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Geology and Structure of the Rough Creek Area, Western Kentucky

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Nomenclature and structure contours do not necessarily conform to current U.S. Geological Survey or Kentucky Geological Survey usage. This work was originally prepared in the late 1990's and is published here with only editorial improvements.

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Geology and Structure of the Rough Creek Area, Western Kentucky

William D. Johnson Jr. and Howard R. Schwalb

Abstract

The Rough Creek area is a rectangular area about 113 mi east to west and 35 mi north to south encompassing about 3,900 mi^2 in west-central and western Kentucky. The Ohio River delineates most of the western border with Illinois and locally also part of the northern border with Indiana. The northeast corner of the area is about 27 mi southwest of Louisville. The principal cities are Owensboro and Henderson.

The Precambrian basement has been penetrated in only two wells in western Kentucky at depths somewhat greater than 14,000 ft. Basement is projected to underlie much of the area at a depth of more than 25,000 ft, and perhaps locally even more than 30,000 ft, in this, the deepest part of the Illinois Basin. Rocks of all geologic ages from Cambrian to Quaternary, except those of Mesozoic age, are present within the Rough Creek area; Upper Cretaceous strata occur as close as 20 mi south of the southeastern corner, however. All Paleozoic rocks older than Early Mississippian are restricted to the subsurface, so that the exposed rocks are dominantly of Mississippian (Meramecian and Chesterian) and Pennsylvanian ages. Strata of the Fort Payne Formation (Osagean) are present locally in the Rough Creek Fault Zone. Also, rocks of Early Permian age have been identified in a graben in the fault zone. Although no Pleistocene ice sheets penetrated south of the Ohio River in the Rough Creek area, the river valley was a major sluiceway for glacial debris from the Wisconsinan ice sheet, so the valley is filled with outwash, and loess blown from the valley blankets the area adjacent on the south. Remnants of Tertiary and Quarternary stream terraces are present in the Ohio and Green River Valleys, and thick lacustrine deposits covered by younger alluvium fill the larger stream valleys tributary to the Ohio River.

The Rough Creek area is in the southern part of the Illinois Basin, and the principal structural features of the region that are present within or close to the study area, and at times influenced depositional patterns during the Paleozoic, include the Rough Creek–Shawneetown Fault System, the Moorman–Eagle Valley Syncline, the Pennyrile Fault System, and faults of the Illinois-Kentucky Fluorspar District. The Rough Creek–Shawneetown Fault System, which extends from western Kentucky into southeastern Illinois, where it is called the Shawneetown Fault Zone, is defined on its northern and western margins in Illinois by a southward-dipping, high-angle reverse fault with as much as 3,500 ft of reverse displacement. The frontal fault extends into Kentucky, but the degree of displacement is less than in Illinois; eastward along the structure, the frontal fault is broken into several long, arcuate segments by high-angle normal faults, and is displaced southward until it is no longer the frontal fault. In Kentucky, the Rough Creek zone is characterized by many steeply dipping fault blocks bounded by high-angle normal and reverse faults. The Moorman–Eagle Valley Syncline lies immediately south of the Rough Creek–Shawneetown Fault System, and that structure forms its steep northern and western limbs; the Kentucky part is the Moorman Syncline. The Pennyrile Fault System defines the gentle southern limb of the Moorman Syncline. In the deepest part of the composite syncline, which is close to its northern limb, structural relief on the Precambrian basement is more than 30,000 ft. The Moorman–Eagle Valley Syncline overlies the Rough Creek Graben in the basement.

The Pennyrile Fault System, which lies mostly south of the Rough Creek area, is a broad feature composed of three branches of east- to northeast-trending, high-angle normal faults in an en echelon pattern that break the gently dipping strata into a series of fault blocks. Displacement on the faults generally increases to the west toward the junction of the fault system with faults of the Illinois-Kentucky Fluorspar District. The Pennyrile overlies the southern margin of the Rough Creek Graben, a structural feature in basement rocks.

The Illinois-Kentucky Fluorspar District, most of which is beyond the southern limit of the Rough Creek area, is an area of complex structure. It is underlain by the broad Tolu Arch that extends from Kentucky northwestward into Illinois and terminates against the Shawneetown Fault Zone. The axis of the arch is broken and offset by an extensive system of northeast-trending, steeply dipping normal faults, which divide the district into numerous elongate horsts and grabens. The faults in the northern part of the district terminate in the Moorman–Eagle Valley Syncline, whereas major faults in the southeastern part merge eastward into faults of the Pennyrile system. Hicks Dome, in Illinois near the northern end of the Tolu Arch, is a nearly circular, extensively faulted uplift that has about 4,000 ft of structural relief. The dome was a product of explosive magmatism fed by an intrusive body to the northeast. The doming originated in the Precambrian basement and involved the entire overlying Paleozoic section. Mafic dikes along the northeast-trending and some north-trending faults are the main sites of the fluorspar-zinc-lead-barite ores in the district.

The Illinois Basin began as a failed rift in the basement, called the New Madrid Rift Complex, that is now largely under the upper Mississippi Embayment. The main segment under the embayment is the Reelfoot Rift; an eastern extension, the Rough Creek Graben, underlies roughly the Moorman–Eagle Valley Syncline and joins with the Reelfoot Rift under the fluorspar district. The rift complex was the center of nearly continuous marine deposition until uplift of the Pascola Arch across the Reelfoot Rift, most likely in the late Paleozoic or early Mesozoic, blocked the seaway from the continental margin to the south. Periodic movement on the Rough Creek–Shawneetown and Pennyrile Fault Systems on the northern and southern margins of the Rough Creek Graben, respectively, as well as along faults in and marginal to the Reelfoot Rift, influenced in part the distribution and thickness of marine sediments in the southern part of the proto-Illinois Basin during most of the Paleozoic.

Initially, marine deposition, probably beginning in the Early Cambrian, was confined to the Reelfoot–Rough Creek Graben rift complex, but with the filling of the rift complex, deposition of so-called pre-Knox Group strata (rocks older than early Late Cambrian) spread out beyond the rift margins. The thickness of pre-Knox strata within the rift complex much exceeds that outside the complex, however. The pre-Knox section is more than 4,000 ft thick in the only well (in McLean County, Ky.) to penetrate the entire section in the Rough Creek Graben, but elsewhere in western Kentucky the projected thickness exceeds 18,000 ft.

The pre-Knox synrift sediments in the Rough Creek Graben consist of a 200-ft-thick basal sandstone, possibly correlative with the Rome Sandstone (Lower Cambrian) of central Kentucky, overlain by a thick, undated sequence of sandstone, green shale, and minor limestone. The Upper Cambrian part of the pre-Knox sequence includes the Mount Simon Sandstone and, at the top, shale, dolomite, and limestone of the Eau Claire Formation. Thick marine shale, correlated on the basis of trilobites with the Conasauga Shale (Middle Cambrian), is recognized in the subsurface of Grayson County.

Overlying the Eau Claire in the Rough Creek area is a sequence more than 3,000 ft thick, principally of dolomite of the Knox Group of Late Cambrian and Early Ordovician age. Following minor uplift and erosion at the end of the Early Ordovician, deposition was continuous for the remainder of the Ordovician and resulted in a thick sequence of mostly dolomite and limestone, but also the distinctive St. Peter Sandstone in the lower part and the widespread Maquoketa Shale at the top. The St. Peter is widespread in the Illinois Basin, but in the Rough Creek area is only present west of an ancient Middle Ordovician shoreline that extended southeastward across the middle of the area. Over much of western Kentucky, the Maquoketa filled a broad northeast-trending submarine channel called the Sebree Valley.

The Silurian rocks of the Rough Creek area show considerable lithologic variation from east to west and north to south, and range in thickness from about 350 to 525 ft. In part the thickness variation is the result of differential erosion below the pre-Upper Devonian (pre-New Albany Shale) unconformity. Rocks of all three series of the Silurian are present, but those of Cayugan (Late Silurian) age are limited. The lower part of the sequence grades from dolomite in the eastern part of the area to limestone in the west. The thin formations of limestone and shale of the Niagaran (Middle Silurian) lose their distinctiveness as they grade westward into thick silty limestone. Locally, near the center of the Rough Creek area, units in the middle part of the Middle Silurian sequence are replaced by vuggy dolomite, which is interpreted as reef-derived detritus equivalent to the Terre Haute reef bank of southwestern Indiana.

Rocks of Early, Middle, and Late Devonian ages are present in the Rough Creek area, but the distribution of the Lower and Middle Devonian units is determined by the depth of erosion below pre-Middle and pre-Upper Devonian unconformities. A complete sequence of Devonian rocks is present in the northwestern part of the area, but eastward, toward the flank of the Cincinnati Arch, Lower and Middle Devonian strata thin by truncation below the two unconformities. The Lower and Middle Devonian units are dominantly limestone, much of it cherty, and lesser amounts of dolomite. Some Lower Devonian crystalline limestone units are so similar that they are easily misidentified in well samples.

In western Kentucky, the Jeffersonville Limestone, the basal Middle Devonian unit, contains a discrete basal sandstone, the Dutch Creek Sandstone, and locally north of the Rough Creek Fault Zone in Union County, a K-bentonite, correlated with the Tioga Bentonite Bed of adjacent Indiana and Illinois, is present in the uppermost part; the bentonite was not observed south of the fault zone. The Jeffersonville rests conformably on Lower Devonian rocks over much of western Kentucky, but toward the margins of the depositional basin the formation rests unconformably on progressively older Devonian and Silurian units. Locally, north of the Rough Creek Fault Zone, the Jeffersonville rests on strata in the lower part of the Lower Devonian. At the end of Jeffersonville time, faulting along the Rough Creek zone and uplift in the northeastern part of the area resulted in erosion of all or part of the formation. To the east, the Jeffersonville is also truncated by the pre-Upper Devonian unconformity.

Argillaceous cherty limestone of the Sellersburg, the upper unit of the Middle Devonian, rests with minor unconformity on the Jeffersonville. The formation contains the fossil spore *Tasmanites,* which is also abundant in the lower member of the overlying Upper Devonian New Albany Shale. Generally, the contact of the Sellersburg with the New Albany is gradational, but locally north of the Rough Creek Fault Zone, pre-New Albany erosion removed all Middle Devonian units, and the New Albany rests on Lower Devonian rocks. In the northwestern part of the area, the maximum thickness of the Lower and Middle Devonian rocks is about 1,700 ft.

The New Albany Shale, almost entirely of Late Devonian age, is the most widespread Devonian unit in the Illinois Basin and is composed of three distinctive and easily traceable members mostly of black shale. In the Rough Creek area, the formation thins eastward—each member progressively overlaps the preceding older member toward the depositional edge of the basin; consequently, the youngest member of the New Albany is the most widespread. In western and central Kentucky, the New Albany overlies formations ranging in age from Middle Devonian to Late Ordovician. In the subsurface of western Kentucky, the base of the formation is placed at the top of the Sellersburg Limestone (Middle Devonian), but the upper boundary is placed at various stratigraphic positions, either at the base of the Rockford Limestone (Lower Mississippian, Kinderhookian), thus incorporating in the New Albany a local thin, olive-gray shale (called the Hannibal Shale), which is very similar to the New Providence Shale that overlies the Rockford; where the Rockford is missing and the Hannibal cannot be distinguished from the New Providence, the top of the formation is placed at the top of the upper black shale member of the New Albany. The maximum thickness of the New Albany in the western part of the Rough Creek area is more than 440 ft, but the formation thins eastward to about 80 ft.

Rocks of all series of the Mississippian System are present in the Rough Creek area; the maximum thickness is more than 2,700 ft in the Moorman Syncline in the western part. A thin sequence of limestone and shale of Kinderhookian (Early Mississippian) age and the thin New Providence Shale (basal Osagean) represent the initial deposits of the Mississippian in the subsurface of the Rough Creek area. The Kinderhookian beds are missing locally in the vicinity of the Ohio River Valley, and the New Providence is very thin or missing in the subsurface at the eastern border of the study area. The outcropping Mississippian strata are mainly of Meramecian and Chesterian ages, but Osagean rocks, represented by the Fort Payne Formation, are exposed in fault blocks in the eastern part of the Rough Creek Fault Zone. Mississippian strata crop out in belts restricted to either end of the Rough Creek area that are separated by a broad area of Pennsylvanian rocks. The exposed Mississippian section is composed of about equal amounts of limestone and detrital rocks, but limestone is dominant in the Osagean and Meramecian units, whereas sandstone, shale, and siltstone constitute most of the Chesterian section. Carbonate deposition probably encroached into the area from the west and was most widespread during the Meramecian, but by the Chesterian westward encroachment of deltaic sediments from the Michigan River system, and perhaps other eastern sources, restricted carbonate deposition, so that Chesterian limestone units in the Rough Creek area generally thin eastward. Only thin remnants of some units in the upper part of the Mississippian section are present in the eastern part. The proto-Illinois Basin was uplifted and eroded before deposition of Pennsylvanian rocks.

It is quite possible that the only complete section of Pennsylvanian strata in the Illinois Basin is present in a graben block in the Rough Creek Fault Zone in the western part of the area; a corehole that bottomed in uppermost Pennsylvanian strata penetrated beds containing Early Permian fusulinids in the upper part of the hole. In the area of the corehole, the complete Pennsylvanian section is about 3,200 ft thick and is the maximum known thickness of Pennsylvanian beds in western Kentucky. Elsewhere in the area, the Pennsylvanian strata are erosional remnants of a once much thicker and more widespread sequence of deposits. Massive, coarse-grained, crossbedded sandstone, containing small quartz pebbles, characterizes the basal Pennsylvanian strata that together with overlying sandstone were laid down on a deeply eroded surface cut by well-developed drainage systems. Coal beds in this part are thin and not regionally persistent. The predominance of sandstone in the lower part of the section gives way upward to mudstone and sandstone in the middle part, but rarely is the amount of sandstone as much as 50 percent and generally much less. The middle part contains several widespread marine limestones and also the thickest and most regionally persistent coal beds in the Illinois Basin. In the upper part of the Pennsylvanian section, mudstone is the dominant lithology, but sandstone is abundant in limited areas, where it filled old stream channels. Coal beds in the upper part are thin and moderately discontinuous, but several thin limestone beds are regionally persistent.

The only known Permian beds in the Illinois Basin were recognized when fusulinids of Early Permian (Wolfcampian) age were discovered in a corehole in a graben block in the Rough Creek Fault Zone in beds previously thought to be of Late Pennsylvanian age. The strata, called the Mauzy Formation, have a minimum thickness of 400 ft in the corehole but may be much thicker elsewhere in the graben. The formation is primarily shale and siltstone, but marine limestone, containing sparse fusulinids, mainly in the lower part, composes 25 percent, and some sandstone is present in the upper part. Permian rocks must have originally been much more widespread, but erosion since their deposition removed all but the lone outcrop preserved in the fault zone, as well as a considerable thickness of Pennsylvanian and Mississippian rocks.

During the active rifting that occurred from the latest Precambrian to the Middle Cambrian, the rift area underwent crustal stretching, extensional faulting, subsidence, and infilling of the basin that developed along the Reelfoot Rift and the Rough Creek Graben. By the end of the Middle Cambrian, the rift complex had evolved into a broad, slowly subsiding cratonic embayment. The proto-Illinois Basin did not exhibit a basinal configuration until the closing of the embayment in the late Paleozoic or early Mesozoic. Regional subsidence of both the rift complex and the adjacent craton continued with only periodic interruption through most of the Paleozoic.

A major withdrawal of the sea at the end of the Early Ordovician ushered in a long period of erosion, during which Knox Group rocks were extensively eroded on the flanks of the basin, in part because of structural uplift in some areas; but there may have been no break in deposition in the deeper parts of the basin, such as the Rough Creek Graben. A relative rise in sea level in the Middle Ordovician resulted in northward transgression of the sea and widespread deposition of the sheet sand of the St. Peter onto the eroded surface. The succeeding Middle Ordovician carbonate rocks were also widely distributed in the basin. Uplift of the Appalachian orogen in the latter part of the Ordovician was reflected in the westward and widespread distribution of fine siliciclastic material, most evident in the Maquoketa Shale. Thickening of the shale in the Rough Creek Graben indicates some subsidence of the feature at that time. A worldwide drop in sea level during latest Ordovician

to earliest Silurian time resulted in a pronounced unconformity at the top of Ordovician rocks over much of the Midcontinent.

Transgression of the Silurian sea filled deep channels in the eroded surface with argillaceous Silurian deposits, but western Kentucky was emergent at this time. The succeeding Silurian was a time of carbonate deposition in a broad embayment that connected southward through the Reelfoot Rift to the open sea. The areas of the present Kankakee and Cincinnati Arches that were uplifted to form the broad Wabash Platform in Indiana and Illinois during the Middle Silurian became the site of extensive reef development, including the Terre Haute bank complex, for the remainder of the Silurian; no reef structures formed in the Rough Creek area, but detritus from later erosion of those structures may have been swept by tidal currents southward into the area.

Deposition was continuous from the Silurian into the Early Devonian in the deeper parts of the proto-basin, including the Rough Creek area, and resulted in a thick sequence of cherty carbonate rocks. Near the end of the Early Devonian, uplift of structures on the flanks of the basin, including the Kankakee and Cincinnati Arches, as well as a eustatic drop in sea level, caused erosion of Lower Devonian and Upper Silurian strata toward the margins of the proto-basin; but deposition was continuous in the deeper parts, including much of western Kentucky. Tectonism in the basin and the drop in sea level were probably responses to convergence and collision between North America and Gondwana that resulted in the Caledonian-Acadian Orogeny.

The initial Middle Devonian deposit was sand eroded from the Ozark Uplift to the west and from the Wisconsin Arch to the north. The presence of a K-bentonite in the overlying bioclastic limestone is evidence of volcanic activity associated with the Acadian Orogeny. At the close of the early Middle Devonian, the north side of the Rough Creek–Shawneetown Fault System was uplifted, and the existing Middle Devonian deposits were partly or completely eroded. Deposition was continuous, however, in the deeper parts of the basin into the late Middle Devonian, as the sea progressively distributed carbonate rocks far beyond the limits of the earlier Middle Devonian strata and also inundated many structures on the flanks of the basin, such as the Cincinnati and Kankakee Arches.

Regression of the Middle Devonian sea exposed areas on the flanks of the basin to minor erosion, and uplift along the Rough Creek–Shawneetown Fault System also resulted in local minor erosion before deposition of the carbon-rich shale of the New Albany Shale. By the late Middle Devonian, a basinal shale facies of the Catskill Delta Complex, of which the New Albany was a part, spread westward from the Appalachian Basin because of uplift of the Acadian orogen, overlapped the Cincinnati, Kankakee, and Sangamon Arches, and at its maximum covered the entire Illinois Basin and reached as far west as Iowa. Over time, deposition of the New Albany progressed outward from depocenters in western Kentucky and adjacent Illinois, south of the Rough Creek–Shawneetown Fault System, and to the north in southeastern Iowa and western Illinois; the oldest member of the formation was the most limited, and each successive member spread progressively farther across the basin and overlapped the previous member. In some areas the youngest member is unconformable on rocks as old as Ordovician. Growth faulting on the Rough Creek–Shawneetown system resulted in a greater thickness of the older members of the New Albany on the south side than on the north. A greater thickness of the formation on its north side indicates that the Pennyrile Fault System was also active at this time. Over most of the basin, deposition of the New Albany was continuous from Late Devonian into the Early Mississippian.

Clastic sedimentation continued without interruption into the Early Mississippian (Kinderhookian), was most pronounced in the Osagean (late Early Mississippian), and resulted in the deposition of distal portions of the Borden delta in western Kentucky, but not as far west as the Rough Creek area. The delta was a part of the vast delta complex that stretched from southern Canada down into the Appalachians during the final stages of the Acadian Orogeny. Near the beginning of the Osagean, the southern part of the proto-Illinois Basin became a deep-water, sediment-starved basin in which siliceous carbonate rocks were deposited adjacent to delta sediments. As active delta growth ceased and the sea began transgressing eastward, car-

bonate rocks were deposited on the delta platform. Carbonate deposition was continuous into the Meramecian (early Late Mississippian) throughout the Illinois Basin, but greater in the deep basin and less toward the basin margins. Uplift of arches on the basin margins near the middle of the Meramecian produced a broad, extensive tidal flat over much of the basin, including the eastern half of the Rough Creek area, on which evaporites and shallow-marine carbonate rocks were cyclically deposited. By the Chesterian (Late Mississippian), carbonate deposition alternated with deltaic deposition in response to fluctuations of the Michigan River delta complex. Also at this time, movement on many of the principal structural features in the basin, such as the lineament underlying the present Rough Creek–Shawneetown and Cottage Grove Fault Systems, affected sediment distribution. Deformation continued periodically through the Early Permian, all in response to compressive stresses created by the collision of Laurentia, Africa, and South America to form the supercontinent Pangea. Igneous activity accompanied the late Paleozoic deformation in the southern part of the basin. At the end of the Mississippian, the sea withdrew from the basin, and extensive erosion resulted in a major hiatus that separates Mississippian strata from those of the overlying Pennsylvanian.

The initial Pennsylvanian strata were deposited over a deeply eroded surface carved by a well-developed drainage network. Drainage in the proto-basin continued southward to a deep basin along the margin of the North American craton. The Pennsylvanian strata are characterized by repetitive sedimentary sequences, or cyclothems, that resulted from alternate advances and retreats of the sea in synchronous relation to advances and retreats of deltas caused by eustatic sea-level changes, caused primarily by waxing and waning of glaciation in Gondwanaland. In many deltaic sequences in the Rough Creek area there are no associated marine units, however. Permian deposition was just a continuation of the style set during the Pennsylvanian.

Uplift of the Pascola Arch across the Reelfoot Rift, probably in the Permian or early Mesozoic, blocked the drainage to the south to the continental margin and gave the basin its present configuration. Compression associated with the Alleghanian Orogeny in the southern Appalachians in the Late Mississippian to Early Pennsylvanian activated boundary faults of the Rough Creek Graben and Reelfoot Rift and resulted in reverse faulting that elevated crustal blocks, including the one south of the Rough Creek–Shawneetown Fault System and west of the Lusk Creek Fault System in Illinois. The block was raised as much as 3,500 ft in Illinois, but less to the east; there was little displacement on the south side of the graben. Orogenesis that migrated westward along the southern continental margin through time after formation of the Alleghanian orogen closed the remnant ocean along the margin, and the basin was filled with sediment. By Late Triassic to Jurassic time, extensional opening of the Gulf of Mexico initiated extensional faulting in the southern part of the Illinois Basin, which allowed the crustal blocks in the Rough Creek Graben and Reelfoot Rift to sink back to their approximate pre-Pennsylvanian positions. By the early Mesozoic, the Pascola Arch had been beveled, thus opening the Mississippi Embayment to a transgressing sea in the Late Cretaceous. Although tectonism in the Illinois Basin largely ceased in post-Cretaceous time, the entire basin has since undergone a change in the stress regime from tensional to the present horizontal compression.

Introduction

This report is one of a number of summary papers evaluating geologic data largely collected between 1960 and 1978 during the U.S. Geological Survey–Kentucky Geological Survey cooperative geologic mapping program. The mapping program resulted in 707 geologic quadrangle maps (GQ's) being published for the entire state at a scale of 1:24,000. Each map encompasses 7.5 minutes of latitude and 7.5 minutes of longitude. This report is a general synthesis of the surface and subsurface geology of a broad area of western Kentucky, the Rough Creek area, and encompasses all or parts of the major structural features of the region. The report is not intended as a detailed summary of the geology and structure of western Kentucky; rather, the emphasis is on the geologic history of the region in the context of the structural evolution of the southern part of the Illinois Basin and the tectonics of the Midcontinent region, as depicted in publications up to the mid-1990's.

The Rough Creek area is generally rectangular, about 113 mi east to west and 35 mi north to south, covering about 3,900 mi^2 in west-central and western Kentucky (Fig. 1). The area is bounded on the east by longitude 86°07′30′′ and on the west in part by longitude 88°07′30′′ and partly by the Ohio River. The southern boundary is latitude 37°22′30′′ and the north boundary generally is latitude 37°52′30′′, but where parts of Indiana lie south of that latitude, the boundary is placed at the north bank of the Ohio River. The northeastern corner of the area is about 27 mi southwest of Louisville, Ky. Owensboro and Henderson are the principal cities within the area. The names of the U.S. Geological Survey 7.5-minute geologic quadrangle maps covering the study area are listed in Appendix A (available for download at kgs.uky.edu/kgsweb/olops/pub/kgs/B1_12); the quadrangle locations are shown on Figure 1.

The Precambrian basement has been penetrated in only two wells in western Kentucky; the wells, one in Webster County and the other in McLean County, only 25 mi apart, bottomed in granitic rocks at a depth slightly more than 14,000 ft. The maximum depth to basement is projected at more than 30,000 ft in western Kentucky, in this, the deepest part of the Illinois Basin (Fig. 2). In the Rough Creek area, the sedimentary column resting on the Precambrian basement ranges in age from Cambrian to Quaternary, except no rocks of Mesozoic age occur within the report area. Upper Cretaceous beds are present in western Kentucky, however, about 20 mi south of the southwestern corner of the Rough Creek area, and may have originally extended into the study area.

All Paleozoic rocks older than the Early Mississippian are restricted to the subsurface in this part of Kentucky. The oldest dated strata are in the upper part of the Conasauga Shale of Middle Cambrian age, but one well has penetrated through a thick, older sedimentary sequence, known as pre-Knox Group strata, which includes all rocks older than early Late Cambrian. These older rocks contain no datable fossils, but a thick basal sandstone may be correlative with the Lower Cambrian Rome Sandstone. In addition, geophysical studies afford considerable information on the distribution and thickness, if not the character, of the pre-Knox sedimentary sequence and its relation to the Precambrian basement.

Rocks of Mississippian and Pennsylvanian age crop out over most of the area, and beds of Early Permian age have been identified in a graben block in the Rough Creek Fault Zone in the western part of the study area. Remnants of Tertiary and Quaternary stream terraces are present in the Ohio and Green River Valleys, and thick loess mantles the uplands adjacent to the Ohio Valley. Although Pleistocene continental ice sheets did not extend as far south as the Rough Creek area, the Ohio Valley served as a major sluiceway and was filled with glacial outwash. Lakes formed in the lower valleys of the major tributaries of the Ohio and were filled with thick lacustrine deposits that have been largely covered by younger alluvium. The Ohio River and its tributaries are now eroding the valley fill.

The geologic map of the Rough Creek area (Plate 1A; all plates are available for download at kgs.uky.edu/kgsweb/olops/pub/kgs/B1_12) summarizes data on the surface geology derived primarily from all or part of 67 geologic quadrangle maps that cover this part of western Kentucky (see References Cited). At the time this report was conceived, no geologic map of Kentucky at a scale suitable to portray the geologic detail of the Rough Creek area was available. In 1981, after completion of the mapping project, McDowell and others compiled the "Geologic Map of Kentucky" at a scale of 1:250,000, using information from the GQ's. Later, Noger (1988) compiled another geologic map of the state at a scale of 1:500,000, using the data on the 1981 map.

The original structural interpretation, depicted as an overlay on each GQ, has been revised in selected quadrangles since the mapping program, based on well data as of November 1, 1979. But because of concentrated oil and gas exploration in the Glenville and Utica quadrangles (south of Owensboro) in the 1980's after publication of the GQ's for those quadrangles, the structural interpretation of the Rough Creek Fault Zone in those quadrangles was revised by Avery E. Smith, who was a co-author of the original maps. Because of the density of wells in parts of the Rough Creek area, no well locations are shown on the geologic map (Plate 1A), but many are shown on the geologic quadrangle maps. In Kentucky, the system of land subdivision used to designate well locations is the Carter coordinate system; an example is shown on Plate 2A. In Indiana and Illinois, land subdi-

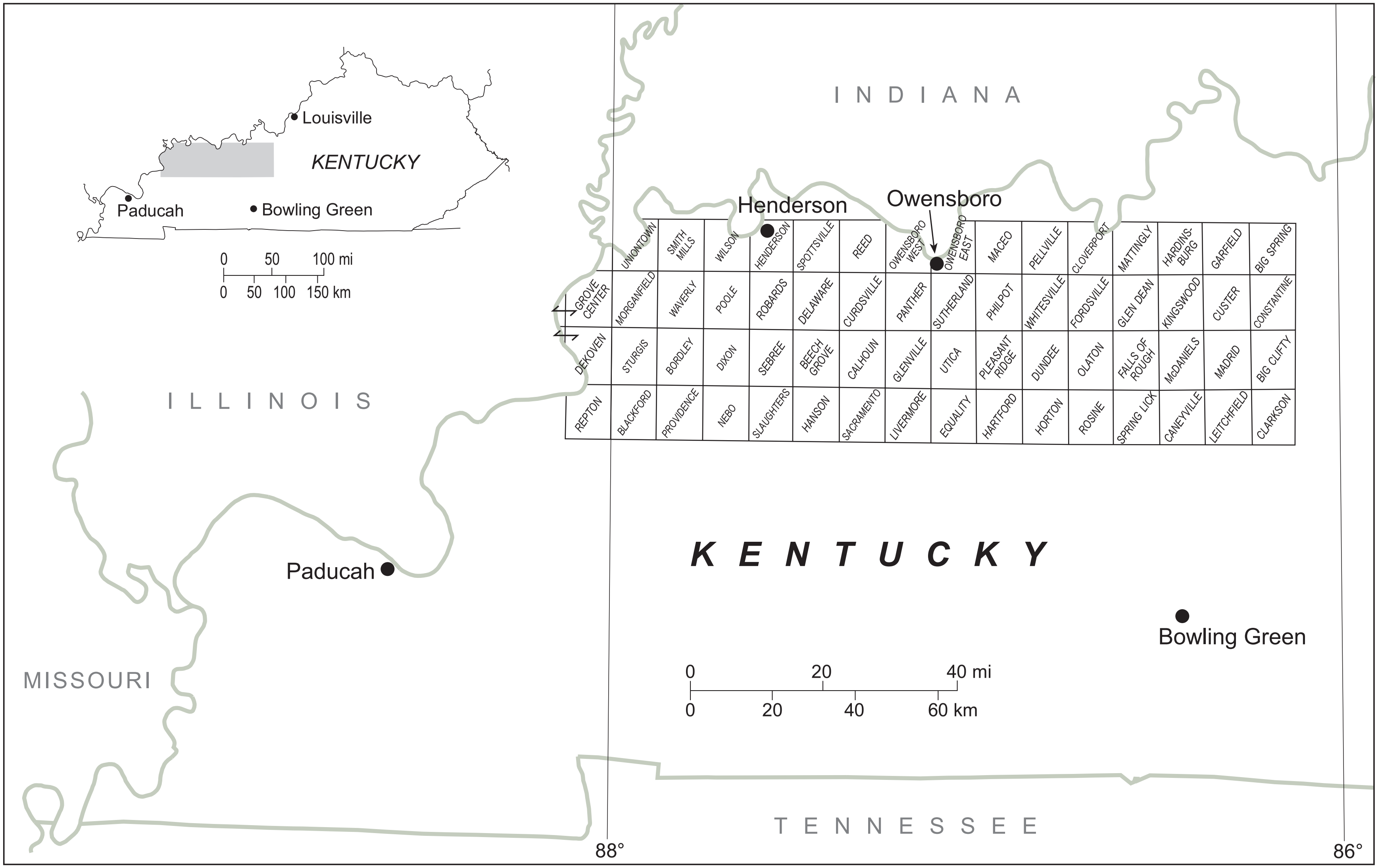

Figure 1. Location of the Rough Creek area, western Kentucky, showing the locations of the U.S. Geological Survey geologic quadrangle maps covering the area (listed in Appendix A). The symbol "⟷" designates that adjacent quadrangles are included on the same map.

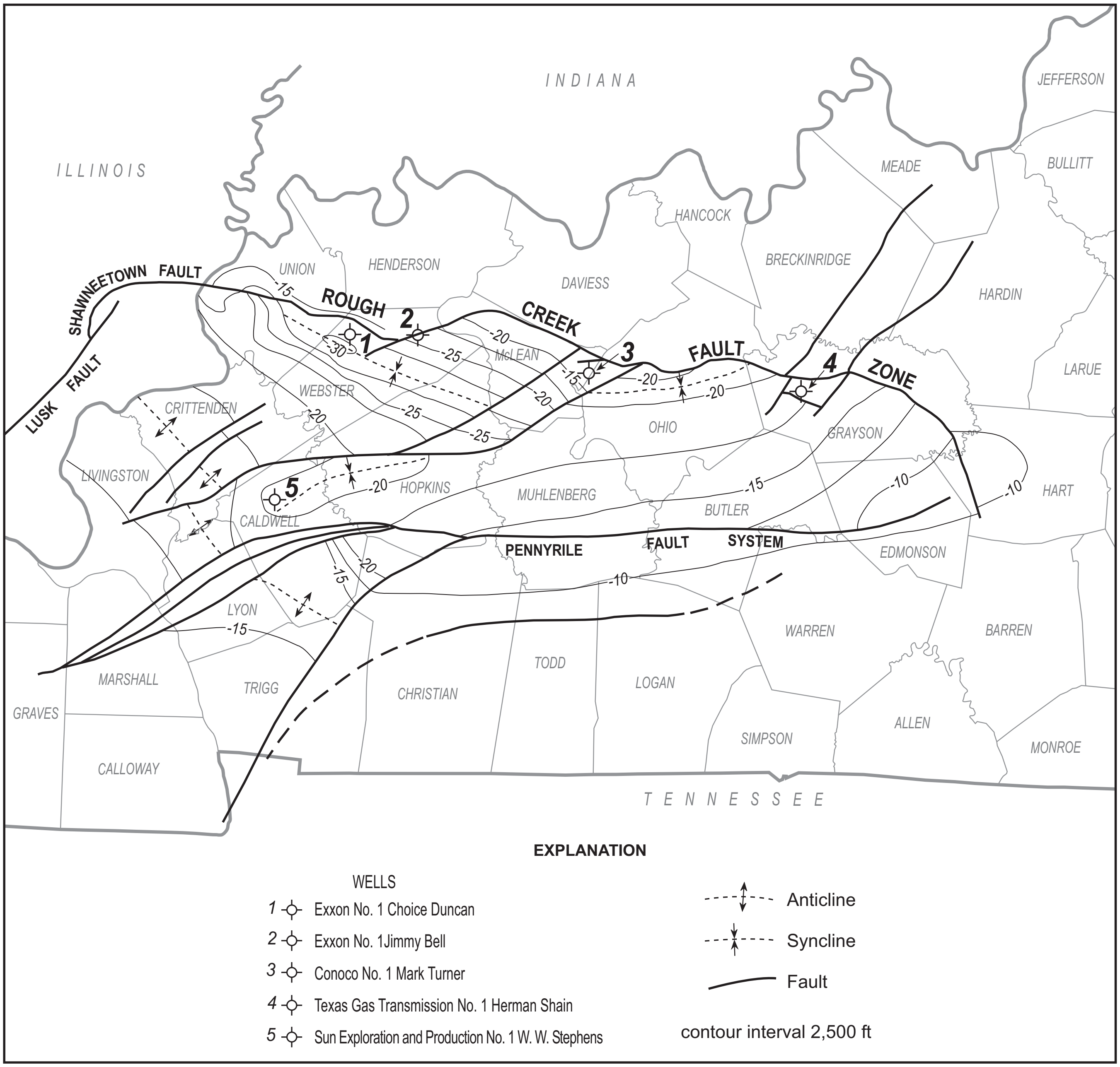

Figure 2. Configuration of the top of Precambrian rocks in the Rough Creek Graben, western Kentucky. Modified from Drahovzal (1994, Fig. 1).

vision follows the U.S. Bureau of Land Management cadastral system. The structure-contour map of the Rough Creek area (Plate 1B) is drawn on two datums: the eastern half is on the base of the Vienna Limestone Member of the Buffalo Wallow Formation (Upper Mississippian) and the western half on the base of the Springfield (W. Ky. No. 9) coal bed in the Carbondale Formation (Middle Pennsylvanian).

The nomenclature of the Paleozoic units, exposed and unexposed, within the Rough Creek area is shown in Appendix B (available for download at kgs.uky.edu/kgsweb/olops/pub/kgs/B1_12). The nomenclature used is that of the state geological surveys of Kentucky, Illinois, and Indiana at the time of the preparation of this report, as well as that in various other reports; there have been later changes in the nomenclature of various Pennsylvanian units, as the three surveys seek greater nomenclatural conformity for stratigraphic units that are common to the three states. The general lithology and stratigraphic correlation of the principal unexposed

Paleozoic units within and adjacent to the Rough Creek area, described in the text and shown on Plate 2, are largely from studies in the Illinois Basin, both published and unpublished, by the junior author, who worked for many years for the Kentucky Geological Survey and later the Illinois State Geological Survey. The identification and lithologic description of the strata in the Conoco No. 1 Mark Turner well in McLean County, Ky. (Carter coordinate sec. 21-M-29), depicted on Plate 2C (well 16), is by David A. Williams, Warren H. Anderson, and David C. Harris of the Kentucky Geological Survey.

The principal structural features of western Kentucky that extend into southeastern Illinois are the Rough Creek–Shawneetown Fault System, the Moorman–Eagle Valley Syncline, and the complex of faults and intrusive structures of the Illinois-Kentucky Fluorspar District (Fig. 3). The Rough Creek–Shawneetown Fault System and the Cottage Grove Fault System to the west separate the shallower part of the Illinois Basin in southeastern Illinois (termed the Fairfield Basin) from the deeper part to the south. The two fault systems are part of the 38th Parallel Lineament (Heyl, 1972), a basement lineament that Heyl extended from Virginia westward into Missouri. An additional structural feature in the southern part of the Illinois Basin, the Pennyrile Fault System, is confined to Kentucky.

The Rough Creek–Shawneetown Fault System extends for about 130 mi from Hart County, Ky., westward to Saline County, Ill. The Kentucky part of the system is the Rough Creek Fault Zone; the Illinois part is the Shawneetown Fault Zone. The Rough Creek–Shawneetown Fault System marks the northern margin of the Moorman–Eagle Valley Syncline; the southern margin is defined by the Pennyrile Fault System. The Moorman–Eagle Valley Syncline is underlain by a complex graben block in basement rocks, the Rough Creek Graben of Soderberg and Keller (1981). Periodic movement on the Rough Creek–Shawneetown Fault System, and to an apparently lesser extent on the Pennyrile system, influenced sedimentation in western Kentucky and adjacent parts of the Illinois Basin throughout much of the Paleozoic. The structural elements of the Illinois-Kentucky Fluorspar District lie generally south and southwest of the Rough Creek area, but a few faults in the area extend across the Ohio River into the district.

Geologic Setting

The Illinois Basin (also called the Eastern Interior Basin) is the dominant negative structural feature in the eastern part of the Midcontinent craton of the United States. The basin, an area of about 60,000 mi^2 (Buschbach and Kolata, 1991), encompasses most of Illinois, southwestern Indiana, the western half of Kentucky, and small parts of Missouri and Tennessee (Fig. 3).

Major positive structural features bounding the basin on the east are the Cincinnati Arch—including the Jessamine Dome, Cumberland Saddle, and Nashville Dome—and the Kankakee Arch. The Ozark Uplift and Pascola Arch border the basin on the southwest, and lesser features along the western margin include the Mississippi River Arch, the Lincoln Fold, the Waterloo-Dupo Anticline, and the Ste. Genevieve Fault Zone. Structures on the northern margin are related to the Wisconsin Arch. The southeast-trending LaSalle Anticlinal Belt bisects the northern part of the basin (Fig. 3).

The Illinois Basin began as a failed rift, or aulocogen (Burke and Dewey, 1973), now largely under the present upper Mississippi Embayment; Ervin and McGinnis (1975) confirmed the presence of the rift and named it the Reelfoot Rift. Later, Soderberg and Keller (1981) recognized an eastern extension of the rift and called it the Rough Creek Graben (Fig. 4).

Two additional rift arms have been postulated (Braile and others, 1982b, 1984; Sexton and others, 1986), extending from the northern end of the Reelfoot Rift; one, the southern Indiana arm, is beneath the Wabash River Valley on the Illinois-Indiana border and the other, the northwest-trending St. Louis arm, straddles the Mississippi River. The Reelfoot Rift and the three postulated arms were called the New Madrid Rift Complex (Braile and others, 1982b). Nelson (1991), in reviewing the geologic and geophysical evidence for the proposed arms, however, pointed out that the existence of the southern Indiana arm is doubtful and that there is even weaker evidence for the St. Louis arm. Because of the uncertainty as to the existence of the St. Louis and southern Indiana arms, in this report only the Reelfoot Rift and the Rough Creek Graben are considered components of the rift complex. The rift complex influenced the tectonics and geologic history of the Illinois Basin since its inception in the Late Proterozoic or Early Cambrian, and the rift is associated with the contemporary earthquake activity of the New Madrid Seismic Zone in the upper Mississippi Embayment.

Our knowledge of the origin of the rift complex and evolution of the Illinois Basin has been greatly enhanced over the past several decades by numerous geological and geophysical studies conducted in the region; mentioned herein are but a few of those studies. Cordell's (1977) regional gravity map showed a correlation with the rift complex, and Hildenbrand and others (1977, 1982, 1992) and Kane and others (1981) used gravity and aeromagnetic data to better define the limits of the Reelfoot Rift and Rough Creek Graben and to infer a thick section of sedimentary rocks filling the rift graben. Later papers by Hildenbrand and Hendricks (1995) and Hildenbrand and others (1996) better defined the geophysical setting of the Reelfoot Rift and the relations

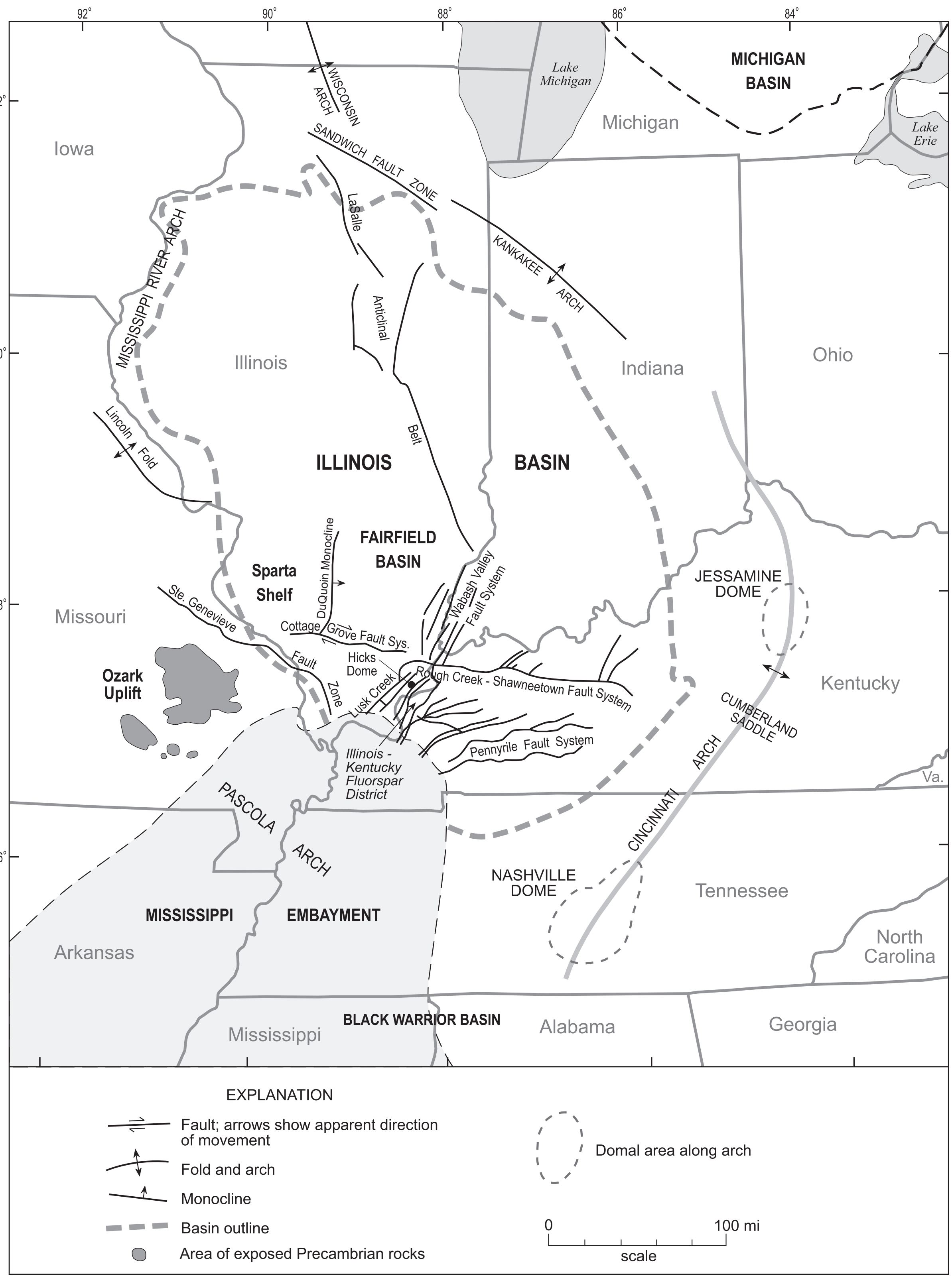

Figure 3. Selected structural features in the Illinois Basin and vicinity. Basin outline drawn on the top of the Middle Ordovician Trenton Group (Limestone) in Illinois and Indiana and top of the Kimmswick and Lexington Limestones in Kentucky. Modified from Noger (1988), Sable and Dever (1990), Buschbach and Kolata (1991, Fig. 1-1; used with permission of the American Association of Petroleum Geologists).

between the rift structures and the New Madrid Seismic Zone along the axis of the graben. The availability of high-quality seismic-reflection data has allowed detailed refinement of the basement and overlying structure in the area of the junction of the Reelfoot Rift and the Rough Creek Graben (Potter and others, 1995), as well as informative interpretation of the character of the fill in the western part of the Rough Creek Graben (Drahovzal, 1994). Hinze and others (1980) gave an excellent overview of the possible causes and timing of the Reelfoot Rift and its relation to possible rifts and tectonic events in nearby areas of the United States. These subjects were also discussed by Keller and others (1983). An excellent summary of the tectonic development of the New Madrid Rift Complex is given by Braile and others (1986); another summary on the tectonic history of the Illinois Basin is by Kolata and Nelson (1991a). In another overview paper, Kolata and Nelson (1991b) focused on the formation of the Illinois Basin. An analysis of seismic data in the junction area of the Rough Creek and Reelfoot Grabens (Potter and others, 1995) has allowed refinement of the structure of the rift, better definition of the timing of fault development, and modification of some of the assumptions expressed earlier by Kolata and Nelson (1991b).

