy. 62, about 1½ mi east of Boston, Ky., Lebanon Junction quadrangle, Kentucky State coords. 1,596,400 E. by 107,700 N.

Gnathodus texanus Roundy (2)
Hindeodella sp. (6)
Spathognathodus sp. (2)
Fish remains and white hollow spheres uneven in size

All of the conodonts are weathered white. The age is presumably the same as USGS 22792-PC and represents the time equivalent of the upper Burlington Limestone, according to Rexroad and Scott (1964).

USGS 22789-PC, field No. 2 of 5/12/65 Huddle and Branson. 0.0–0.6 ft above base of New Providence Shale Member, same locality as USGS 22788-PC.

Bactrognathus distorta? Branson and Mehl (1)
Bryantodus sp. (1)
Hindeodella sp. (17)
Polygnathus communis Branson and Mehl (2)
**Siphonodella* sp. (two or more species) (17 fragments)
**Polygnathus inornata* Branson (8)
**P. longiposita*? Branson (2)
**P.* cf. *P. scorbiformis* Branson (10)
**Prioniodina* sp. (1)
**Spathognathodus aculeatus* (Branson and Mehl) (21)
**S. costatus*? (Branson) (3)
**Spathognathodus* aff. *S. disparilis* (Branson and Mehl) (5)
Spathognathodus sp. (4)

The conodonts in this collection are weathered white and the forms starred are thought to be reworked. It is possible that there are thin layers at the base representing the *Spathognathodus costatus* zone and the *Siphonodella* zones, but reworking of the older forms seems more probable. This collection apparently belongs in the *Bactrognathus–Taphrognathus* zone of Collinson and others (1962) and is equivalent to the upper part of the Burlington Limestone.

USGS 22790-PC, field No. 7 of 5/12/65 Huddle and Branson. Basal 0–1.3 ft of the New Providence Shale in roadcut on north side of Blue Gap, coord. 2,053,500 E. by 493,500 N., New Haven quadrangle, Kentucky.

Gnathodus texanus Roundy (2)
Hindeodella sp. (1)

TABLE 6.—*Conodonts from basal part of New Providence Shale Member of the Borden Formation in central Kentucky*—Continued
[Locations shown in fig. 67; identifications by J.W. Huddle, 1967; number of specimens shown in parentheses; starred forms may be reworked]

Prioniodina sp. (1)
**Pseudopolygnathus prima* Branson and Mehl (3)
**Siphonodella* sp. (4)
**Spathognathodus aculeatus* Branson and Mehl (8)
S. sp. (4)

Most of the conodonts are fragmented, and only a few can be identified. They are weathered white, and some are stained with limonite.

The presence of *Gnathodus texanus* indicates that the upper part of this sample, at least, belongs in the *Bactrognathus-Taphrognathus* zone.

USGS 22791-PC, field No. 2 of 5/11/65 Huddle, Branson, Sable, Peterson, and Kepferle. Basal 0.8 ft of the New Providence Shale Member, new roadcut in Kentucky. State Hwy. 247, Ky. State coord. 2,053,200 E. by 470,300 N., Howardstown quadrangle, Kentucky.

Bryantodus sp. (1)
Gnathodus antetexanus Rexroad and Scott (14)
G. distorta Branson and Mehl (3)
Hindeodella sp. (35)
Lonchodina sp. (1)
Ozarkodina sp. (1)
**Palmatolepis gracilis* Branson and Mehl (1)
Polygnathus communis Branson and Mehl (27)
**Polygnathus inornata* Branson (12)
**P. permarginata* Branson (2)
**P. symmetrica* Branson (12)
Prioniodina sp. (1)
Prioniodina sp. (1)
Pseudopolygnathus prima Branson and Mehl (12)
**Siphonodella duplicata* (Branson and Mehl) (10)
**S.* sp. (10)
**Spathognathodus aculeatus* (Branson and Mehl) (60)
**S. anteposicornis* Scott (3)
**S. disparilis* (Branson and Mehl) (3)
S. aff. *S. werneri* Ziegler (54)
S. sp. (6)

Conodonts and fish remains are abundant in this sample, but most of them are broken and cannot be identified. The relative abundance of the species is not properly represented by the counts above.

The interpretation of this collection is uncertain. A zone of large phosphate nodules at the base suggests slow deposition and lag concentration. The starred forms represent Late Devonian and Early Mississippian conodonts. They may have been reworked or several zones may be present in the basal 0.8 foot interval of the New Providence Shale Member. Inch by inch collecting would be necessary to prove or disprove this possibility.

The youngest form present is *Gnathodus antetexanus*, which suggests that at least the upper part of the interval is equivalent to the upper part of the Rockford Limestone; and the presence of *Spathognathodus anteposicornis* suggests that the equivalent of the Louisiana Limestone is present.

USGS 22792-PC, field No. 3 of 5/11/65 Huddle, Branson, Sable, Peterson and Kepferle. 0.8–1.9 ft above the base of the New Providence Shale Member. Same locality as USGS 22791-PC.

Gnathodus texanus Roundy (15)
Hindeodella sp. (22)
Polygnathus communis Branson and Mehl (3)
Prioniodina acuta Branson (3)
P. pulcher Branson (2)
Pseudopolygnathus prima Branson and Mehl (3)
**Siphonodella* sp. (1 fragment)
**Spathognathodus aculeatus* (Branson and Mehl) (3)
**S.* cf. *S. abnormis* (Branson and Mehl) (6)
**S. subrecta* (Holmes) (1 weathered white)
Cusp fragments, clear with no white matter (7)

Gnathodus texanus has not been reported previously below the upper Burlington Limestone and first appears in the *Bactrognathus-Taphrognathus* zone, according to Rexroad and Scott (1964). Starred forms probably reworked.

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