The primary focus of this report is on those parts of the New Madrid Rift Complex that were integral to the geologic and structural development and evolution of the Rough Creek area of western Kentucky, notably the Rough Creek Graben and the northern part of the adjacent Reelfoot Rift. The Rough Creek Graben underlies the Rough Creek area and merges westward in a dogleg bend with the Reelfoot Rift in western Kentucky and southern Illinois, largely under the Illinois-Kentucky Fluorspar District (Fig. 5). Nelson (1991) noted that the two structural features have essentially the same structural geometry; in particular, pre-Knox strata thicken markedly on the downthrown side of basement normal faults bounding both graben margins.

The Rough Creek Graben apparently is little more than 10 mi wide at its eastern end (Drahovzal, 1994, Fig. 1), but expands rapidly in width to the west; in the area of its junction with the Reelfoot Rift (Fig. 5), the width across strike is about 80 mi (Hildenbrand and others, 1996, Fig. 1). The northern margin of the Rough Creek Graben is defined both at the surface and at the top of Precambrian basement by the Rough Creek–Shawneetown Fault System, and the southern margin by the Pennyrile Fault System (Hildenbrand and Keller, 1983). The graben is generally asymmetrical, the deepest part—in excess of 35,000 ft below sea level (Drahovzal, 1994, Fig. 1)—being along the northern margin against the south-dipping Rough Creek Fault Zone in Webster County, Ky. The general tilt of the graben floor is to the north, but near its junction with the Reelfoot Rift, the tilt is to the southeast (Potter and others, 1995, Plate 1). On the south side of the graben, the maximum depth to basement is about 21,600 ft along the north side of the north-dipping Pennyrile Fault System in Caldwell County (at the junction of the north branch of the Pennyrile with the Tabb Fault System of the Western Kentucky Fluorspar District). A major transition in rift polarity occurs within the dogleg bend in the Cambrian rift system; such transfer zones between opposite-dipping half grabens are common in rift systems (Potter and others, 1995).

The Rough Creek Graben is not a unified downdropped block, but is instead broken into sub-blocks in the southern part, in the junction area with the Reelfoot Rift (Bertagne and Leising, 1991; Potter and others, 1995), and across the middle of the graben (Drahovzal, 1994, Fig. 1).

The Rough Creek Fault Zone west of Webster County, Ky., is expressed seismically as a south-dipping normal listric fault that penetrates basement (Bertagne and Leising, 1991). Above the level of the Cambrian sequence, it splits into a series of high-angle reverse and normal faults that are the result of post-Cambrian re-

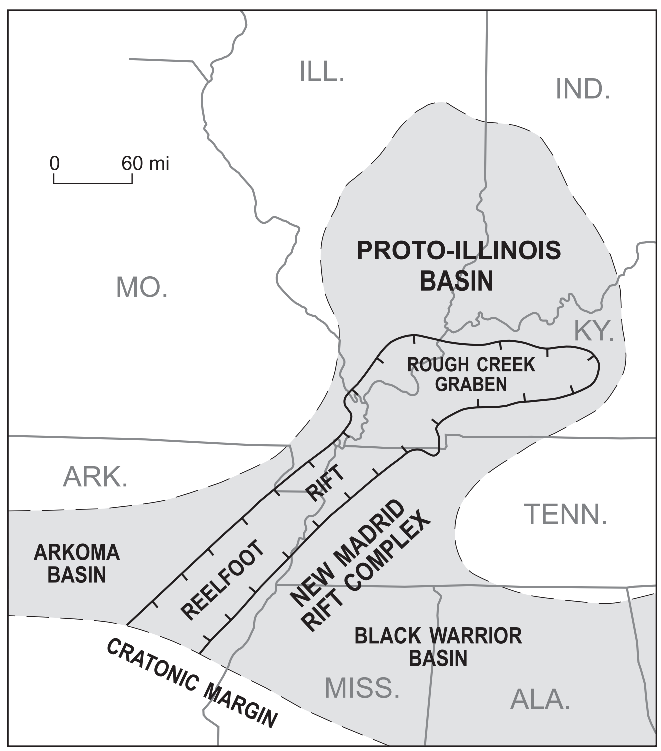

Figure 4. Development of the proto-Illinois Basin as a cratonic embayment centered on the New Madrid Rift Complex and its relation to the cratonic margin in the early Paleozoic. Shading indicates where Paleozoic rocks are more than 5,000 ft thick. Modified from Kolata and Nelson (1991a, Fig. 18-6; used with permission of the American Association of Petroleum Geologists), Hildenbrand and Hendricks (1995, Fig. 11).

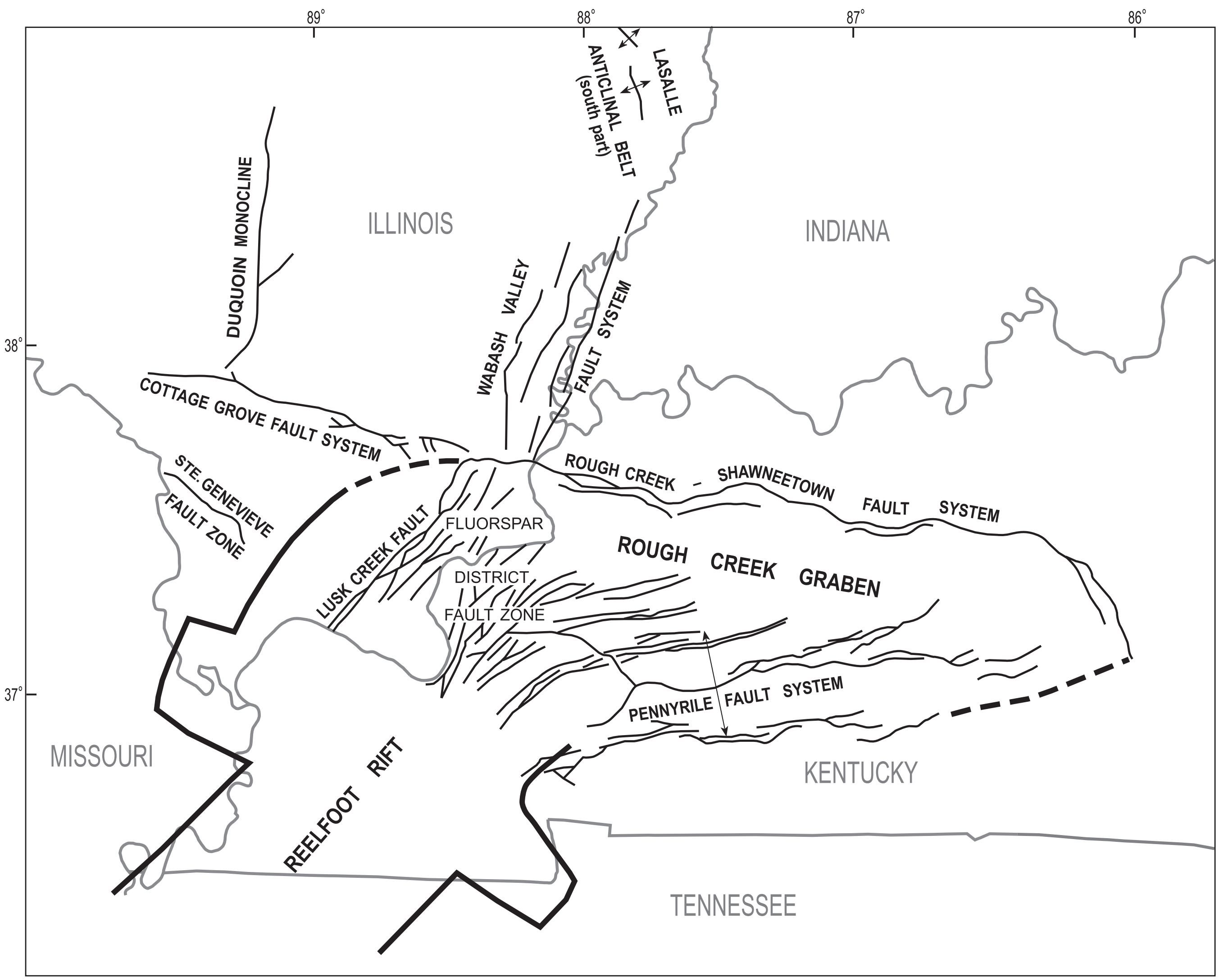

Figure 5. Postulated margins (heavy solid and dashed lines) of the Rough Creek Graben and Reelfoot Rift in relation to the major structural features of western Kentucky and southern Illinois and Indiana. After Noger (1988), Lumm and others (1991b, Fig. 3; used with permission of Southeast Missouri State University), Treworgy (1991; used with permission of the American Association of Petroleum Geologists), Drahovzal (1994, Fig. 1), Hildenbrand and Hendricks (1995, Fig. 11), and Hildenbrand and others (1996, Fig. 6).

activation (Nelson, 1991). Vertical separation is 6,600 to 10,000 ft at the top of Precambrian crystalline rocks, but much less at the top of the Knox Group (Middle Cambrian and Lower Ordovician)—a well-defined seismic reflection horizon—and in younger strata (Nelson, 1991). Eastward from Webster County, Ky., the amount of offset on the basement fault diminishes, and several south-facing normal faults apparently are present (Nelson, 1991). At the western end of the Rough Creek–Shawneetown system in Illinois, where it merges with the southwest-trending Lusk Creek Fault System (Fig. 5), there is no significant basement offset on the Shawneetown Fault and no significant thickening of pre-Knox strata across the zone (Goldhaber and others, 1992).

Bertagne and Leising (1991) postulated that the Lusk Creek Fault System and the southwestern segment of the Shawneetown Fault Zone mark the northwestern margin of the Reelfoot–Rough Creek Rift Complex. A seismic-reflection section (Potter and others, 1995, Plate 1) shows, however, that the southwestern segment of the Shawneetown zone was not active during pre-Knox deposition and that the pre-Knox fill does not vary appreciably in thickness across the Lusk-Herod Fault System, as would be expected if the fault system coincided with the rift margin during the Early Cambrian. Hildenbrand and others (1996, Fig. 6) presented potential-field data that suggest that the rift boundary in southern Illinois extends westward from the sharp southward bend in the Shawneetown Fault Zone, and is about 18 mi northwest of the Lusk Creek system (Fig. 5).

A sequence of as much as 18,000 ft of pre-Knox Group strata—Upper Cambrian Eau Claire Formation and Mount Simon Sandstone, and underlying unnamed Middle and Lower Cambrian rift-fill shale and sandstone (Drahovzal, 1994, Fig. 1)—is present in the deepest part of the graben adjacent to the northern boundary of the Rough Creek Graben in western Webster County, Ky. Pre-Knox strata were first identified from seismic-reflection data by Bertagne and Leising (1991), who reported a thickness of 3,000 to 11,000 ft within the graben; later seismic data allowed Drahovzal (1994) to upgrade the maximum thickness to about 18,000 ft. The pre-Knox section thins markedly westward along the northern side of the graben; close to the northwest margin of the rift complex, west of the Shawneetown Fault Zone, the pre-Knox section is only about 3,600 ft thick (Potter and others, 1995). About 50 mi north of the rift complex, pre-Knox strata are about 1,300 ft thick (Potter and others, 1995).

The distribution and thickness of pre-Knox strata in the Rough Creek Graben east of its deepest part are less well known from published reports. The Conoco Oil Co. No. 1 Turner well on the southern margin of the Rough Creek Fault Zone in extreme eastern McLean County, drilled in 1992, penetrated more than 4,000 ft of pre-Knox strata and bottomed in Precambrian granite at a depth of 14,202 ft (Harris, 1994). This is the only well in the Rough Creek Graben within Kentucky that penetrates the entire pre-Knox sequence. The well is located on a large horst block in the basement floor (Drahovzal, 1994, Fig. 1). Immediately east of the well, the basement floor is 20,000 ft below sea level next to the Rough Creek Fault Zone, but the floor rises rapidly to the south and east and is less than 10,000 ft below sea level at the eastern end of the graben (Drahovzal, 1994).

The southern margin of the Rough Creek Graben is marked in general by a broad belt of faults in the subsurface that coincides in part at the surface with the three branches of the Pennyrile Fault System (Fig. 5) and possibly also with an unnamed belt of faults farther south in Kentucky (Nelson, 1991). In earlier reports, most authors applied the name "Pennyrile" to the main or central branch of the fault system, but geophysical data (Lumm and others, 1991b; Potter and others, 1995) suggest that all three branches are present in the basement and were involved in the structural evolution of the Rough Creek Graben.

The placement of the southern margin of the Rough Creek Graben and the location and configuration of the junction area of the graben and the Reelfoot Rift have been modified over time as additional geophysical data became available. In the initial geophysical evaluation of the Rough Creek Graben (Soderberg and Keller, 1981), the southern boundary, although not well defined, was said to trend northwestward across the Pennyrile Fault System. A magnetic anomaly map (Hildenbrand, 1985, Fig. 2) clearly shows the well-defined southeastern margin of the Reelfoot Rift trending northeast across the Kentucky-Tennessee state line in the area between the Tennessee and Cumberland Rivers, then bending in a dogleg to the east around latitude 37°N, longitude 87°45′W (Hildenbrand and others, 1996) to join the well-defined southern margin of the Rough Creek Graben. The junction of the two structures is in the general area where the Tabb Fault System of the Western Kentucky Fluorspar District merges with the southern branch of the Pennyrile Fault System. Hildenbrand and others (1996) did not identify a particular branch of the Pennyrile system that marks the southern margin of the Rough Creek Graben, however. Gravity data and modeling by Lumm and others (1991b) strongly suggest that the southern branch of the Pennyrile system marks the southern edge of the Rough Creek Graben; also, as depicted by the gravity data (Lumm and others, 1991b, Fig. 5.3), the margin of the rift north of the Tennessee-Kentucky state line bulges eastward, rather than trending northeastward, before joining the southern margin of the Rough Creek Graben. The gravity profiles (Lumm and others, 1991b, Fig. 5.3) did not extend south of the southern branch to investigate the belt of unnamed faults that may be part of the southern margin of the graben (Nelson, 1991). An interpretation of seismic-reflection data by Drahovzal (1994, Fig. 1) supports the general picture by Lumm and others (1991b) of the merger of the Rough Creek Graben and the Reelfoot Rift. As summarized by Potter and others (1995), the available geologic and geophysical data support the conclusion that a broad Pennyrile Fault System (about 20 mi perpendicular to strike), rather than a more localized fault zone, formed the southern margin of the Rough Creek Graben in Cambrian time.

The faults of the Pennyrile system are mostly high-angle, normal, and downdropped to the north. The total displacement across the system probably is less than 3,300 ft (Nelson, 1991); however, later seismic data (Potter and others, 1995) show that at the intersection of the Tabb and north branch of the Pennyrile Fault Systems in the junction area of the Rough Creek Graben and the Reelfoot Rift, the tilt of the graben floor is to the southeast, and displacement of the pre-Knox Cambrian section is about 4,000 ft. About 3.1 km of pre-Knox Cambrian synrift sedimentary rocks were deposited against the north side of the north branch of the Pennyrile system at the junction with the Tabb Fault System of the Western Kentucky Fluorspar District (Potter and others, 1995). The two fault systems differ in strike by about

45°; the Tabb strikes northwestward and the Pennyrile northeastward (Potter and others, 1995). About 50 mi to the east, apparently along the north branch of the Pennyrile, the pre-Knox Cambrian section is approximately 5,400 ft thick on the north side (calculated by us from seismic-reflection data in Bertagne and Leising [1991, Fig. 15-5]).

Prior to development of the Reelfoot–Rough Creek Graben Complex, the surface on Precambrian basement, at least in the Rough Creek Graben, had little nonfaulted topographic relief (Bertagne and Leising, 1991). As the graben subsided along faults on its margins, the graben floor was ruptured by a series of faults that were active and influenced pre-Knox marine synrift deposition (Bertagne and Leising, 1991; Potter and others, 1995). With the filling of the graben, deposition of pre-Knox post-rift strata spread onto the adjacent land surface, which had undergone much less deposition during the rift-filling period. The thickness of pre-Knox strata within the graben greatly exceeds that deposited beyond the graben margins.

Following the rift stage in the Late Cambrian, the rift complex and adjacent cratonic areas underwent slow regional subsidence that continued with only periodic interruption throughout most of the Paleozoic. The area was transformed into a cratonic embayment in which the depocenters for most Paleozoic sedimentary sequences apparently were within the rift complex to the southwest of the present borders of the Illinois Basin (Kolata and Nelson, 1991a). A major marine transgression in the Late Cambrian spread northward from the rift complex, covering the pre-Knox strata adjacent to the complex and onto a Precambrian erosional surface that had isolated hills so high that the initial deposits of the Mount Simon Sandstone did not cover them. The late Mount Simon sediments and younger Eau Claire deposits did overlap the highest hills, and by the end of Cambrian time all Precambrian rocks in the proto-Illinois Basin were covered. The pronounced growth faulting so evident in the pre-Knox sedimentary strata diminished considerably, and during later Paleozoic time the influence on deposition by movement on the bounding faults of the Rough Creek Graben was much reduced.

Deposition in the shallow epeiric seas over the Illinois Basin area was nearly continuous until the end of the Mississippian. There was, however, a long period of erosion at the end of the Early Ordovician (Canadian), minor but widespread erosion at the end of the Late Ordovician (Cincinnatian), and deep and widespread erosion at the end of the Early Devonian and again at the end of the Middle Devonian. Deposition in deeper parts of the proto-Illinois Basin, however, generally was continuous during the erosional cycles. Marine deposition came to an end with uplift in latest Mississippian to Early Pennsylvanian time, followed by deep and extensive erosion, then deposition of the nonmarine, largely deltaic sediments during the Pennsylvanian and Permian. Minor transgressions of the seas, however, are recorded by thin marine limestones and black shales scattered through the Pennsylvanian section and in units now identified as Lower Permian.

The southern part of the Illinois Basin was an area of concentrated structural and igneous activity during the latest Pennsylvanian to Late Cretaceous. Most of the present bedrock structures assumed their present form during this period. The southern block of the Rough Creek–Shawneetown Fault System was uplifted as much as 3,500 ft near its western end (Nelson and Lumm, 1984), but progressively less toward the east. Later, regional change to a tensional-stress field allowed the block to collapse to its approximate previous position; this resulted in the formation of the Moorman–Eagle Valley Syncline. A substantial thickness of Permian sedimentary rocks has been eroded from the basin area in the long period from uplift to the present.

In the Early Permian, ultramafic rocks (Zartman and others, 1967) were intruded as dikes along faults in the Illinois-Kentucky Fluorspar District close to the Rough Creek area. Uplift of the Pascola Arch (Fig. 3) across the Reelfoot Rift, probably during the Mesozoic (Schwalb, 1982b), structurally closed the Illinois Basin on the south. By the Late Cretaceous, erosion of the arch and renewed subsidence in the rift allowed deposition of a thick wedge of Upper Cretaceous and Tertiary sedimentary rocks and development of the present Mississippi Embayment of the Gulf Coastal Plain.

Stratigraphy of Unexposed Rocks

Precambrian Rocks

The Precambrian basement complex underlying the Illinois Basin is part of the Eastern Granite-Rhyolite Province, one terrane in a collage of Archean to Middle Proterozoic tectonic terranes forming the North American craton (Sims and others, 1987). The Eastern Granite-Rhyolite terrane formed 1,480 to 1,450 Ma and probably is a veneer lying on older Proterozoic crust (Bickford and others, 1986). In the Rough Creek area, the Precambrian basement is buried beneath as much as 30,000 ft of Paleozoic strata (Drahovzal, 1994). Only two wells, the Conoco No. 1 Turner well in McLean County and the Exxon No. 1 Jimmy Bell well in Webster County (Plate 2C, wells 16 and 15, respectively), have penetrated to the basement complex in western Kentucky, and only a few wells have reached basement elsewhere in the southern part of the Illinois Basin. The closest exposed basement rocks representative of the granite-rhyolite terrane are in the St. Francois Mountains at the structural apex of the Ozark Uplift in southeastern Missouri, and they consist of unmetamorphosed volcanic and related epizonal intrusive rocks of late Precambrian age (Kisvarsanyi, 1974). The volcanics are mainly rhyolitic in composition, but include trachyte and trachyandesite, and the associated silicic intrusive rocks include granite and adamellite porphyries, alkali granite, syenite, and adamellite (Kisvarsanyi, 1974).U-Pb ages from those rocks are about 1,480 Ma, except for a small pluton (Munger granite porphyry) that yielded an age of 1,380 Ma (Bickford and others, 1986).

Cambrian System

Lower(?) and Middle Cambrian Rocks

The drilling of the Conoco No. 1 Turner well in McLean County in 1992 afford the first opportunity to discern the lithology and character of the initial synrift deposits in the Rough Creek Graben. Although the Exxon No. 1 Jimmy Bell well also penetrated the Precambrian basement, there the basal Paleozoic unit has been identified as the Mount Simon Sandstone of Late Cambrian age. The Turner well penetrated more than 4,000 ft of Lower(?) and Middle Cambrian sedimentary rocks of marine origin. All except the 200-ft-thick basal sandstone was initially assigned by the Kentucky Geological Survey (David C. Harris, written commun., 1997) to the Eau Claire Formation (Upper Cambrian); the basal sandstone was unnamed. Later, however, Harris (written commun., April 28, 1997) stated that all of the pre-Knox sedimentary rocks probably should not be assigned to the Eau Claire (no other formation assignment was suggested), and the unnamed basal sandstone might be correlative with the Rome Sandstone. The closest Rome Sandstone is in the Rome Trough in the subsurface of central Kentucky. During the Early and Middle Cambrian, a structurally stable area separated the subsiding Rome Trough on the east from the subsiding Rough Creek Graben to the west, however (Drahovzal and others, 1992). So, if the unnamed basal sandstone is actually correlative with the Rome, the two units were not deposited in the same basin. As described by Harris (1994), the oldest part of the rift sequence is 1,900 ft thick, dominantly of fine- to coarse-grained glauconitic lithic sandstone, containing abundant rhyolite grains, thin green shale, and minor oolitic limestone. Overlying the clastic sequence is a 1,150-ft-thick sequence of fine- to medium-grained glauconitic lithic sandstone, oolitic and fossiliferous limestone, and green shale; small-scale, shallowing-upward cycles are recognizable in this sequence, which is interpreted as a late synrift deposit. Overlying the synrift deposits are post-rift deposits consisting of a 600-ft-thick unit of dolomitized, oolitic grainstone overlain by a dominantly shale sequence, 350 ft thick, of green shale, siltstone, and oolitic and fossiliferous limestone. No fossils that could be used for dating were reported from the rift or post-rift strata in the Turner well.

Using seismic-reflection data, Drahovzal (1994) found relatively strong evidence for basin-floor fan deposition in the basal sedimentary rocks in the Rough Creek Graben, at least in the western part. Reflector patterns indicate that the basin-floor fans are bidirectional, downlapping, and mounded, and those in the northern, deepest part of the graben overlap and pinch out southward onto the Precambrian basement surface. The geometry of the individual fans suggests that the sediment transport direction was longitudinal to the axis of the basin. This orientation suggests that sediment sources were both the Precambrian granite and rhyolite of the uplands surrounding the rift graben and the East Continent Rift Basin to the east and northeast (Drahovzal, 1994). Houseknecht and Viele (1984) considered the basal arkose in the Reelfoot Graben farther to the south as possibly equivalent to the Lower Cambrian Rome Formation, and the thick sequence of carbonate rocks overlying the arkose they tentatively correlated with the Conasauga Formation (Middle Cambrian).

In the Rough Creek area, rocks equivalent to the Conasauga are present in the subsurface in Grayson County, Ky. Marine shale, correlated on the basis of trilobites (Christina Lochman-Balk, U.S. Geological Survey, written commun., 1978) with the upper part of the Conasauga Shale (Middle Cambrian) of the southern Appalachian area, composes the lower 2,360 ft of strata penetrated in the Texas Gas Transmission No. 1 Herman Shain well (Plate 2A, well 5). The shale is light to dark gray and brownish gray, and contains some interbeds of gritty, arkosic limestone and oolitic limestone, and scattered, very fine laminae of arkosic material. The shale is apparently restricted to the Moorman Syncline south of the Rough Creek Fault Zone. The presence of arkosic material may indicate that basement rock was exposed adjacent to the graben.

The Conasauga, together with the overlying Mount Simon Sandstone, compose the upper part of a thick sequence of pre-Knox rift-fill sediments that was originally defined by seismic-reflection data (Bertagne and Leising, 1991) within the Rough Creek Graben. Bertagne and Leising (1991) calculated the sequence to be 3,000 to 11,000 ft thick. In the junction area of the Rough Creek Graben and the Reelfoot Rift, seismic data (Potter and others, 1995, Plate 1) show that the pre-Knox sequence is about 3,600 ft thick near the northern margin of the rift complex in southeastern Illinois, thickens to more than 10,000 ft against the north side of the Tabb Fault System at its junction with the Pennyrile system in western Kentucky, and then thins rapidly southeastward to about 6,000 to 7,000 ft within 8 mi. Thinning of the pre-Knox sequence probably continues southward to the boundary of the Rough Creek Graben in the vicinity of the southern branch of the Pennyrile Fault System. Beyond the northern and southern margins of the graben, limited well data show the pre-Knox clastic sequence ranges from about 700 to 1,300 ft in thickness (Potter and others, 1995). The abrupt thinning of the pre-Knox section beyond the margins of the Rough Creek Graben is well illustrated in Figure 6.

Upper Cambrian Rocks

The Mount Simon Sandstone (also called the Lamotte Sandstone around the Ozark Uplift), the initial deposit of Late Cambrian age, spread over the Precambrian terrane and the limited areas of pre-Knox rocks adjacent to the Rough Creek Graben and inundated all but isolated hills. Description of the sand is not available from wells in the Rough Creek area, but in wells in southeastern Illinois the Mount Simon Sandstone is white to very light gray and pink to reddish brown, very fine grained, in part calcareous and glauconitic, and slightly to moderately friable. The formation also includes some pink, reddish-brown, and dark-red, very sandy siltstone. In Lawrence County, Ind. (Plate 2A, well 1), it contains some maroon to grayish-black micaceous shale and a small amount of whitish-red argillaceous dolomite; the sandstone is very fine to very coarse grained and commonly frosted.

The Mount Simon is generally considered a shallow marine sandstone deposited as terrigenous sand and mud in a shallow subtidal environment (Droste and Shaver, 1983, Fig. 4). The clastics largely represent alluvial-plain deposits peripheral to the ancestral St. Francois Mountains, but deposits in paleotopographic lows on the Precambrian surface within the mountains represent alluvial-fan and braided fluvial processes (Houseknecht and Ethridge, 1978). Near the close of Mount Simon deposition, both alluvial and shallow-marine sediments were deposited in the advancing Late Cambrian sea. In northeastern Illinois, Mount Simon Sandstone filled a secondary basin to a thickness of as much as 2,500 ft (Sargent, 1991, Fig. 3-2). In the Reelfoot Rift, the Mount Simon grades southward into the lower

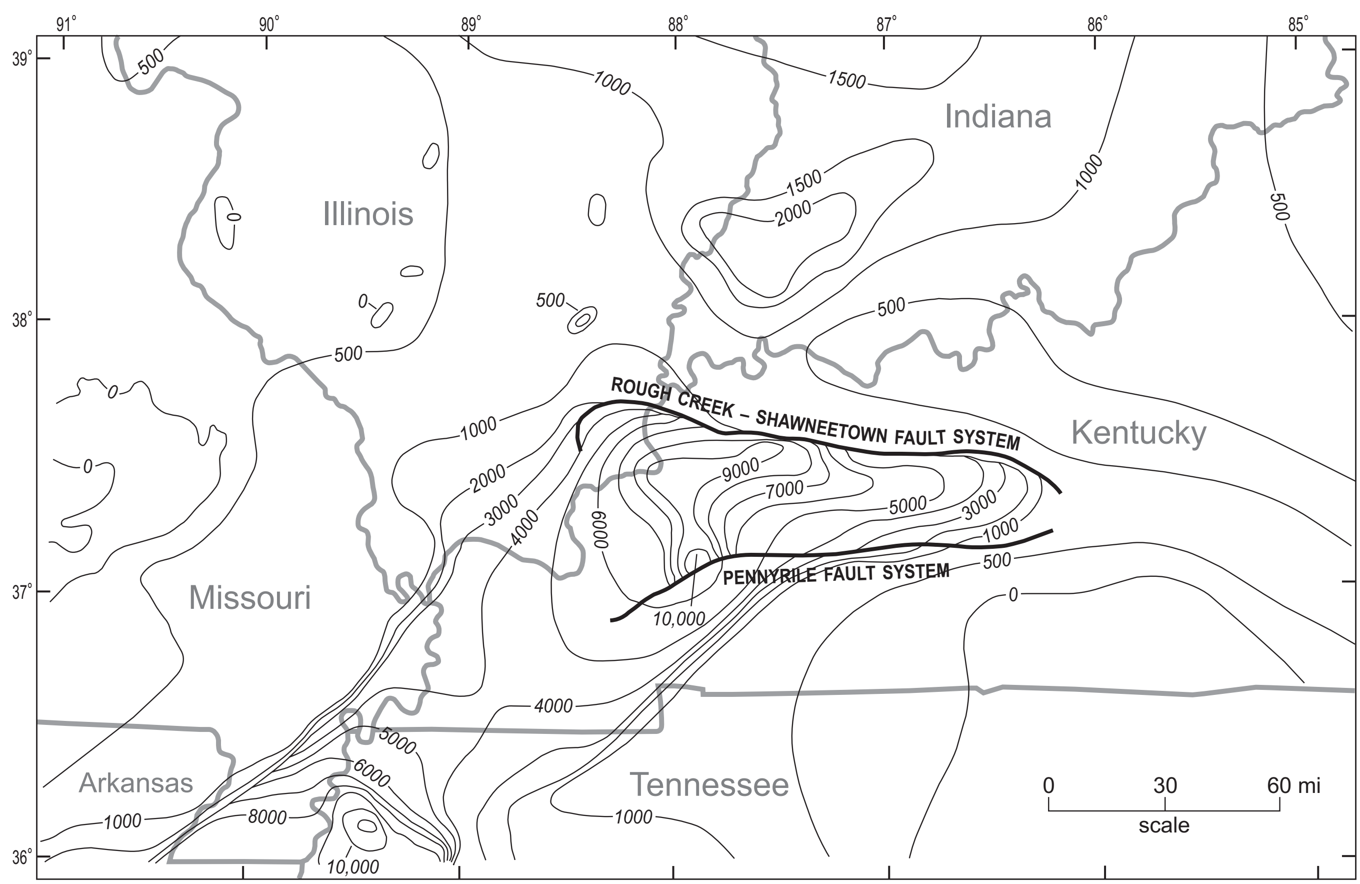

Figure 6. Thickness of the lower Sauk sequence (Cambrian strata from top of Precambrian rocks to base of Upper Cambrian Eau Claire Formation) in southern part of the Illinois Basin. Faults are very generalized. Contour interval=500 and 1,000 ft. Modified slightly from Sargent (1991, Fig. 3-2; used with permission of American Association of Petroleum Geologists) using data from Potter and others (1995, Plate 1) and deep wells.

part of a 1,500-ft-thick Upper Cambrian marine shale (Houseknecht and Viele, 1984).

In the Rough Creek area, the distribution of the Mount Simon is inadequately known, because few wells have penetrated sufficiently deep to encounter the formation. It probably covers most of the area, but is missing locally in Grayson County (see Plate 2A, well 5), where the overlying Eau Claire Formation rests directly on shale equivalent to the Conasauga Formation (Middle Cambrian).

The maximum known thickness of the Mount Simon is 810 ft in the Exxon No. 1 Jimmy Bell well, located within the Rough Creek Fault Zone in Webster County (Plate 2C, well 15). The thickness ranges from less than 500 ft to more than 1,000 ft in the Rough Creek area on the north side of the fault zone (Sargent, 1991, Fig. 3-2). On the south side of the fault zone, the range in thickness of the Mount Simon is not known, because the formation was not differentiated on seismic-reflection profiles (Bertagne and Leising, 1991) from other parts of the pre-Knox clastic sequence in the Rough Creek Graben. West of the report area in Johnson County, Ill., the lower part of the Mount Simon Sandstone is arkosic sandstone, which Schwalb (1982a) originally thought was a separate unit he called the Mermet sandstone. The arkosic sandstone was penetrated in the Texas Pacific Oil Co. No. 1 B. Farley well (sec. 34, T. 13 S., R. 3 E.) from 13,720 ft to the total depth of 14,276 ft. A thin mylonite zone at the top of the arkosic sandstone may mark a fault separating the arkosic unit from the overlying Mount Simon Sandstone (Schwalb, 1982a, Fig. 6). The well is about 20 mi southwest of the deep Texas Pacific No. 1 Mary Streich well (see Plate 2C, well 12) in Pope County, Ill., which bottomed in the Mount Simon Sandstone. The Farley well is west of the Lusk Creek Fault System and within the northwest boundary of the Reelfoot Rift, as defined by Hildenbrand and Hendricks (1995, Fig. 11). The arkosic sandstone is dominantly shades of pink, orange, and red, but includes some white and green. It is mostly coarse grained or pebbly, but contains some siltstone and fine-grained sandstone. Nearly unabraded crystals of pyroxene, a rather easily abraded mineral, are present in the lower part of the unit, and their presence indicates that the mineral probably was derived from a nearby area of Precambrian rocks. Thin zones of red and maroon shale and traces of siltstone also occur in the sandstone. The mineral suite of the arkosic sandstone differs from the pyroxene-free suite in overlying Mount Simon beds. Because the arkosic sandstone apparently is unfossiliferous, its age is unknown, and its relation to pre-Mount Simon rocks, such as the Conasauga Formation in western Kentucky, is also unknown.

Over most of the Rough Creek area, the Eau Claire Formation conformably overlies the Mount Simon Sandstone, but locally in Grayson County, Ky., the Eau Claire is unconformable on the Middle Cambrian Conasauga Formation. The Eau Claire is mostly biotitic shale that is gray in the upper part and red and maroon in the lower part. Oolitic and argillaceous dolomites are dominant in the upper and middle parts, but are generally interbedded with shale and oolitic limestone in the lower part. About 30 ft of arkosic material (granite wash) is present at the basal Eau Claire in the Texas Gas No. 1 Herman Shain well in Grayson County (see Plate 2A, well 5); the material probably came from nearby, formerly exposed basement rocks. The Eau Claire was deposited as a shallow-water oolitic carbonate facies in southern Illinois, Indiana, and Kentucky, north of the rift complex (Sargent, 1991), but within the rift complex, shale, in facies relation with oolitic carbonate sediments, accumulated in a deeper-water environment (Schwalb, 1982a).

The maximum known thickness of identified Eau Claire in the Illinois Basin is 3,565 ft in the Herman Shain well in Grayson County. To the west in Webster County, 2,700 ft of the Eau Claire was penetrated in the Exxon No. 1 Choice Duncan well (Plate 2C, well 14); however, the base of the formation was not reached in the well. The thickness of the Eau Claire in adjacent parts of southwestern Indiana ranges from about 700 to more than 1,000 ft (Becker and others, 1978, Fig. 12) and in southeastern Illinois from about 900 to 1,000 ft (Buschbach, 1975, Fig. C-8). The Eau Claire is equivalent to the Bonneterre Formation of Missouri.

A thick sequence largely of dolomite of Late Cambrian and Early Ordovician age, comprising the Knox Group, overlies the Eau Claire Formation in western Kentucky. The Knox underlies the Everton Dolomite; where the Everton is missing, either the St. Peter Sandstone or Dutchtown Formation is present. The upper contact of the Knox Group is defined by the major pre-Middle Ordovician unconformity, which marks the top of the Sauk sequence of Sloss (1963). In western Kentucky, the Upper Cambrian units of the Knox, in ascending order, are the Elvins Formation (Shaver and others, 1984) and the Potosi and Eminence Dolomites; the Lower Ordovician units are the Gunter Sandstone, Gasconade Dolomite, Roubidoux Formation, and Jefferson City and Cotter Dolomites. Because of the difficulty in distinguishing the various dolomite units, no attempt was made to identify and correlate all the formations of the Knox Group in the wells whose locations are shown on Plate 2.

In the Rough Creek area, three wells (within or just south of the Rough Creek Fault System) have penetrated complete sections of the Knox Group, as identified on sample logs: the Herman Shain well in Grayson County (Plate 2A, well 5), the Conoco No. 1 Mark Turner well in McLean County (Plate 2C, well 16), and the Choice

Duncan well in Webster County (Plate 2C, well 14). The westward thickening of the Knox, demonstrated by the thicknesses in the wells from 4,530 ft to 4,550 ft to 4,760 ft, respectively, corresponds generally to the direction of thickening of the combined Knox Group and Eau Claire Formation toward the center of deposition in the Illinois Basin in the Jackson Purchase Region of western Kentucky, where the units together are more than 8,000 ft thick (Fig. 7).

Kolata and Nelson (1991a) pointed out a puzzling anomaly in the thickness of the Knox Group along the Rough Creek–Shawneetown Fault System bounding the north side of the Rough Creek Graben. Seismic-reflection profiles across the graben (Bertagne and Leising, 1991), as well as proprietary seismic data, show an abrupt thickening of Knox strata in several areas along the north side of the fault system. Growth faulting is evident in the thick pre-Knox section in the graben, and if the same process were active in Knox time, then Knox strata would be expected to be thicker south of the fault than to the north. Interpretation of the seismic data, however, points to as much as 1,600 ft of displacement down to the north along the Rough Creek–Shawneetown system during deposition of the lower Knox (Kolata and Nelson, 1991a).

In southern Indiana, the Eau Claire Formation is conformably overlain by the Davis Formation, which, in Lawrence County (Plate 2A, well 1), is a 35-ft-thick unit of shaly dolomite transitional between the Eau Claire and the overlying Knox Dolomite (the Knox has formation status in Indiana).

The lowest unit of the Knox Group in western Kentucky is the Elvins Formation, which is predominantly dolomite that is in part very cherty. Some of the chert is oolitic, and in places oolitic structures are preserved in the dolomite. A small amount of anhydrite occurs in the upper part of the Elvins in western Kentucky. Most of the Elvins and correlative units in adjacent parts of Indiana and Illinois were deposited as carbonate sand and mud in shallow subtidal to somewhat deeper subtidal

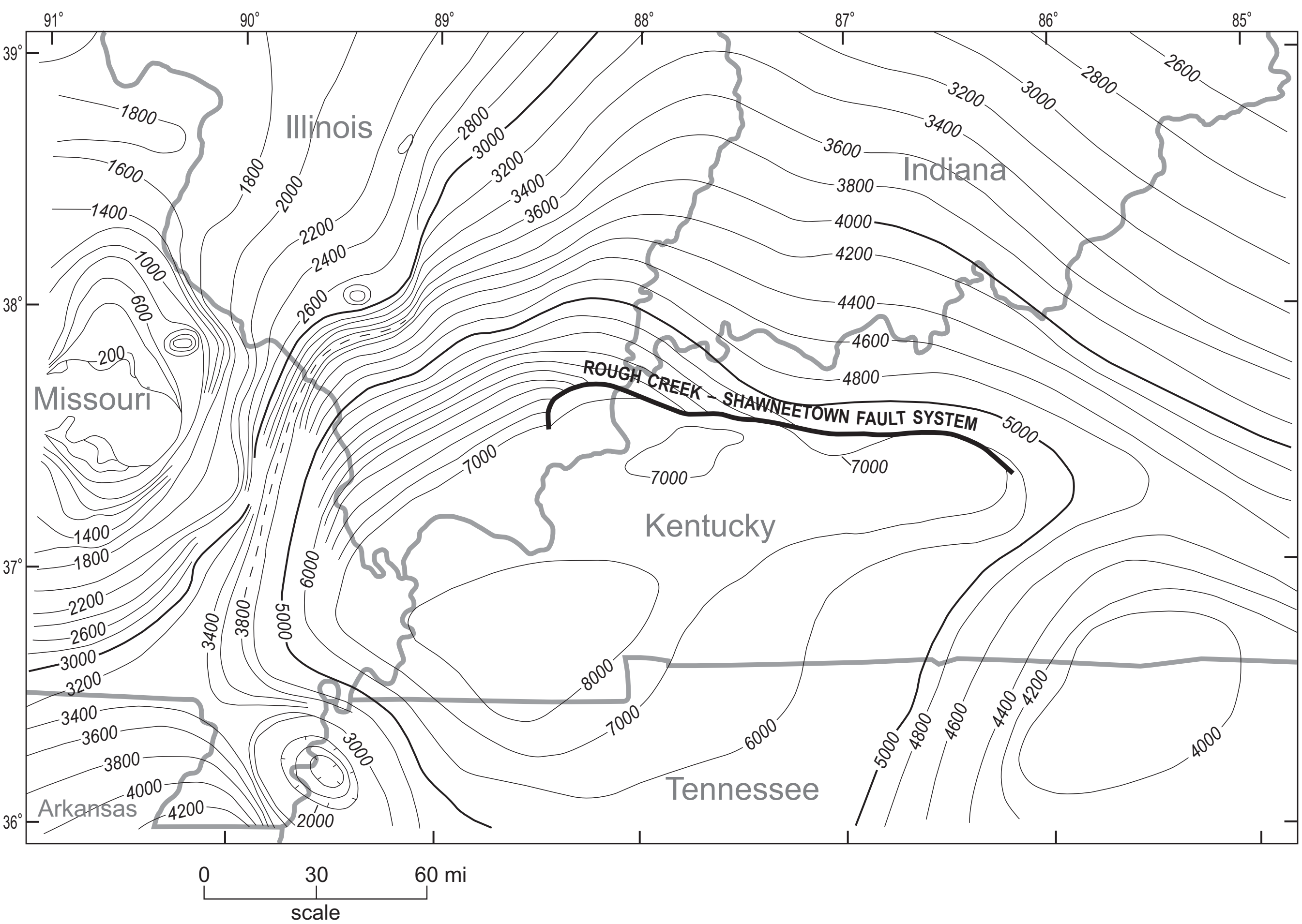

Figure 7. Thickness of the upper Sauk sequence (mostly Knox Group—Upper Cambrian and Lower Ordovician strata from base of Eau Claire Formation to base of Everton Formation or St. Peter Sandstone) in southern part of the Illinois Basin. Fault system generalized. Contour interval=200 and 1,000 ft. Modified from Sargent (1991, Fig. 3-4; used with permission of American Association of Petroleum Geologists).

conditions (Droste and Shaver, 1983, Fig. 7), including the accumulation of oolitic shoals (Droste and Patton, 1983). Where the Elvins could be differentiated in western Kentucky (but not shown on Plate 2), the unit is almost 1,200 ft thick. In adjacent areas of southern Illinois, the Franconia Formation, the equivalent of the Elvins, is about 700 ft thick (Buschbach, 1975, Fig. C-11). These units thicken southward in the Illinois Basin to the margin of the Reelfoot Rift, as is the pattern with all Knox units.

The Potosi Dolomite conformably overlies the Elvins throughout western Kentucky, but both the lower and upper contacts of the Potosi are difficult to recognize. The formation is moderate- to dark-brown dolomite, containing variable amounts of sand, oolitic chert, and anhydrite. Drusy quartz, which is common in the Potosi in other parts of the Illinois Basin, was not noted in well samples in the study area.

A relative rise in sea level with the beginning of Potosi deposition shifted the shoreline substantially higher onto the craton, and the Reelfoot Rift became connected with a depositional center to the north in the Great Lakes area (Droste and Shaver, 1983). The Potosi and overlying Eminence Dolomite were deposited as carbonate mud and sand in peritidal to shallow subtidal environments (Droste and Shaver, 1983, Fig. 9). The Potosi is about 800 ft thick.

The Eminence Dolomite, the uppermost unit of Cambrian age, is lithologically similar to the Potosi but contains more cream and tan dolomite and no anhydrite. The upper contact of the Eminence in western Kentucky is at the base of the Gunter Sandstone. Where it could be defined, the Eminence is about 850 ft thick.

Ordovician System

The Ordovician System in the report area is divided, in ascending order, into the Canadian, Champlainian, and Cincinnatian Provincial Series. The Canadian conforms to the Lower Ordovician Series, the Champlainian to the Middle and lower part of the Upper Ordovician of former usage, and the Cincinnatian to the remainder of the Upper Ordovician (Shaver and others, 1984).

At the end of Cambrian time, there was slight interruption of carbonate deposition and minor erosion across southern Illinois and possibly into southwestern Indiana (Shaver and others, 1984), but apparently carbonate deposition was continuous in western Kentucky, and the resulting lowermost Ordovician dolomites closely resemble the Cambrian dolomites that underlie them. As a consequence, the Cambrian-Ordovician boundary is not easily recognized in the subsurface of western Kentucky. The lowermost formation of Ordovician age, the Gunter Sandstone, is a thin, widespread sandstone, but it has patchy distribution in the Illinois Basin (Willman and Buschbach, 1975), and is not easily distinguished from other sandy zones in the Knox Group above and below the Gunter horizon.

Canadian Rocks

The Canadian (Lower Ordovician) units comprising the upper part of the Knox Group in western Kentucky are, in ascending order, the Gunter Sandstone, Gasconade Dolomite, Roubidoux Formation, and Jefferson City and Cotter Dolomites. Because of general lithologic similarity, the formations are difficult to differentiate. The Gunter is medium- to fine-grained quartz sandstone (Willman and Buschbach, 1975), but at some localities sandy dolomite is present at the position of the Gunter. The unit accumulated in a peritidal environment (Sargent, 1991) as sand, possibly from a northern source (Droste and Patton, 1983). The Gunter apparently is present north of the Rough Creek Fault Zone, but no thickness is given (Shaver and others, 1984); south of the zone it is 20 to 50 ft thick (Shaver and others, 1984). The Gunter was recognized in two wells south of the Rough Creek Fault in the Rough Creek area (see Plate 2C).

In the Rough Creek area, the Gasconade is light-colored cherty dolomite. The abundance of oolitic chert, the occurrence of small amounts of anhydrite, the presence of a few zones of silicified ooliths, and the light color help to distinguish the Gasconade from the underlying darker Eminence Dolomite (Upper Cambrian) where the Gunter Sandstone is missing. A peritidal to shallow subtidal environment covered all the Illinois Basin area during Gasconade deposition (Droste and Shaver, 1983, Fig. 11). Where it could be differentiated in wells in the report area, the Gasconade is about 700 ft thick. A thickness of about 600 to 900 ft is reported in the Rough Creek Graben (Shaver and others, 1984). The Gasconade is equivalent to the Oneota Dolomite of Illinois and Indiana, which, just north of the Rough Creek area, is more than 500 ft thick (Droste and Patton, 1985, Fig. 14).

The Roubidoux Formation rests conformably on the Gasconade and in western Kentucky is mainly sandy dolomite and dolomitic sandstone. The chert of the formation is sandy and oolitic. The Roubidoux is as much as 800 ft thick locally in western Kentucky within the Rough Creek Graben. Equivalents of the Roubidoux in southern Illinois probably are included mostly in the upper part of the Oneota Dolomite and lower part of the Shakopee Dolomite. The New Richmond Sandstone that is present between the Oneota and Shakopee mainly in northern and central Illinois has been reported in southeastern Illinois, however (Shaver and others, 1984), where it is 0 to 85 ft thick. The New Richmond is equivalent to the lower part of the Roubidoux Formation in Missouri (Willman and Buschbach, 1975).

The environmental conditions in Gasconade time persisted to the end of Knox deposition, but with minor fluctuations, especially near the northern margin of the basin. Subsidence rates during all of Knox deposition were greater in the southern part of the proto-Illinois Basin and rift complex than in the northern part, as indicated by the substantially greater thicknesses of the Knox units.

Overlying the Roubidoux is the Jefferson City Dolomite, which is largely oolitic and cherty dolomite but includes oolitic and pelletal limestone. The uppermost part of the Jefferson City lacks distinguishing characteristics to readily differentiate it from the overlying dolomite of the Cotter. The lesser amount of sand and chert in the dolomites younger than the Jefferson City is a possible aid. The carbonate rocks, composing the uppermost part of the Knox Group in western Kentucky, are assigned to the Cotter Dolomite (Shaver and others, 1984). In Illinois and Indiana, the Shakopee Dolomite includes the equivalents of the Jefferson City and Cotter Dolomites. Because of pre-Middle Ordovician erosion, rocks equivalent to the Powell Dolomite and Smithville Formation of southeastern Missouri, generally the two uppermost units of the Lower Ordovician sequence, probably are not present as far to the east as the Rough Creek area in western Kentucky.

The thickness of the Canadian (Lower Ordovician) part of the Knox Group ranges from about 1,500 ft in extreme southwestern Indiana (Droste and Shaver, 1983, Fig. 10) to slightly more than 3,000 ft in western Kentucky (Plate 2C, well 14) and about 3,200 ft in southeastern Illinois (Plate 2C, well 12).

Champlainian Rocks

The formations composing the Champlainian (Middle and lower Upper Ordovician) sequence in the Rough Creek area are, in ascending order, the Everton Dolomite, St. Peter Sandstone, Dutchtown Formation, Joachim Dolomite, Pecatonica Formation, Plattin Limestone, and Kimmswick Limestone and its eastern equivalent, the Lexington Limestone. In the eastern part of the Rough Creek area, the rocks of the High Bridge Group, composed of the Camp Nelson and Tyrone Limestones undifferentiated, are equivalent to the Joachim, Pecatonica, and Plattin formations.

There is some disagreement as to the placement of the Champlainian-Cincinnatian boundary—the Ordovician correlation chart by Ross and others (1982) shows the tentative boundary at the top of the Lexington Limestone, but the COSUNA (Correlation of Stratigraphic Units of North America project) correlation chart (Shaver and others, 1984) places it within the Lexington and Kimmswick Limestones.

The Everton Dolomite, the initial deposit in the northward-transgressing Middle Ordovician sea, is light-tan to brown dolomite, containing lenses and streaks of sandstone. The sand grains are rounded and frosted, show bimodal sorting, and are similar to the sand of the overlying St. Peter. Conodonts from the Everton of southern Illinois confirm the early Middle Ordovician (Whiterockian) age (Norby and others, 1986). The carbonate mud and terrigenous sand composing the Everton were deposited in a peritidal to deeper subtidal environment (Droste and Shaver, 1983, Fig. 14). Anhydrite in the Everton in White County, southeastern Illinois, and in Union County, Ky., suggests that the environment was somewhat restricted (Kolata and Noger, 1991). The Everton in western Kentucky ranges in thickness from 0 to about 550 ft; it is thickest in Crittenden County, Ky. (see Plate 2C, well 13), south of the Rough Creek Fault Zone. The formation is only present over the western half of the Rough Creek area (Kolata and Noger, 1991, Fig. 5-6).

The depocenters of the Everton, as well as the younger carbonate units below the base of the Kimmswick and Lexington Limestones (late Middle Ordovician), was in the Reelfoot Rift–Rough Creek Graben complex. The unconformity that separates the Everton from the underlying Cotter Dolomite apparently represents a short hiatus in deposition between Whiterockian and Canadian strata in parts of southern Illinois (Kolata and Nelson, 1991a), but the actual time span of the hiatus, based on later study of conodont faunas, still is undecided (Rodney D. Norby, Illinois State Geological Survey, oral commun., 1992). Farther south in the rift complex, deposition may have been continuous. The Everton Dolomite is largely confined to southern Illinois, southwestern Indiana, and western Kentucky, but farther north it appears likely that arenite of the Everton may have been deposited in shallow embayments on the post-Canadian erosion surface (Droste and Shaver, 1983; Kolata and Noger, 1991); because of similarity to the overlying St. Peter Sandstone, sandstone of the Everton would be difficult to distinguish from the St. Peter.

Over much of the Illinois Basin, the St. Peter Sandstone lies unconformably on the Everton Dolomite or on eroded units in the upper part of the Knox Group. In the area south of the Rough Creek Fault Zone (Plate 2C, wells 13 and 14), however, the contact between the Everton and St. Peter is apparently gradational. In southern Indiana, southern Illinois, and western Kentucky, the St. Peter is in partial facies relationship with the overlying Dutchtown Formation and the younger Joachim Dolomite (Droste and others, 1982). The St. Peter consists of medium to coarse, rounded and frosted quartz grains, which are variably cemented by calcium carbonate. The sand is at an extreme level of textural and mineralogic maturity, which suggests derivation from Cambrian and Lower Ordovician sandstones and from Keweenawan sandstone of the Canadian Shield (Kolata and Noger, 1991). The sand of the St. Peter was derived from coastal eolian and fluvial-deltaic sources and deposited largely in moderately deep waters of the inner shelf, but also in the near-shore zone of the basin (Mazzullo and Ehrlich, 1983; Dott and others, 1986). A basal nonmarine facies was commonly reworked into the sand sheet in the transgressing sea (Dapples, 1955) as it encroached onto an erosion surface characterized by deep valleys and, commonly, karst features (Buschbach, 1964).

The St. Peter covers most of the Rough Creek area west of an ancient Middle Ordovician shoreline that extended southeastward across McLean, Ohio, and Butler Counties, Ky. The formation was also deposited over the western half of Indiana and over all of Illinois (Droste and Shaver, 1983, Fig. 15). Over most of western Kentucky, the St. Peter is less than 100 ft thick; its maximum thickness in the Rough Creek area is 115 ft in the Exxon No. 1 Choice Duncan well (Plate 2C, well 14) in Webster County. In the southern half of the Illinois Basin, the sandstone generally is 100 to 200 ft thick, but a few wells have penetrated more than 300 ft (Willman and Buschbach, 1975, Fig. O-17). Where the St. Peter is abnormally thick, the underlying Knox is reciprocally thin. In Indiana, the St. Peter generally is 0 to 140 ft thick, but in places abruptly increases in thickness to 335 ft (Shaver and others, 1986).

The Dutchtown Formation conformably overlies the St. Peter Sandstone over most of western Kentucky, but east of the depositional edge of the St. Peter, through McLean, Ohio, and Butler Counties, it rests directly on the post-Knox erosional surface. Rexroad and others (1982), from their study of conodonts, concluded that the Dutchtown in southwestern Indiana correlates with and interfingers with the St. Peter Sandstone; the same relationship should occur in adjoining western Kentucky and southern Illinois. In Kentucky, the Dutchtown is mainly gray dolomite that is sandy in the lower part; it includes some dolomitic limestone. In Illinois, the Dutchtown is characterized by its dark-gray, almost black, color and strong fetid odor (Willman and Buschbach, 1975). It was deposited mainly as carbonate mud and terrigenous mud largely from southern sources; some sand was contributed to the Dutchtown from nearby land areas in northern Indiana, Ohio, and Missouri. Some sand was also transported beyond the locus of St. Peter deposition. The Dutchtown accumulated in a peritidal to shallow subtidal environment (Droste and Shaver, 1983, Fig. 17). Strata recognized as Dutchtown in western Kentucky are 20 to 95 ft thick; it is from 200 to more than 300 ft thick in the depocenter in extreme southern Illinois and westernmost Kentucky, but thins rapidly northward to a depositional shoreline across central Illinois and Indiana (Droste and Shaver, 1983, Fig. 16). The Dutchtown grades eastward into the Wells Creek Dolomite in the eastern part of the Rough Creek area (Shaver and others, 1984). Kolata and Noger (1991, Fig. 5-3 [well 13 in that cross section should be well 11], Table 1-3) shows less than 50 ft of Wells Creek Dolomite in the Texas Gas No. 1 Shain well; the junior author of this report did not identify and describe any Wells Creek in the Rough Creek area.

The Joachim Dolomite conformably overlies the Dutchtown in the Rough Creek area. It is principally brown and dark-brown limestone, but contains a minor amount of dolomitic limestone and some dolomite in the basal part. In southeastern Illinois, it contains a mixture of limestone, dolomite, and some sandstone (see Plates 2B and 2C); elsewhere in southern Illinois, the Joachim includes shale, anhydrite, and gypsum (Willman and Buschbach, 1975). A similar mixture of dolomite, limestone, sandstone, and shale, but no bedded evaporites, allows the identification of the various members of the Illinois section within Indiana (Droste and others, 1982).

The Joachim was deposited in a large sabkha (Okhravi and Carozzi, 1983) that covered the southern part of the proto-Illinois Basin and had a connection southward to the open sea. Northward and eastward in the basin, the environment was peritidal and shallow subtidal (Droste and Shaver, 1983, Fig. 19). Deposition of the Joachim was contemporaneous with the marine-bar complex of the Starved Rock Sandstone Member of the St. Peter Sandstone in northern Illinois (Willman and Buschbach, 1975; Okhravi and Carozzi, 1983). In the Rough Creek area, the Joachim, where it could be distinguished, is about 220 to 320 ft thick. The greatest thickness, more than 400 ft, is in the Jackson Purchase Region of western Kentucky. The contact with the overlying Pecatonica Formation is not easily defined on well-sample logs from the Rough Creek area. The Joachim is equivalent to the lower part of the High Bridge Group (Camp Nelson and Tyrone Limestones) in the subsurface of the eastern part of the Rough Creek area (Shaver and others, 1984).

Because of lithologic similarity to both the underlying Joachim Dolomite and the overlying Plattin Limestone, the Pecatonica Formation is difficult to recognize from well samples in the Rough Creek area. The formation, particularly the basal part, records an easily recognized pattern on gamma-ray and neutron logs, however (see Plate 2C, well 13). The Pecatonica is limestone that is partly altered to dolomite. It is 70 to 135 ft thick in western Kentucky and reaches a thickness of 150 ft in extreme southern Illinois (Willman and Buschbach, 1975). In the eastern part of the Rough Creek area, the Pecatonica is equivalent to part of the High Bridge Group (Shaver and others, 1984). The Pecatonica, together with the overlying Plattin Limestone, composed the Black River Group in Indiana, and the Pecatonica is the basal formation of the Platteville Group of Illinois.

The Plattin Limestone is mostly dark-brown, sublithographic, slightly cherty limestone, but includes some tan to dove-gray layers. Over much of the Rough Creek area, an oolitic marker bed (Brickeys oolite) occurs near the base of the Plattin. At the top of the formation is a thin metabentonite that is probably equivalent to the Mud Cave bentonite at the top of the Tyrone Limestone (the uppermost formation of the High Bridge Group in the Cincinnati Arch area) and to the Millbrig K-bentonite bed at the base of the Spechts Ferry Formation of western Illinois and adjacent Missouri (Kolata and others, 1986). The Tyrone Limestone was identified in a number of wells in the eastern part and to the south of the Rough Creek area; its equivalent in a well in Lawrence County, Ind. (Plate 2A, well 1), was called the Black River Limestone; the name “Black River” is properly applied as a group designation. The Plattin Limestone is laterally equivalent to roughly the upper half of the High Bridge Group. The Plattin and equivalent rocks in the High Bridge Group in western Kentucky were deposited as carbonate mud in supratidal, intertidal, and shallow subtidal environments (Cressman and Noger, 1976). The Plattin and equivalent formations range in thickness from less than 300 to about 600 ft in the area. Locally, the Plattin is partly eroded beneath the regional unconformity at the base of the Upper Ordovician sequence. In the depocenter in the Reelfoot Rift in western Kentucky, the Plattin Limestone and Pecatonica Formation together are more than 800 ft thick (Droste and Shaver, 1983, Fig. 20).

The uppermost carbonate units of Ordovician age in the Rough Creek area are the Kimmswick Limestone in the western part and its lateral equivalent, the Lexington Limestone in the eastern part, both of late Champlainian age. The two limestones do not come into contact with each other in the area, for they are separated in the subsurface by a broad channel called the Sebree Valley (Fig. 8) by Schwalb (1982a), filled by the Maquoketa Shale (Upper Ordovician, Cincinnatian). The Kimmswick is brown, coarsely crystalline limestone, and the Lexington is gray and brown, fossiliferous, commonly shaly limestone containing considerable interbeds of shale; it is sandy at a few localities. The Kimmswick and Lexington Limestones were deposited as mostly carbonate mud and sand, but some terrigenous mud, in relatively shallow but highly agitated water (Cressman, 1973) in a peritidal to deeper subtidal environment (Droste and Shaver, 1983, Fig. 23). The source of the fine terrigenous material in the Lexington was to the east in the Appalachian orogenic belt (Cressman, 1973). In the Rough Creek area, the Kimmswick ranges from 0 to 125 ft in thickness and the Lexington from 0 to 160 ft. Both limestones generally are missing in the central part of the area—either because of nondeposition or erosion, or possibly a combination of both—where the broad clastic-filled channel (Maquoketa Shale) extends down into the underlying Plattin or Tyrone Limestones. The long-established depocenter in the Reelfoot Rift is no longer evident at this time; the Lexington Limestone thickens eastward toward the Appalachian trough. In Indiana, the Trenton Limestone is the subsurface equivalent of the Lexington Limestone of the Cincinnati Arch area. In Illinois, the Galena Group is the equivalent of the Trenton.

Cincinnatian Rocks

Strata of Cincinnatian (Late Ordovician) age over most of the Rough Creek area are largely represented by the Maquoketa Shale. On outcrop on the western flank of the Cincinnati Arch in central Kentucky, the rocks equivalent to the Maquoketa are a sequence of intertonguing rock types, subdivided, in ascending order, into the Clays Ferry Formation, Callaway Creek Limestone, Grant Lake Limestone, and Drake Formation (see Weir and Cressman, 1978). Westward into the subsurface, the relationship of the various units has not been studied in detail, but it is probable that not all of the units, particularly the limestones, persist as far to the west as the eastern part of the Rough Creek area. On the COSUNA correlation chart (Shaver and others, 1984) for the areas north and south of the Rough Creek–Shawneetown Fault System, however, the Calloway Creek Limestone is identified and assigned a thickness of 128 ft; this unit was not identified in the wells examined by the junior author.

The Maquoketa is principally gray to brown silty shale and siltstone, which in well samples has a blocky and gritty appearance. Some is clayey and much is calcareous. Silty, in part calcareous sandstone, which in some of the wells on the cross sections (Plate 2) may be shown as calcareous siltstone, occurs near the middle of the Maquoketa over much of the Rough Creek area. Phosphatic pellets and small phosphatized fossils (dwarf fauna) are found in the shale throughout most of the area. In the eastern part, the unit is largely shale, but lighter in color than the normal Maquoketa; it may be equivalent to the Clays Ferry Formation. The shale contains many interbeds of dark-colored, commonly argillaceous limestone that in places includes ostracodes. Locally, in the vicinity of the Rough Creek Fault Zone, some of the limestone is dolomitic, and there are thin units of locally argillaceous dolomite. The light-colored

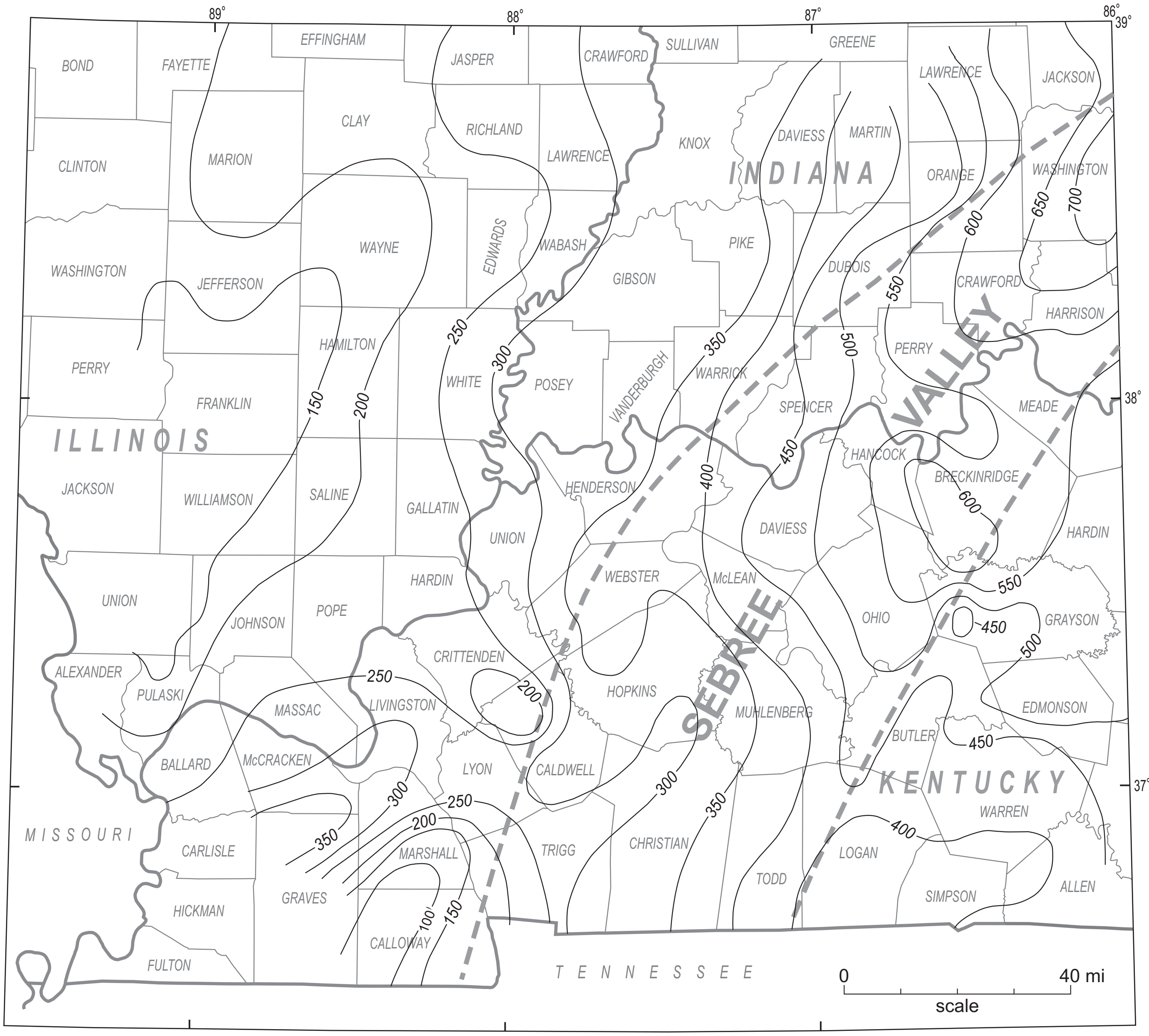

Figure 8. Thickness of the Upper Ordovician Maquoketa Shale and Clays Ferry Formation and their relation to the Sebree Valley in western Kentucky and adjacent parts of Indiana and Illinois. Contour interval=50 ft.

Clays Ferry(?) shale is locally interbedded with the darker shale of the Maquoketa in the Sebree Valley.

Over most of Illinois, Indiana, and western Kentucky, the Maquoketa Shale rests disconformably on the Kimmswick and Lexington Limestones and equivalent units. In western Kentucky, the broad, northeast-trending submarine channel, the Sebree Valley (also called the Sebree Trough [Bergstrom and Mitchell, 1987] and Kope Trough [Keith, 1988, Fig. 4]), which separates the Kimmswick and Lexington Limestones, cuts down locally into the Plattin Limestone. The boundaries of the valley are not well defined, but in general a tongue mostly of fine clastics, which thickens northeastward from western Kentucky across southern Indiana into western Ohio, outlines the valley. Gutstadt (1958) recognized an abrupt linear boundary between the Trenton Limestone and Cincinnatian shales along the approximate position of the Sebree Valley in southern Indiana. Keith (1985), however, envisioned intertonguing of the limestone and shale units along the valley sides in Indiana rather than abrupt erosional contact. Cressman (1973) believed that the channel in Kentucky was in existence during deposition of the Kimmswick and Lexington strata and that at least part of the shale in the channel was deposited contemporaneously with the limestones on either side. A study of graptolites (Bergstrom and Mitchell, 1987) from the valley fill (Utica shale of drillers) confirmed that major parts of the Utica and the Lexington and Trenton Limestones are correlative.

The facies map of Rockfordian time (late early Champlainian) (Keith, 1988, Fig. 3) shows a deep subtidal trough filled with terrigenous mud in the position of the Sebree Valley that is largely confined to western Kentucky and southern Indiana, but does trend into western Tennessee. This feature is considered to be a bathymetric trough that probably deepened as it expanded with time (Keith, 1988). During succeeding Kirkfieldian (early late Champlainian) time, the trough expanded northeastward almost to Ohio (Keith, 1988, Fig. 4), and by the Edenian (early Cincinnatian), the trough and accompanying deeper subtidal environment extended even farther eastward into Pennsylvania (Keith, 1988, Figs. 5–6). A narrow band of clastic rocks prograded over carbonate rocks bounding the northwest side of the Sebree Valley in the late Champlainian, and a similar relationship evolved along the southeast side during late Champlainian and early Cincinnatian expansion of the valley (Keith, 1988, Figs. 5–6). By Maysville (middle Cincinnatian) time, the valley was overlapped by a blanket of terrigenous sediments associated with the incursion of the distal part of the Queenston delta complex into Ohio and Michigan (Droste and Shaver, 1983, Fig. 28). A peritidal environment bordered both sides of the Sebree Valley through most of the Late Ordovician. Carbonate sand and mud characterized the facies on either side, but in addition, the southeastern side received terrigenous mud (Droste and Shaver, 1983, Figs. 23, 26, 28). The peritidal environment deepened and expanded over all of the proto-Illinois Basin toward the end of the Ordovician. And at that time, the basin area was uplifted and extensively, but not deeply, eroded.

In western Kentucky, the Maquoketa Shale west of the Sebree Valley ranges in thickness from less than 100 to more than 350 ft. Within the valley, Upper Ordovician (Cincinnatian) rocks are about 200 to 600 ft thick, and to the east they are slightly less than 400 to about 600 ft thick. Regionally, the Maquoketa thickens northeastward toward its source area from about 100 ft in extreme southwestern Kentucky to more than 1,000 ft in northern Ohio (Kolata and Noger, 1991, Fig. 5-13).

Silurian System

The Silurian rocks in the Rough Creek area include strata of the Alexandrian, Niagaran, and Cayugan Series. The rocks show considerable lithologic variation, both from east to west and north to south. They are principally carbonate rocks that together with the overlying Lower and Middle Devonian carbonate rocks form the Hunton Group. The thickness map of the Hunton (Fig. 9) reflects the depositional trends of the Silurian and Devonian carbonate rocks, as well as the thinning and truncation of Lower and Middle Devonian rocks by both pre- and post-Middle Devonian erosion. The Hunton Group ranges in thickness from about 700 ft at the east side of the area to about 1,800 ft at the west side. The maximum thickness of the group, about 2,100 ft, is in southeastern Illinois.

The thickness of Silurian rocks in the Rough Creek area ranges from about 350 to 525 ft. In part, the thickness variation is the result of differential erosion below the pre-Upper Devonian (pre-New Albany Shale) unconformity; the greatest erosion was along the north side of the Rough Creek Fault Zone near its east end.

Alexandrian Rocks

In the eastern part of the Rough Creek area, the basal Silurian unit, the Brassfield Dolomite, is of Alexandrian age. In its outcrop belt along the western side of the Cincinnati Arch, the Brassfield is demonstrably time-transgressive (Rexroad, 1967). It is progressively younger from east-central Kentucky northward and westward into southeastern Indiana. In the Rough Creek area, the Brassfield is mostly light-tan dolomite containing light-gray to white chert and variable amounts of glauconite, but includes some medium-gray, finely crystalline limestone (David Williams, Kentucky Geological Survey, written commun., 1994). The formation is 10 to 70 ft thick. Westward in the study area, the Brassfield grades into the Sexton Creek Limestone; the latter unit is 20 ft to about 75 ft (Seale, 1985, Plate 3) of gray limestone containing much black chert and glauconite. The greatest thickness of Alexandrian rocks is in southern Illinois, where they are as much as 125 ft thick (Willman and Atherton, 1975, Fig. 5-14).

During the Early Silurian, the sea advanced into southeastern Indiana and Kentucky from the south and east across a relatively indurated platform that was mostly swept clean of sediments by modest wave or current action (Laferriere and others, 1986). Along the western side of the Cincinnati Arch in Kentucky, the Brassfield Dolomite overlies the Drakes Formation of Late Ordovician age on a minor unconformity marked primarily by an irregular surface having a maximum local relief of 2 ft (Peterson, 1981). The contact marks a major hiatus that is greatest to the south and diminishes northward in Indiana (Rexroad, 1967). The irregularity in the regional thickness of the combined Sexton Creek Limestone and Brassfield Dolomite and their correlatives in the Illinois Basin is partly because of the greater erosional relief on the post-Ordovician surface in the southern part of the basin (Droste and Shaver, 1983, Fig. 29). During middle Alexandrian time, a lowland area covered most of Indiana and much of Kentucky, separating the Appa-

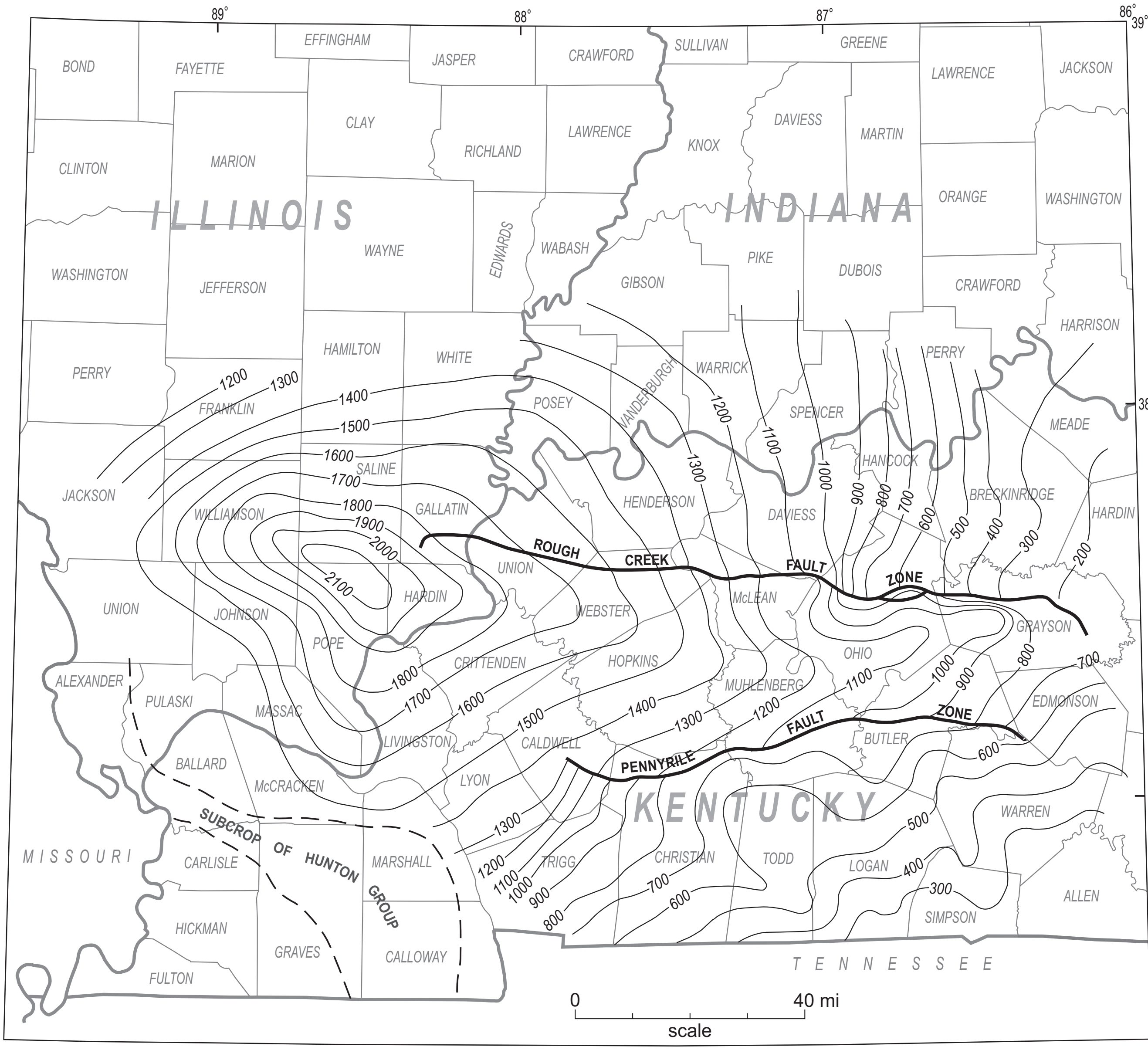

Figure 9. Thickness of the Hunton Group (Silurian and Lower and Middle Devonian) in western Kentucky and adjacent areas, showing the relation of thickness trends to the Rough Creek Fault Zone and Pennyrile Fault System. Contour interval=100 ft.

lachian Basin from the proto-Illinois Basin. In addition, a narrow, east-trending land area across the middle of Illinois split the Illinois Basin into two seas (Droste and Shaver, 1983, Fig. 30). In the shallow seas bordering the land masses, deposition of terrigenous sand and carbonate mud was in a peritidal environment (Droste and Shaver, 1983, Fig. 30). By late Alexandrian time, the sea had overlapped the land masses, except for a small area called Ripley Island along the axis of the Cincinnati Arch (Rexroad, 1967). Depositional environments in the basin varied from peritidal to deeper subtidal (Droste and Shaver, 1983, Fig. 31).

Niagaran Rocks

In the eastern part of the Rough Creek area, the Niagaran units are the Osgood Formation at the base, overlain by the Laurel Limestone, Waldron Shale, Louisville Limestone, Dixon Limestone, and the two lower units of the Brownsport Formation, the Beech River and Bob Limestone Members; the Lobelville Shale Member at the top of the Brownsport is thought to be of Cayugan age (Shaver and others, 1984).

The Osgood consists of about 25 ft of maroon limestone and reddish shale; the Laurel, of red-speckled, light-gray limestone about 50 ft thick containing arenaceous foraminifera; the Waldron, of 0 to 10 ft of greenish-gray calcareous shale; and the Louisville, of white to red limestone speckled with pink and red, 40 to 50 ft thick. The Louisville correlates with the Lego Limestone of local usage in western Tennessee (Berry and Boucot, 1970). Seale (1985) extended the Lego into western Kentucky, including a small part of the Rough Creek area south of the Rough Creek Fault Zone in Grayson County. In this report, however, the name "Louisville" is used wherever this limestone unit is recognized. The Dixon Limestone, 50 to 90 ft thick, is red and maroon limestone south of the Rough Creek Fault Zone, but north of the zone in the eastern part of the area, it lacks the reddish color and is silty and shaly. The Beech River Limestone Member of the Brownsport Formation is light to dark gray, dolomitic, argillaceous, and cherty, and ranges from 20 to 80 ft in thickness. The Bob Limestone Member of the Brownsport is a thin but generally persistent unit, averaging 10 ft in thickness, south of the Rough Creek Fault Zone as far west in the Rough Creek area as Ohio County; farther west, it grades into the Moccasin Springs Formation, and north of the fault zone its apparent absence in the northeastern part of the Rough Creek area is the result of gradation into the Mississinewa Shale Member of the Wabash Formation of Indiana (Seale, 1985). Rocks equivalent to the Mississinewa Member are included in the Moccasin Springs Formation in Kentucky. The Bob is gray to brownish-gray limestone characterized by large brown ooliths.

In parts of Grayson County and possibly in eastern Ohio County on both sides of the Rough Creek Fault Zone, the normal sequence of Silurian formations from the top of the Osgood Limestone to the upper part of the Dixon Limestone is replaced by vuggy, crystalline dolomite that is interpreted as reef-derived detritus equivalent to the Terre Haute reef bank of southwestern Indiana (Droste and Shaver, 1975). The detritus probably originated in Indiana, moved southward by current action, and was deposited to a thickness of about 25 ft along the north side of the Rough Creek Fault Zone and to almost 180 ft on the south side.

Because of facies changes, the individual Niagaran units of the eastern part of the Rough Creek area are not recognizable west of a southeast-trending line across the eastern third of Daviess and Ohio Counties (Seale, 1985, Fig. 4). There, the beds equivalent to the section from the Osgood through the Louisville Limestone are included in the St. Clair Limestone. The St. Clair generally is maroon, very silty limestone, but includes some light-colored beds that are speckled with pink and maroon. It contains ostracodes and arenaceous foraminifera. Near the center of the Rough Creek area, the limestone is white to medium gray and finely to medium crystalline and contains some friable, sucrosic dolomite (David Williams, Kentucky Geological Survey, written commun., 1994). The St. Clair generally is 50 to 60 ft thick, but locally south of the Rough Creek Fault Zone is as much as 115 ft thick (Seale, 1985, Plate 4). The contact of the St. Clair with the overlying Moccasin Springs Formation appears to be time-transgressive; it becomes younger to the east (Droste and Shaver, 1987).

Overlying the St. Clair Limestone in the western part of the area is the Moccasin Springs Formation, mostly of late Niagaran age, but the uppermost part may be of Cayugan (Late Silurian) age (Shaver and others, 1986, Plate 2). The Moccasin Springs is equivalent to the beds in the eastern part of the Rough Creek area contained in the Dixon Limestone and the Brownsport Formation. The Moccasin Springs is silty limestone that typically includes thin, shaly streaks and locally red and green shale, and commonly is partly dolomitic. The colors are variations of cream, greenish gray, red, maroon, and light to dark gray. A thin, dark-brownish-gray calcareous shale, or locally dark-gray carbonaceous limestone containing abundant brownish-gray calcite, is present at the top of the Moccasin Springs in western Kentucky and southwestern Indiana (Becker and Droste, 1978). The shale, called the Randol shale by Seale (1985), is 10 to 30 ft thick over the western two-thirds of the Rough Creek area and grades eastward into the Lobelville Shale Member of the Brownsport Formation. In Indiana, the shale is placed in the Moccasin Springs Formation; it can be traced northeastward into the Terre Haute bank (Becker and Droste, 1978). In the few wells in the area that have penetrated the Moccasin Springs, the formation is about 60 ft thick; however, David Williams (Kentucky Geological Survey, written commun., 1994) logged 240 ft of Moccasin Springs, including the Randol unit, in the Conoco No. 1 Turner well (Plate 2C, well 16). To the west, it is about 185 ft thick in southeastern Illinois (see Plate 2B, well 8) and reaches as much as 120 ft in southwestern Indiana (Becker and Droste, 1978).

Middle Niagaran time, represented by the Osgood Formation and Laurel Limestone in western Kentucky and the Salamonie Dolomite in Indiana, was characterized by the first major development of extensive reefs and carbonate banks around the proto-Illinois Basin and even more extensive reefs around the Michigan Basin and into the Appalachian Basin; reef development began initially during deposition of the St. Clair Limestone (Droste and Shaver, 1987). No reef bank has been reported in Kentucky, but the vuggy dolomite occupying the Osgood-Dixon interval in parts of Grayson County may represent a southward extension of the Terre Haute bank of southwestern Indiana and southeastern Illinois or, as postulated earlier, detritus from the Terre Haute bank. In his study of possible Silurian reef trends (including the Bailey Limestone of Early Devonian age of this report) in western Kentucky, Seale (1985) concluded that the Terre Haute bank does not extend into western Kentucky; however, he (1985, Plate 8) recognized possible reef lithology in rocks equivalent to the lower part of the Bailey Limestone, which he correlated with the Decatur Limestone of Tennessee, in several wells in Grayson County within the Rough Creek area. Seale (1985, Plate 8) also recognized reef lithology in the same interval in a well in northern Hancock County just north of the Rough Creek area, which he assigned to the Liston Creek Member of the Wabash Formation of Indiana.

The reef banks marked the boundary between a peritidal to shallow subtidal environment on the Wabash Platform (Becker and Droste, 1978) that bordered the Terre Haute bank on the north and east and a deeper, subtidal environment in the basin (Droste and Shaver, 1983, Fig. 33). A significant facies change occurred between the platform and the basin at the Terre Haute bank: carbonate sand was limited to the platform, whereas the basin sediment was only carbonate mud (Mikulic, 1991). The environments of the platform and the basin continued with very little change until the end of the Early Devonian, although there was some deepening of the seas covering the general region and introduction of fine terrigenous sediments to the platform and basin, some from delta complexes to the north and southeast (Droste and Shaver, 1983, Fig. 38). The reef systems, both on the platform and peripheral to the basin, flourished in the late Cayugan (Droste and Shaver, 1983).

Cayugan Rocks

In the eastern part of the Rough Creek area, the Lobelville Shale Member of the Brownsport Formation represents rocks of Cayugan (Late Silurian) age. The unit is laterally equivalent to the uppermost part of the Moccasin Springs Formation in the western part. The Lobelville is gray to dark-gray calcareous to dolomitic shale, 10 to 40 ft thick. It is present both north and south of the Rough Creek Fault Zone. Both the Moccasin Springs and the Lobelville Member of the Brownsport Formation are conformably overlain by the Bailey Limestone of Early Devonian age. In the deeper parts of the proto-Illinois Basin, deposition was continuous from the Silurian into the Devonian, but eastward from the Rough Creek area, erosion cut progressively deeper and removed all Silurian rocks from the crest of the Cincinnati Arch on the southern flank of the Jessamine Dome prior to deposition of Devonian strata (Peterson, 1981).

Devonian System

The placement of the Silurian-Devonian boundary in the southern part of the Illinois Basin has long been a contentious subject. It is placed at the gradational contact between the Moccasin Springs and Brownsport Formations and the overlying Bailey Limestone (Becker, 1974; Willman and Atherton, 1975). Droste and Shaver (1987) suggested that all of the Bailey is Silurian in age, whereas Collinson (1967) believed that only part is Silurian. The COSUNA correlation chart for the Illinois Basin (Shaver and others, 1984) places all of the Bailey in western Kentucky in the Upper Silurian. Mikulic (1991) reported, however, that a comprehensive study in progress indicates that most, if not all, of the Bailey is Devonian; no further published information is available on that study. On the cross sections shown on Plate 2 of this report, the Silurian-Devonian boundary is placed at the top of the Moccasin Springs Formation, and the Bailey Limestone is described with the Lower Devonian strata.

Rocks of Early, Middle, and Late Devonian ages are present in the Rough Creek area, but the distribution of the Lower and Middle Devonian units is determined by the depth of erosion below pre-Middle and pre-Upper Devonian unconformities. The most complete sequence of Devonian rocks is in Union, Webster, and Henderson Counties. Eastward, toward the western flank of the Cincinnati Arch, Lower and Middle Devonian strata thin by truncation below the two unconformities. The eastern limit of Lower Devonian rocks in western Kentucky (Seale, 1985, Plate 2) extends from Meade County southwestward across extreme southeastern Breckinridge County, then parallel to the northern and eastern borders of Grayson County (also parallel to the Rough Creek Fault Zone) to western Hart County (just east of the Rough Creek area); from there it extends southwestward to the Simpson-Allen County line at the Tennessee border. Lower Devonian rocks apparently are thicker and more widespread on the south than on the north side of the Rough Creek Fault Zone (Droste and Shaver, 1987, Figs. 4–6; the location of the Rough Creek Fault is not shown), probably because of uplift and erosion along the fault zone in pre-Middle and pre-Late Devonian times. The lack of well data, however, limits detailed knowledge of the subcrop pattern of both the Lower and Middle Devonian units north of the zone.

Lower and Middle Devonian strata in the Rough Creek area are dominantly limestone, much of it cherty, and lesser amounts of dolomite. The Upper Devonian rocks are principally shale.

Lower Devonian Rocks

The Lower Devonian Series in western Kentucky consists, in ascending order, of the Bailey, Flat Gap, Grassy Knob, Backbone, and Clear Creek Limestones; in Illinois and Indiana, the Grassy Knob and Clear Creek are called Cherts. The Grassy Knob, Backbone, and Clear Creek have a basin-to-shelf facies relationship that was investigated in southwestern Indiana by Becker and Droste (1978) and in deeper parts of the Illinois Basin in an expanded study by Droste and Shaver (1987). Intertonguing units of the Grassy Knob and Clear Creek have generally similar lithology and are difficult to distinguish where they are not separated by the medium- to coarsely crystalline, bioclastic carbonate rocks of the Backbone, which also is a facies of both the Grassy Knob and Clear Creek (Shaver and others, 1986).

The Bailey in the Rough Creek area consists mainly of olive-gray to grayish-brown, cherty, slightly dolomitic limestone; it includes a basal zone of shaly dolomitic limestone containing the ostracodes *Dizygopleura swartzi.* The Bailey conformably overlies the Moccasin Springs Formation in the western part of the area and also apparently is conformable on the Lobelville Shale Member of the Brownsport Formation in the eastern part. In the eastern part south of the Rough Creek Fault Zone, the Bailey is about 200 ft thick and increases in thickness westward in the Moorman Syncline to as much as 370 ft in Webster County. North of the fault zone in the eastern part of the area, the formation is only about 130 ft thick, because it is truncated by the pre-Upper Devonian unconformity. To the west, it increases in thickness to 270 ft.

The Flat Gap Limestone in the Rough Creek area conformably overlies the Bailey Limestone. Its presence locally in southern Illinois is inferred (Shaver and others, 1984), although apparently the unit has not actually been described there. The Flat Gap is white to light-gray, coarsely crystalline limestone with yellow to pink speckling. It contains variable amounts of glauconite and minor amounts of chert and dolomite. The absence of Chitinozoa in the Flat Gap, in contrast to its presence in both the underlying Bailey and overlying Grassy Knob Limestones, is an aid in distinguishing the formation in the subsurface. Locally, in Webster County, Ky., in the Exxon No. 1 Choice Duncan well (Plate 2C, well 14), a bentonite is present at the base of the Flat Gap. The Flat Gap ranges in thickness from about 20 to 170 ft, and even seems to be missing locally because of nondeposition. It is also missing in Grayson County north of the Rough Creek Fault Zone beneath the pre-Upper Devonian erosional surface.

The Flat Gap Limestone was first described in western Tennessee (Dunbar, 1918), where it is a member of the Olive Hill Formation, and on outcrop unconformably underlies the Harriman Chert (equivalent of the Grassy Knob Chert of the Illinois Basin). D.H. Swann (*in* Collinson, 1967) stated that the Flat Gap is equivalent to an unnamed limestone member (also called the limestone at Ozora) at the top of the Bailey Limestone in central and western Illinois. In Indiana, a carbonate unit just above the Bailey, termed the Ozora or Beaucoup by drillers, was included in the Backbone Limestone by Droste and Shaver (1987); no Flat Gap is recognized in Indiana. Spirakis (1978) traced the unconformity at the top of the Flat Gap northward from Tennessee into a chert rubble zone at the top of the Bailey that he believed marked an unconformity in the subsurface of extreme western Kentucky. This proposed unconformity, however, has not been recognized in deeper parts of the Illinois Basin by the Kentucky Geological Survey or the surveys of Illinois or Indiana (Shaver and others, 1984). In deeper parts of the Illinois Basin where the Flat Gap is missing or not recognized, the Bailey Limestone is conformably overlain by the Grassy Knob Limestone, except in parts of southwestern Indiana where the Backbone Limestone overlies the Bailey (Shaver and others, 1984).

The Grassy Knob Limestone (Chert) is apparently conformable on the Flat Gap Limestone in Kentucky and on the Bailey Limestone elsewhere in the southern part of the Illinois Basin. The Grassy Knob in western Kentucky is white to gray to brown limestone containing abundant light-colored chert and scattered zones of glauconite. Dark-gray granules impart a mottled appearance to the limestone. Shiny black tests of Chitinozoa are common in the chert. The Grassy Knob was removed by pre-Middle or pre-Upper Devonian erosion, or by both, in parts of Grayson County north of the Rough Creek Fault Zone. The formation generally is 60 to 280 ft thick and attains its greatest thickness in the western part of the area. Droste and Shaver (1987, Fig. 7) showed a much more restricted occurrence of the Grassy Knob in the Rough Creek area (just the extreme western edge) than we do; they apparently assigned carbonate rocks herein identified as Grassy Knob to the overlying Backbone Limestone and perhaps some to the Clear Creek Limestone.

The Backbone Limestone in the Rough Creek area conformably overlies the Grassy Knob Formation and is overlain by the Clear Creek Limestone, but commonly the formation is difficult to distinguish from the adjacent limestone units. Typically, the Backbone is white to light-gray limestone mottled with specks of gray, pink, and green and includes grains of glauconite and locally small amounts of light-colored chert. In lithology and in its lack of Chitinozoa, it is very similar to the older Flat Gap Limestone. The thickness of the Backbone ranges from 10 to 80 ft and averages about 20 ft. In the Rough Creek area, the erosional edge of the Backbone is across western Breckinridge County. The unit thickens westward to a maximum of about 600 ft in a very limited area in the northwestern corner of the Rough Creek area (Droste and Shaver, 1987, Fig. 7); the general range in thickness of the formation is 100 to 400 ft. North of the Rough Creek Fault Zone in Grayson County and parts of Ohio County, the formation is missing because of pre-Middle Devonian erosion.

The uppermost formation of Early Devonian age, the Clear Creek Limestone, is light-colored limestone, which has been extensively altered to dolomite. Chert is abundant, glauconite is a common accessory mineral, and locally chitinozoan microfossils are profuse. The Clear Creek and Grassy Knob Limestones are very similar in appearance and lithology, and where the Clear Creek and Backbone Limestones are missing and wells do not penetrate as deeply as the Bailey, the Grassy Knob is easily misidentified as the Clear Creek.

In the Rough Creek area, the Clear Creek Limestone was either not deposited or was removed by erosion along the north side of the Rough Creek Fault Zone from the eastern third of Daviess County eastward to the eastern border of the area. This structurally high area was called McDaniels Island by Devera and Fraunfelter (1988). Immediately south of the fault zone, the Clear Creek is also missing in the Texas Gas Transmission No. 1 Herman Shain well in west-central Grayson County (Devera and Fraunfelter, 1988), but farther to the south in northeasternmost Butler County, 75 ft of Clear Creek is present in the Columbus Exploration No. 1 Williams well (Devera and Fraunfelter, 1988). Clear Creek–Bailey strata are recorded in several wells in south-central Grayson County (Freeman, 1951). The distribution of the formation indicates that uplift along the Rough Creek Fault Zone may have been extensive and not confined to just the north side.

The Clear Creek Limestone in the Rough Creek area has a maximum thickness of about 450 ft on the west side near the Ohio River (Droste and Shaver, 1987, Fig. 8); the greatest thickness in the Illinois Basin is about 700 ft, in extreme southeastern Illinois. The sequence of Lower Devonian carbonate units, from the Flat Gap Limestone through the Clear Creek Limestone in Kentucky and the New Harmony Group in Indiana (the Flat Gap is not recognized), reaches a maximum thickness of 1,000 ft near the common corner of the three states (Droste and Shaver, 1987, Fig. 6).

Sedimentation was continuous in the southern part of the proto-Illinois Basin from the Silurian into the Early Devonian, but under deeper subtidal conditions in which carbonate and terrigenous mud and chert were the sediments (Droste and Shaver, 1987, Figs. 11A–B). Development of the Terre Haute reef bank also continued until at least the end of Bailey time (Droste and Shaver, 1987, Fig. 1), when lowering of sea level caused a shift of shallow-water sedimentation over the sites of Silurian reef development. During deposition of the Lower Devonian limestone units, the area was subjected to minor fluctuations of sea level that caused lateral transgression and regression of the peritidal and deep-subtidal environments within the basin, and resulted in the interfingering of limestone lithologies, particularly the Backbone and Grassy Knob. The Grassy Knob and Clear Creek Limestones represent deposition in deeper water, whereas the Backbone apparently was deposited rapidly in very shallow water as a basinward prograding unit (Droste and Shaver, 1987). The Backbone environment prograded farthest toward the center of the basin from a broad, shallow shelf along the eastern margin during the middle of the Early Devonian, but it did not reach the deepest part (Droste and Shaver, 1987, Fig. 6).

By the end of the Early Devonian, withdrawal of the sea exposed a broad upland along the Cincinnati Arch in Kentucky and Indiana, along the Kankakee Arch in Indiana, and across the northern half of Illinois (Droste and Shaver, 1983, Fig. 41). The Ozark area was also emergent at this time, and probably had been emergent continuously since the Early Silurian. The sea did not entirely evacuate the basin, and sedimentation in the central part was continuous from the Early into the Middle Devonian (Droste and Shaver, 1975).

Middle Devonian Rocks

The Jeffersonville Limestone, the basal unit of the Middle Devonian in most of western Kentucky, has been studied in detail in Indiana by Droste and Shaver (1975) and as part of a study of Silurian and Devonian rocks of southwestern Indiana by Becker (1974). The formation is equivalent to the Grand Tower Limestone of Illinois. The Jeffersonville is light colored, contains tan and brown chert in the lower part, and commonly is sandy at the base. In western Kentucky where a discrete basal sandstone is present, the unit is called the Dutch Creek Sandstone (Shaver and others, 1984); the unit has member status in the Jeffersonville of Indiana and in the Grand Tower Limestone of Illinois. The Dutch Creek is sandy limestone and sandstone composed of well-rounded, well-sorted, coarse quartz grains (Becker, 1974). In western Kentucky, the Dutch Creek is 0 to 40 ft thick (Shaver and others, 1984). Sand in the Dutch Creek and Jeffersonville is the first appearance of sand in western Kentucky in rocks younger than Middle Ordovician. In Union County north of the Rough Creek Fault Zone, a K-bentonite, correlated with the Tioga Bentonite Bed of southwestern Indiana and adjacent parts of Illinois, is present in the uppermost part of the Jeffersonville. The Tioga was not observed south of the fault zone. There is considerable doubt as to the proper correlation of the Tioga from its type area in Potter County, Pa. (Ebright and others, 1949), into the Illinois and Michigan Basins; see Shaver and others (1986) for a summary of the correlation problems and the present status of resolution.

The Jeffersonville ranges in thickness from 100 to more than 250 ft in western Union County. In the central part of the Middle Devonian proto-Illinois Basin in western Kentucky, southwestern Indiana, and southeastern

Illinois, there is no unconformity between the underlying Clear Creek Limestone and the Jeffersonville Limestone, but toward the basin margins, the Jeffersonville rests unconformably on the Clear Creek and progressively older Devonian and Silurian rocks. In parts of Ohio County, Ky., north of the Rough Creek Fault Zone, the Jeffersonville rests on the Backbone or Grassy Knob Limestones. At the end of Jeffersonville deposition, faulting along the Rough Creek zone and uplift of an area north of the zone in parts of Grayson, Breckinridge, and Meade Counties led to erosion of all or part of the Jeffersonville (Devera and Hasenmueller, 1991). Farther to the east, Jeffersonville strata were also truncated by the pre-Upper Devonian unconformity.

The Sellersburg Limestone, the upper unit of Middle Devonian age, rests with minor unconformity on the Jeffersonville. The Sellersburg is dark-brown to gray argillaceous limestone, which contains generally thin units of dark shale that is very similar to the overlying New Albany Shale. The limestone is more argillaceous in the lower part of the formation. In parts of western Kentucky, a coarse bioclastic limestone in the upper part of the Sellersburg, composed mainly of disarticulated crinoids and other coarse invertebrate fragments, has been correlated with the Beechwood Member of the equivalent North Vernon Limestone in southern Indiana (Devera and Hasenmueller, 1991). Chert is a conspicuous constituent of the Sellersburg, and the fossil spore *Tasmanites* is common in both limestone and shale facies. In Kentucky, the maximum thickness of the Sellersburg is 94 ft (Devera and Hasenmueller, 1991), the average is about 40 ft, and the area of greatest thickness is around the common corner of Kentucky, Indiana, and Illinois. Generally, the contact of the Sellersburg with the overlying New Albany Shale is gradational through a sequence of interbedded limestone and dark shale. Locally, however, north of the Rough Creek Fault Zone in Ohio County (see Plate 2B, well 11), pre-New Albany erosion removed all Middle Devonian strata, and the New Albany rests on Lower Devonian rocks. The Sellersburg is equivalent to the North Vernon Limestone of Indiana and the Lingle Limestone of Illinois.

The northward transgression of the Middle Devonian sea from the depocenter around the common corner of Kentucky, Illinois, and Indiana overlapped a pronounced erosional surface on Lower Devonian and Silurian rocks, including the Terre Haute reef bank. The initial sediments, those of the Dutch Creek Sandstone, were irregularly distributed as tidal sand over a shallow carbonate shelf (Tissue, 1977) surrounding the depocenter. The source of the sand was primarily the Ozark Uplift to the west and the Wisconsin Arch to the north of the basin (Summerson and Swann, 1970). During deposition of the Jeffersonville Limestone, open-marine, subtidal waters covered southwestern Indiana, most of Kentucky, and a small adjoining part of Illinois (Droste and Shaver, 1983, Figs. 44–45). Carbonate mud and sand and chert were the principal sediments. Bounding this subtidal belt on the north across most of Illinois and Indiana were a variety of environments ranging from peritidal to supratidal, including coastal flats, that expanded and shifted with slight changes in sea level. Near the end of Jeffersonville time, a K-bentonite bed, correlated with the Tioga bed, was deposited over much of the Illinois Basin as a result of volcanic activity associated with the Acadian Orogeny.

A period of minor erosion preceded deposition of the upper Middle Devonian rocks. By the end of the Middle Devonian, widespread submergence in the proto-Illinois Basin had displaced the very shallow-water environments farther north, and all of western Kentucky and the southern half of Indiana and Illinois were in peritidal to subtidal environments (Devera and Hasenmueller, 1991). There was increased influx of terrigenous sediments, most likely from the Ozark Uplift, but small amounts of clay probably were also transported into the basin from the rising Acadian Mountains to the east (Swann, 1968). Near the close of the Middle Devonian, the marginal areas of the basin were uplifted and slightly eroded, but in the deeper parts, sedimentation was continuous from the latest Middle Devonian into the Early Mississippian, and resulted in deposition of the New Albany Shale.

Upper Devonian Rocks

The New Albany Shale of latest Middle Devonian to earliest Mississippian (Kinderhookian) age is the most widespread Devonian unit in the Illinois Basin. The New Albany was named by Borden (1874) for exposures along the Ohio River in the vicinity of New Albany, Ind. The first subdivision of the New Albany was by Campbell (1946), but the stratigraphic revision by Lineback (1968, 1970) is the accepted nomenclature for the outcrop area along the eastern margin of the Illinois Basin. The subdivision of the New Albany in this report incorporates nomenclature from both the eastern and western margins of the basin. In the Rough Creek area, the New Albany is divided, in ascending order, into the Blocher, Selmier, and Grassy Creek Shale Members; included with the New Albany, but not designated as a member, is a thin shale called the Hannibal Shale, which locally overlies the Grassy Creek (Schwalb and Norris, 1980a). In adjacent southeastern Illinois and southwestern Indiana, the New Albany formally includes all strata between the top of the Grassy Creek Member and the base of the Rockford Limestone or equivalent Choteau Limestone.

The New Albany Shale in the Illinois Basin has been the subject of numerous investigations of its geology, structure, hydrocarbon potential, geochemistry, and other features, but only a few of the more pertinent reports on the stratigraphy and environments of deposition are cited herein. Additional investigations are cited in the reports that resulted from the coordinated study of the Devonian black shale by the Illinois, Indiana, and Kentucky geological surveys undertaken for the U.S. Department of Energy. The results of those studies are summarized for Illinois by Bergstrom and others (1980) and Cluff and others (1981), for Kentucky by Schwalb and Norris (1980a), for Indiana by Hasenmueller and Woodard (1981), and for the entire basin by Lineback (1981). Maps and cross sections by Schwalb and Norris (1980b–h) present detailed data on the structure of the New Albany Shale in western Kentucky and on the distribution and thickness of the various members, derived from geophysical logs.

In the subsurface of western Kentucky, the lower boundary of the New Albany is placed at the top of the Sellersburg Limestone (Middle Devonian) and the upper boundary at the base of the New Providence Shale, or locally south of the Pennyrile Fault System at the base of the Hannibal Shale (Shaver and others, 1984). Schwalb and Norris (1980b, c), however, placed the upper boundary at the base of the Rockford Limestone (Kinderhookian), and included the thin, olive-gray Hannibal Shale above the black shale of the Grassy Creek Member and below the Rockford in the New Albany, where it is present. The occurrence of the Hannibal is sporadic both north and south of the Rough Creek Fault Zone. Where the Rockford Limestone is missing, the gray shale of the Hannibal cannot be differentiated from similar shale in the younger New Providence Shale, so at those localities the top of the New Albany was placed at the top of the Grassy Creek Member.

In adjacent parts of Indiana and Illinois, the New Albany Shale (Group in Illinois) includes all strata from the top of the Middle Devonian limestones to the base of the Rockford Limestone or its equivalent, the Choteau Limestone in Illinois. In southwestern Indiana, an additional member, the Ellsworth, forms the uppermost unit of the New Albany and rests on the Grassy Creek Shale Member (Shaver and others, 1984). In adjoining southeastern Illinois, the equivalents of the Ellsworth are included in the undifferentiated Saverton and Hannibal Shales. In their type areas in the Mississippi River Valley, the Saverton and Hannibal are separated by limestone, but eastward from those areas the limestone is missing, and as a consequence the two shales cannot be differentiated over parts of the southern depocenter of the New Albany, including some of western Kentucky (Cluff and others, 1981, Fig. 30). In addition, the Saverton-Hannibal sequence in parts of the depocenter grades laterally into the Grassy Creek Shale and cannot be separated from the Grassy Creek on geophysical logs (Cluff and others, 1981, Fig. 36).

In the Rough Creek area, the Blocher Member of the New Albany Shale of latest Middle and earliest Late Devonian age is brownish-black, carbon-rich shale, which contains some argillaceous dolomite, limestone, and minor amounts of chert near the middle of the member. The Blocher is the only shale member of the New Albany that is significantly calcareous (Cluff and others, 1981). Brown spores of *Tasmanites* are abundant. The Blocher was named by Lineback (1968) for outcrops along the eastern margin of the Illinois Basin in Indiana. Later, the boundary with the overlying Selmier Member was redefined on outcrop in Indiana (Hasenmueller and Bassett, 1981), and Cluff and others (1981), in their study of the New Albany in the subsurface of southeastern Illinois, restricted the black calcareous shale in the basal New Albany to the Blocher Member and assigned the overlying black dolomitic shale, originally in the upper Blocher, to the Selmier Member. Lineback (1981) accepted the redefined Blocher-Selmier contact in his summary report on the New Albany in the Illinois Basin; this resulted in a more restricted Blocher Member and a more expansive Selmier Member than previously defined. There is some variance in the projected maximum thickness of the Blocher in the Moorman–Eagle Valley Syncline at the Kentucky-Illinois state line: Lineback (1981, Fig. 4) showed a thickness of more than 80 ft; Cluff and others (1981, Fig. 9), more than 90 ft; and Schwalb and Norris (1980d), more than 150 ft. In that area but on the north side of the Rough Creek Fault Zone, the member is 30 to 40 ft thinner (Schwalb and Norris, 1980d). In Kentucky, the member thins eastward to its depositional edge just beyond the eastern border of the Rough Creek area (Schwalb and Norris, 1980b), where it is overlapped by the Selmier Member. The Blocher does, however, crop out locally farther east at the Falls of the Ohio River at Louisville, Ky. (Powell, 1970). Conodont studies (Collinson, 1967; Lineback, 1968) suggest that most of the Blocher Member is Middle Devonian in age, but the upper part is earliest Late Devonian.

The Selmier Member of the New Albany Shale in this report was called the Sweetland Creek Member in the study by Schwalb and Norris (1980a). Cluff and others (1981) pointed out, however, that the Sweetland Creek Shale grades eastward from its type area in southeastern Iowa into the lower part of the Grassy Creek Shale in Illinois, and the use of the name "Sweetland Creek" in southeastern Illinois and western Kentucky is inappropriate. The Selmier is mostly dark-gray to greenish-gray shale, but locally grades into black shale. The member is more than 200 ft thick in the subsurface in western

Kentucky along the Ohio River just south of the Rough Creek Fault Zone (Lineback, 1981, Fig. 6); Schwalb and Norris (1980e) inferred a thickness of the Sweetland Creek (Selmier) in the same area of more than 170 ft, which is 20 to 30 ft thicker than on the north side of the fault zone. The Selmier wedges out eastward and is overlapped by the Grassy Creek Member. The presence of the Selmier in outcrop is sporadic south of Louisville, and farther south the depositional edge of the member is west of the New Albany outcrop belt (Schwalb and Norris, 1980e).

The Grassy Creek Member of brownish-black to black, carbon-rich shale is the most widespread member of the New Albany Shale and overlaps the older members and onto the pre-Middle Devonian unconformity toward the flanks of the Illinois Basin. The Grassy Creek is more than 160 ft thick in the Moorman Syncline at the Ohio River (Schwalb and Norris, 1980g), thins eastward, and is less than 30 ft thick on outcrop in western Kentucky to the east of the Rough Creek area. There is not much change in thickness of the member across the Rough Creek Fault Zone.

The Grassy Creek Member is equivalent, in ascending order, to the Morgan Trail, Camp Run, and Clegg Creek Members of the New Albany in Indiana (Lineback, 1968). The type Grassy Creek Shale of eastern Missouri and western Illinois is equivalent to only a small part of the thick Grassy Creek in the southern depocenter of the New Albany (Cluff and others, 1981). In much of the depocenter, the Grassy Creek is not readily distinguishable from the overlying Saverton and Hannibal Shale equivalents (Cluff and others, 1981), because the contact is gradational from the black shale of the Grassy Creek to the greenish-gray shale of the undivided Saverton and Hannibal Shales. Where greenish-gray shale assignable to the Saverton-Hannibal is absent, the uppermost black shale of the Grassy Creek is probably Kinderhookian in age (Cluff and others, 1981).

The New Albany Shale in the Rough Creek area is about 80 ft thick along the east side, but thickens westward to a maximum of more than 440 ft in the Moorman–Eagle Valley Syncline along the Ohio River in western Kentucky and adjacent Illinois (Fig. 10). In western and central Kentucky the New Albany overlies formations ranging in age from Middle Devonian to Late Ordovician.

During deposition of the New Albany Shale, a deep-water anoxic basin was centered over the area around the junction of Illinois, Indiana, and Kentucky, including the Rough Creek Graben (Cluff and others, 1981). A deep-shelf environment occupied the area in Kentucky south of the basinal deep and also to the east over much of Indiana. In Illinois, the basin sloped upward to the north and west as a gentle ramp to a shallow shelf that occupied northwestern Illinois (Devera and Hasenmueller, 1991, Fig. 8-5). As Cluff and others (1981) pointed out in their detailed analysis of the depositional environment of the New Albany Shale, the unit is characterized in some parts of the basin by widespread lateral intertonguing and gradation of lithofacies and in others by thin interbedding of lithofacies, all of which indicate that the depositional conditions were not static, but fluctuated on both local and regional scales. The regional interfingering of gray and black shale is interpreted as the result of vertical fluctuations in the position of the anaerobic-dysaerobic boundary in the water column. During most of New Albany deposition, the fluctuations in the oxygenation conditions were restricted to the deep basin, and most of the conspicuous facies changes occurred on the surrounding basin slopes or shelf margins. If we assume low to moderate depositional slopes in the basin, a modest rise in the anaerobic-dysaerobic boundary could allow the area of black shale deposition to transgress over a broad region; and conversely, a drop in the boundary could allow the gray shale to extend into the deeper parts of the basin. The transition from the Devonian to the Mississippian was marked by deposition of carbonate sediments and the continued deposition of siliciclastic muds in dysaerobic and anaerobic environments.

The fine clastic sediments of the New Albany largely represent distal sediments of the extensive Upper Devonian Catskill and the Lower Mississippian Bedford-Berea delta systems (Rich, 1951), which debouched a vast load of detritus from a large land mass in the northeastern United States. Much of the sediment in the northern part of the Illinois Basin, however, probably reached the basin from the far distant Franklin Mountains of the Canadian Arctic (Swann, 1968). The Ozarks could also have supplied some detritus, for the area was emergent and was not inundated until the middle of the Mississippian (Conant and Swanson, 1961).

Mississippian System

Rocks of all series of the Mississippian System are present in the Rough Creek area, but outcropping strata are mainly confined to the Meramecian and Chesterian. Outcropping rocks of Osagean age, represented by the Fort Payne Formation, are exposed locally in fault blocks in the eastern part of the Rough Creek Fault Zone, however.

Mississippian rocks in western Kentucky are more than 2,700 ft thick in the Moorman Syncline in Webster, Hopkins, and Crittenden Counties, but the greatest thickness in the Illinois Basin is in excess of 3,200 ft in southern Illinois (Fig. 11). Carbonate rocks, both chemically precipitated and biologically derived, dominate the Mississippian. Terrigenous clastics are most evident

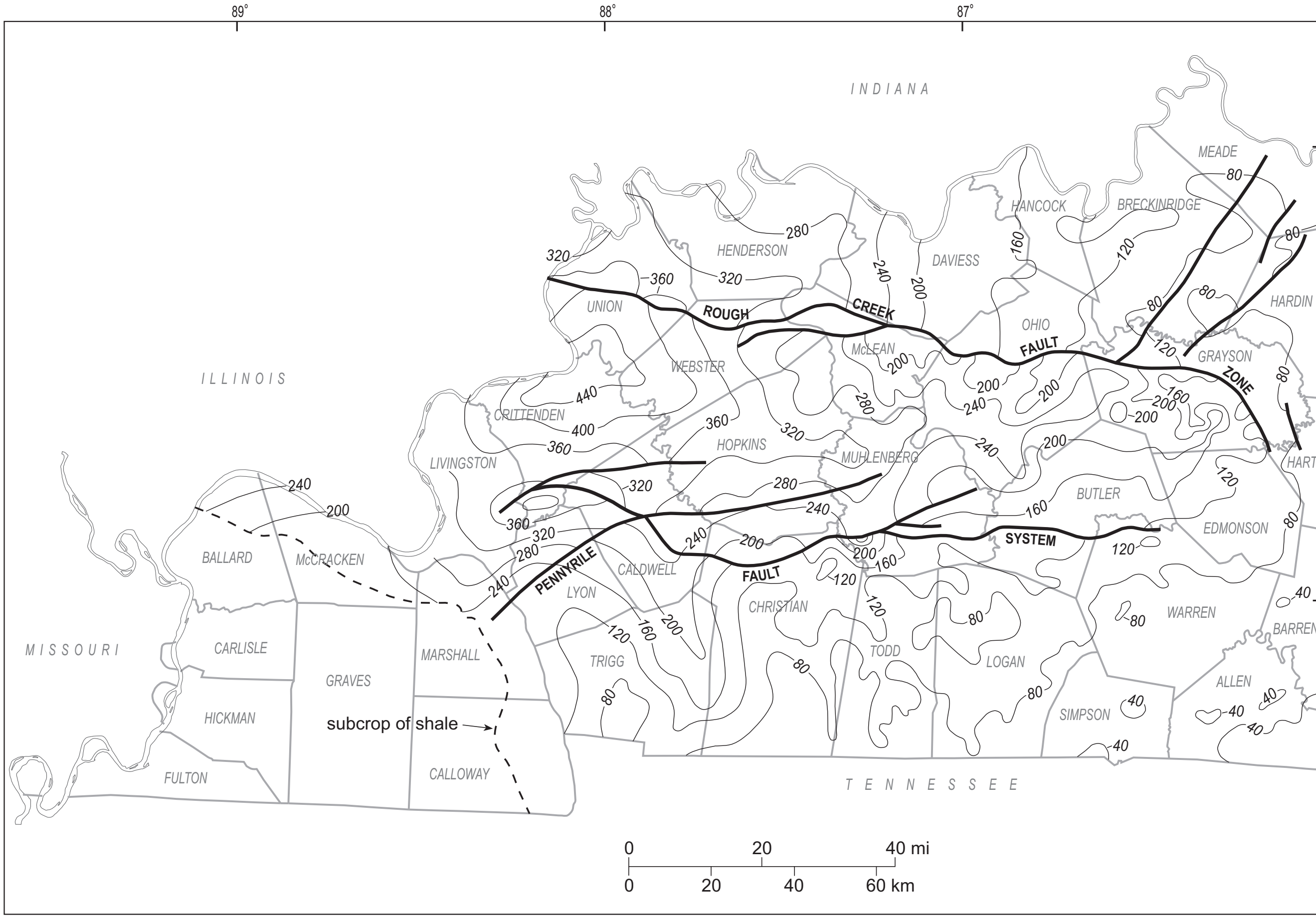

Figure 10. Thickness of the New Albany Shale in western Kentucky, showing relation of its thickness to the Rough Creek Fault Zone and Pennyrile Fault System. Contour interval=40 ft. Modified from Schwalb and Potter (1978).

in the Kinderhookian, in the Osagean (which contains the distal equivalents of the extensive Borden delta that reached into western Kentucky), and in the Chesterian (where carbonate deposition alternated with deltaic sedimentation). Evaporites occur in rocks of Meramecian age throughout the eastern half of the Rough Creek area.

As noted previously, there is considerable uncertainty as to the exact position of the Devonian-Mississippian boundary in the deeper parts of the Illinois Basin in western Kentucky and adjacent areas. Sable (1979a) discussed the stratigraphic relationships and faunal problems in the rock units spanning this part of the section that have contributed to the uncertainty, and cited various workers who have contributed to faunal studies of the boundary problem. The faunal elements generally are considered to be transitional across the boundary, but conodonts seem to be the most reliable fauna for differentiating Devonian and Mississippian marine rocks. As shown in Appendix B, the Devonian-Mississippian boundary in western Kentucky is placed at the base of the Hannibal Shale Member of the New Albany Shale (also designated as the undifferentiated Saverton and Hannibal Shales).

Kinderhookian Rocks

Locally in western Kentucky, conformably overlying the Grassy Creek Member of the New Albany Shale, is gray to greenish-gray shale that is designated as undifferentiated Saverton and Hannibal Shales in Illinois (Cluff and others, 1981); but Schwalb and Norris (1980a) called the unit in Kentucky the Hannibal Shale and included it in the New Albany. The shale is recognizable as a distinct unit only where the overlying Rockford Limestone separates it from the New Providence Shale of similar color and lithology. In western Kentucky, the contact of the undifferentiated Saverton and Hannibal Shales with underlying black shale of the Grassy Creek Member of the New Albany is generally well defined on geophysical logs. The Saverton and Hannibal sequence is restricted, apparently by nondeposition (Schwalb and Norris, 1980a), to limited areas generally west of Daviess County on the north side of the Rough Creek Fault Zone, but on the south side it extends farther east. In

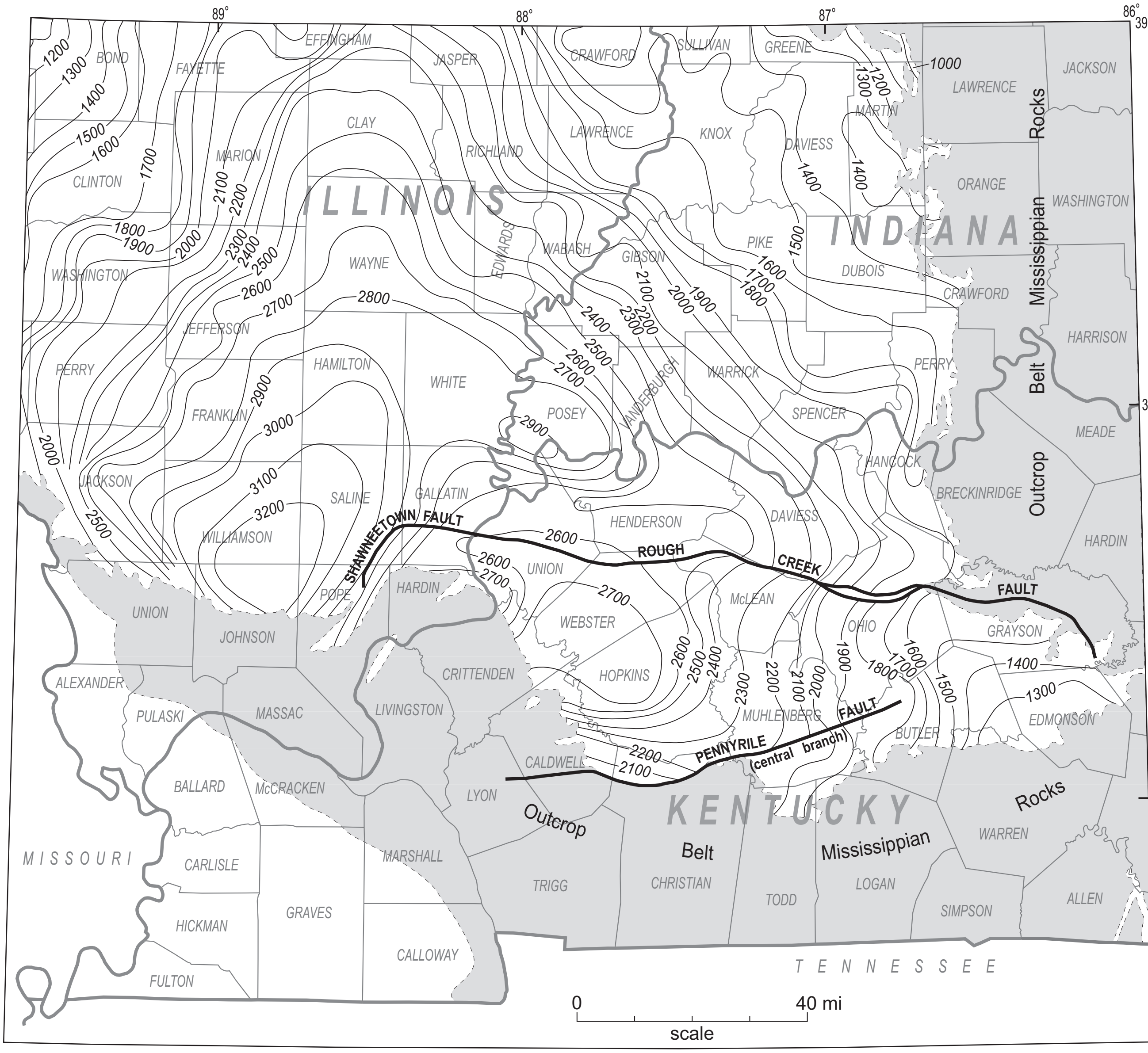

Figure 11. Thickness of Mississippian strata beneath Pennsylvanian strata in the southern part of the Illinois Basin. Contour interval=100 ft. Modified from Gray and others (1970; used with permission of the Indiana Geological Survey), Atherton and others (1975, Fig. M-2; used with permission of the Illinois State Geological Survey), Craig and Conner (1979, Plate 7).

the Canton quadrangle (Fox and Seeland, 1964), along the Cumberland River in western Kentucky (south of the Rough Creek area), a 34-ft-thick olive-black shale with light-olive-gray laminations underlies a thin limestone probably equivalent to the Rockford and overlies the Chattanooga Shale (equivalent to the New Albany Shale); the shale is probably correlative with the undifferentiated Saverton and Hannibal Shales. The equivalent of the Saverton and Hannibal Shales in southwestern Indiana is the Ellsworth Member of the New Albany Shale (Shaver and others, 1984), which is from 0 to more than 40 ft thick (Devera and Hasenmueller, 1991). The maximum thickness of the undifferentiated Saverton and Hannibal Shales in western Kentucky apparently is less than 10 ft (Schwalb and Norris, 1980b, c).

In its type area in western Illinois, the Saverton Shale is of latest Devonian age, but as the Saverton grades eastward into the Grassy Creek Shale, the base of the Saverton becomes younger (Cluff and others, 1981). On outcrop in southeastern Indiana, the equivalents of the Saverton and Hannibal Shales are in the upper part of the Clegg Creek Member of the New Albany Shale. The Upper Devonian–Kinderhookian boundary occurs in the uppermost part of the Clegg Creek, based on the first occurrence of a Kinderhookian conodont fauna (Lineback, 1970).

The thin Rockford Limestone overlies the undifferentiated Saverton and Hannibal Shales, or Hannibal Shale, over parts of western Kentucky, and is quite extensive in adjacent areas of Indiana. In the subsurface from Owensboro, Ky., eastward, generally in the vicinity of the Ohio River in both Kentucky and Indiana, the Rockford is missing because of pre-New Providence erosion (Lineback, 1970), or perhaps locally because of nondeposition (Fig. 12), and the overlying New Providence Shale or Fort Payne Formation (Osagean) rests directly on the New Albany Shale. The Rockford is also missing along either side of the Ohio River above Paducah, Ky. The Rockford consists of less than 10 ft of light-greenish-gray or buff to gray, fine- to coarse-grained limestone, which locally contains a trace of glauconite. The Rockford is of late Kinderhookian and early Osagean age over much of Indiana (Shaver and others, 1986), but on outcrop in southernmost Indiana and adjacent Kentucky in the vicinity of Louisville (Kepferle, 1974), it contains only Kinderhookian foraminifera (Conkin and Conkin, 1979). The Rockford Limestone is continuous with the

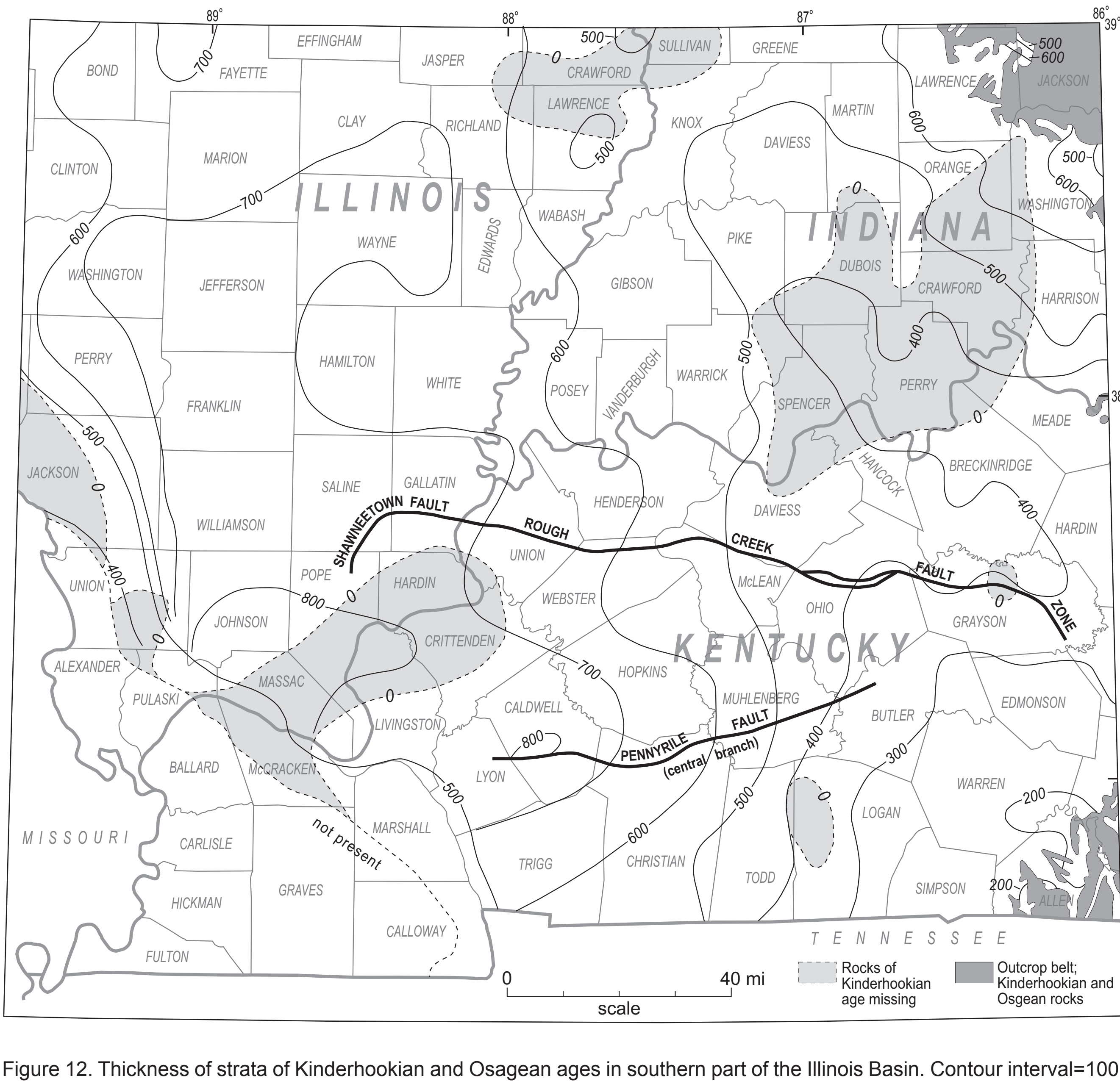

Figure 12. Thickness of strata of Kinderhookian and Osagean ages in southern part of the Illinois Basin. Contour interval=100 ft. Modified from Branson (1966), Gray and others (1970; used with permission of the Indiana Geological Survey), Craig and Conner (1979, Plate 3A, 4A), Hasenmueller and Basset (1981, Fig. 11; used with permission of the Indiana Geological Survey).

Chouteau Limestone of Illinois, which extends over the southern half of the Illinois Basin.

In the southern depocenter of the proto-Illinois Basin in western Kentucky and southeastern Illinois, the anaerobic conditions reflected in deposition of the black shale of the Grassy Creek Member of the New Albany Shale gave way to a better-oxygenated environment during deposition of the mostly gray shale of the undifferentiated Saverton and Hannibal Shales. A brief return to more anaerobic conditions, however, is reflected in a thin tongue of organic black shale in the Ellsworth Member of the New Albany in southwestern Indiana and in the undivided Saverton and Hannibal Shales in southeastern Illinois in early Kinderhookian time.

The depositional environment of the carbonate rock of the Rockford in Indiana and northern Kentucky was of notably low energy, on a sea floor with little relief (Sable and Dever, 1990). Glauconite in the Rockford and also in an extremely thin, highly glauconitic zone at the base of the New Providence Shale, together with scattered phosphatic nodules where the Rockford is missing, point to slow deposition (Kepferle, 1979). The dolomite beds in the Rockford in Indiana suggest an intratidal environment, but the enclosing sediments indicate a subtidal marine environment (Sable and Dever, 1990). The depositional extent of the Chouteau Limestone in Illinois coincides with the shelf-margin, slope, and basin environments during New Albany Shale deposition (Treworgy, 1991). If a shelf-trough depositional and tectonic model is invoked, the thin and widespread Rockford Limestone in Kentucky could have accumulated on the southern part of a broad, stable shelf (Sable and Dever, 1990). If, however, the environment was that of a trough without transition to a shelf, a eustatic rise in sea level could have initiated or extended starved-basin conditions, and the Rockford Limestone then might represent deep-water carbonate deposition (R.C. Kepferle, U.S. Geological Survey, personal commun., 1985, *in* Sable and Dever, 1990).

Osagean Rocks

Rocks of Osagean age over much of Kentucky, west-central Indiana, and central Illinois are dominated by terrigenous clastics of the Borden deltaic sequence in the lower part of the section and by carbonate rocks in the upper part. Westward thickening of the carbonate rocks and reciprocal thinning of the underlying detrital units are characteristic of the lithologic relationships within the Borden (Sable and Dever, 1990). In Kentucky, the Borden delta front trended northwestward, and depositional dip was generally southwestward (Kepferle, 1968). The delta lay to the east and north of the Rough Creek area. Rocks of Osagean age, which constitute most of the total thickness of Kinderhookian and Osagean rocks shown in Figure 12, range in thickness from about 400 ft in the eastern part of the Rough Creek area to more than 800 ft near the western border. Osagean rocks in the Rough Creek area are represented by the New Providence Shale and overlying Fort Payne Formation. On outcrop to the east of the Rough Creek area, siliceous, dolomitic siltstone or silty dolomite of the Muldraugh Member of the Borden Formation represents the youngest Osagean rocks.

The basal Osagean unit over much of western and west-central Kentucky is the thin New Providence Shale. It is the lateral equivalent of the Springville Shale of southeastern Illinois, and east of the Rough Creek area, the New Providence forms the basal member of the Borden Formation, where deltaic sediments are exposed. The New Providence is not exposed in the Rough Creek area, but in outcrops to the east it consists of greenish-weathering, gray, silty clay shale and subordinate siltstone and crinoidal and bryozoan limestone (Peterson and Kepferle, 1970). Large ironstone concretions are abundant, and a persistent layer of phosphatic nodules is present at the base of the unit. Where the underlying Rockford Limestone is missing in the subsurface of western Kentucky, the basal contact of the New Providence with the New Albany Shale is marked by a very thin, highly glauconitic zone (Schwalb and Norris, 1980a).

The New Providence may be as much as 220 ft thick in its outcrop area, but thins abruptly southwestward and is very thin or missing in the subsurface at the eastern border of the Rough Creek area (Peterson and Kepferle, 1970, Fig. 4-C). In outcrop along the Cumberland River in western Kentucky (south of the study area), the New Providence is 30 to 50 ft thick (Rogers, 1963). Where the New Providence is missing, the overlying Fort Payne Formation rests on the New Albany Shale.

Stratigraphy of Exposed Rocks

Mississippian System

Osagean Rocks

Fort Payne Formation. The Fort Payne Formation constitutes the majority of Osagean rocks in western Kentucky. About 200 ft of the formation is exposed in fault blocks in the Rough Creek Fault Zone in the eastern half of the Rough Creek area. The formation consists of dark-gray, siliceous, dolomitic to very calcareous siltstone; dark, very finely to coarsely crystalline, in part argillaceous, fossiliferous limestone; and medium-gray, silty, calcareous and dolomitic sandstone. Crinoid debris, large brachiopods, and fenestrate bryozoans are conspicuous locally in both siltstone and limestone. Calcite- and quartz-filled geodes and chert nodules are common. In the subsurface in the vicinity of the Ohio River, the Fort Payne contains a dark-shale facies as a tongue-shaped body 5 to 15 mi wide and 80 mi long that extends from northern Grayson County northwestward to Henderson County (Sable and Dever, 1990, Fig. 54). The Fort Payne is about 600 ft thick in wells a short distance southwest of the southwestern corner of the Rough Creek area (Trace and Amos, 1984), but is thinner to the east, where it abuts and probably overlaps Borden delta sediments east of the Rough Creek area. In western Kentucky, relationships of the Borden Formation to the Fort Payne indicate that both the Muldraugh Member of the Borden (the upper carbonate unit of the Borden) and the Fort Payne are younger than Borden detrital rocks, and that at least the lower part of the Fort Payne is correlative with the Muldraugh (Sable, 1979a).

In western Kentucky, the initial Osagean deposit above the Rockford Limestone was distal prodelta mud of the westward-prograding Borden delta, comprising the New Providence Shale, deposited in a relatively deep basin (Peterson and Kepferle, 1970). The main Borden delta lobe extended west from Indiana across central Illinois, then south into southwestern Illinois. In Kentucky, a lobe of the delta advanced west on a broad depositional shelf (Sable and Dever, 1990), but the clastic wedge did not reach as far as the Rough Creek area. Deposition of fine-grained siliciclastic sediments increased the area of the shallow-water shelf in the basin, but the deltaic sequence did not fill the entire basin (Cluff and Lineback, 1981). With cessation of active delta growth, dark, siliceous carbonate rocks of the Fort Payne Formation, representing fine carbonate material winnowed from the shelves (Treworgy, 1991), were deposited initially in the deep-water part of the basin under dysaerobic conditions (Lineback and Cluff, 1985), but later on foreset slopes of the delta (Sable and Dever, 1990) in an eastward-transgressing sea. The Muldraugh Member of the Borden Formation, the youngest Osagean strata in west-central Kentucky, was deposited over the Fort Payne Formation in an intralittoral environment on the delta platform (Kepferle, 1977).

Meramecian Rocks

In the Rough Creek area, the Osagean-Meramecian series boundary is placed at the contact between the Fort Payne Formation and the overlying Warsaw Limestone. No regional hiatus marks this series boundary in the Illinois Basin. In fact, placement of the boundary is complicated by problems in age assignments and complex facies relations of limestone and shale of the Warsaw Formation (or Warsaw Shale) in its type area in western Illinois with strata eastward in the subsurface of the Illinois Basin, with rocks termed “Warsaw” on outcrop in western Kentucky and Tennessee, and with the Harrodsburg and Salem Limestones in Indiana and adjacent Kentucky (Sable, 1979a; Sable and Dever, 1990); see these studies for details of the boundary problem.

Rocks of Meramecian age in the Rough Creek area include, in ascending order, the Warsaw, Salem, St. Louis, and Ste. Genevieve Limestones. Only the Ste. Genevieve and upper part of the St. Louis are exposed in the eastern half of the area, but the Warsaw and Salem appear to be present everywhere in the subsurface. Meramecian rocks range in thickness across the Rough Creek area from less than 600 ft near the eastern border to more than 1,100 ft in the western part in Henderson County (Fig. 13).

Warsaw Limestone

In west-central Kentucky in the outcrop area of Borden deltaic sediments, east of the Rough Creek area, the basal unit of Meramecian age is the Harrodsburg Limestone, which overlies the Muldraugh Member of the Borden Formation. The Harrodsburg is traceable as a distinct unit northwestward across Indiana into central Illinois in association with Borden delta deposits, where it forms the upper member of the Ullin Limestone (Lineback, 1966). The Harrodsburg has not been recognized separately west of the delta, either in Illinois or in the subsurface of Kentucky west of its outcrop belt, however (Sable, 1979a). Rocks in the subsurface of Kentucky equivalent in part to the Harrodsburg are included in the Warsaw Limestone, and Harrodsburg-like lithologies are conspicuous parts of the thick Warsaw on outcrop in the Western Kentucky Fluorspar District (Sable, 1979a). In fact, the limestone unit in western Kentucky correlated by Butts (1915) with the Warsaw includes lithologic and age equivalents of the Salem (Meramecian) and Harrodsburg (late Osagean and Meramecian) Limestones and the Muldraugh Member of the Borden Formation (Osagean) (Sable and Dever, 1990). Because the type Warsaw of Illinois (Hall, 1857) is neither directly traceable into or lithologically identical with the Warsaw of Kentucky and Tennessee as described by Butts (1917, 1925), Sable and Dever (1990) recommended that use of the name “Warsaw” in Kentucky and Tennessee should be discontinued.

The Warsaw Limestone, as identified in the subsurface of the Rough Creek area, is finely to coarsely fossil-fragmental, in part dolomitic limestone, which locally is very oolitic and pelletal. In places, the basal part is very argillaceous to silty. Dense, partly silty and calcareous dolomite commonly is interbedded with limestone, particularly in the upper part of the unit. The carbonate rocks contain little chert.

Well records from western Kentucky reflect various problems in consistent placement of the contact between the Warsaw and overlying Salem Limestone.

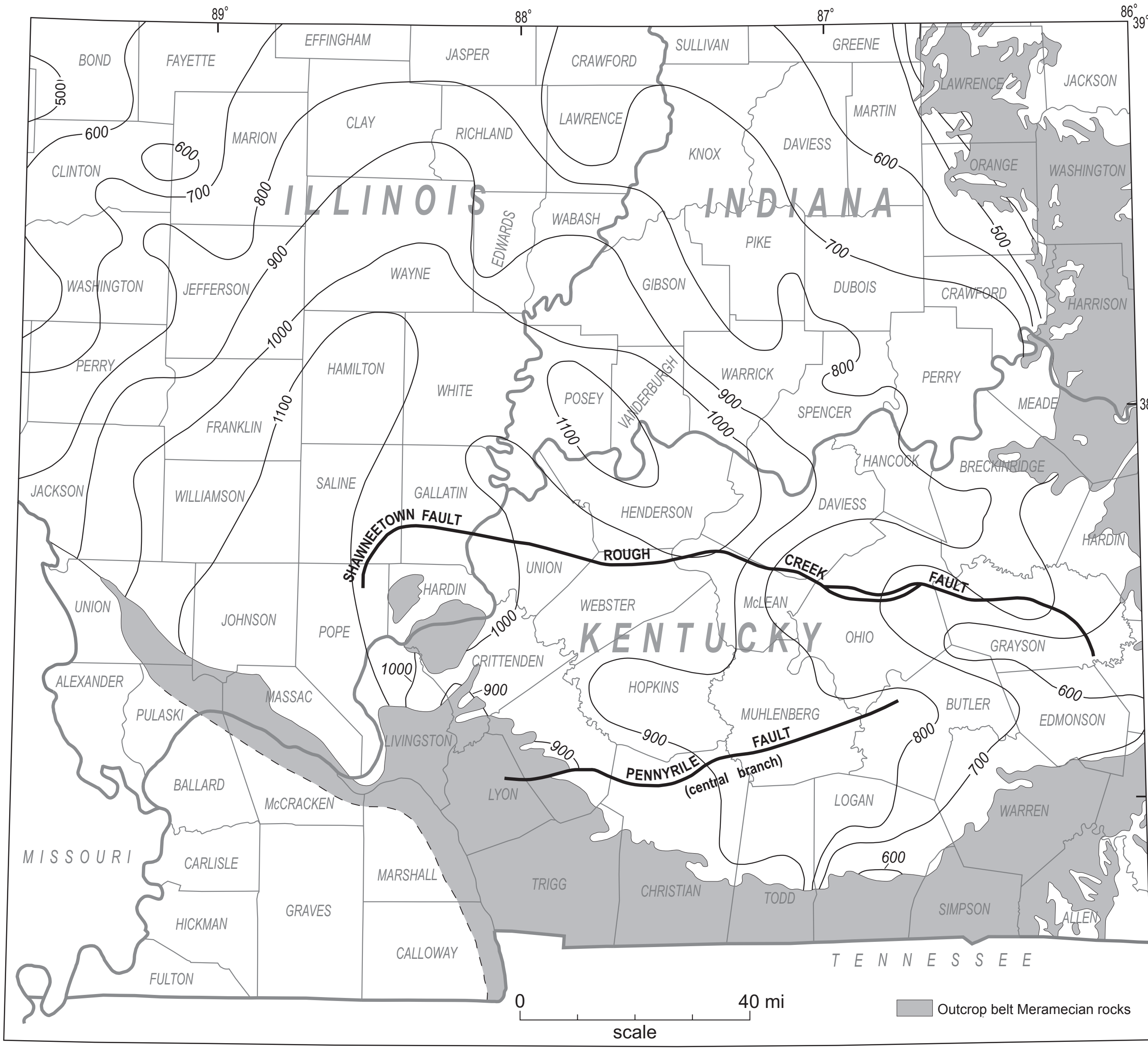

Figure 13. Thickness of rocks of Meramecian age in southern part of the Illinois Basin. Contour interval=100 ft. Modified from Willman and others (1967), Gray and others (1970), Craig and Conner (1979, Plate 5A), Noger (1988).

The contact probably is gradational, and commonly the two formations are not separated. Abrupt changes in thickness of the two units between adjacent wells probably reflect both the gradational nature of the contact, as well as a lack of a consistent marker for positioning the contact. In the limited number of well records examined in the Rough Creek area, the recorded thickness of the Warsaw ranged from 40 to 490 ft; this wide range in thickness more likely reflects lack of consistency in placing the contact rather than true thickness variations. In the Western Kentucky Fluorspar District, the Warsaw ranges from 225 to 260 ft in thickness (Trace and Amos, 1984). In outcrops just northeast of the northeastern corner of the Rough Creek area, the Harrodsburg Limestone, which is laterally equivalent to at least part of the Warsaw of western Kentucky, is 25 to 45 ft thick (Withington and Sable, 1969).

Salem Limestone. The Salem Limestone in the subsurface of the Rough Creek area consists of fine- to coarse-grained, commonly dolomitic, fossil-fragmental limestone and locally very oolitic and pelletal limestone, speckled limestone, and cherty limestone. Fine-grained, silty to argillaceous, locally slightly gypsiferous dolomite and gray, locally calcareous shale mixed with argillaceous limestone are also present. Ostracodes and endothyrid foraminifera are evident in some beds in well samples, and outcrops in west-central Kentucky yield abundant crinoid debris, bryozoans, brachiopods, corals, blastoids, and gastropods (Withington and Sable, 1969). On outcrop in the Western Kentucky Fluorspar District (southwest of the Rough Creek area), the Salem is characterized by finely to coarsely crystalline, calcarenitic limestone, which is partly argillaceous or dolomitic. The upper part commonly is oolitic and contains abundant tests of the foraminifer *Globoendothyra (Endothyra) baileyi* (Trace and Amos, 1984).

As noted in the discussion of the Warsaw Limestone, the Warsaw-Salem contact probably is conformable and gradational. In western Kentucky the Salem is 110 to 160 ft thick (Trace and Amos, 1984), and on outcrop near the northeastern corner of the Rough Creek area it is 90 to 140 ft thick (Withington and Sable, 1969). Thickness of the Salem in the subsurface of the Rough Creek area is generally less than 150 ft. Maximum thickness of the Salem Limestone is more than 500 ft in the Illinois Basin in southeastern Illinois (Atherton and others, 1975), but the formation thins toward the basin margins (Lineback, 1972), and in southwestern Indiana is less than 100 ft to more than 250 ft thick (Keller and Becker, 1980).

St. Louis Limestone. The upper part of the St. Louis Limestone is exposed within and along the south side of the Rough Creek Fault Zone in the eastern half of the Rough Creek area. The formation consists of very fine-grained to sublithographic, commonly dolomitic limestone and dolomite, which locally are silty. Olive-gray to medium-dark-gray chert is abundant as irregular to spherical nodules and irregular lenses, which weather white to light yellowish gray and yellowish brown to dark brown. In places, ovoid quartz nodules are abundant. Locally, in the subsurface of western Kentucky, limestone mainly in the upper part of the St. Louis is oolitical and pelletal. Thin beds of dark-gray carbonaceous shale and dark-green calcareous shale are present throughout the St. Louis, but are more numerous in the lower part. Gypsum and anhydrite, commonly interbedded with dolomite and some shale, occur in units 10 to 20 ft thick in the lower part in the northeastern corner of the Rough Creek area (Fig. 14), and are related to evaporites in the St. Louis in southwestern Indiana and south-central Illinois. An individual bed of gypsum and anhydrite almost 10 ft thick is locally present in the subsurface in the Custer quadrangle near the eastern border of the Rough Creek area (Amos, 1977). Locally, crinoid columnals, brachiopods, and fenestrate bryozoans are found in profusion in the St. Louis. Silicified colonial corals, identified as *Lithostrotionella castelnaui Hayasaka* and *"Lithostrotion" proliferum,* are scattered to abundant in the lower half of the formation, together with the foraminifer *Endothyra* (Trace and Amos, 1984).

The contact of the St. Louis Limestone with the underlying Salem Limestone is difficult to precisely determine in the subsurface, for, as Lineback (1972) observed in the subsurface of Illinois and Indiana, the biocalcarenite of the Salem grades laterally and intertongues with fine-grained limestone, dolomite, and evaporites of the basal St. Louis. A precise contact also is difficult to pick on outcrop in the Western Kentucky Fluorspar District where medium- to coarsely crystalline and partly oolitic calcarenite of the upper part of the Salem is interbedded with finely crystalline limestone of the overlying St. Louis, which contains abundant *Lithostrotion* (Trace and Amos, 1984). The base of the St. Louis is placed at the lowest occurrence of abundant colonial lithostrotionoid corals, which approximately coincides with the lithologic change described above (Trace and Amos, 1984). This definition of the Salem–St. Louis contact is believed by Trace and Amos (1984) to agree with the definition given by Lineback (1972).

The St. Louis and Salem Limestones together comprise the bulk of Meramecian rocks in the deep part of the Illinois Basin in southeastern Illinois, and like the Salem, the St. Louis also thins toward the basin margins. The St. Louis is about 500 ft thick in southeastern Illinois (Atherton and others, 1975), is of similar thickness in the Western Kentucky Fluorspar District (Trace and Amos, 1984), but thins eastward and generally is 250 to 400 ft thick in the Rough Creek area.

Ste. Genevieve Limestone. The Ste. Genevieve Limestone crops out over a large area in the northeastern part of the Rough Creek area and in two very limited areas in the extreme southwestern part. In the eastern outcrop area, the Ste. Genevieve is an undivided formation. In the western part, which is toward the deeper part of the Illinois Basin, the upper part of the formation contains a thin but laterally extensive unit of sandstone and sandy limestone that allows the Ste. Genevieve to be divided into the lower Fredonia Limestone Member, the middle Rosiclare Sandstone Member, and the upper Levias Limestone Member (Trace and Amos, 1984).

In the eastern outcrop area, the formation is dominantly a carbonate unit largely of oolitic and fossil-fragmental limestones. Olive-gray calcareous shale is locally present as interbeds and partings in the upper part of the formation. A few beds of silty dolomite are also present locally. Chert generally is a minor constituent of the formation, but in the Rough Creek area a distinctive cherty limestone, the Lost River Chert Bed (Elrod, 1899), is present in the basal part of the Ste. Genevieve, and one or two beds of nodular or blocky-weathering chert

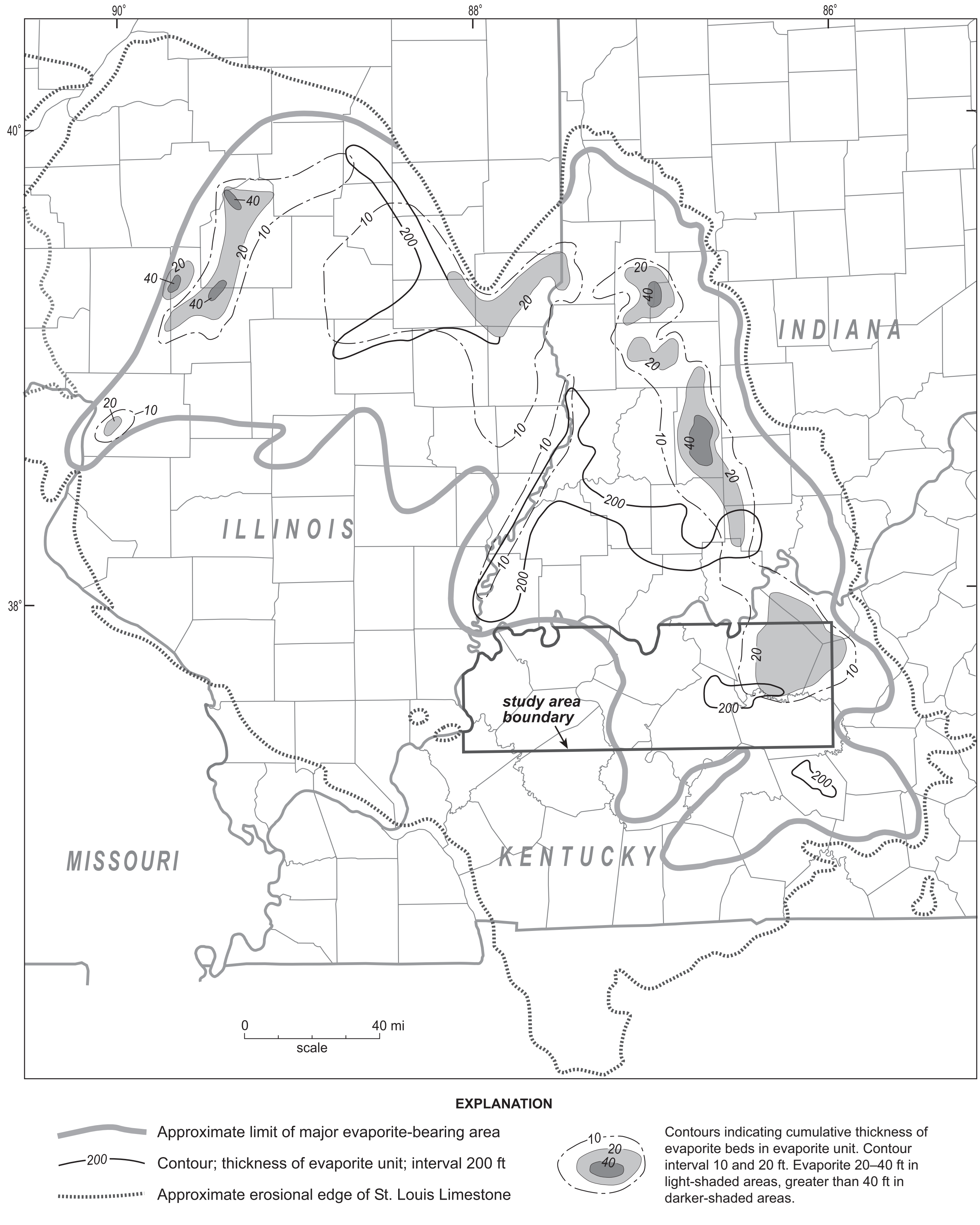

Figure 14. Distribution and thickness of evaporites in the St. Louis Limestone in the Illinois Basin and the Rough Creek area. Modified from Sable (1979b, Fig. 90).

are present near the middle. The Lost River Bed is very fossiliferous, siliceous limestone that weathers to white to light-gray angular fragments and porous blocks and is characterized by large fenestellid bryozoan fronds and large orthotetid, productid, and spiriferoid brachiopods; it also contains blastoids, horn corals, and crinoid fragments. Red clay stains and outlines the fossil casts. The Lost River Bed, generally about 10 ft thick, has been recognized on outcrop from northern Barren County in south-central Kentucky, northwestward to its type area in Orange County, Ind., and also is recognizable in cuttings from coreholes in the subsurface west of the outcrop belt (Kepferle and Peterson, 1964). On outcrop in west-central Kentucky and adjacent Indiana, the Lost River is 20 to about 35 ft above the defined base of the Ste. Genevieve Limestone. This bed is a valuable mapping horizon in areas of low relief, poor exposures, and thick residual soil (Sable and Dever, 1990).

At numerous localities in its eastern outcrop area, the uppermost part of the Ste. Genevieve contains a breccia bed composed of well-cemented, light-gray to brownish-black chert fragments in a limestone matrix. It weathers shades of gray and black and forms angular fragments and small float blocks as much as 1.5 ft thick. This is the Bryantsville Breccia Bed of Indiana (Malott, 1952). The chert breccia was not recognized on outcrop in the western part of the Rough Creek area, but an unnamed 1-ft-thick limestone breccia is present to the south around Princeton, Ky. (Trace, 1972), at the top of the Levias Limestone Member of the Ste. Genevieve. The Bryantsville is extensive on both sides of the Cincinnati Arch in Kentucky (Sable and Dever, 1990), is also extensive in Indiana, and is present in some areas of Illinois (Swann, 1963).

In the western part of the Rough Creek area, the Fredonia Limestone Member, the basal member of the Ste. Genevieve, is very light gray to white, very oolitic, thick bedded, and interbedded with minor amounts of darker, finely crystalline limestone. Fossils are predominantly brachiopods. In the subsurface where this part of the Ste. Genevieve develops zones of porosity, they are known collectively as the McClosky oolite of drillers. The Fredonia is 170 to 250 ft thick in the Western Kentucky Fluorspar District (Trace and Amos, 1984).

The Rosiclare Sandstone Member is light greenish gray, very fine grained, thin bedded, and calcareous. Locally, it includes light-gray, sandy limestone and greenish-gray shale. The member is only 5 to 10 ft thick. The overlying Levias Member of the Ste. Genevieve is mostly light-gray oolitic limestone; the remainder is interbedded light-gray to olive-gray finely crystalline limestone and dolomitic limestone. Fossils include the crinoid *Platycrinites,* spiriferoid and composited brachiopods, and fenestellid bryozoans. The member is 10 to 20 ft thick. In Illinois, the Rosiclare equivalent is called the Aux Vases Sandstone; the Levias is included as the lower member of the overlying Renault Limestone.

Because the contact of the Ste. Genevieve Limestone with the underlying St. Louis Limestone is based on lithologic differences, it is regionally inconsistent in Illinois (Swann, 1963) and also in western Kentucky. Although the St. Louis is typically lithographic, cherty, and darker limestone than the lighter-colored, oolitic and bioclastic limestone of the Ste. Genevieve, the lithologies commonly are gradational through a transitional zone. Details of the St. Louis–Ste. Genevieve contact throughout Kentucky are discussed in Sable and Dever (1990). In the Western Kentucky Fluorspar District, the contact is placed at the top of abundantly cherty limestone (Trace and Amos, 1984). In the eastern part of the Rough Creek area, the distinctive Lost River Chert Bed about 35 ft above the base of the Ste. Genevieve is very useful in determining the position of the top of the St. Louis.

Measured thicknesses of Ste. Genevieve Limestone in or close to the Rough Creek area range from about 160 to 250 ft. The formation thickens somewhat toward the west, and in the Western Kentucky Fluorspar District is 200 to 300 ft thick (Trace and Amos, 1984).

Marine conditions continued without interruption from Osagean time into the Meramecian in all parts of the Illinois Basin. Although the basin had been mostly filled by Borden clastic sediments and Fort Payne and Ullin carbonate rocks, and thereby largely transformed into a shallow-water shelf, deep-water areas persisted in extreme southern Illinois and western Kentucky (Cluff and Lineback, 1981). The Meramecian units (Salem, St. Louis, and Ste. Genevieve Limestones and Aux Vases Sandstone of Illinois) record an essentially continuous sequence of closely related shallow-water carbonate environments that shifted across the basin through time (Cluff and Lineback, 1981). Only in the latter part of the epoch did terrigenous clastics interrupt the carbonate regime. Sable (1979a) and Sable and Dever (1990) summarized three depositional environments of Meramecian strata:

(1) “High-energy environments, produced by wind-driven and (or) tidal currents in shallow marine waters (less than 100 ft), that are indicated by the fossil-fragmental, crossbedded, and interlensing limestone beds of the Harrodsburg, Warsaw, Salem, and Ste. Genevieve Limestones, and the Rosiclare Sandstone Member of the Ste. Genevieve (Aux Vases Sandstone of Illinois)”; textures of the rocks reflect a variety of depositional conditions, including oolite shoals, lagoons, reefoid or bank-detritus areas, and bars. The Aux Vases in Illinois was deposited as a complex tidal-sandbar system

(Seyler, 1984) that was most extensively developed in the southwestern part of the proto-Illinois Basin (Treworgy, 1991, Fig. 9-6), but whether that environment persisted into less-marginal areas of the basin, as in western Kentucky, is not known.

(2) Moderately deep (more than 500 ft?) turbid waters recorded by the high argillaceous content of parts of the Warsaw and Salem and lower part of the St. Louis Limestones in western Kentucky.

(3) A hypersaline environment, as indicated by dolomitic beds, relative scarcity of fossils, and occurrence of gypsum, persisted in some areas throughout much of St. Louis time.

The lower part of the St. Louis was deposited during a worldwide sea-level low (Ridgley and others, 1994). There was probable supratidal sabkha and adjacent restricted lagoon from west-central Kentucky northward and westward across Indiana and Illinois parallel to the Cincinnati-Kankakee Arch trend (Jorgensen and Carr, 1973). Sable and Dever (1990) thought the highly argillaceous limestone of the Salem and lower St. Louis may reflect a moderately deep-water environment, but Ridgley and Nuccio (1994), working in south-central Indiana, found the carbonate-evaporite sequence in the organic-rich, lower part of the St. Louis to be characterized by many transgressive-regressive sedimentary cycles. The organic-rich strata were deposited during peak transgression (maximum flooding) or in restricted environments commonly associated with gypsum and anhydrite precipitation, when input of clastic material decreased and anoxic conditions prevailed. The source of marine waters was mainly to the south, but seaway connections with the Appalachian Basin to the east across the Cincinnati Arch were intermittent through the Cumberland Saddle (Sable and Dever, 1990), and Sable (1979b) inferred that the source of the water during deposition of the evaporates in the lower St. Louis was the Michigan Basin.

Chesterian Rocks

Strata of Chesterian age in western Kentucky are characterized by cyclic alternations of terrigenous, clastic sedimentary rocks and marine limestone. In the Rough Creek area, the Chesterian strata, which constitute the majority of exposed Mississippian rocks, are divisible into as many as 15 formations (see Appendix B), and correlation of named units is generally consistent into Indiana and Illinois. Because of lithologic variations across the Illinois Basin, however, some units that are recognizable in some areas are not in others, and terminology or nomenclatural rank, grouping of units, and placement of formational contacts vary from state to state and even within the western part of Kentucky itself. The Chesterian units in the Rough Creek area are contiguous between the eastern and western outcrop areas, although some units in the upper part of the section undergo considerable change in thickness and some change in character. Also, in the southeastern part of the Rough Creek area around the town of Leitchfield, most clastic units in the lower part are missing, so that the section from the top of the Ste. Genevieve Limestone (Meramecian) to the top of the Beech Creek Limestone Member of the Golconda Formation is almost entirely limestone (Gildersleeve, 1978). As a consequence, individual limestone units present elsewhere in the Rough Creek area are generally not recognizable here, so the entire section is called the Girkin Formation (Appendix B). A number of units, particularly in the lower part of the Chesterian, are designated by different names in the eastern and western parts of the Rough Creek area. In the discussion of the stratigraphic units that follows, the name of the western equivalent of a formation or member is enclosed in parentheses after the name of the eastern unit.

The Chesterian rocks in the eastern part of the Rough Creek area dip gently to the west and southwest, and as a consequence crop out in belts of increasingly younger rocks from east to west. Symmetry is broken locally by the Rough Creek Fault Zone and associated faults. Chesterian rocks exposed in the extreme southwestern part of the study area dip to the northeast into the Moorman Syncline, and the belts of Chesterian strata are increasingly younger toward the east. A broad area of Pennsylvanian rocks separates the two Chesterian outcrop areas.

The thickness pattern of Chesterian strata in the Illinois Basin reflects deep erosion prior to Pennsylvanian deposition. Extensive valleys were cut into Chesterian rocks, some in the Rough Creek area as deeply as the middle of the Glen Dean Limestone (Gildersleeve and Johnson, 1978b), and even more deeply, into the Big Clifty Sandstone Member of the Golconda Formation, a few miles south of the southeastern part of the area (Shawe and Gildersleeve, 1969). Although pronounced local variations in thickness are best seen on individual geologic quadrangle maps, the thickness map of Chesterian rocks (Fig. 15) displays well regional trends and variations. In western Kentucky, Chesterian rocks are about 400 ft thick in the eastern outcrop area and thicken westward and southward to more than 1,100 ft in Hopkins County. The greatest thickness of Chesterian beds, more than 1,400 ft, is in southern Illinois.

The Chesterian limestone units in the Rough Creek area are widespread and very consistent in lithology regionally. They consist, in ascending order, of the Paoli (Renault), Beaver Bend, and Reelsville Limestones, the Beech Creek and Haney Limestone Members of the Golconda Formation, and the Glen Dean, Vienna, Menard,

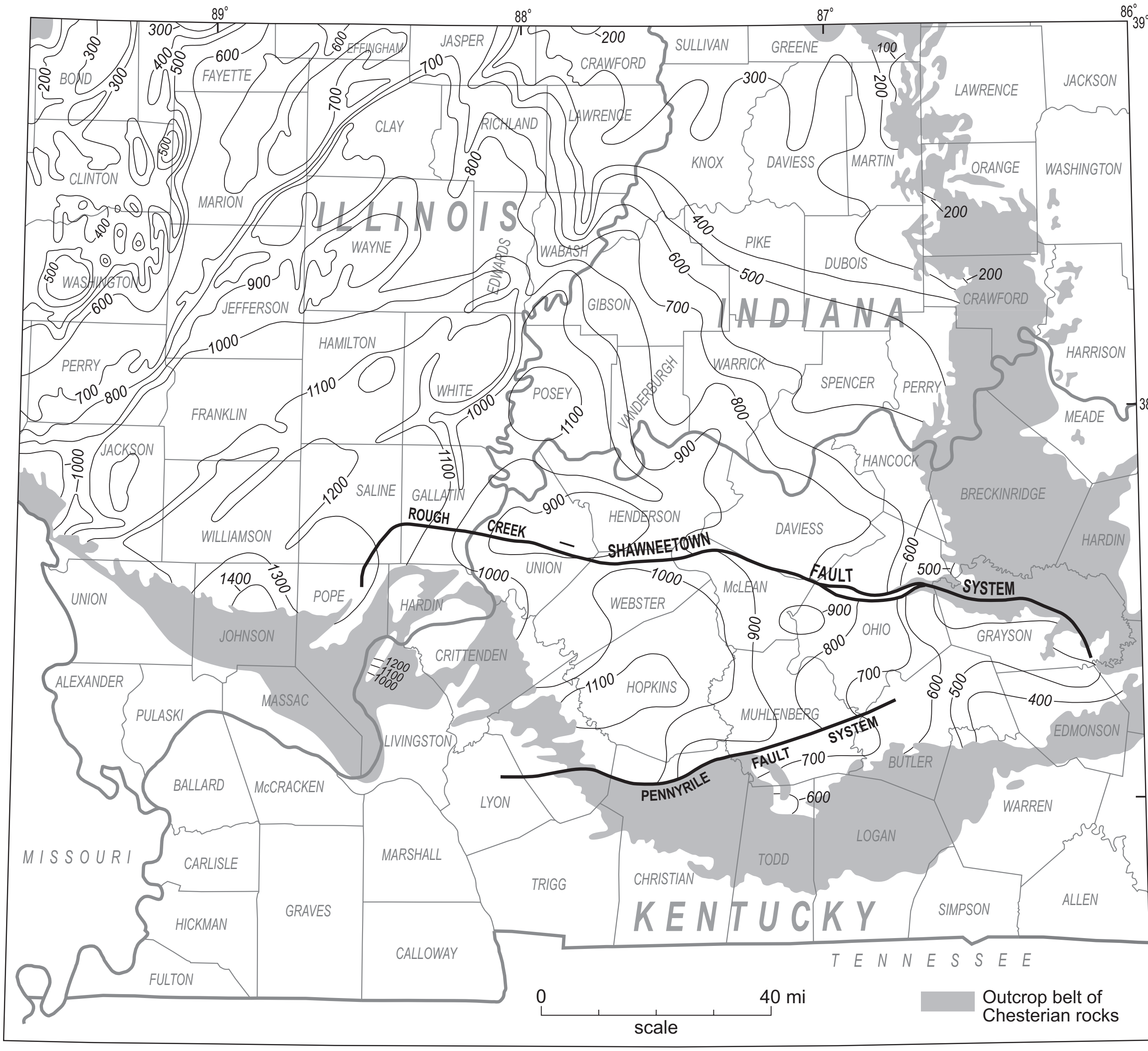

Figure 15. Thickness of rocks of Chesterian age where overlain by Pennsylvanian rocks in the southern part of the Illinois Basin. Fault systems generalized. Contour interval=100 ft. Modified from Gray and others (1970; used with permission of the Indiana Geological Survey), Willman and others (1975, Fig. M-26; used with permission of the Illinois State Geological Survey), Craig and Conner, 1979, Plate 6A), Noger (1988).

Clore, and Kinkaid Limestones. Most are relatively pure limestone; dolomite is a minor constituent. Fossil-fragmental limestone is common, and oolitic limestone occurs locally in most limestone units, but is most prevalent in the Reelsville Limestone, in the Haney Limestone Member of the Golconda Formation, and in the Vienna Limestone. Argillaceous limestone, commonly interbedded with small amounts of shale and sandstone, is a minor constituent, but is more abundant in the upper half of the Chesterian section. Chert is characteristic of several limestone units but is not nearly as abundant as in underlying Meramecian rocks. The presence and variety of chert in Chesterian limestones are particularly helpful for correlation.

The clastic units of Chesterian age in the Rough Creek area are, in ascending order, the Mooretown Formation (Bethel Sandstone), Sample Sandstone, Elwren (Cypress) Sandstone, Big Clifty Sandstone Member (Frailey Shale Member) of the Golconda Formation, and Hardinsburg, Tar Springs, Waltersburg, Palestine, and Degonia Sandstones. Most are composed of various proportions of shale and siltstone, lesser amounts of sandstone, and minor amounts of limestone, but in places thick sandstone composes most, or, locally, all of a clastic formation. Most sandstones are deltaic deposits of the ancient Michigan River system (Swann, 1963), the most striking of which are the channel-fill sandstones. Although rarely recognized, some channel fills are of mudstone, in places mixed with sandstone (Sable and Peterson, 1966, Fig. 9).

Potter (1963) has described in detail the petrology and texture, internal structures, and size and dimensions of sand bodies in the upper Chesterian of the Illinois Basin. Treworgy's (1988) basinwide investigation of the Big Clifty Sandstone, Frailey Shale, and Haney Limestone Members of the Golconda Formation revealed depositional and structural details not previously recognized. Calvert (1967) studied the Tar Springs Sandstone across much of the Rough Creek area north of the Rough Creek Fault Zone, and Wescott (1982) worked out the depositional history of the Tar Springs in its outcrop belt across southern Illinois. Chesterian sandstone in the Rough Creek area is dominantly very fine- to fine-grained orthoquartzite, composed mostly of quartz and minor amounts of feldspar, fossil fragments, chert, and heavy minerals (Sable and Dever, 1990). Other constituents include pyrite grains, clay-ironstone concretions, pebbles of shale, coal, and coaly materials, and, very rarely, quartz granules and pebbles.

The contacts of clastic units with underlying limestone units commonly are conformable or even transitional, but where thick channel-fill sandstone composes much of a unit, underlying beds generally are truncated, and one or more older formations may have been removed. There was a break in carbonate sedimentation at the end of Ste. Genevieve time, as shown by the Bryantsville Breccia Bed, which is a paleosol that resulted from subaerial exposure and vadose diagenesis (Sable and Dever, 1990).

Lower Chesterian Rocks

Paoli (Renault) Limestone. The basal limestone unit of Chesterian age in the Rough Creek area is the Paoli Limestone and its western equivalent, the Renault Limestone. The Paoli crops out mainly in the northeastern part and along the eastern edge of the Rough Creek area, but is exposed locally in the Rough Creek Fault Zone as far west as Dundee in Ohio County. The Renault is exposed along the western edge of the area. The Paoli Limestone generally is light to medium gray, sublithographic to finely crystalline, but locally medium grained, and thick to very thick bedded. Crossbedded, locally sandy limestone is conspicuous in places near the middle of the formation. Oolitic limestone is an important constituent over much of the outcrop area. The Paoli is very fossiliferous, and fragments of the diagnostic Chesterian crinoid *Talarocrinus* are common. Quartz spherules, as much as 3 inches in diameter, are present locally in the lower part, and the unit contains scattered small chert nodules. Greenish-gray, calcareous, fossiliferous shale occurs as thin interbeds in the middle of the formation.

In places, the basal few feet of the Paoli consists of crossbedded sandy limestone, limy sandstone, and sandy shale, and the sequence is probably equivalent to the Popcorn Member (originally named the Popcorn Sandstone Bed by Swann [1963]) of the Paoli in Indiana (Shaver and others, 1986). Locally, in the subsurface in western Grayson County, Ky., as much as 8 ft of sandstone and shale are reported by drillers in the basal part of the Paoli.

The Paoli crops out as thick ledges with conspicuous vertical joints. The limestone ranges in thickness on outcrop from 20 to as much as 85 ft, but is missing locally northeast of Leitchfield, where it was channeled out during deposition of the overlying Mooretown Formation.

In the western part of the Rough Creek area, the Renault Limestone (equivalent of the Paoli) consists of light- to medium-gray, generally finely crystalline limestone, which is in part oolitic, and much pale-olive, calcareous, very fossiliferous shale. The shale is most abundant in the lower part, where it commonly is interbedded with argillaceous limestone. Sandy limestone, which in places is conglomeratic, marks the basal part of the formation. Outcrops of the Renault, which is 70 to 90 ft thick, are limited in the southwestern part of the Rough Creek area, but the unit is very extensive in the adjacent Western Kentucky Fluorspar District.

In the Rough Creek area, the Paoli and Renault Limestones disconformably overlie the Ste. Genevieve Limestone. The discordant relationship is indicated by the presence of a paleosol, the Bryantsville Breccia Bed (Garland Dever, Kentucky Geological Survey, personal commun., 1988, *in* Treworgy [1991]), at the top of the Ste. Genevieve, the occurrence of local channeling into the uppermost Ste. Genevieve, the presence of clastic sediments in the basal part of the Paoli Limestone, and a major change in crinoid genera from the Ste. Genevieve to the Paoli. The Meramecian-Chesterian boundary is located on the basis of a change in crinoid occurrence from *Platycrinites penicillus* (Meramecian age) to *Talarocrinus* spp. (Chesterian age), and this change conforms to the contact between the Ste. Genevieve and the Paoli and Renault Limestones.

Mooretown Formation (Bethel Sandstone). The Mooretown Formation and its western equivalent, the Bethel Sandstone, is the oldest widespread clastic unit in the Chesterian sequence. The Mooretown crops out over much of the northeastern part of the Rough Creek area as a poorly exposed unit generally 1 to 60 ft thick. Where the formation is composed of mostly channel-fill deposits, it may have a thickness on outcrop of as much as 120 ft. It overlies a prominent bench on top of the Paoli Limestone. The Mooretown is apparently missing over a large area around Leitchfield, and the overlying Beaver Bend Limestone rests directly on the Paoli Limestone.

The Mooretown generally is composed of silty to clayey shale, siltstone, and argillaceous fine-grained sandstone. Marly limestone and sandy, fossiliferous, coal-bearing limestone are present locally at the top of channel fill near the eastern border of the area and may grade laterally into channel-fill deposits. In places, shale in the Mooretown is calcareous, and elsewhere coal stringers as much as 6 in. thick and much carbonized plant material are found locally in shale in the upper part. Sandstone generally is medium to thin bedded, but locally, thick to massive, crossbedded units are present.

A striking, deep channel fill, largely of sandstone, occurs in the Mooretown Formation over a distance of more than 150 mi in west-central and western Kentucky. It is contiguous with deposits of similar lithology, stratigraphic position, and map pattern in southern Indiana that were formerly known as the Ohio River Formation (Ashley, 1903), but later were determined by petrologic study (Sedimentation Seminar, 1969) to belong to the Bethel Formation. Outcrop of the channel sandstone in Kentucky extends from a short distance south of the Ohio River near Fort Knox, which is about 9 mi northeast of the Rough Creek area, southwestward for about 30 mi; then the unit passes into the subsurface near the center of the Custer quadrangle, north of Madrid, Ky. The subsurface trend of the channel and its distributaries has been plotted by Reynolds and Vincent (1967, Fig. 1). A detailed study of the Mooretown (Bethel) channel deposit in its outcrop area in Kentucky and Indiana was published in 1969 by the Sedimentation Seminar of Indiana University and the University of Cincinnati.

The fill in the Mooretown channel is mostly light-gray, fine- to medium-grained, well-sorted, quartzose sandstone, which weathers yellowish brown. Thick planar and trough crossbeds are the most conspicuous sedimentary structures (Sedimentation Seminar, 1969), and the mean southwest orientation of crossbeds closely parallels the trend of the sandstone body. Plant fragments and coaly material are incorporated in the sandstone, and, locally, a few brachiopods are present in the basal part. The resistant beds form prominent cliffs, in places as much as 100 ft high. The sandstone body is 150 to 205 ft thick, as judged by well records, and fills a steep-walled, narrow (0.5 to 0.8 mi wide), slightly sinuous channel cut into the Paoli, Ste. Genevieve, and St. Louis Limestones. Away from the channel the Mooretown Formation rests with slight disconformity on the Paoli, but within the channelway, it is in sharp contact with beds as old as the upper part of the St. Louis.

Along the western edge of the Rough Creek area, the Bethel Sandstone (Mooretown equivalent) is 40 to 70 ft of sandstone that is lithologically similar to the Mooretown to the east and weathers to similar landforms. There, the sandstone probably represents off-channel deposits, for the main Bethel channel lay to the south (Reynolds and Vincent, 1967, Fig. 1). Relief on the basal contact of the Bethel Sandstone away from the main channel is as much as 10 ft (Trace and Amos, 1984).

Beaver Bend Limestone (Lower Part, Paint Creek Shale). The Beaver Bend Limestone crops out over much of the northeastern and eastern parts of the Rough Creek area and in isolated structural blocks in the Rough Creek Fault Zone as far west as Dundee, in Ohio County. On outcrop it generally forms low ledges in which weathered beds are well defined and break down to flaggy to slabby fragments.

The Beaver Bend is dominantly light- to medium-gray, fine- to medium-grained limestone in which texture is due to fossil fragments. Some beds are medium to finely crystalline, and a few sublithographic. Oolitic limestone, containing abundant ooliths with dark nuclei of fossil fragments, is common in the upper part, and argillaceous limestone is locally present in the lower part. The limestone is mainly medium to thick bedded, but thin beds are common in the basal part. Large aggregations of clear calcite crystals and calcite-filled vugs are common in the formation along the eastern edge of the study area, and a 4- to 5-ft-thick bed containing carbonate nodules is reported in the basal part near Dundee. Greenish-gray to medium-gray calcareous shale is present as thin lenses and discontinuous beds, especially in the lower part, and in places is interbedded with argillaceous limestone. Abundant crinoids, including rare *Agassizocrinus,* weather as white fragments on outcrop surfaces; other fossils represented are large blastoids *(Pentremites),* productid and spiriferoid brachiopods, horn corals, and fenestrate bryozoans.

The Beaver Bend ranges in thickness from about 10 to as much as 50 ft; it apparently is missing locally in the northeastern part of the area and locally in the Rough Creek Fault Zone in the Falls of Rough quadrangle southwest of Short Creek, possibly because of nondeposition over a large sandstone body. The contact with the underlying Mooretown Formation appears to be gradational; however, generally east of Leitchfield, Ky., and locally in the Rough Creek Fault Zone, the Beaver Bend directly overlies the Paoli Limestone. The Beaver Bend Limestone composes part of the Girkin Formation

(Appendix B), generally southward from Leitchfield, where the lack of recognizable clastic units in the lower Chesterian hinders subdivision of the dominantly limestone section above the Ste. Genevieve Limestone.

In the fluorspar district of western Kentucky, the Paint Creek Shale encompasses the stratigraphic equivalents of the Beaver Bend Limestone and overlying Sample Sandstone and Reelsville Limestone of the eastern outcrop area (Trace and Amos, 1984). Over a considerable area around Princeton, Ky., which is south of the Rough Creek area, the Paint Creek is mostly limestone; the lower part is oolitic and fossil-fragmental limestone and is the lateral equivalent of the Beaver Bend Limestone (Trace and Amos, 1984). Within the Rough Creek area itself, however, only stringers of limestone are present in the thin Paint Creek Shale. Outcrops of the Paint Creek Shale in the Rough Creek area are rare, and on the geologic map (Plate 1A) the unit is combined with the Bethel and Cypress Sandstones.

Sample Sandstone (Middle Part, Paint Creek Shale). Sandstone, shale, and siltstone constitute the Sample Sandstone, and the formation exhibits considerable local variation in thickness and in proportion of rock types. Sandstone is more common in the lower and middle parts and locally forms cliffs as much as 25 ft high. The sandstone generally is light gray to yellowish gray and yellowish brown, but weathered surfaces commonly are darkly stained by iron compounds. It is composed mainly of fine to medium, well-sorted quartz grains, which are weakly cemented. Medium to thick beds are characteristic, but thin, even beds are present locally. Crossbeds and ripple marks are common in the thicker sandstones, which locally fill intraformational channels. Claystone pebbles, which are abundant in places in the sandstone, weather out and leave pitted surfaces. Thinner sandstone beds generally weather to hard, rectangular fragments that show small, smooth, shallow, saucer-like depressions on exposed surfaces. Carbonized plant fragments are common, and locally a 4-in.-thick coal bed is present in the basal part of the Sample. In a few places, brachiopods also are present in the basal part. Sandstone commonly grades laterally and vertically into shale and siltstone, particularly in the upper part of the formation.

The shale of the Sample Sandstone is light to medium dark gray and greenish gray, clayey to silty, locally calcareous in the uppermost part, and in places carbonaceous in the basal part. Generally, the shale is interbedded with siltstone and sandstone, but a few shale units in the upper part are as much as 30 ft thick. The siltstone is light gray to light brown and occurs mainly in thin, even beds in the upper part. Sandy limestone in beds as much as 1 ft thick is present locally in the lower part of the Sample along the eastern border of the area.

The Sample Sandstone shows a wide range in thickness, from as little as 1 ft to as much as 90 ft where massive sandstone fills apparent channels. The overlying Reelsville Limestone is thinnest in those areas where the Sample reaches maximum thickness. The basal contact, poorly exposed except along streams, generally is sharp and conformable, but locally in the Madrid quadrangle, a sandstone-filled channel has eroded slightly into the underlying Beaver Bend Limestone, and a very thin breccia of sandstone and limestone fragments marks the channel base.

In the southeastern part of the Western Kentucky Fluorspar District, beds equivalent to the Sample Sandstone compose the middle unit of the Paint Creek Shale, but within the Rough Creek area (Repton quadrangle), no lithic representative of the Sample is present in the thin Paint Creek unit.

Reelsville Limestone (Upper Part, Paint Creek Shale). The Reelsville is dominantly light- to medium-gray and light-olive- to light-brownish-gray, fine-grained to finely crystalline, fossiliferous limestone, but in places contains sublithographic and medium- to coarse-grained layers. It is thin to thick bedded, but locally massive bedded. Beds of biocalcarenite commonly are crossbedded. Oolitic, partly crossbedded limestone is common in the lower part of the Reelsville and is also present in places in the upper part. The uppermost beds contain disseminated grains and small nodules of pyrite, which on weathering stain the rock shades of brown. Greenish-gray to light-gray calcareous shale forms several thick beds in the middle and lower parts of the Reelsville along the eastern boundary of the Rough Creek area, but to the west, it is present as partings throughout the formation. Crinoid fragments, including large plates of *Agassizocrinus* and some of *Talarocrinus,* are abundant, together with brachiopods, blastoids *(Pentremites),* horn corals, and fenestrate bryozoans. Fossil fragments weather in low relief on outcrop surfaces. Limestone of the Reelsville weathers whitish gray and forms resistant, rounded blocks in the upper part that are iron-stained on upper surfaces.

The Reelsville ranges in thickness from 5 to 55 ft, but generally is about 30 ft thick. The formation is thin in areas where the underlying Sample Sandstone is thick. The upper part of the Reelsville forms a prominent topographic bench, and the lower part steep, partly covered slopes. The basal part of the Reelsville generally contains sandy oolitic limestone and calcareous shale, which interfinger with shale and calcareous sandstone of the uppermost Sample Sandstone.

Over much of western Kentucky, fossil-fragmental, partly oolitic limestone equivalent to the Reelsville Limestone forms the upper unit of the Paint Creek Shale (Trace and Amos, 1984), but in the western part of the Rough Creek area, the limestone is missing, and the thin Paint Creek is mostly shale.

Paint Creek Shale. In the Chesterian outcrop belt of the western part of the Rough Creek area, the Paint Creek Shale is the stratigraphic equivalent of the Beaver Creek Limestone, Sample Sandstone, and Reelsville Limestone of the eastern part. The Paint Creek is now called a formation by the Kentucky Geological Survey (Shaver and others, 1984). In the Illinois part of the fluorspar district, the name "Paint Creek" has been replaced by the name "Ridenhower Formation" (Atherton and others, 1975). In the Rough Creek area, the Paint Creek is composed of only 10 to 20 ft of dark-gray, calcareous or sandy shale containing thin stringers of limestone, but over much of the adjacent Western Kentucky Fluorspar District, the Paint Creek is locally as much as 115 ft thick; there it consists mostly of limestone (equivalents of the Beaver Bend and Reelsville Limestones) and subordinate amounts of shale and sandstone (equivalent of the Sample Sandstone) (Trace and Amos, 1984). Because the Paint Creek is thin in the Rough Creek area and occurs between two thick sandstone units, outcrops are rare.

Elwren Formation (Cypress Sandstone). The formational unit above the Reelsville Limestone and below the Golconda Formation on outcrop in the eastern part of the Rough Creek area is the Elwren Formation (Shaver and others, 1984); it was originally called the Elwren Sandstone in Indiana (Malott, 1919). This unit was designated the Elwren Sandstone equivalent on maps produced under the cooperative geologic mapping program. In the subsurface of Indiana and Kentucky and on outcrop in the Western Kentucky Fluorspar District, it is called the Cypress Sandstone.

The Elwren Formation is composed of shale, sandstone, and siltstone in various proportions, but sandstone is more common in the middle of the unit. The shale is mainly light to medium gray and greenish gray, in places streaked with grayish red, and clayey to silty but locally sandy. Commonly, it is calcareous at the base of the formation and locally contains small conspicuous orange- to yellowish-brown-weathering siltstone nodules. The sandstone, in shades of gray and yellowish brown, is fine to medium grained, locally very fine grained and micaceous, and occurs in mostly even, platy to thin beds. In places, medium beds are ripple-marked. The siltstone in the Elwren is light to medium gray, light olive gray, and light brown and generally argillaceous. It is in very thin to medium beds commonly interbedded with shale. Some argillaceous fossiliferous limestone is present in the basal part, and along the eastern border of the area the Elwren contains a few streaks of coaly material and small plant impressions.

The Elwren, which is 3 to 45 ft thick, is poorly exposed in a gentle slope above the bench on the underlying Reelsville Limestone. The contact with the Reelsville generally is sharp, but locally along the eastern border of the area, gradational.

The Cypress Sandstone, the equivalent of the Elwren Formation on outcrop in the western part of the Rough Creek area, consists of a lower unit 30 to 60 ft thick of light-gray, fine- to medium-grained, medium- to thick-bedded quartzose sandstone, which locally is calcareous in the basal part, and an upper unit 50 to 60 ft thick mainly of medium-dark-gray shale, containing lenticular bodies of thin, crossbedded, light-brownish-gray to white sandstone. Several 1-in.-thick beds of coaly material are present in the shale; just south of the Rough Creek area around Marion, Ky., two coal beds as much as 2 ft thick are present in the upper half of the Cypress Sandstone (Trace, 1966). On the geologic map (Plate 1A), the Cypress is combined with the underlying Paint Creek Shale and Bethel Sandstone.

Golconda Formation. The Golconda Formation in the eastern Chesterian outcrop area is composed, in ascending order, of the Beech Creek Limestone Member, Big Clifty Sandstone Member, and Haney Limestone Member. In the western outcrop area, however, the middle unit is dominantly shale and is designated the Fraileys Shale Member (Trace and Amos, 1984), following the usage of McFarlan and others (1955). Poor exposures in the western area make consistent recognition of the various members difficult, however. Thickness of the Golconda Formation in the eastern part of the Rough Creek area ranges from about 65 to 175 ft and in the western part, from 120 to 165 ft.

Beech Creek Limestone Member—The Beech Creek Limestone Member is only 3 to 15 ft thick, but is widespread over west-central and western Kentucky and adjacent parts of Indiana and Illinois. It is readily recognized both on outcrop and in the subsurface, where it is called the Barlow lime by drillers. The limestone is medium to dark gray and brownish gray, finely to medium crystalline, but in places medium to coarse grained and bioclastic. Generally, it is medium to thick bedded, but locally it is thin bedded and argillaceous in the upper part. The upper surface of the Beech Creek is locally sandy and pyritic; in places the basal part also is pyritic. Dark-centered ooliths are common near Dundee, Ky., but less abundant at some other localities. Large crinoid columnals, brachiopods, horn corals, and gastropods are very abundant. The large brachiopod *Inflata inflatia* (McChesney) is abundant in the upper 1 to 3 ft and is an excellent biostratigraphic marker. Brownish- and olive-gray, fossiliferous, calcareous shale occurs as interbeds and locally as thin beds in the upper and lower parts.

The Beech Creek weathers light bluish gray to brownish gray and forms a low ledge. It commonly is poorly exposed, except in steep slopes and along streams. Locally, the unit has been entirely removed by a sandstone-filled channel in the Big Clifty Member. The basal contact of the Beech Creek generally is sharp and planar. In the western part of the Rough Creek area, the Beech Creek, although not always identifiable, is medium-gray, medium- to coarsely crystalline, fossiliferous limestone about 5 to 10 ft thick.

Big Clifty Sandstone Member (Fraileys Shale Member) – The Big Clifty Sandstone Member, named for exposures along Clifty Creek (Norwood, 1876) in the eastern part of the Rough Creek area, consists mainly of sandstone, lesser amounts of shale and siltstone, and minor amounts of limestone. Around Dundee, the member is predominantly siltstone, however. Shale and siltstone compose thick units in the upper and lower parts, but in many places in the lower part of the member, channel-fill sandstone replaces those lithologies. In the upper part of most channel deposits, the sandstone grades vertically and laterally into shale and siltstone. Regionally, the Big Clifty is a westward-thinning sandstone body (Sable and Dever, 1990, Fig. 46) and near its distal end in western Kentucky is probably represented by a thin unit of sandstone and sandy shale in the upper part of the Fraileys Shale Member (Trace and Amos, 1984).

The sandstone of the Big Clifty generally is light gray to yellowish gray and light yellowish brown to light brown, fine to medium grained, well sorted, quartzose, and locally cemented by iron oxides and hydroxides. In places, very fine-grained, silty, micaceous sandstone forms thin beds. Most sandstone is in thick to massive beds, but thin layers in the upper part of channel fills are intercalated with shale and siltstone. Crossbeds and ripple marks are common. On weathering, the thicker beds commonly are honeycombed, contain Liesegang banding of iron compounds, and form cliffs as much as 80 ft high. Carbonaceous plant fragments, brachiopods, and pelecypods are sparse locally.

Shale of the Big Clifty generally is light to dark gray and olive gray, silty to sandy, but clayey and calcareous in the upper- and lowermost parts of the member. Conspicuous grayish-red shale is present near the top of the Big Clifty over a large part of western Kentucky and at a similar position in the Fraileys Shale (formation in Illinois) in southeastern Illinois (Atherton and others, 1975). Some grayish-black carbonaceous shale is locally present in the upper and basal parts in association with 6-in.-thick coal beds.

Siltstone of the Big Clifty generally is white to light brownish gray, rarely black and carbonaceous, clayey, locally micaceous, and in thin, even beds. At a few localities, lenses and thin beds of light-brownish-gray, very finely crystalline, fossiliferous limestone are present in the upper part of the member.

The Big Clifty Sandstone Member ranges in thickness from 35 to 120 ft, the greatest thickness being where channel-fill sandstone constitutes most of the member. The basal contact with the Beech Creek Limestone Member generally is conformable, in places slightly gradational, but is disconformable where channels filled with sandstone have cut into or through the Beech Creek.

In the western part of the Rough Creek area, the Fraileys Shale Member of the Golconda Formation is mostly grayish-olive to dark-gray, clayey, partly sandy shale. In the Repton quadrangle, about 10 to 25 ft of light-gray to greenish-gray, fine-grained sandstone in the upper part of the Fraileys immediately below the Haney Limestone Member is the lithic equivalent of the Big Clifty. The sandstone is calcareous, micaceous, laminated to platy, crossbedded, and contains some sandy shale and abundant carbonaceous plant fragments. The lower part of the Fraileys contains interbeds of medium- to light-gray, fossiliferous limestone. In places, the contact with limestone probably equivalent to the Beech Creek Member is difficult to determine. The Fraileys Shale Member in the southwestern part of the Rough Creek area is about 60 to 95 ft thick.

Haney Limestone Member – Throughout the Rough Creek area, the Haney Limestone Member of the Golconda Formation is predominantly very light gray to medium-gray and light-brownish-gray, medium- to coarse-grained, bioclastic limestone. Some of the limestone, however, is finely to coarsely crystalline and contains sparse to very abundant ooliths. Oolitic limestone appears to be much less abundant in the western outcrop area. The limestone generally weathers light gray to light brownish gray, but in a few places dolomitic beds weather yellowish brown. The limestone forms mostly medium to thick beds, locally thin beds, and is argillaceous or sandy near the top and base of the member. Medium- to light-gray, in places blackish-gray, finely textured chert and fossiliferous, oolitic chert, in thin lenses and nodules as much as 1.2 ft long, are common in the upper and lower parts of the Haney, and at some localities are even present throughout the lower half. The chert weathers to angular white to light-gray and light-brownish-gray fragments, which are abundant in the red clay residuum on the member. In a few places, some pyrite nodules are present in limestone in the basal part. Light- to medium-gray and greenish-gray, in part calcareous shale is common as partings and locally as thin beds, especially in the uppermost part. Silicified crinoids columnals, including *Agassizocrinus,* fenestrate bryozoans *(Archimedes),* blastoids *(Pentremites),* brachiopods, and horn corals are abundant in the soil.

The Haney, 20 to 75 ft thick in the eastern part of the Rough Creek area and 40 to 60 ft in the western part, forms well-developed ledges or low cliffs on steep slopes. The basal contact is sharp and generally well exposed.

Hardinsburg Sandstone. The Hardinsburg Sandstone was named (Brokaw, 1916, Plate 3; see Brokaw, 1917; Butts, 1917) for exposures in the vicinity of Hardinsburg, Ky., which is in the northeastern part of the Rough Creek area. It is dominantly sandstone, but includes considerable shale and siltstone, especially as thick units locally in the upper and basal parts of the formation, and in some areas is mostly a mixture of those lithologies.

In the eastern outcrop area, the sandstone is white to light gray and light brown to yellowish brown and weathers shades of brown and yellowish brown. It is fine to medium grained, but in places mostly very fine grained, quartzose, well sorted, and in part argillaceous. In its type area, it is generally medium bedded, but varies from thin to thick bedded and even has a few massive layers. Away from the type area, the Hardinsburg generally is very thin to thin bedded. Crossbeds, ripple marks, and sole marks are common. In places in the basal part, light-gray clay pellets are common. The sandstone is commonly interbedded with shale and siltstone. Fossils in the sandstone include a few brachiopods and plant fragments, but east of Dundee, Ky., brachiopods and bryozoans are locally abundant at the top of the formation.

The shale of the Hardinsburg in the eastern part generally is light to medium gray and greenish gray, but locally medium dark gray at the base and reddish gray in the upper 5 ft. It is silty to clayey, in part sandy, commonly calcareous in the basal part, and intercalated with siltstone and sandstone. The siltstone is light gray to light olive gray, weathers light brown, is in part clayey, locally micaceous, and thin bedded. A small amount of light-gray, silty to sandy, fossil-fragmental limestone is present in the Hardinsburg west of Short Creek. It weathers light yellowish brown, grades into sandstone, and contains brachiopods, crinoids, and bryozoans.

The Hardinsburg in the eastern outcrop area ranges in thickness from about 10 to 75 ft; generally, the greater thicknesses occur where the formation is mainly sandstone. Low cliffs are common on the lower part of the formation, and gentle slopes characterize the upper part. In general, the Hardinsburg is conformable on the Haney Limestone Member of the Golconda Formation, and over much of the eastern area the basal 10 ft is interbedded with the Haney.

In the western outcrop area, the Hardinsburg is 100 to 150 ft thick and consists of a lower 45- to 70-ft-thick cliff-forming sandstone, and an upper 60- to 80-ft-thick, poorly exposed unit of shale interbedded with very thin-bedded sandstone. The sandstone is similar in color and grain size to that in the eastern area. It forms thinner beds than in the eastern part, but does contain some massive, crossbedded layers. The shale is dark gray and sandy. The Hardinsburg in the western part of the Rough Creek area lies along a major distributary channel (and area of greatest thickness) that extends in the subsurface from southwestern Indiana southwestward across Henderson and Union Counties, Ky. (Potter, 1963, Plate 1G).

Glen Dean Limestone. The Glen Dean Limestone, named for exposures around Glen Dean in the northeastern part of the Rough Creek area (Butts, 1917), is readily divisible into a lower limestone unit and an upper unit of limestone and shale. The lower unit is everywhere present on outcrop, but in many areas the upper unit was not deposited or is partly eroded or entirely missing because of channeling that occurred during deposition of the overlying Tar Springs Sandstone. The contact between the Glen Dean and the Tar Springs Sandstone is placed at the top of the highest Glen Dean–type limestone in the section above the lower Glen Dean limestone unit. Where Glen Dean–type limestone is missing, the shale and sandstone of the upper Glen Dean cannot be distinguished from similar strata in the Tar Springs. Consequently, in those areas the contact between the Glen Dean and the Tar Springs was mapped at the top of the lower Glen Dean limestone unit. The Glen Dean–Tar Springs contact, therefore, is not a time-stratigraphic contact throughout the Rough Creek area.

The lower unit of the Glen Dean, which is 15 to 50 ft thick, is light- to medium-gray and light-brownish-gray, generally medium- to coarse-grained bioclastic limestone. Some is finely to medium crystalline, however, and some oolitic and argillaceous. Most is medium bedded, but some is thin bedded and some massive and crossbedded. In a few places, the upper part of the lower unit contains abundant, angular, fossiliferous chert, which weathers mainly light yellowish gray to light yellowish brown. The presence throughout the lower unit of light- to medium-gray, greenish-gray, and light-olive-brown, clayey to silty shale partings is diagnostic of the lower Glen Dean. In places, shale also forms beds as much as 10 ft thick near the middle of the lower Glen Dean. Most shale is calcareous, some sandy. The lower Glen Dean contains abundant crinoids, including *Pterocrinus,* fenestrate bryozoans (including *Archimedes),* and also many blastoids *(Pentremites),* horn corals, brachiopods, and some gastropods.

The upper unit, generally 5 to 60 ft thick but locally removed, is composed of shale, limestone, and a little sandstone and siltstone, in widely varying proportions. The shale is light to medium gray and light greenish gray, clayey, less commonly silty, in part calcareous, and fossiliferous. It occurs as partings and in places as beds of considerable thickness containing lenses of limestone and sandstone. The limestone of the upper Glen Dean is similar in color, texture, and bedding to that of the lower unit, but thick, crossbedded, coarse bioclastic layers generally are more conspicuous. Locally, argillaceous, very oolitic limestone that weathers to shades of brown and closely resembles the stratigraphically younger Vienna Limestone is present in the upper Glen Dean. In places, scraggly chert is also present in limestone at the top of the unit. The abundance of chert and ooliths in the upper Glen Dean limestone is markedly less than that in the Vienna, and this greatly assists in the identification of the upper Glen Dean. On drillers' logs, the upper Glen Dean limestone is commonly called the Second Vienna.

A small amount of light-gray to yellowish-gray to light-brownish-gray, very fine-grained, silty, calcareous sandstone and laminated to thin-bedded, calcareous siltstone are interbedded with shale and limestone in the upper part. Fossils are abundant in the upper Glen Dean and include the same genera as in the lower unit.

In the eastern outcrop area, the thickness of the composite Glen Dean Limestone is 30 to 80 ft, but locally may be as much as 100 ft. The range in thickness, recorded on the geologic quadrangle maps, is partly because of variable placement of the upper boundary, as described above. The lower unit commonly forms ledges or low cliffs; exposures of the upper unit commonly are poor and limited to thin limestone layers.

In the western part of the Rough Creek area, the Glen Dean is mostly medium-dark-gray to medium-light-gray, medium- to coarsely crystalline, fossiliferous limestone, and is not readily divisible into separate units as in the eastern part. A distinctive dusky-red, coarsely crystalline, shaly, crinoidal limestone is present locally at the top of the formation, and sandy limestone occurs at places in the middle. Locally, medium-light-gray shale, as much as 15 ft thick, is present in the lower part; it grades laterally into limestone. The Glen Dean is 55 to 90 ft thick in the western outcrop area. The formation is poorly exposed, but it can usually be identified by a thick, dark-red soil containing sparse angular fragments of chert (Trace and Amos, 1984). Generally, the basal contact of the Glen Dean is sharp and conformable, but locally the basal 1 ft is transitional with shale of the underlying Hardinsburg Sandstone (Calvert, 1967).

Tar Springs Sandstone. The Tar Springs Sandstone was named for exposures of channel-fill sandstone at Tar Springs on Tar Fork about 3 mi south of Cloverport, Ky., in the northeastern part of the Rough Creek area (Owen, 1856; Butts, 1917). On a number of geologic quadrangle maps covering parts of west-central Kentucky, the Tar Springs is included as the basal member of the Leitchfield Formation, as used by Weller (1927), but in this report, because the Vienna Limestone is traceable around Leitchfield, Ky., the Tar Springs is mapped as a separate formation underlying the Vienna Limestone, the basal member of the Buffalo Wallow Formation, and overlying the Glen Dean Limestone.

The Tar Springs is composed of sandstone, shale, siltstone, and minor amounts of limestone, all of which vary widely, and often abruptly in proportions within the formation in the Rough Creek area. Where the Tar Springs represents deposition near the longitudinal axis of a delta channel, it is dominantly sandstone; off-channel deposits are mainly shale and siltstone. Other sandstone bodies may be bar-finger and tidal-current deposits (Calvert, 1967).

The sandstone generally is very light gray to light yellowish gray and light brown and weathers to shades of brown. Most is fine to medium grained, but locally coarse grained in the basal part of channel fills, and argillaceous and micaceous. Commonly, in the lower part of channel fills, it is thick to massive bedded and shows festoon crossbedding. Crossbeds in the sandstone body in the type area in the eastern outcrop belt have a mean azimuth of S35°E (Calvert, 1967). In the western outcrop area (Repton quadrangle), planar crossbeds in sets 1 to 2 ft thick are abundant. Laterally from the axis and vertically within a typical channel fill, the sandstone becomes thinner bedded, commonly ripple marked, and grades into shale and siltstone. Reddish-brown-weathering pyrite nodules are abundant locally, and shale laminae and carbonaceous material are present on many bedding planes. In places, the sandstone contains poorly preserved brachiopods and bryozoans. Sandstone of the Tar Springs is an important oil producer in western Kentucky. In fact, the formation name is derived from Tar Springs, where tarry residue slowly flows from outcrops of petroliferous sandstone.

Commonly, the shale of the Tar Springs is medium to light gray, olive green, and greenish gray and clayey to sandy. Clay shale is common just beneath the Vienna Limestone. In a few places in the eastern part of the Rough Creek area, very dark gray, coaly, carbonaceous shale occurs in the uppermost part, and to the west in the Western Kentucky Fluorspar District, a very thin, impure coal is present at this horizon and a continuous bed as much as 1 ft thick occurs 20 to 30 ft below the top (Trace and Amos, 1984). Siltstone of the Tar Springs is similar in color to the shale and occurs as platy to thin, wavy, in part crossbedded layers. Commonly, it is argillaceous, micaceous, and in places calcareous and fossiliferous. Small, hard siltstone nodules are abundant locally.

Light-yellowish-brown and light- to medium-gray, very fine- to medium-grained limestone is present in a few places in the lower part of the Tar Springs. Some is sandy, finely crossbedded, and contains a thin conglomerate of subangular to subrounded pebbles as much as 0.1 ft in diameter of yellowish-brown siltstone. The limestone, which closely resembles beds in the upper part of the underlying Glen Dean Limestone, contains abundant brachiopods, fenestrate bryozoans, and crinoid columnals. South of Leitchfield, Ky., limestone conglomerate is reported (Gildersleeve, 1978) to contain vertebrate teeth and bones, in addition to fossil invertebrates and plants.

The Tar Springs Sandstone generally is 20 to 60 ft thick, but where it is dominantly channel-fill sandstone, it is as much as 130 ft thick. Over much of the Rough Creek area, the basal contact of the Tar Springs is sharp and conformable; locally, however, limestone of the Glen Dean grades vertically and laterally into calcareous sandstone of the Tar Springs. In places, channels in the Tar Springs cut as deeply as the uppermost part of the lower unit of the Glen Dean.

Upper Chesterian Rocks

The formations in the Chesterian Series above the Tar Springs Sandstone were originally defined from outcrops in the Chester district of southwestern Illinois and in southern Illinois. In ascending order, they are the Vienna Limestone, Waltersburg Sandstone, Menard Limestone, Palestine Sandstone, Clore Limestone, Degonia Sandstone, Kinkaid Limestone, and Grove Church Shale. All of these units, except the Grove Church Shale, are recognizable on outcrop in the Western Kentucky Fluorspar District (Trace and Amos, 1984), but most of the limestone and sandstone units thin eastward and grade into mainly shale and siltstone in the eastern part of the Rough Creek area. This mostly detrital part of the Chesterian was named the Buffalo Wallow Formation (Butts, 1917) for exposures about 2 mi west of Cloverport, Ky., in the northeastern part of the Rough Creek area. Only the Vienna and Kinkaid Limestones, and to a much more limited extent, the Menard Limestone, are widely recognizable units within the Buffalo Wallow. The Buffalo Wallow is lithologically similar to the Leitchfield Formation; however, the Tar Springs Sandstone, the basal member of the Leitchfield, is excluded from the Buffalo Wallow.

Individual formations in the upper Chesterian are recognizable in the western part of the Rough Creek area, but because the outcrop area is so limited, for convenience they are discussed and included as members of the Buffalo Wallow Formation on the geologic map (Plate 1A). This usage does not imply extension of the Buffalo Wallow Formation as a viable stratigraphic unit into the Western Kentucky Fluorspar District. In the southeastern corner of the Rough Creek area, in the Leitchfield (Gildersleeve, 1978) and Clarkson (Glick, 1963) quadrangles, the Chesterian beds above the Glen Dean Limestone were assigned to the Leitchfield Formation (as used by Weller [1927]); in this report and on the geologic map (Plate 1A), however, the beds are included in the Tar Springs Sandstone and overlying Buffalo Wallow Formation.

Buffalo Wallow Formation. The Buffalo Wallow Formation varies considerably in thickness on outcrop in the eastern part of the Rough Creek area because of the major pre-Pennsylvanian unconformity. Locally, the unconformity cuts stratigraphically at least as deeply as the basal part of the Tar Springs Sandstone, and possibly as deeply as the lower limestone unit of the Glen Dean Limestone. In the western outcrop area the depth of cutting is considerably less, only down to the upper part of the Degonia Sandstone in the upper part of the Chesterian section. The maximum thickness of the Buffalo Wallow in the eastern outcrop area is about 270 ft; in the western area the equivalent section is about 425 to 500 ft thick.

Vienna Limestone Member—The basal member of the Buffalo Wallow Formation, the Vienna Limestone, is thin but widespread across southern Illinois, southwestern Indiana, and western Kentucky. The Vienna is a rather distinctive limestone on outcrop, and its distinctive kick on electrical logs makes it a valuable marker bed in the subsurface. The Vienna Limestone is light to medium dark gray and light brownish gray, and weathers to shades of brown and gray. It is both very finely to coarsely crystalline and fine to coarse grained, because of fossil fragments. Oolitic limestone is common, particularly in the upper part. Over broad areas the member contains irregular nodules and lenses, as much as 0.3 ft thick and 8 ft long, of blackish-gray to black, locally light-gray, fossiliferous, locally oolitic chert. The chert weathers to white to brownish-gray and dark-brown, angular fragments. In many places only chert residuum marks the Vienna outcrop. Commonly, the upper part of the limestone is argillaceous and in places slightly dolomitic; the lower part contains sand locally. Generally, the Vienna is thin to thick bedded and weathers to long, rectangular blocks. In a few places, especially in the upper part, it contains very thin interbeds of limy clay shale. Fossils are abundant and include brachiopods, crinoid columnals and calyxes, fenestrate bryozoans (including *Archimedes)*, horn corals, and some gastropods. The Vienna Member is 20 to 35 ft thick in the western outcrop area, but thins eastward and is only 2 to 15 ft thick in the eastern area. The Vienna rests conformably on the Tar Springs Sandstone.

Waltersburg Sandstone Member—In the western part of the Rough Creek area, the Waltersburg is 30 to 50 ft of interbedded dark-gray shale, dark-greenish-gray, very thin- to thin-bedded siltstone, and a few beds of dark-gray, fine-grained, laminated to very thin-bedded sandstone. Because the limestones in the basal part of the overlying Menard Limestone that define the upper contact of the Waltersburg thin and wedge out eastward in the Rough Creek area into clastic sedimentary rocks, the stratigraphic position of the contact rises to the east; in general, the Waltersburg could be readily differentiated only as far east as the vicinity of Owensboro, Ky. In a few areas to the southeast (Goudarzi and Smith, 1968a, b; Goudarzi, 1970), however, locally persistent limestone beds in the basal part of the Menard allow placement of the upper contact of the Waltersburg.

Interbedded shale and siltstone are also the dominant lithologies in the Waltersburg in the eastern outcrop area and generally are similar in color to those in the west. The shale is clayey to sandy and locally calcareous in the upper part. A thin light- to yellowish-gray and yellowish-brown sandstone, near the middle of the member, is very fine to medium grained, very thin to thin bedded, but locally massive and ripple-marked. In places, it is calcareous and contains brachiopods. Commonly, the sandstone grades into shale and siltstone. In those parts of the eastern outcrop area where the Waltersburg can be differentiated, it is 30 to 60 ft thick; elsewhere, beds equivalent to the Waltersburg are included in the lower part of the undivided Buffalo Wallow Formation. Generally, the Waltersburg Member is conformable on the Vienna Limestone Member, but locally north of Rough River Reservoir the basal part of the member is interbedded with limestone of the Vienna (Amos, 1978). In the subsurface locally at Owensboro (Goudarzi and Smith, 1971), sandstone in the Waltersburg fills a channel more than 65 ft deep that cuts through the underlying Vienna into the upper part of the Tar Springs Sandstone.

Menard Limestone Member—The Menard is a well-defined unit in the western outcrop area, where it is 80 to 110 ft, dominantly of medium- to medium-dark-gray, finely to coarsely crystalline, very thin- to thin-bedded, fossiliferous limestone and a subordinate amount of medium- to dark-gray, in part calcareous shale. Locally, the limestone is argillaceous in the upper part and dolomitic in the middle. The shale is mainly in the lower part of the member, but some is interbedded with limestone in the middle.

Eastward in the Rough Creek area, the limestone beds of the Menard, particularly in the basal and uppermost parts, thin and wedge out into clastic sediments of the Buffalo Wallow Formation. The Menard can be differentiated with reasonable certainty as far east as the Dundee area. The Menard was mapped locally farther east, around Glen Dean, Ky. (Goudarzi, 1970), but the contact with the overlying Palestine Sandstone Member was placed stratigraphically lower, at the top of a conspicuous limestone marker bed.

Over much of the eastern outcrop area of the Buffalo Wallow Formation, the principal recognizable lithic equivalent of the Menard Limestone is a 3- to 20-ft-thick, generally cherty limestone about 100 to 110 ft above the base of the Vienna Limestone Member of the Buffalo Wallow Formation. The bed, commonly called the Menard limestone marker bed, is a very useful marker in the upper Chesterian. It consists of light- to dark-gray and brownish-gray, dense, finely crystalline to very fine-grained limestone. It is locally silty and contains some light-gray, calcareous shale in the lower part. Over much of the area the limestone bed contains nodules and bands as much as 6 in. thick of dark-gray to black, fossiliferous chert. The bed contains abundant crinoids, brachiopods, horn corals, fenestrate bryozoans, gastropods, and in a few places small algal(?) masses. The limestone forms one or two vertically jointed beds, and crops out as a low ledge or as partly concealed boulders on gentle slopes.

Other limestone beds in the Menard part of the Buffalo Wallow generally are poorly exposed, but are rather well defined on electric logs of wells downdip from the outcrop belt. On outcrop they are fine to coarse grained and argillaceous, and in places a basal limestone in the unit is crinoidal and locally cherty. Scattered, thin dolomitic beds in the upper part of the Menard section weather bright yellowish brown.

Shale and siltstone, which constitute the majority of the Menard Member, are light to dark gray and olive gray to greenish gray, and commonly are interbedded with and grade into limestone and sandstone. The shale is clayey to sandy and locally calcareous. Sandstone, which is present mainly in the lower part of the Menard, is very light gray and grayish yellow to brown, very fine to medium grained, and thin bedded to massive. In the western part of the eastern outcrop area where the Menard Member is easily recognized, it is about 65 to 115 ft thick; as noted above, over much of the eastern area, however, the member is generally represented by a limestone 5 to 20 ft thick. The Menard conformably overlies the Waltersburg Sandstone Member, and regionally the basal contact is gradational.

Palestine Sandstone Member—The sandstone of the Palestine Sandstone Member in the western outcrop belt of the Rough Creek area is light gray to greenish gray, fine grained, thin to medium bedded, crossbedded, and ripple-marked. In the upper part of the member, the sandstone is calcareous and interbedded with medium- to greenish-gray, locally dusky-red calcareous clay shale. Commonly, the sandstone forms prominent cliffs. In the western area the Palestine is 45 to 70 ft thick and conformably overlies the Menard Limestone Member.

Eastward across the Rough Creek area, the limestone beds in the Menard and Clore Limestones that define the lower and upper contacts, respectively, of the Palestine Sandstone thin and are replaced mostly by clastic rocks in the upper part of the Buffalo Wallow Formation. Consequently, in the eastern outcrop belt, a lithic equivalent of the Palestine Member is not recognized. Strata in the upper part of the Buffalo Wallow roughly equivalent to the Palestine are primarily light- to dark-gray and greenish-gray, clayey to sandy shale and brownish-gray to olive-gray, laminated to thin-bedded siltstone. Locally, in the Rough River Valley adjacent to Ky. 54, a ledge-forming sandstone as much as 17 ft thick, which probably is equivalent to part of the Palestine, is present 50 to 60 ft above the top of the limestone marker bed of the Menard Limestone Member. The sandstone is very light yellowish gray, very fine grained, thin to medium bedded, and locally crossbedded. Sandstone beds at or close to this horizon also are present locally elsewhere in the area. Along Rough River Reservoir near the mouth of Cave Creek, an 8-ft-thick crossbedded sandstone lies with slight disconformity on the Menard limestone marker bed. At places near Cloverport, Ky., a 15- to 20-ft-thick conglomeratic sandstone, containing abundant limestone pebbles and cobbles, rests on the marker bed (Bergendahl, 1965).

Clore Limestone Member—The Clore Limestone Member in the western part of the Rough Creek area is 80 to 105 ft thick and composed mainly of calcareous shale and thin limestones. The shale is dark gray, fissile, sparsely fossiliferous, and constitutes from one-third to two-thirds of the member. Medium-gray to medium-greenish-gray, finely to medium-crystalline limestone forms beds commonly 1 to 3 ft thick. A thin bed of light-gray, fine-grained sandstone is present in the upper half of the member.

The limestone beds in the Clore wedge out eastward in the Rough Creek area, so that in the eastern outcrop area, the upper part of the Buffalo Wallow Formation between the Menard and Kinkaid Limestone Members is mostly shale and siltstone. Consequently, a definitive Clore Member is not recognizable. A few thin beds of argillaceous to sandy limestone in this part of the formation may be equivalent to part of the Clore. Some of the limestone is dolomitic and weathers to conspicuous light-yellowish-brown to light-yellowish-orange beds containing abundant black dendrites. A 13-ft-thick unit of limestone and shale probably equivalent to part of the Clore Limestone is present locally in the Dundee area (Goudarzi and Smith, 1968a).

Degonia Sandstone Member—The Degonia Sandstone Member in the western part of the Rough Creek area is represented by 20 to 30 ft of gray silty shale, dark-greenish-gray siltstone, and some thin beds of light-brownish-gray, very fine-grained sandstone containing abundant brachiopod molds. In the eastern outcrop area, the part of the Buffalo Wallow Formation just below the Kinkaid Limestone Member is lithologically similar to the Degonia of the western area, but sandstone is less abundant. Because the Clore Limestone Member could not be defined in the eastern area, no lower contact of the Degonia section could be mapped. In the eastern area, the upper part of the Buffalo Wallow Formation between the limestone marker bed of the Menard Limestone Member and the Kinkaid Limestone Member, which includes beds equivalent to the Palestine Sandstone, Clore Limestone, and Degonia Sandstone Members, averages about 100 ft in thickness.

Kinkaid Limestone Member—The youngest outcropping rocks of Chesterian age in the Rough Creek area are in the Kinkaid Limestone, which in its type area in southwestern Illinois (where the unit has formation rank) is composed, in ascending order, of the Negli Creek Limestone, Cave Hill Shale, and Goreville Limestone Members. Because of pre-Pennsylvanian erosion, generally only the lower two members crop out in the Rough Creek area; however, remnants of the upper member, the Goreville Limestone, are exposed locally in the upper limit of the Kinkaid outcrop belt in the western part of the area in the Blackford quadrangle (Amos, 1970). Isolated erosional remnants of the Goreville Member are also present in the subsurface in the western part. The limestones of the Negli Creek and Goreville Members record distinctive and readily identifiable resistivity curves on electrical well logs. As previously stated, for convenience the Kinkaid in the western outcrop belt of the Rough Creek area is included as a member of the Buffalo Wallow Formation, and the members of the Kinkaid of the type area are herein called units.

Outcrops of the Kinkaid Limestone Member in the western part of the area are confined principally to the eastern part of Crittenden County. There are also limited exposures along the Rough Creek Fault Zone near the western border of the area, at and west of Sebree, and north of Calhoun. In the eastern part of the study area, the Kinkaid is exposed in the upper part of the outcrop belt of the Buffalo Wallow Formation and along the Rough Creek Fault Zone as far west as the vicinity of Dundee.

The Kinkaid in the western outcrop belt is composed of a lower limestone unit (Negli Creek equivalent) as much as 40 ft thick; a middle unit of shale, limestone, siltstone, and sandstone (Cave Hill equivalent), 70 to 95 ft thick; and a very restricted upper limestone unit (Goreville equivalent), as much as 25 ft thick. The limestone of the lower unit is medium gray to brownish gray, generally finely crystalline but locally fine or coarse grained, and argillaceous to shaly in the upper 5 ft. It is mostly medium to thick bedded but locally thin bedded, and abundantly fossiliferous. In places, the limestone contains partings of dark-gray, partly calcareous clay shale.

In the eastern outcrop belt, the lower limestone unit of the Kinkaid Member of the Buffalo Wallow Formation is lithologically similar to that in the western part, but its lighter color; its weathered mottling of light gray, brownish gray, and yellowish brown; its wavy bedding; and subconchoidal fracture are more conspicuous. Fossils are abundant in both outcrop areas, and include large bellerophontid gastropods, brachiopods, crinoids, bryozoans (including *Archimedes),* horn corals, cephalopods, the colonial coral *Chaetetella* sp., biscuit-shaped algal growths *(Girvanella),* some fusulinids, and very small masses of spongiostromatoids. The lower Kinkaid unit in the eastern part is as much as 45 ft thick; a thickness of 60 ft, reported in the Cloverport (Bergendahl, 1965) and Fordsville (Bergendahl and Smith, 1964) areas, could not be confirmed. The lower Kinkaid unit is sharply conformable on clastic sedimentary rocks in the upper part of the Buffalo Wallow Formation.

The lower Kinkaid limestone forms vertically jointed ledges and low cliffs, and commonly blocks as much as 200 ft long slump onto slopes below. In Breckinridge County along the southwestern side of the valley of Rock Lick Creek near its junction with the Rough River, blocks of Kinkaid slumped during pre-Pennsylvanian erosion and were later covered by Pennsylvanian sediments that filled ancient valleys. Erosion has uncovered the blocks, which are only about 30 ft above the limestone marker bed in the upper part of the Menard Limestone Member of the Buffalo Wallow Formation, about 70 ft below the normal stratigraphic position of the lower Kinkaid. Well logs show that blocks of slumped Kinkaid Limestone are numerous in the subsurface throughout the Rough Creek area and along major pre-Pennsylvanian valleys elsewhere in the Illinois Basin (Bristol and Howard, 1974, Figs. 9–10).

Outcrops of the middle unit (Cave Hill equivalent) of the Kinkaid Limestone Member are confined mainly to the southwestern part of the Rough Creek area, but there are very limited exposures in the Rough Creek Fault Zone about 8 mi west of Sebree. The only recognized exposures of the middle unit in the eastern part of the area are near Caneyville (Gildersleeve and Johnson, 1978b), where 10 to 15 ft of gray, fossiliferous shale, containing a few thin beds of limestone, overlies the lower Kinkaid unit.

In the western outcrop area, the middle unit is medium- to dark-gray, greenish-gray, and in places grayish-red, clayey to sandy, commonly calcareous shale, which locally contains siderite lenses and concretions. Interbedded with the shale are thin to medium beds of olive-brown, in part argillaceous siltstone and light- to medium-gray, very fine- to fine-grained, calcareous sandstone, especially in the lower part of the middle unit. Limestone in the unit is medium gray, brownish gray, and light greenish gray, finely to medium crystalline, some sublithographic, and in part argillaceous. Generally, it is thin to medium bedded, and in places slightly dolomitic in the upper part of the middle unit.

The upper limestone unit (Goreville equivalent) of the Kinkaid Limestone Member in limited exposures in the western outcrop area is light- to medium-gray, finely to medium-crystalline, in part sublithographic, thick-bedded limestone. A discontinuous bed or nodular layer of medium- to dark-gray chert is present in the upper half. The upper unit of the Kinkaid forms low bluffs, and caves are common in the basal part.

Because of pre-Pennsylvanian erosion, the thickness of the Kinkaid Limestone Member of the Buffalo Wallow Formation varies markedly throughout the Rough Creek area, and the member is missing at many localities. The maximum thickness of the Kinkaid probably does not exceed 170 ft, for that is the thickness of the member in wells near Sebree, where a 40-ft unit of gray shale and some dark-gray limestone, questionably correlated with the Grove Church Shale, the uppermost formation of Mississippian age in the Illinois Basin, overlies the upper limestone unit of the Kinkaid (Hansen, 1975).

The Chesterian is characterized by transgressive-regressive cycles of siliciclastic and carbonate deposition. The deltaic regime of the Michigan River system (Swann, 1963, 1964) was the dominant depositional control during Chesterian time. The river, which flowed southward from sources in eastern Canada (Potter and Pryor, 1961), built a bird-foot delta into the shallow epeiric sea occupying the proto-Illinois Basin. The delta shifted over a range of as much as 200 mi to the northwest or southeast, and the shoreline in the basin oscillated from southwest to northeast by as much as 600 to 1,000 mi as base level changed (Swann, 1963, Fig. 4). The complex depositional environments resulting from the interplay of marine and deltaic conditions are reflected throughout Chesterian strata.

The proto-Illinois Basin was a low-angle, low-relief ramp during at least the deposition of the Big Clifty (Frailey) Sandstone and Haney Limestone Members of the Golconda Limestone (Treworgy, 1988), and likely during all of Chesterian time. In reconstructing the depositional environments of those members, Treworgy (1988) found that the distribution of carbonate facies in the basin was consistent with the characteristic facies patterns for a carbonate ramp (Ahr, 1973)—clean, coarse carbonate sand, deposited in shallow subtidal to low intertidal, upper-ramp facies along the eastern and western margins of the basin, grades downslope and offshore into progressively more argillaceous and finer middle and lower facies in deeper parts of the basin (Treworgy, 1988, Fig. 10). The paleocurrent direction in the basin during most of Chesterian time was southwesterly (Potter and others, 1958), but during deposition of the Big Clifty (Frailey) Member of the Golconda, the paleocurrent was dominantly westerly (Treworgy, 1988), probably because of a northerly shift of the delta. Tidal processes in the basin (Treworgy, 1988) controlled the distribution of the siliciclastics, and probably also the carbonate sands, deposited along the eastern margin of the basin and at times even into the center of the basin, in the deltaic and fluvial environments associated with the Michigan River system. The terrigenous sediments were derived from sources principally to the northeast of the basin. The lithologic similarity of the Buffalo Wallow and Leitchfield Formations in west-central Kentucky to the Pennington and Paragon Formations in eastern Kentucky may reflect a contribution of fine material from the Appalachian Basin to the east, however (Sable and Dever, 1990).

Facies distribution and thickness, at least during Big Clifty and Haney time, were also influenced by limited synsedimentary movement on several major structural features in the basin, the LaSalle Anticlinal Belt, the DuQuoin Monocline, and the Rough Creek Lineament (Treworgy, 1988) across the southern part of the basin. The area south of the lineament, called the Southern Shelf by Treworgy (1988, Fig. 10), was largely a broad, shallow shelf that gave way to the east and west to middle- or upper-ramp environments and to the north to middle- and lower-ramp environments during both Big Clifty and Haney time. Tidal influence is strongly reflected in the distribution of offshore tidal bars in the Big Clifty Sandstone Member of the Golconda Formation (Fig. 16), especially in western Kentucky and adjacent Indiana and to a lesser degree in southeastern Illinois. The Hardinsburg Sandstone, deposited as a rapidly south-prograding delta onto a tidally influenced, shallow shelf (Heidlauf, 1985), reflects a variety of fluvial-deltaic depositional styles that are typical of most Chesterian sandstones. The best-preserved prodelta and delta-front sediments of the Hardinsburg are on the flanks of the channel sandstones. On the shallower southern shelf, tidally influenced ripple- and flaser-bedded sandstones predominate, whereas in the slightly deeper areas to the north, parallel-bedded sandstone reflects influences from storms and waves (Heidlauf, 1985).

The Tar Springs was deposited in prograding fluvial environments similar to those of the Hardinsburg (Wescott, 1982). The deltaic sand bodies were reworked by marine currents, and the sand was transported to the northwest by longshore currents and redeposited onto beaches. Northwest of the deltas, where the supply of terrigenous sediments was minimal, thin marine sheet sands were deposited by tidal processes over broad tidal flats. When the influx of terrigenous sediment significantly decreased toward the end of Tar Springs time, the sediments were reworked into destructional bars on subsiding, abandoned lobes of the Michigan River delta prior to the return of carbonate deposition (Wescott, 1982). The youngest Chesterian strata in the Illinois Basin are the marine shale and fossiliferous limestone of the Grove Church Shale, which is preserved below the major pre-Pennsylvanian unconformity only at scattered localities in western Kentucky and southern Illinois; it is not exposed in the Rough Creek area, but is reported in the subsurface (Hansen, 1975). Broad uplift of the proto-Illinois Basin marked the close of Mississippian time.

Pennsylvanian System

Pennsylvanian rocks crop out over most of the Rough Creek area. The Caseyville, Tradewater, Carbondale, and Sturgis Formations, in ascending order, crop out in the eastern part of the area in broad north- to northwest-trending belts to the west of the Mississippian outcrops. In the southwestern part of the Rough Creek area, the dip of the Pennsylvanian strata is to the northeast, and the formational belts are much narrower. The youngest Pennsylvanian rocks are in the deepest part of the Moorman Syncline in the northwestern part of the Rough Creek area. Locally, along the Rough Creek Fault Zone, upthrown blocks expose various parts of the Pennsylvanian section.

Pennsylvanian rocks in the Rough Creek area overlie Mississippian strata on a major erosional unconformity, but on the northern flanks of the Illinois Basin they rest on rocks as old as the St. Peter Sandstone of early Middle Ordovician age (Wanless, 1975). The greatest thickness of Pennsylvanian strata in the basin, ranging from about 3,200 ft (as estimated by Wanless [1975]) to a maximum of about 3,900 ft (Rice and others, 1979), is in the Moorman Syncline in the western part of Kentucky (Fig. 17). The thickness of existing Pennsylvanian

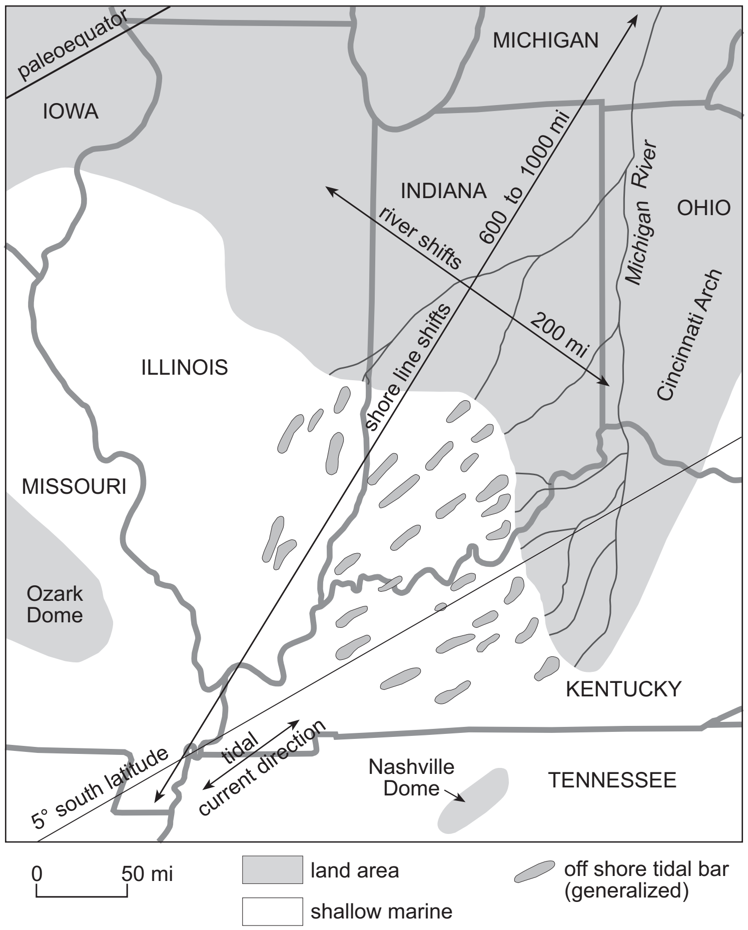

Figure 16. Distribution of off-shore tidal bars in the Big Clifty Sandstone Member of the Golconda Formation in the southern part of the Illinois Basin in relation to the Michigan River delta. From Treworgy (1988); used with permission of the Illinois State Geological Survey.

rocks in the Rough Creek area is determined partly by structural features in the area, partly by relief on the pre-Pennsylvanian erosional surface, and partly by post-Pennsylvanian erosion that has progressively removed greater amounts of Pennsylvanian rocks generally outward from the deepest parts of the Illinois Basin toward the basin margins. Along the structurally high Rough Creek Fault Zone, Pennsylvanian strata have been deeply eroded, and in places underlying Mississippian rocks are exposed. Over almost all of western Kentucky, Pennsylvanian strata represent an incomplete record of the system, for they are erosional remnants of an originally thicker and more widespread sequence of deposits. The discovery of fusulinids of probable Early Permian age (Douglass, 1979) in beds previously thought to be of Late Pennsylvanian age raises the possibility that a complete section of 3,200 ft of Pennsylvanian strata (Williams and others, 1982) is preserved in a narrow graben block in the Rough Creek Fault Zone, about 5 mi southeast of Morganfield, Ky.

Pennsylvanian rocks were laid down on an erosional surface that was cut by a system of generally southwest-trending, steep-sided valleys (Fig. 18), some as deep as 450 ft and as wide as 20 mi (Siever, 1951; Potter and Siever, 1956; Potter and Desborough, 1965; Shawe and Gildersleeve, 1969; Bristol and Howard, 1971; Davis and others, 1974; Howard, 1979; Howard and Whitaker, 1988; Droste and Keller, 1989; Greb, 1989a). Consequently, variations in thickness of Pennsylvanian strata from areas overlying the old valleys to areas above the former stream divides are quite abrupt. Because of the irregularity of the erosion surface, basal Pennsylvanian strata commonly overlie a number of Chesterian units within a short distance, especially along the former valleys. Post-Pennsylvanian erosion also markedly affects the thickness of Pennsylvanian beds throughout the Rough Creek area, for the Ohio, Green, Rough, and Tradewater Rivers have incised broad valleys as much as 200 ft deep across areas underlain by Pennsylvanian rocks.

In a summary of the lithologic character of the Pennsylvanian rocks, Wanless (1975) pointed out that massive, coarse-grained to pebbly, crossbedded sandstone containing small quartz pebbles characterizes the basal Pennsylvanian strata. Above, finer-grained sandstone and dark mudstone are present in nearly equal amounts, although in local areas sandstone predominates, especially in the section immediately overlying basal Pennsylvanian deposits. Coal beds are highly variable in thickness and local in distribution. Marine limestone and shale of restricted distribution also are present. Cyclic sedimentation, evident in these lower beds, becomes better developed in younger sediments, particularly in the middle part of the Pennsylvanian sequence.

Rocks constituting the middle of the Pennsylvanian section are mostly gray mudstone and sandstone, but only rarely is the amount of sandstone greater than 50 percent and commonly is less than 20 percent (Wanless, 1975). This part of the Pennsylvanian represents a diversity of environmental conditions, which resulted in multiple repetition of nearly similar lithologic types. At least 14 cyclothems, recording alternating marine and nonmarine transgressions and regressions, are recognized (Wanless, 1975). Marine limestone, fluviatile and deltaic mudstone and sandstone, coal, black shale, and marine shale compose the typical cyclothem. The middle part of the Pennsylvanian contains the thickest and most widespread coal beds in the Illinois Basin.

In the upper part of the Pennsylvanian, mudstone is the dominant lithology, but sandstone is more abun-

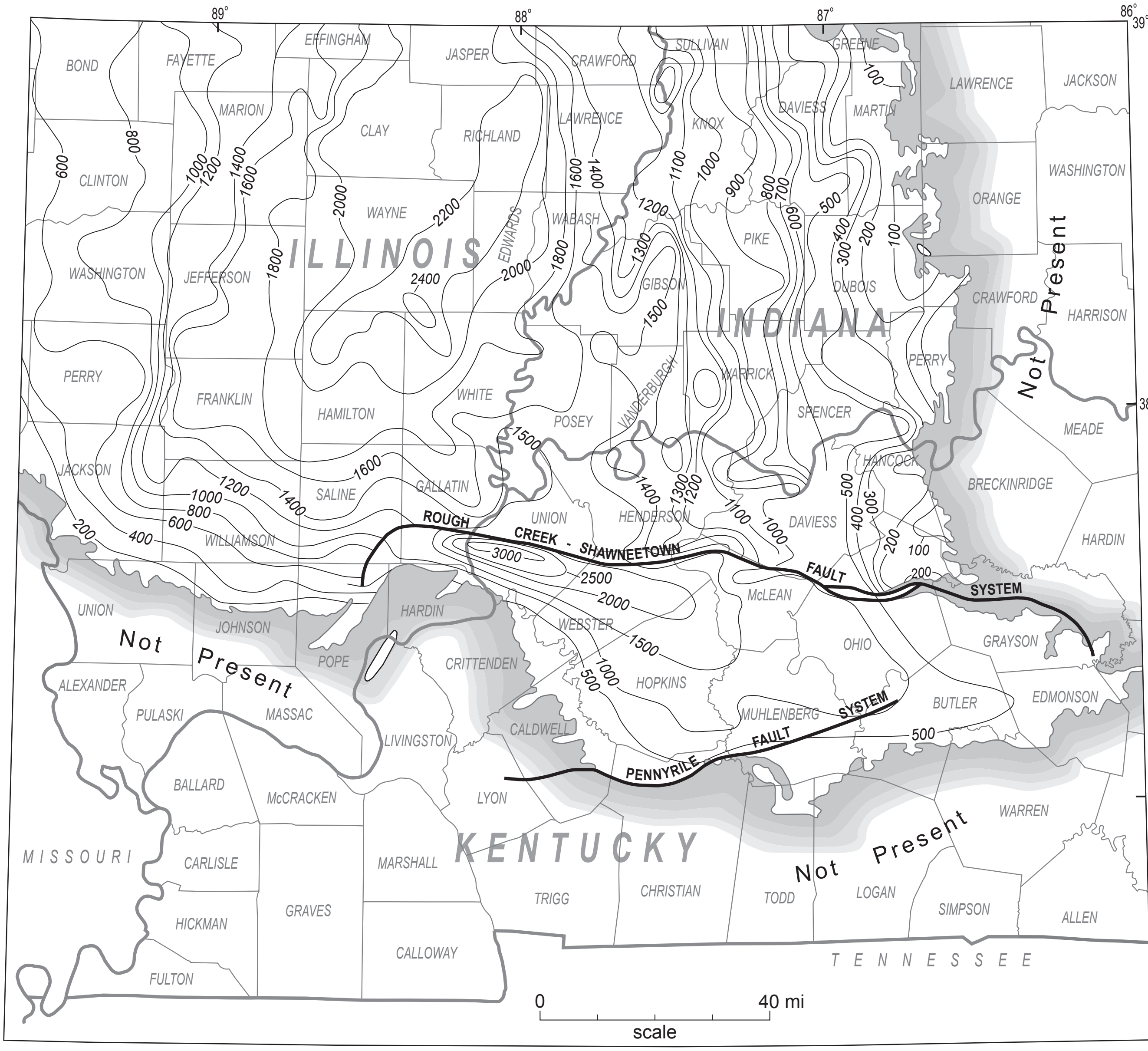

Figure 17. Thickness of Pennsylvanian rocks in the southern part of the Illinois Basin. Thinning toward limit of Pennsylvanian outcrops partly because of post-depositional erosion. Contour interval=100, 200, and 500 ft. Modified from McKee and Crosby (1975, Plate 11), Willman and others (1975, Fig. P-1; used with permission of the Illinois State Geological Survey).

dant than mudstone in limited areas where sandstone fills old channels (Wanless, 1975). In the uppermost part of the section in the Moorman Syncline, sandstone does exceed mudstone. The coal beds are thin and moderately discontinuous. Several thin but regionally persistent limestone beds are present in the Upper Pennsylvanian in western Kentucky. Strata formerly considered to be in the uppermost Pennsylvanian have been found to contain fossils of Early Permian age (Douglass, 1979).

At the time of the geologic mapping program, the laterally persistent nature of some of the limestone and coal beds in the Pennsylvanian section, especially in the Tradewater Formation, was not recognized, mostly because of limited exposures, the lack of detailed stratigraphic drillhole data covering the entire Western Kentucky Coal Field, and the lack of comprehensive paleontologic data to facilitate the proper correlation of limestone and coal beds between the eastern and western parts of the coal field. As a consequence, many thin limestones and coal beds either were not recognized on outcrop or were miscorrelated with named beds by the authors of the various quadrangle reports. Williams and others (1982) and later Greb and others (1992) identified many of the original errors and presented the proper

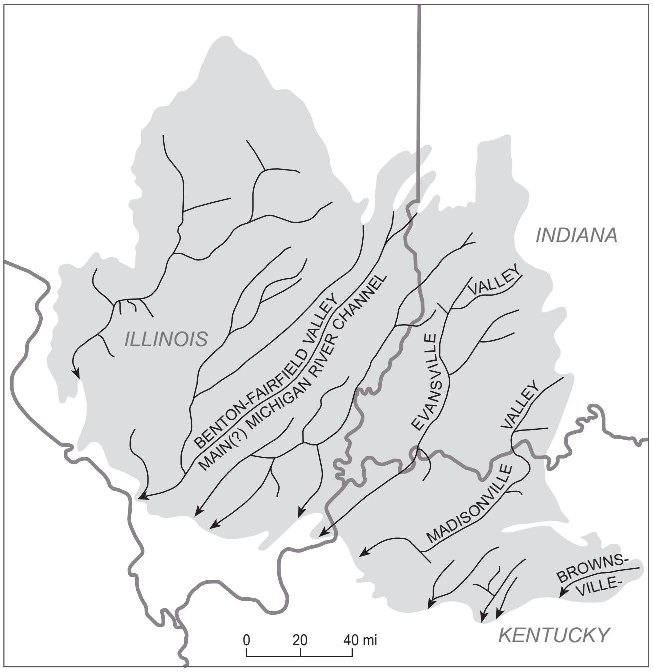

Figure 18. Sub-Pennsylvanian valley systems in the Illinois Basin. Modified from Bristol and Howard (1971; used with permission of the Illinois State Geological Survey), Davis and others (1974).

correlations (Fig. 19) of both the limestone and coal beds throughout the Pennsylvanian section in the coal field. Also, in the latter report the Kentucky Geological Survey accepted the recommendations of the Tri-State Committee on Correlations in the Pennsylvanian System in the Illinois Basin (Jacobson and others, 1985), which applied regional names to some of the principal limestone beds and most of the numbered coal beds in the Western Kentucky Coal Field. In this report, in order to tie the nomenclature used on the geologic quadrangle maps to the current nomenclature of the Kentucky Geological Survey, the former numerical designation of the coal bed is included in parentheses after the current name of the bed: for example, Springfield (W. Ky. No. 9) coal bed. On the geologic map (Plate 1A), however, the coal beds are identified by number only, similar to their designation on the geologic quadrangle maps. Also, because of the close proximity of some coal beds to limestone units in the Tradewater, Carbondale, and Sturgis Formations, not all coal beds or limestone units discussed in the text are shown on the geologic map.

The Pennsylvanian rocks of the Rough Creek area are divided, in ascending order, into the Caseyville, Tradewater, Carbondale, and Sturgis Formations. The Caseyville and Tradewater are combined on the geologic map.

Caseyville Formation

The Caseyville Formation, named for Caseyville along the Ohio River in southwestern Union County, Ky. (Owen, 1856), is divided in Illinois into the basal Lusk Shale Member, the Battery Rock Sandstone Member, the Drury Shale Member, and the Pounds Sandstone Member. Although the members of the Caseyville of Illinois were not recognized with consistency in Kentucky during the geologic mapping project, several thick sandstone units in parts of western Kentucky are probably correlative with the sandstone members of the Caseyville of Illinois. In the southwestern part of the Rough Creek area, the Caseyville crops out along the Ohio and Tradewater Rivers, and in the eastern part it extends in a broad arcuate belt from the Ohio River at Cloverport on the north to the southeastern corner of the study area. East and north of its outcrop belt, the Caseyville caps large and small outliers. The formation is also exposed in numerous fault blocks in the Rough Creek Fault Zone.

In Kentucky, the Caseyville Formation includes all Pennsylvanian strata of Morrowan age between the Mississippian-Pennsylvanian unconformity and the base of the Bell (W. Ky. No. 1b) coal bed at the base of the Tradewater Formation. Along the Ohio River in the western part of the Rough Creek area, the coal bed is at or close to the top of a thick sandstone unit probably equivalent to the Pounds Sandstone Member of the Caseyville in Illinois. Where the Bell coal bed is missing or was not mapped, the top of the Caseyville is placed at the top of the Pounds equivalent. Along the Tradewater River, however, several workers (Seeland, 1968; Amos, 1970) placed the Caseyville-Tradewater contact at the top of a thick sandstone about 40 to 70 ft below the Bell coal bed.

Over much of the eastern outcrop area, a coal bed either is not present or was not identified at the approximate position of the Bell (W. Ky. No. 1b), so the Caseyville and Tradewater Formations generally were not separated on the geologic quadrangle maps. Later work (T.M. Kehn, U.S. Geological Survey, written commun., 1980) has shown that the Hawesville and Deanefield coal beds in the eastern outcrop area are equivalent to the Bell coal bed, so locally the two formations can be differentiated. In the Sebree quadrangle (Hansen, 1975) in the western part of the Rough Creek area, the contact was placed at the top of a thick sequence of crossbedded sandstone and conglomeratic sandstone. Because the basal Pennsylvanian contains many thick sandstone units and the position of individual units within the Pennsylvanian section and their lateral correlation are commonly quite uncertain, however, lithologic placement of the Caseyville-Tradewater boundary is tenuous.

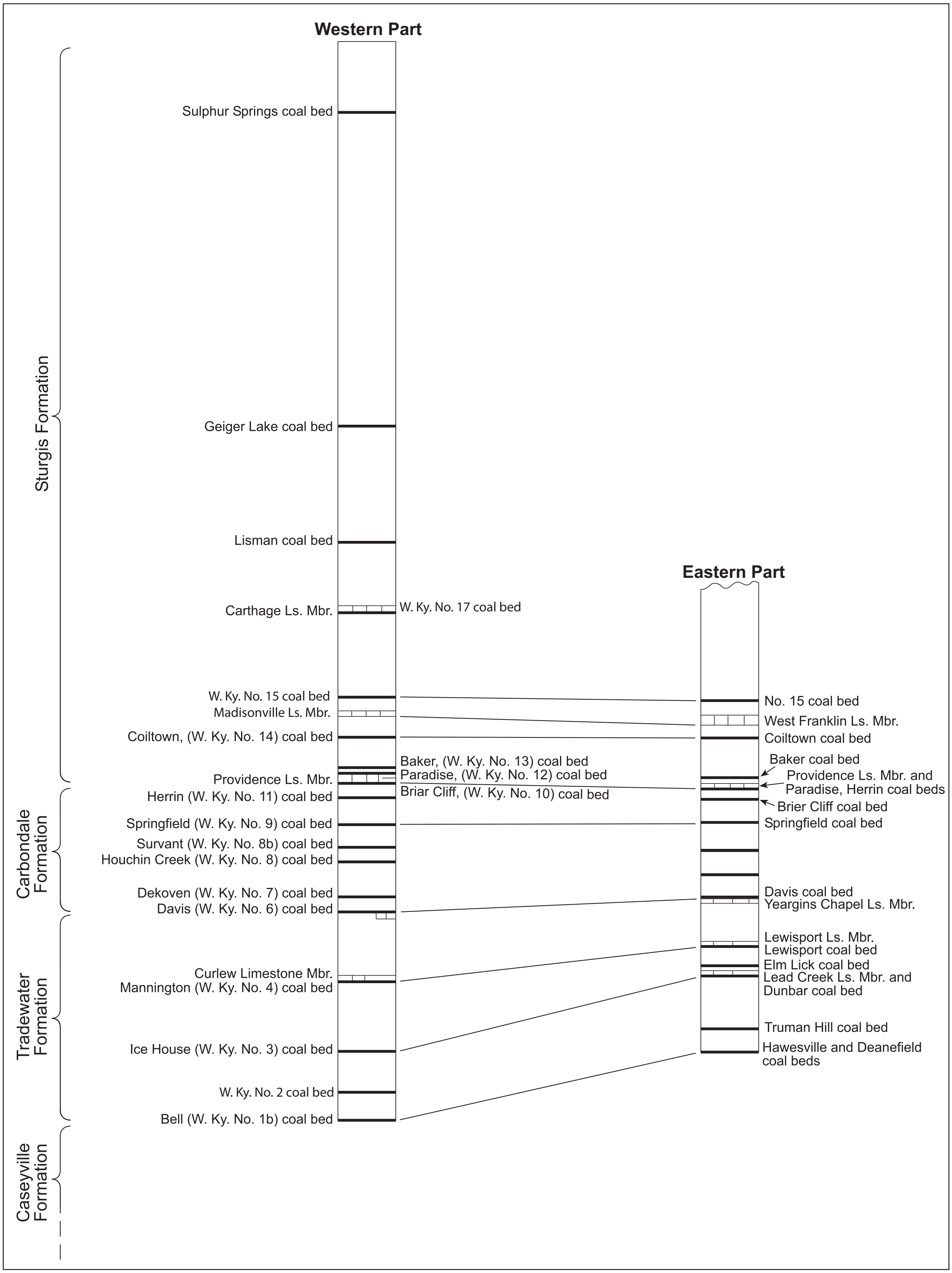

Figure 19. Relative position of the major coal beds and limestone members in the Pennsylvanian section of the Rough Creek area and their correlation between the western and eastern parts.

In the Rough Creek area, the Caseyville Formation consists dominantly of sandstone and lesser amounts of siltstone and silty to sandy shale. Clay shale, limestone, and coal beds are much less abundant. The thicker sandstones, commonly containing quartz pebbles, fill stream valleys that were cut into the pre-Pennsylvanian surface as part of a southwest-trending drainage network. The boundaries of the channel sandstones generally are well defined. In areas beyond the ancient valleys or where the valleys received less sand, the Caseyville is mainly siltstone and shale.

Sandstone of the Caseyville generally is white to light gray and light brown to light yellowish brown, mostly fine to medium grained, but coarse grained in basal channel facies, and varies from litharenite (Greb, 1989a) to orthoquartzite. Most are thin to medium bedded, but some are thick bedded to massive, and include planar and trough crossbeds in channel facies. Sandstone in the crossbedded, conglomeratic facies fines upward. The thinner beds commonly are micaceous, and carbonaceous material is present on many bedding planes.

Most of the sand of the Caseyville is relatively mature, having been derived from older sandstones; other constituents reflect erosion of other types of sedimentary rocks, as well as crystalline rocks (Siever and Potter, 1956; Wanless, 1975). Pebbles as much as 1.5 inches in diameter, as well as white quartz granules, are locally abundant, especially in the lower part of channel sandstones, where they are on bedding-plane surfaces and along foresets. Clay balls, ironstone concretions, and fragments of limestone and shale are also present in places in the basal part. The quartz pebbles resemble those in the Lee and New River Formations of eastern Kentucky, Virginia, and West Virginia, and probably had a common source. At least some of the quartz was probably derived from schists in the Virginia Piedmont (Wanless, 1975); this source was termed the "Appalachian metamorphic source area" by Rice and Weir (1984). During Early Pennsylvanian time, a major drainage, the Sharon-Brownsville Paleovalley System (Rice and Weir, 1984), transported debris southwest from Pennsylvania, Ohio, and West Virginia, across eastern and south-central Kentucky. The basal Pennsylvanian channel fill, exposed along the Nolin River in Edmonson and Hart Counties (just south of the Rough Creek area), is part of the Brownsville system (Pryor and Potter, 1979).

In the Rough Creek area, conglomeratic layers are conspicuous in the Caseyville over much of the western outcrop belt and also in the eastern part in the Ohio River Valley west of Cloverport (generally north of the Rough Creek area), where crossbeds in a channel fill, described by Greb (1989a), indicate an average paleocurrent direction of S40°W. The sedimentology of one of the basal Pennsylvanian channel fills, the Kyrock Sandstone (McFarlan, 1943) in Edmonson and Hart Counties, Ky., adjacent to the southeastern part of the Rough Creek area, has been studied by Pryor and Potter (1979). The Caseyville sandstone weathers shades of yellowish and reddish brown and in places shows Liesegang-type layering. It forms prominent ledges and cliffs as much as 100 ft high that exhibit honeycomb weathering. Sandstone in channels commonly grades laterally and vertically into sandy shale, siltstone, or thinner-bedded sandstone.

Shale in the Caseyville is light to dark gray and yellowish brown, silty to sandy but locally clayey and carbonaceous. Siltstone is white to medium light gray and yellowish brown, in part sandy or argillaceous, micaceous, and in thin, even beds. In places both the shale and siltstone contain small, dark-brown clay-ironstone concretions. Thin, lenticular beds of shaly coal, generally less than 2 ft thick, and associated light-gray to medium-dark-gray underclay are present locally. At several localities, however, beds of greater thickness have been mined, such as a 4-ft-thick bed of shaly coal questionably correlated with the Main Nolin coal bed, near the southeastern corner of the Rough Creek area, and a discontinuous bed 2 to 3 ft thick about 5 mi southeast of Caneyville (Gildersleeve and Johnson, 1978b); because of map scale, neither of these beds is shown on the geologic map (Plate 1A).

An unusual sequence of marine beds, as much as 35 ft thick, of Early Pennsylvanian age, which rests unconformably on Mississippian strata just above the Vienna Limestone Member of the Buffalo Wallow Formation, crops out in several small areas near the southeastern corner of the Rough Creek area (Glick, 1963); some of the unit is now covered by water of the Nolin Reservoir in the valley of Rock Creek. The unit probably occupies the base of a post-Mississippian channel, and in turn is overlain by a Pennsylvanian channel deposit containing quartz-pebble conglomerate. The upper part of the marine unit is medium-dark-gray shale interbedded with medium-gray, finely micaceous, sandy siltstone; it grades downward into a 5-ft-thick bed of brownish-gray, silty, calcareous, very fine-grained sandstone containing brachiopods, pelecypods, and gastropods. The basal bed of the sequence is a 2-ft-thick bed of iron-stained, calcareous, silty to sandy conglomerate containing limestone pebbles, quartz granules, and marine fossils. These beds indicate marine invasion of the post-Mississippian drainage system in at least this part of Kentucky before deposition of the Pennsylvanian deltaic sediments. These marine beds may result from the extensive marine transgression in the eastern part of the Illinois Basin and the western part of the Appalachian Basin in the Early Pennsylvanian, inferred by Rice and Weir (1984, Fig. 35).

In the type area of the Caseyville Formation along the Ohio River at the western edge of the Rough Creek area, the formation is about 260 to 450 ft thick; maximum thickness of 677 ft is in Union County (Wanless, 1975). In the eastern outcrop area, the Caseyville appears to be about 350 to 400 ft thick; however, because the upper contact of the Caseyville was rarely recognized during the geologic mapping program, this is a general thickness. The thickness of only 215 ft in the Cloverport area given by Bergendahl (1965) is erroneous, probably because a coal bed low in the Caseyville was misidentified as the stratigraphically higher Hawesville coal bed.

Basal Pennsylvanian sedimentary rocks of Morrowan age overlie rocks of Chesterian age on a pronounced unconformity that extends as low stratigraphically as the lower part of the Tar Springs Sandstone, and even locally as low as the upper part of the lower unit of the Glen Dean Limestone (Gildersleeve and Johnson, 1978a).

Tradewater Formation

The Tradewater Formation, named by Glenn (1912) for exposures along the Tradewater River in the southwestern part of the Rough Creek area, includes strata of Atokan age in the lower two-thirds and of Desmoinesian age in the upper third (McKee and Crosby, 1975, pt. 3, Plate 13). The Tradewater of Kentucky is equivalent to the Abbott and lower part of the Spoon Formations of Illinois[1] and to the upper part of the Mansfield, Brazil, and lower part of the Stanton Formations of Indiana (Shaver and others, 1984).

Regionally, the Tradewater is composed of about equal amounts of sandstone and mudstone, but in a few areas sandstone or mudstone constitutes as much as 80 percent of the formation. The sandstone generally contains no quartz pebbles and is finer grained that that in the Caseyville Formation. Siltstone and sandy shale constitute the majority of the finer sediments, although thick units of clay shale are locally present, especially in the upper part. Coal beds and associated underclays are numerous, highly variable in thickness, and generally of local distribution. The principal beds of the Tradewater in the Rough Creek area are shown in Figure 19. Marine limestone is commonly associated with the coal beds, especially in the upper part of the formation.

Sandstone of the Tradewater is white and light gray to light brown, fine to medium grained, although commonly coarse grained in the thicker quartzarenite beds in the lower part. There is an upward transition in the Tradewater sandstones from quartzarenite to subgraywacke. Mica and argillaceous material are common constituents of the subgraywacke (Potter and Glass, 1958). In places, sandstone cemented by iron oxide forms abundant concretions and boxwork. The sandstone beds are thin to very thick and in channel fills show well-developed trough and planar crossbeds. The thicker sandstone units, which may be as much as 50 ft thick in some intraformational channels, form prominent ledges and cliffs.

The shale of the Tradewater is light to dark gray, but black, carbonaceous, and pyritic where associated with coal beds. Most is silty to sandy, commonly interbedded with sandstone and siltstone, but clayey and calcareous where associated with limestone. The proportion of shale to siltstone generally increases upward in the formation. Hard, reddish-brown clay-ironstone concretions are locally abundant in shale and siltstone. Brachiopods, gastropods, pectenoid pelecypods, sponge spicules, and worm tubes are abundant in the black shale. Siltstone of the Tradewater generally is light to light medium gray and greenish gray, in part argillaceous or sandy, micaceous, and thin bedded.

The limestone of the Tradewater is light to medium gray and weathers to shades of gray and yellow brown. It is finely to medium crystalline, thin to thick bedded, and very fossiliferous. Locally, a few beds are cherty, and some limestone grades laterally into light-blue to white, dense, vuggy, fossiliferous chert. Most limestones are thin, of limited distribution, and in cyclic relation to coal beds. Fossils include abundant crinoid fragments, brachiopods, bryozoans, corals, and locally fusulinids.

The Lead Creek Limestone Member of the Tradewater Formation (called the Lead Creek limestone of Crider [1943] on the geologic quadrangle maps), 1 to 8 ft thick, is the oldest identifiable, regionally persistent Pennsylvanian unit in the Western Kentucky Coal Field. It was named for outcrops in Hancock County, in the eastern part of the Rough Creek area, and was described by Crider (1913) as three or four limestone beds in an interval 30 to 40 ft above the Lead Creek coal bed. In the cooperative geologic mapping program, the name was restricted to the principal limestone bed immediately above the coal bed; however, the Kentucky Geological Survey (Greb and others, 1992) now defines the member as originally described by Crider. The limestone member is in the lower part of the Tradewater, about 60 ft to possibly as much as 120 ft below the extensive Curlew Limestone Member. The Lead Creek is about 365 ft above the Mississippian-Pennsylvanian contact in corehole Gil-6 in the Pleasant Ridge quadrangle (Williams and others, 1982).

In the western part of the Rough Creek area, several thin, discontinuous, unnamed limestone beds in the interval 100 to 140 ft below the Curlew Limestone Mem-

[1]The Illinois State Geological Survey has adopted the name "Tradewater Formation," as defined in Kentucky.

ber that may be correlative with the Lead Creek were recognized in surface exposures by Kehn (1966, 1975b). Williams and others (1982, Fig. 7) also questionably correlated two 2-ft-thick limestone beds separated by 25 ft of shale in coal test hole Gil-31 in the Providence quadrangle with the Lead Creek Limestone Member. The lower of the two beds is about 355 ft below the Davis (W. Ky. No. 6) coal that marks the top of the Tradewater Formation. The Lead Creek Member is in the fusulinid zone of *Profusulinella* (Douglass, 1987).

The Curlew Limestone Member of the Tradewater Formation, the thickest and regionally most persistent limestone in the formation, is in the upper third of the formation, about 165 to 210 ft below the top in the western outcrop area; the member is not everywhere present in the Western Kentucky Coal Field. The limestone, named for exposures in Union County (Owen, 1856, 1857), is 3 to about 10 ft thick, but is missing locally. The Curlew contains a fusulinid fauna in the zone of *Fusulinella* of late Atokan age, and the same fauna is in the Seville Limestone Member of the Spoon Formation in Illinois (Douglass, 1987).

The Lewisport Limestone Member of the Tradewater Formation in the eastern part of the Rough Creek area is correlative with the Curlew Limestone Member of the western part. The Lewisport outcrop area centers on Hancock County. On a number of the earlier geologic quadrangle maps, the unit was designated the "Lewisport Limestone of Chisholm (1931)." The limestone immediately overlies the Lewisport coal bed.

In the eastern part of the Pennsylvanian outcrop area, the limestone bed immediately underlying the Davis (W. Ky. No. 6) coal bed, which is at the base of the overlying Carbondale Formation, is a very useful marker; the limestone was not named on the geologic quadrangle maps, but was informally called the Yeargins limestone member of the Tradewater Formation by Douglass (1979). The name was modified to Yeargins Chapel limestone by Williamson and Whaley (1979) and that name was later adopted by the Kentucky Geological Survey (Greb and others, 1992), although Greb and others (on their Figure 22) were not consistent in their use of the dual name for the limestone.

The limestone of the Yeargins Chapel Member generally is dark gray, argillaceous, weathers mottled brown and gray, has a brecciated appearance, and locally is as much as 8 ft thick. In places it is separated from the Davis coal bed (W. Ky. No. 6) by a thin underclay or black fissile shale. Because of its close proximity to the coal bed, the Yeargins Chapel Member was not identified separately on the geologic map (Plate 1A). The top of the Yeargins Chapel Member defines the base of the overlying Carbondale Formation in those parts of the Western Kentucky Coal Field where the Davis coal bed is not persistent (Williams and others, 1982). Douglass (1979) reported that the limestone contains the first good Desmoinesian fusulinids in the Pennsylvanian section of western Kentucky. The genus *Wedekindellina euthysepta* is characteristic of the Yeargins Chapel Member (Douglass, 1987).

As many as 17 coal beds are present in the Tradewater Formation in western Kentucky (Kehn, 1974), but only four are of sufficient thickness and regional extent to have been named or numbered (Owen, 1857). As stated earlier, the coal-bed nomenclature and correlation within the Western Kentucky Coal Field and in adjacent Illinois and Indiana have been modified since the U.S. Geological Survey–Kentucky Survey mapping program, and the nomenclature shown in Figure 19 is generally recognized in western Kentucky, southern Illinois, and southwestern Indiana.

In the western part of the Rough Creek area, the Bell (W. Ky. No. 1b) coal bed at the base of the Tradewater ranges in thickness from 12 to 55 in., but locally is split into two benches separated by as much as 15 ft of carbonaceous shale (Kehn, 1974). The next higher, persistent coal bed, the Mannington (W. Ky. No. 4), at or close to the base of the Curlew Limestone Member, is 6 to 24 in. thick and is the only other coal of regional significance in the western outcrop area. The Ice House (W. Ky. No. 3) coal bed locally is as much as 36 in. thick, but of very limited extent. The other coal beds in the western area are less than 25 in. thick and also of very limited extent.

In the eastern outcrop area of the Tradewater Formation, because much of the country, especially in the vicinity of the Ohio River, is mantled by loess, exposures of coal beds are limited, and the beds are not easily traced for long distances. Consequently, local names were applied by early workers to the coal beds in the scattered outcrop areas. At the time of the geologic mapping program, the correlation of the coal beds between local areas was not well known, nor was the proper correlation of the various beds in the eastern part of the Rough Creek area with the principal numbered beds in the western part well established. Later work in the eastern area (T.M. Kehn, U.S. Geological Survey, written commun., 1980) has demonstrated that the Hawesville coal bed west of Cloverport and the Deanefield coal bed to the southwest are correlative with the Bell (W. Ky. No. 1b) bed of the western area; those beds mark the base of the Tradewater Formation. Nevertheless, the two beds cannot be traced laterally into each other. Calvert (1965) erroneously thought that the Hawesville in the Whitesville quadrangle was about 40 to 50 ft below the Deanefield coal bed. Over the eastern area, the Hawesville coal bed is as much as 5 ft thick, but locally contains a 3- to 6-in.-thick parting of "smutty" coal and pyrite; the Deanefield is as much as 4 ft thick locally.

The coal bed immediately underlying the Lead Creek Limestone Member in Hancock County was originally named the Lead Creek coal bed, and that name was used in the cooperative mapping program. Later, a study of fusulinid-bearing limestones, some in proximity to coal beds, in the Pennsylvanian strata of Kentucky (Douglass, 1979, 1987) was the basis of the correlation of the Lead Creek coal bed with the Dunbar coal bed around Morgantown, Ky., south of the Rough Creek area, and for recognition of a local, unnamed limestone and coal bed correlative with the Lead Creek sequence in the western part of the Western Kentucky Coal Field (Williams and others, 1982). So, the name "Dunbar" is now applied throughout the coal field to the bed formerly called the Lead Creek (Williams and others, 1982). The Dunbar is less than 4 ft thick.

The Lewisport coal bed, underlying the Lewisport Limestone Member, is correlative with the Mannington (W. Ky. No. 4) of the western part of the coal field. The Lewisport bed crops out over a large area around Knottsville, Ky., but is channeled out locally. Outcrops of the Lewisport have been recognized as far south as the vicinity of the Green River Parkway along the Daviess-Ohio County line. The Lewisport is 1 to 7 ft thick, commonly contains pyrite and siliceous partings, and in places is split into two benches by a 5-ft-thick shale parting.

A number of coal beds are present in the Tradewater Formation in the eastern outcrop area, both above and below the Lewisport coal bed, but most are less than 3 ft thick, of local extent, and their correlation with beds in the western part of the coal field is uncertain. One of these local beds, the Elm Lick coal bed, has been strip mined north of Hartford, where it is 1 to 6.5 ft thick; the Elm Lick in the mine was described in detail by Greb and others (1994). A coal bed questionably correlated with the Elm Lick is 230 ft below the top of the Tradewater (Williams and others, 1982, Fig. 6, DDH No. 5); its geographic distribution appears to be restricted to southeastern Ohio County. Greb and others (1992) mistakenly placed the Elm Lick below the Lead Creek Limestone, but later work by Kentucky Geological Survey geologists (D.A. Williams, written commun., 1994) indicates that the Elm Lick coal bed actually occurs between the Lead Creek and Curlew Limestone Members.[1] In its outcrop area, it is about 125 ft below a cherty limestone (exposed in the town of Hartford [Goudarzi, 1968]), which may correlate with the Curlew Limestone Member.

Two beds of white to light-gray, very fossiliferous chert as much as 1.4 ft thick are present in the upper part of the Tradewater Formation around the town of Livermore. The chert weathers to porous white to light-brown angular fragments and contains brachiopods, horn corals, and crinoid columnals.

In its type area, the Tradewater Formation is 570 to 620 ft thick, although a minimum thickness of about 450 ft in the Blackford quadrangle (Amos, 1970) seems possible. In the eastern part of the Rough Creek area, the Tradewater thickness ranges from about 360 to 620 ft; uncertainty in identifying the Tradewater-Caseyville contact probably is a factor in the wide thickness variation. In the type area, the base of the Bell (W. Ky. No. 1b) coal bed marks the base of the Tradewater Formation. In other parts of the Rough Creek area, the base has been placed at the top of a thick sequence of massive sandstone assigned to the Caseyville.

Carbondale Formation

The Carbondale Formation, named for exposures around Carbondale, Ill., is defined in Kentucky as the sequence of shale, siltstone, sandstone, thick coal beds, and limestone of Desmoinesian age above the base of the Davis (W. Ky. No. 6) coal bed and below the base of the Providence Limestone Member of the Sturgis Formation. Although formerly the boundaries of the Carbondale Formation of Kentucky differed considerably from those of the Carbondale of Illinois and the Carbondale Group of Indiana (see Shaver and others, 1984), the geological surveys of Illinois and Kentucky have now agreed to the same boundaries (Greb and others, 1992).

Siltstone and shale are the dominant rock types in the Carbondale, but locally thick channel-fill sandstone occupies much of the formation. The commonly interbedded siltstone and shale of the Carbondale are light to medium gray, but some shale is dark gray to black and some siltstone is brownish gray. Most shale is silty to sandy; in places calcareous clay shale grades into limestone, and black, carbonaceous, finely laminated shale is associated with most coal beds. The siltstone generally is argillaceous to sandy, micaceous, and thin bedded. Hard, dark-yellowish-brown-weathering ironstone concretions are common in both siltstone and shale above the Springfield (W. Ky. No. 9) coal bed and to a lesser extent above the Davis (W. Ky. No. 6) bed.

Carbondale sandstone is white and light to medium gray, some brownish gray, mainly fine to medium grained, micaceous, and thin to thick bedded. The finer sandstone commonly is interbedded with siltstone and shale. Thick and massive, crossbedded, channel-fill sandstone forms ledges and cliffs. Medium-gray, argillaceous, partly sandy, fine-grained, lenticular to thin-bed-

[1]Also, palynomorph composition confirms the placement of the Elm Lick coal bed below the Mining City (W. Ky. No. 4) coal and above the Dunbar (Lead Creek) coal (Eble and others, 2001).

ded limestone is present locally both above and below coal beds and is particularly common below the Springfield (W. Ky. No. 9) coal bed generally east of Sebree.

The coal beds of the Carbondale are regionally persistent and, together with coal beds in the lower part of the overlying Sturgis Formation, contain the principal coal resources of the Western Kentucky Coal Field. As noted earlier, the nomenclature of the coal beds has undergone considerable revision through the years, and that shown in Figure 19 is now generally recognized throughout western Kentucky, Illinois, and Indiana. The coal beds in the Carbondale in the western part of the Rough Creek area crop out along the Ohio River Valley and in the valley of the Tradewater River. In the eastern part of the study area, the outcrop belt extends from central Ohio County northwest into southern McLean County, where it is broken by the Rough Creek Fault Zone. North of the fault zone, the outcrop belt covers central and western Daviess County.

The Davis (W. Ky. No. 6) coal is at the base of the Carbondale in both the eastern and western outcrop belts of the Rough Creek area, but locally, west of Sebree, the bed is missing because of channeling, and in a few places the coal is replaced by carbonaceous shale. On outcrop in the western part of the Rough Creek area, the Davis coal bed is overlain by black shale. In the Sturgis quadrangle, however, no black shale was recorded above the coal bed (Kehn, 1975b), but David A. Williams of the Kentucky Geological Survey (personal commun., 2004) later confirmed that a black shale does overlie the coal bed in that quadrangle. In the eastern part of the study area around Owensboro, a poorly exposed, previously unnamed coal bed, underlain by a thin, fossiliferous limestone considered the Yeargins Chapel Limestone Member of the Tradewater Formation, is now generally recognized as the Davis (W. Ky. No. 6) coal bed; earlier, based on palynological data, Kosanke (1965) correlated the bed with the Dekoven (W. Ky. No. 7) coal of western Kentucky. The Davis coal bed is locally about 6 ft thick in the western outcrop area; in the eastern area it is generally less than 2.5 ft thick, but locally in drillholes as much as 4 ft is reported. The conclusion by Greb and others (1992) that the Davis splits into several beds in the subsurface of Henderson County seems to be discounted by a later study for the Kentucky Geological Survey (Whitsett, 1994). The Davis bed apparently is very thin or missing east of Beaver Dam, but the underlying Yeargins Chapel Limestone Member (not named on the geologic quadrangle maps) is present, although locally both are cut out by channel-fill sandstone.

The Dekoven coal bed was named by Lee (1916) for exposures around Dekoven, Ky., and was correlated with the No. 7 coal bed by Glenn (1922). In its type area, the Dekoven (W. Ky. No. 7) is 1 to 4 ft thick; elsewhere, the coal bed mapped as the No. 7 is less than 2 ft thick.

In 1974 Kehn mapped the No. 7 coal bed in the Dekoven quadrangle and extended the bed eastward into the adjacent Sturgis quadrangle (Kehn, 1975b). Earlier, to the southeast, Kehn (1966) in the Providence quadrangle and Amos (1970) in the Blackford quadrangle had mapped a coal bed they called the No. 7. The extension of the No. 7 coal bed away from its type area is controversial. Based on self-potential/resistivity logs and corehole logs, Smith in 1967 concluded that away from the type area the coal bed mapped as the No. 7 is actually the coal he called the “S” or Schultztown in the Carbondale between the No. 7 coal and the Survant (W. Ky. No. 8). Smith (1967) further concluded that the No. 7 coal bed is absent over much of the Western Kentucky Coal Bed. Although Kehn (1966, 1975b) and Amos (1970) acknowledged Smith’s disagreement with their correlation and extension of the No. 7 coal bed from the Dekoven area, the correlation problem was not resolved during the period of the geologic mapping program.

Detailed study (Jacobson, 1987) of the Seelyville coal bed of the Spoon Formation of southeastern Illinois and southwestern Indiana has shown that southward in the Illinois Basin, the Seelyville splits into two beds, the lower becoming the Davis (W. Ky. No. 6) coal bed and the upper, the Dekoven (W. Ky. No. 7) bed; in western Union County, Ky., the beds are 10 to 60 ft apart. This refutes the earlier correlation (Jacobson and others, 1985) of the Dekoven with the Colchester coal bed of southwestern Indiana, which is above the Seelyville bed.

Smith’s (1967) contention that the No. 7 coal bed has limited distribution in the Western Kentucky Coal Field is supported by a 1994 unpublished study by T.M. Whitsett for the Kentucky Geological Survey of the stratigraphic relations of the lower Carbondale coal beds in the Western Kentucky Coal Field, based on gamma-ray/density logs, self-potential/resistivity logs, and corehole logs, that concluded that the No. 7 coal bed eastward from the outcrop area in the western part of the coal field was truncated by erosion in eastern Union County prior to deposition of the Colchester coal bed and that the No. 7 bed is not present in the subsurface in Henderson County, as cited by Greb and others (1992), or farther to the east in the Rough Creek area. Whitsett (1994) did conclude, however, that the Davis (No. 6) does extend across the coal field.

At the time of the geologic mapping program, no coal bed was identified and mapped in western Kentucky as the Colchester. A thin coal bed (less than 1 ft thick) that is overlain by black shale was recorded in the section 100 to 115 ft above the base of the Davis (No. 6) in the Dekoven and Sturgis quadrangles, however (Kehn, 1974, 1975b, respectively). This is the bed that Smith

(1967) called the "S" or Schultztown coal bed, which was later correlated (Jacobson, 1987) with the Colchester coal bed of Illinois and Indiana. As described by Jacobson (1987), the Colchester sequence, a well-developed claystone underlying a thin coal bed that is overlain by black shale, gives a distinctive signature on the normal resistivity curve of a spontaneous-potential resistivity log. The radioactive, carbonaceous black shale of the sequence also gives a well-defined signature on a gamma-ray/density log. These two types of geophysical logs have been used extensively to identify the Colchester throughout the Western Kentucky Coal Field.

Although geophysical studies, both published and unpublished, have confirmed the presence and stratigraphic position of the Colchester coal bed above the Dekoven (W. Ky. No. 7) bed in the subsurface of the Western Kentucky Coal Field, uncertainties still need to be investigated and the results reported in a publication: namely, the uncertainty of the correlation of the No. 7 coal bed along the Carbondale outcrop belt beyond the Dekoven area; also, the recognition of the Colchester in the outcrop belt; and possibly the proper correlation of mapped but unidentified coal beds in this part of the Carbondale Formation in various quadrangles in the eastern part of the coal field. Perhaps spore analysis of outcrop and core samples from beds mapped as the No. 7, from the bed identified as the Colchester (Schultztown) in the western part of the Rough Creek area, and from the Davis bed could help to resolve the uncertainties.[1]

In the western outcrop area, the Survant (W. Ky. No. 8) and Houchin Creek (W. Ky. No. 8b) coal beds crop out over much of the area, but are quite variable in thickness, and only locally are they as much as 4 ft thick. The names "Survant" and "Houchin Creek" have replaced the names "Well" and "Ruff," respectively (Beard and Williamson, 1979), for these coal beds (see Jacobson and others, 1985, for discussion). In the eastern outcrop area, most coal beds between the Davis (W. Ky. No. 6) and the Springfield (W. Ky. No. 9) appear to be present over much of the area, but only on a few of the geologic quadrangle maps were they correlated with beds of the western area. Most of these coal beds are less than 2.5 ft thick, but locally are reported as 3 to 4 ft thick in drillholes.

The Springfield (W. Ky. No. 9) coal bed, the economically most important bed in western Kentucky, occurs 60 to 150 ft below the top of the Carbondale Formation and is easily identified in the subsurface by the distinctive kick that the coal and overlying black shale make on an electrical-resistivity log. The bed ranges in thickness from 2 to 7 ft. It is missing locally because of intraformational channeling, such as along the Henderson Channel (Beard and Williamson, 1979) in Henderson and Webster Counties, and also because of channeling during deposition of the Anvil Rock Sandstone Member in the lower part of the overlying Sturgis Formation. The close proximity of the Anvil Rock Sandstone, or other thick sandstone bodies, to the top of the Springfield coal bed locally may cause bad roof conditions in mines.

The Briar Hill (W. Ky. No. 10) coal bed is present near the middle or in the upper part of the Carbondale section above the Springfield bed, but is missing at many localities. Locally, in the vicinity of Owensboro (Goudarzi, 1971), near Henderson (Johnson, 1973a), and near Hartford (Goudarzi, 1968), two coal beds are present above the Springfield (No. 9) and below the Herrin (W. Ky. No. 11) coal beds; the lower of these beds was probably misidentified as the Briar Hill (W. Ky. No. 10) at several localities on the geologic maps of those areas. The thickness of the Briar Hill is 0 to 4.5 ft.

The Herrin (W. Ky. No. 11) coal bed at the top of the Carbondale Formation is widely distributed in the western outcrop area, where it is as much as 7 ft thick. On outcrop in the eastern area it generally is thinner and is missing locally, either because of nondeposition or channeling before deposition of the Anvil Rock Sandstone Member of the Sturgis Formation. The Herrin either directly underlies the Providence Limestone Member of the Sturgis or is separated from the limestone by a thin, carbonaceous clay shale. The coal bed commonly contains a gray shale parting 1 to 2 in. thick, the blue band of miners, in the lower part, especially in the western outcrop area.

The normal thickness of the Carbondale Formation is about 265 to 420 ft in the Rough Creek area, but where channel sandstone of the Sturgis Formation eroded deeply into the unit, as little as 210 ft of Carbondale strata remains. Over most of the area, the Carbondale is conformable on the Tradewater Formation, but locally channels have cut as deep as 60 ft into the Tradewater.

Sturgis Formation

The Sturgis Formation, named by Kehn (1973) for exposures in the Sturgis area of Union County, Ky., includes Pennsylvanian strata ranging from late Desmoinesian through Virgilian in age; it encompasses strata previously assigned to the abandoned Lisman and Henshaw Formations. Beds in the uppermost part of Kehn's original Sturgis Formation, however, were later found to contain Early Permian fusulinids (Douglass, 1979), so those beds are now assigned to the Mauzy Formation (Kehn and others, 1982), and the Sturgis is re-

[1]Cortland Eble of the Kentucky Geological Survey (written commun., 2004) stated that the spores in the Dekoven (No. 7) coal bed and those in the Colchester (Schultztown) coal bed are distinctly different.

stricted to strata of Late Pennsylvanian age. The contact between the restricted Sturgis Formation and the Mauzy Formation is about 1,560 to 1,630 ft above the base of the Carthage Limestone Member of the Sturgis and at the base of a predominantly limestone sequence containing Permian fusulinids. Because the Mauzy Formation appears to be confined to a fault block in the Rough Creek Fault Zone in an area largely covered with loess, and because the type section is primarily in a drillhole, the outcrop position of the lower contact is largely inferred.

In order to achieve uniformity of nomenclature of the Upper Pennsylvanian strata in the Illinois Basin between the state geological surveys of Illinois, Kentucky, and Indiana, the Kentucky Geological Survey (Greb and others, 1992) agreed to assign the strata encompassed in the Sturgis Formation to the McLeansboro Group; subdivide the group into, in ascending order, the Shelburn, Patoka, Bond, and Mattoon Formations; and to place the formational boundaries at either the top or base of basinwide limestone beds. In addition, some modification of previous formational boundaries was required to achieve consistency with the nomenclature of the other state surveys. Because the Sturgis Formation was mapped throughout much of the Western Kentucky Coal Field during the cooperative geologic mapping program, however, that name is retained in this report for the uppermost Pennsylvanian formation.

The Sturgis is composed of interbedded sandstone, siltstone, shale, limestone, and coal beds. In the type area, sandstone, the dominant rock type, composes 30 to 50 percent of the formation; siltstone, about 30 to 40 percent; shale, about 20 to 30 percent; and limestone, less than 5 percent (Kehn, 1973). These percentages also appear to be valid for other parts of the outcrop belt in the Rough Creek area.

Sandstone of the Sturgis Formation is white and light to medium gray and weathers yellowish brown. It is generally very fine to medium grained, but locally coarse grained, and contains scattered very small, white quartz pebbles in the basal part of channel deposits. Most is thin to medium bedded, but is thick to massive bedded and crossbedded in channel deposits. The sandstone commonly is micaceous, silty to shaly, and interbedded with siltstone and shale. Where well indurated, as in many channel deposits, it forms low cliffs.

The Anvil Rock Sandstone Member locally occupies much of the lower part of the formation below the Coiltown (W. Ky. No. 14) coal bed, and in most outcrops appears to erode deeply into the upper part of the Carbondale Formation. In a study of the Anvil Rock in southern Illinois, Hopkins (1958) recognized a thin sheet-sand phase and a thick channel-sand phase. Kehn (1974) restricted the name "Anvil Rock" in the Dekoven quadrangle to the channel phase. The member occupies a sinuous channel, termed the Henderson Channel (Beard and Williamson, 1979), in Henderson and Webster Counties, Ky., that extends from the Ohio River at Evansville, Ind., south for about 28 mi to the Rough Creek Fault Zone west of Sebree. Locally, the channel cuts down almost to the top of the Houchin Creek (W. Ky. No. 8b) coal bed. Where it eroded through the Springfield (W. Ky. No. 9) coal bed, it is about 1,000 to 4,000 ft wide (Johnson, 1973b, c; Fairer, 1973a, b); along the Ohio River the channel may be almost 6,000 ft wide (Johnson, 1973b, e). Because of the lack of well data, the location of the channel south of the Rough Creek Fault Zone is uncertain, although Beard and Williamson (1979) suggested that it may have an east-west orientation. Another, but more shallow, channel filled by the Anvil Rock Sandstone Member follows a southward course across Henderson County about 5 mi to the west of the Henderson Channel (Hopkins, 1958, Plate 1). Channel phases of the Anvil Rock and perhaps of other channels are recognized both in the surface and subsurface at many other localities in western Kentucky. Other channel-fill sandstone bodies, including the unranked Dixon sandstone (Glenn, 1912) in the upper part of the Sturgis just below the Geiger Lake coal bed, are recognized locally in the Rough Creek area.

Siltstone of the Sturgis is light to dark gray and yellowish gray, clayey to sandy, commonly micaceous, and in thin, even to wavy beds. The shale is light to dark gray and greenish gray but black and carbonaceous where associated with coal beds. Locally, a thin grayish-red shale, the red rock of drillers, is present below the West Franklin Limestone Member. Most shale is sandy to silty and micaceous, but calcareous clay shale, in places containing brachiopods and crinoids, is present separately or associated with limestone beds.

The limestone of the Sturgis Formation generally is light to dark gray and weathers light gray and yellowish brown. It is finely to medium crystalline or fine grained, dense, in part argillaceous to sandy, and sparsely to very fossiliferous. Most is platy to thin bedded, but some units contain very thick to massive beds. Brachiopods and crinoids are the most abundant fossils, but fenestrate bryozoans and fusulinids also are included. The formation contains many lenticular limestone beds, but only three beds are of sufficient thickness and lateral distribution to have been named. They are the Providence Limestone Member at the base of the Sturgis; the West Franklin Limestone Member (called the Madisonville Limestone Member on the geologic quadrangle maps), about 100 to 250 ft above the base; and the Carthage Limestone Member, about 200 to 325 ft above the base of the West Franklin. The greater intervals between the limestone members are in the deeper parts of the Moorman Syncline.

The Providence Limestone Member includes all limestone and interbedded clastic units between the top of the Herrin (W. Ky. No. 11) coal bed and the base of the Baker (W. Ky. No. 13) coal bed (Kehn, 1973). As originally described (Glenn, 1922), the member consisted of the limestone beds between the No. 11 (now the Herrin) coal bed and the No. 12 (now the Paradise) coal bed, but later work revealed that Glenn's No. 12 bed is actually the No. 13 bed. On early geologic quadrangle maps of the Western Kentucky Coal Field, the Providence was restricted to the limestone beds below the Paradise (W. Ky. No. 12) bed, or essentially to the basal limestone bed, but later maps reflect the proper boundaries of the Providence Member. The Providence includes as many as four limestone beds separated by clay shale; it locally contains thin lenses of calcareous sandstone. In places, the thin, discontinuous Paradise (W. Ky. No. 12) coal bed is just above the basal limestone bed. The Providence is missing over parts of the Rough Creek area, either because of nondeposition or channeling during deposition of the Anvil Rock Sandstone Member. The Providence generally is about 20 ft thick, but locally is as much as 50 ft thick.

On the geologic quadrangle maps covering the Rough Creek area, a conspicuous, widespread limestone unit in the lower part of the Sturgis Formation was called the Madisonville Limestone Member; such usage was long established in Kentucky. Because the correlative limestone, the West Franklin, was named first by Lesquereux (1862) for outcrops along the Ohio River in Indiana, Jacobson and others (1985) recommended, and the state surveys of Kentucky, Indiana, and Illinois have agreed, that the name "Madisonville" be superseded by the name "West Franklin." Consequently, in this report the unit is designated the West Franklin Limestone Member of the Sturgis Formation. The West Franklin is a member of the Shelburn Formation in Indiana and Illinois.

The West Franklin Limestone Member consists of as many as four limestone beds, but more commonly one or two beds, separated by shale, siltstone, sandstone, and coal beds. The limestone is characterized by weathered colors of light gray and dark yellowish brown, high density, and abundance of fossils. Some beds are composed mostly of fragments of brachiopods and crinoids, but include small foraminifers. The limestone beds range considerably in thickness and regional persistence; locally, some beds are as much as 16 ft thick, but generally are less than 10 ft thick. The clastic sediments of the West Franklin are typically those of the Sturgis Formation. One or two lenticular coal beds less than 1 ft thick are present locally in the West Franklin. The member makes an easily recognizable kick on an electrical-resistivity log. The West Franklin is continuous throughout western Kentucky; it is missing only where channeled out. The member is as much as 55 ft thick, but generally is much less.

The Carthage Limestone Member of the Sturgis Formation, named for exposures along the Ohio River about 2 mi downstream from Uniontown, Ky. (Owen, 1856), is a regionally persistent marker that is easily recognized on electrical-resistivity and well-sample logs, but is not conspicuous on outcrop. It generally consists of a single bed as much as 10 ft thick, but on a few well logs is reported as two limestone beds. It is missing locally because of nondeposition and in a few places possibly because of channeling. At its type locality, the limestone is medium to light gray, weathers brown to olive gray, and is very fine grained to very finely crystalline. It is very thin to thin bedded, and the upper part has a vague conglomeratic appearance. Small brachiopods, crinoid columnals, horn corals, and bryozoans are abundant.

Except for the Baker (W. Ky. No. 13) and Coiltown (W. Ky. No. 14) in the lower part, the coal beds of the Sturgis Formation are thinner and of more limited distribution than those in the underlying Carbondale Formation. The Paradise (W. Ky. No. 12) bed, immediately above the basal limestone bed of the Providence Member, generally is thin or missing, but locally is as much as 4 ft thick. The Baker (No. 13) coal bed, just above the top of the Providence Limestone Member, commonly consists of one or two, but in a few places, three coal beds, separated by shale, siltstone, sandstone, and locally limestone, all in a zone as much as 40 ft thick. The lowest coal bed is the thickest, as much as 9 ft, and the most persistent. The Baker coal zone commonly is abruptly terminated by channel sandstone assigned to the Anvil Sandstone Member, but which may actually be in other channel sequences.

The Coiltown (W. Ky. No. 14) coal bed, which is in the upper half of the section between the Providence and West Franklin Limestone Members, generally is thin and discontinuous, but thickens abruptly, and locally is as much as 9 ft thick. In the Rough Creek area, it crops out in western Ohio County to the south and west of Centertown (Plate 1A). In general, the coal beds in the Sturgis Formation above the top of the West Franklin Member are thin, discontinuous, and poorly exposed, and most can be identified only in drillholes. Most are less than 2 ft thick, rarely as much as 3 to 4 ft thick. The Western Kentucky No. 17 coal bed lies just below or within a few feet of the Carthage Limestone Member, but is missing over much of the Rough Creek area. The Lisman coal bed, generally identifiable on drill logs 140 to 235 ft above the base of the Carthage Limestone Member, is as much as 4 ft thick on outcrop in the vicinity of Nebo in the southwestern part of the Rough Creek area.

The Geiger Lake coal bed occurs in the upper part of the Sturgis Formation above the Dixon sandstone and about 500 to 590 ft above the base of the Carthage Member. Greb and others (1992, Fig. 56) erroneously placed the Geiger Lake bed below a sandstone body they identified as the Dixon sandstone of Glenn (1912). Kehn (1974, 1975a, b), Hansen (1975, 1976a), and Palmer (1976) mapped the Geiger Lake bed over a large area south of the Rough Creek Fault Zone in the southwestern part of the Rough Creek area, and all placed the coal bed above sandstone identified as the Dixon or above thick, unnamed sandstone bodies in the stratigraphic position of the Dixon. Also, Kehn (U.S. Geological Survey, written commun., 1993) stated that detailed correlation of numerous coal-test logs in this part of the Rough Creek area confirmed the position of the Geiger Lake above the Dixon. As noted by Greb and others (1992), the presence of several sandstones of similar thickness, texture, and position above and below thin coal beds in the upper part of the Sturgis Formation could easily contribute to miscorrelation. The Geiger Lake coal bed generally is less than 2 ft thick, but locally is reported to be as much as 4 ft thick.

The Sulphur Springs coal bed, about 200 ft below the top of the Sturgis Formation, is present in the Rough Creek Fault Zone at Cap Mauzy Lake, about 5 mi southeast of Morganfield. Based on palynological data (R.A. Peppers, Illinois State Geological Survey, written commun., *in* Kehn and others, 1982), the Sulphur Springs is equivalent to or younger than the Pittsburgh coal bed of the Appalachian area, and is the youngest coal bed of Late Pennsylvanian age presently identified in western Kentucky.

The restricted Sturgis Formation is about 2,050 to 2,120 ft thick in the Cap Mauzy Lake area, where it is overlain by the Mauzy Formation of Early Permian age; elsewhere, the upper part of the formation is removed by erosion. The Sturgis Formation overlies the Carbondale Formation with which it intergrades (Kehn, 1973). For convenience of mapping, the contact is placed at the base of the Providence Limestone Member. The Providence rests directly on or in close proximity to the Herrin (W. Ky. No. 11) coal bed of the Carbondale. The Providence Limestone and the Herrin bed together form a zone that is easily recognized.

Withdrawal of the sea at the end of the Mississippian Period exposed a vast, low plain covering the eastern Midcontinent region. Drainage on this southwest-sloping plain was through an intricate system of major and minor stream valleys whose ultimate destination was the Ouachita Trough along the continental margin. Deposition of Pennsylvanian strata represented a resurgence of the ancient Michigan River system, and was dominated by many prograding and shifting delta lobes (Pryor and Sable, 1974). The deposits record the complex and fluctuating relationships between the fluvial and deltaic environments of the river system and the shallow-marine environment into which much of the sediment load was discharged. The sandstone and conglomerate of the Caseyville Formation, the oldest Pennsylvanian unit, represent mostly deltaic deposits that filled the valleys and eventually overtopped the stream divides.

The infilling of the valley system may have been accomplished in several stages of aggradation, as illustrated by the Brownsville Paleovalley (see Fig. 18) in Edmonson and Hart Counties, Ky. (Pryor and Potter, 1979). The Brownsville Paleovalley fill is well exposed in the spillway of the dam of Nolin Reservoir, which is about 7 mi south of the southeastern corner of the Leitchfield quadrangle in the Rough Creek area. The initial fill was deposited in that paleovalley by a braided stream of low sinuosity, but a younger fill was deposited by a meandering stream of high sinuosity.

Brief and limited incursions of marine waters into paleovalleys, as recorded by a thin sequence of marine sedimentary rocks in the basal part of the Caseyville Formation near the southeastern corner of the Rough Creek area (Glick, 1963), occurred locally before widespread infilling. A later marine transgression that overtopped the Mississippian-Pennsylvanian unconformity on a paleo-upland surface about 400 ft topographically above the Brownsville Paleovalley, is recorded in basal Pennsylvanian siltstone and shale containing many and diverse marine trace fossils along the Wendell H. Ford Western Kentucky Parkway just west of Leitchfield (Greb, 1989b) in the southeastern part of the Rough Creek area.

Other marine incursions, recorded by the Drury Shale Member of the Caseyville Formation and the very limited Sellers Limestone Bed in the Drury Member of southeastern Illinois, occurred between deposition of the progradational deltaic sandstones of the Battery Rock Member and those of the younger Pounds Member of the Caseyville. No equivalent of the Sellers Bed has been observed in western Kentucky. The Drury Member contains marine fossils in some areas and coal and terrestrial plants in others; thus, the member represents a variety of depositional environments from marine to distributary embayment to delta-front to swamp-and-marsh deposition on a delta plain (Fraunfelter, 1979; Dever and others, 1987). The Sellers Limestone Bed may represent bay-mouth bar sedimentation (Fraunfelter, 1979). Trace-fossil assemblages in Lower Pennsylvanian rocks of southern Illinois (Devera, 1989) indicate a greater degree of marine influence than deltaic influence than was previously interpreted for these strata. Complementing that observation is the recognition in south-central Illinois of finely laminated siltstone and claystone in rocks equivalent to the Caseyville Formation that show tidal influences (Kvale and Archer, 1989).

The Caseyville sandstones are primarily distributary-channel deposits but include deposits of characteristically related deltaic environments (Koeninger and Mansfield, 1979). According to Wanless (1975), most of the sand of the Caseyville was derived from sources northeast of the Illinois Basin, namely the Canadian Shield and the northern Appalachian Highlands, but crystalline rocks in the Virginia Piedmont (also called the Appalachian metamorphic source area by Rice and Weir [1984]) probably was the source of at least some of the quartz gravel so conspicuous in the channel-fill deposits. Nelson (1989) questioned the validity of the Canadian Shield as a major source area, however, and pointed out that the area is composed of Precambrian igneous and high-grade metamorphic rocks overlain by carbonate rocks that should yield arkose or subgraywacke, not pebbly quartzarenite. Deposition of the Caseyville and related Morrowan sediments was restricted to the southeastern part of the proto-Illinois Basin, centered around the common corner of Illinois, Kentucky, and Indiana.

During deposition of the Tradewater Formation, mostly during the Atokan and early Desmoinesian, the depocenter in the basin remained at the junction of the three states, but Atokan strata overlapped Morrowan beds toward the margins of the basin. A great thickness of deltaic sand filled the rapidly subsiding depocenter, and the sand intertongued westward into thinner, fine-grained marine beds. Marine transgressions to at least the present erosional limits of the Tradewater are recorded by the Lead Creek Limestone Member and the younger Curlew (Lewisport) Limestone Member of the Tradewater in Kentucky and their equivalents in Indiana.

Fossiliferous marine facies in sandstones at several localities across southern Illinois that were thought by previous workers to be roughly equivalent to the informal Boskydell sandstone of Jackson County, Ill., called the "golden sandstone" by Nelson and Lumm (1990), have been dated by Peppers (1993) on the basis of the palynology of coal beds above and below the sandstones. Peppers found that the marine sandstones range stratigraphically from the lowest to the middle part of the Tradewater Formation, the age range being from earliest Atokan to the boundary between the Atokan and the Desmoinesian, which is in the middle of the Tradewater. The zone of marine fossils in the Boskydell sandstone in Jackson County, Ill., which is just above the middle of the Tradewater, probably is equivalent to the Curlew Limestone Member of western Kentucky (Peppers, 1993). No limestone counterparts of the several fossiliferous, marine-sandstone facies identified as older than the "golden sandstone" are known elsewhere in the Illinois Basin.

Wanless (1975) thought that the Curlew and the equivalent Perth Limestone in Indiana and older limestone units along the eastern margin of the basin may have been deposited in seas that transgressed from the east. In southwestern Indiana, sedimentation on a lower delta plain was interpreted by Nelson and others (1991) for the clastic beds of the Brazil Formation of Indiana that are equivalent to Tradewater strata below the Curlew (Lewisport) Member in Kentucky.

During the Desmoinesian, the depositional period of the Carbondale Formation, sedimentation was mostly in deltaic environments (Wanless and others, 1970) associated with southwest-prograding deltas centered in southeastern Illinois and adjacent parts of Indiana and western Kentucky. The Desmoinesian strata are shale and siltstone and lesser amounts of subgraywacke. Numerous thin but widespread beds of underclay, coal, black fissile shale, and marine limestone are characteristic of this part of the Pennsylvanian section. A synthesis of deltaic and eustatic processes probably best explains Desmoinesian sedimentation (Nelson and others, 1991). As described by those authors, the proto-Illinois Basin at this time was part of a vast coastal plain and shelf area of very low gradient over which, with each eustatic marine transgression, the shoreline advanced hundreds of miles. Marine black shale and limestone, containing marine to brackish-water invertebrate faunas (Atherton and Palmer, 1979), were deposited during transgression onto abandoned deltas. The black fissile marine shale was laid down in very quiet water in which anoxic-reducing conditions prevailed.

Upon standstill or gradual regression, the deltas again prograded into the basin, and typically deposited coarsening-upward clastic wedges, which were in turn incised by fluvial and distributary channels. Coal-forming swamps developed on the deltaic platform. The intimate relation of nonmarine and marine depositional environments in a delta setting is well illustrated by the facies of the Energy Shale Member of the Carbondale Formation, which overlies the Herrin coal bed in parts of southern Illinois. The facies, described by Burk and others (1987), represent proximal-crevasse splay, distal-crevasse splay, nonmarine-bay, brackish-marine-bay, marginal-marine, and pond deposits.

Most limestone in the Carbondale is marine and was deposited, as was the Brereton Limestone Member in Illinois and its equivalent in Kentucky, the Providence Limestone Member at the base of the overlying Sturgis Formation, as shallow-water open-marine carbonate rock (O'Connell and Utgaard, 1983). Some limestone, however, particularly that beneath coal beds, may be lacustrine or lagoonal (Wanless and others, 1970). The major source areas for Desmoinesian sediments probably were in the northern Appalachians and Canadian Shield, but the Cincinnati Arch may have been a minor source, and some sediment in the northern part of the basin came from a northern, unnamed source (Wanless, 1975).

Deposition of the Sturgis Formation in Kentucky and rocks of the McLeansboro Group in Illinois and Indiana, which encompass late Desmoinesian, Missourian, and Virgilian time, reflects a continuation of the fluvial and deltaic conditions of the Carbondale. Successive development of eight to 15 deltas in the basin is recorded in Missourian strata (Wanless, 1975). The center of Late Pennsylvanian deposition remained in southeastern Illinois and western Kentucky, and during the early and middle Missourian, the major source areas also remained to the northeast. Later, during the Pennsylvanian, clastic wedges that have been interpreted as deltas prograded from the southeast, south, and to a lesser degree from the southwest (Horne, 1968; Giffin, 1978) from apparent source areas in the southern Appalachian or Ouachita Mountains (Nelson and others, 1991).

Coal and underclay frequently developed on the abandoned deltaic platform (Wanless, 1975) and commonly graded into marine mudstone and limestone. Rocks of Missourian age, especially in the western part of the basin, contain a greater proportion of limestone than the older Pennsylvanian units. In western Kentucky, however, only the Providence Limestone Member at the base of the Sturgis Formation and the younger West Franklin and Carthage Limestone Members are regionally persistent. The distribution of the Missourian deltas indicates both deepening of the sea and sediment transport southward (Wanless and Wright, 1978) into the shrinking Arkoma Basin north of the rising Ouachita orogenic belt. At odds with that observation was Wanless's earlier statement (1975) that the late Missourian and Virgilian limestone units in Illinois were deposited in a sea that transgressed from the west around the north side of the emergent Ozark uplands.

Houseknecht and Kacena (1983) postulated that by Missourian time the Pascola Arch had been uplifted sufficiently to close the Illinois Basin to the south and divert sediment dispersal around the north side of the Ozarks. Kolata and Nelson (1991a) disagreed, however, with both the timing of uplift of the Pascola Arch and the assumption of a northern dispersal pattern. Kolata and Nelson (1991a) pointed out: (1) the lack of sediment shed northward into the basin from the Pascola Arch during Missourian and Virgilian time, (2) the existence of an open-marine environment in the southern part of the basin during deposition of the Lower Permian Mauzy Formation rather than a terrestrial environment, which would be expected on the flanks of an arch, and (3) the presence of the Mississippi River Arch (Fig. 3) on the northwestern margin of the basin by Missourian time, which would have blocked sediment transport around the northern side of the Ozarks.

Little is known about the depositional conditions in western Kentucky in the Late Pennsylvanian, but the analysis by Scheihing and Langenheim (1985) of the depositional environments of the Shumway Limestone Member of the Mattoon Formation of early Virgilian age gives insight into the marine conditions in southeastern Illinois at that time. In the Shumway sequence, after the development of a coal swamp on coastal-plain sediments, marine shale was deposited in a deepening, transgressive sea. Continued transgression resulted in limestone deposited on a shallow-water, open-marine shelf. As the water deepened, anaerobic conditions developed and persisted during deposition of black shale at the time of maximum transgression. Shallowing of the sea is reflected first by deposition of nearshore-marine shale, then by deposition of the Shumway limestone on an open-marine shelf. The cycle ended with the return of floodplain and fluvial-channel deposition (Scheihing and Langenheim, 1985, Table 1). Only the Shumway limestone, the black shale, and a gray nonmarine shale occur throughout the known distribution area of the Shumway cyclothem. No equivalent of the Shumway is recognized in western Kentucky. The environmental conditions of the Late Pennsylvanian continued into the Permian without major change or interruption.

Permian System

Mauzy Formation

The discovery of fusulinids of Early Permian (Wolfcampian) age (Douglass, 1979, 1987) in strata formerly assigned to the uppermost part of the Sturgis Formation in western Kentucky led Kehn and others (1982) to describe those beds and to remove them from the Sturgis and assign them to a new formation, the Mauzy. The only known occurrence of the Mauzy is in a graben block in the Rough Creek Fault Zone at Cap Mauzy Lake about 5 mi southeast of Morganfield, Ky. The type section is mostly in a core test hole drilled about 2 mi west of the lake in an area where the surface rocks are generally covered by loess. The Mauzy consists of shale and siltstone (70 percent), limestone (25 percent), and sandstone (5 percent). The contact between the Mauzy and the underlying Sturgis Formation is gradational and is placed at the base of a sequence of marine limestone and siltstone about 200 ft above the Sulphur Springs coal bed of the Sturgis Formation, which is equivalent to or slightly younger than the Pittsburgh coal bed of the Appalachian area (R.A. Peppers, Illinois State Geological Survey, written commun., *in* Kehn and others, 1982).

The Mauzy Formation has a minimum thickness of about 400 ft, but based on structural projections within the graben block, it may be as much as 1,300 ft thick.

The shale of the Mauzy is medium to dark gray and greenish gray, clayey to silty, and commonly interlaminated with light-gray siltstone and less commonly with sandstone. The shale is calcareous where associated with limestone and locally contains siderite bands. Some thin layers are very dark gray to black, carbonaceous and coaly, and fossiliferous.

The limestone of the Mauzy is light gray to yellowish brown, finely crystalline, dense, commonly argillaceous, and interbedded with clay shale. Fossils in the limestone include a few large *Triticites* sp. of Early Permian age (Douglass, 1979). The sandstone of the Mauzy, which is confined mainly to the upper part, is medium gray, fine grained, in part calcareous, and commonly interlaminated with shale. A very thin streak of bone coal, associated with carbonaceous shale, is present in the basal part of the formation.

The deltaic and marine environments recorded in Upper Pennsylvanian rocks of western Kentucky and adjacent parts of Illinois and Indiana appear to have continued without interruption into the Lower Permian. Post-Permian erosion has removed all strata of Permian age except that preserved in the Rough Creek Fault at Cap Mauzy Lake, but rocks of Permian and possibly younger ages must have been more extensive in the proto-Illinois Basin. Studies on the relation of lithification of Pennsylvanian coal beds and underclays to former depths of burial (Altschaeffl and Harrison, 1959; Damberger, 1971, 1974) indicate a thickness of original overburden of 4,500 ft in west-central Indiana to possibly 10,500 ft in the Moorman Syncline in western Kentucky (Nelson and others, 1991). Because the increase in the rank of coal beds in the southern part of the Illinois Basin probably was partly the result of thermal metamorphism related to a deep-seated pluton (Damberger, 1971, 1974), the calculated overburden thickness in that area could be excessive.

Fossils in limestone of the Mauzy Formation indicate that in the Early Permian an open-marine environment interfaced with continued deltaic environments of the Michigan River system. The abundance of fine, terrigenous sediment and the paucity of sand in the Permian strata point to deposition of the clastic sediments away from the main delta channel of the Michigan River system, perhaps as prodelta muds or delta-plain deposits. The fineness of the sediments also indicates distant source areas, probably the same ones to the northeast in Canada or in the northern Appalachians that supplied most of the detritus during the Late Pennsylvanian.

Tertiary and Quaternary Deposits

Gravel deposits, preserved as terrace remnants, loess on uplands, and glacial outwash and alluvium in stream valleys, mantle the rocks of Carboniferous age throughout the Rough Creek area. Deposits of Late Cretaceous age are extensive at the head of the Mississippi Embayment in southernmost Illinois and western Kentucky, but the closest of these deposits is about 15 mi southwest of the Rough Creek area in the Ohio River Valley just east of Paducah, Ky., and along the valley of the Cumberland River. Cretaceous sediments may have been laid down as deltaic deposits over part of the Rough Creek area by a river system flowing west across western Kentucky, as inferred by Pryor (1960, Fig. 17), but no remnants of these deposits remain.

The long interval of geologic time between deposition of Permian strata and deposition of materials from the continental glaciers during the Quaternary apparently was one of subaerial erosion, and much of the Midcontinent region was reduced to a low-lying plain of slight relief. The erosional surface, called the Lexington Plain by Campbell (1898), was uplifted, perhaps in the middle Tertiary (Miocene) (Ray, 1965); Potter (1955b) assigned a Pliocene age to the epeirogenic uplift. Stream dissection has greatly reduced the plain, so that the only relicts are upland flats, ridge crests, and hilltops that rise to roughly accordant summit levels. No relicts of the Lexington Plain are recognized in the Rough Creek area. Relicts of an old surface, capped by brown chert gravel, however, are present at an altitude of about 500 ft on the Shawneetown Hills of southeastern Illinois (Butts, 1925), just west of the Ohio River floodplain from Kentucky. Might this surface be correlative with the Lexington Plain, or is it more likely that it is correlative with a Pliocene-Pleistocene surface in the Rough Creek area described below?

In western Kentucky, streams flowed from the east and southeast down the paleoslope on the Lexington Plain toward the Gulf Embayment. With uplift, the streams dissected the Lexington Plain, and through intermittent and possibly differential uplift during the Pliocene cut a sequence of gravel-capped erosional surfaces on which the scattered deposits in the Rough Creek area are now the only identifiable remnants. By the close of the Tertiary Period, the present landscape of the area probably was largely defined. The Ohio River was flowing in a deeply incised bedrock valley whose bottom at places is about 200 ft below the top of the present alluvial fill. Tributary valleys of the Green and Tradewater Rivers were graded to the Ohio. A bedrock bench, now concealed by valley alluvium, is present along the side of the Ohio River Valley in the Owensboro and Henderson areas. It occurs below the bench along the valley wall at the 400-ft level that is capped by the lowest exposed

Pliocene-Pleistocene chert gravel and above the bedrock bottom of the river valley (Ray, 1965). The beginning of alluviation of the valley in response to the advance of the first continental glacier into this part of the Midcontinent marked the beginning of the Quaternary Period.

Pliocene and Pleistocene Gravel Deposits

Remnant deposits of gravel, sand, and silt of Pliocene and Pleistocene age are present on stream divides and as terrace remnants along the Green, Rough, Pond, and Ohio Rivers within the Rough Creek area. Many of the deposits are too small to show on the geologic map (Plate 1A) or are mostly concealed by loess and only exposed in gravel pits. The gravel was deposited on former erosional surfaces, but because of dissection of the hills, slope movement of the gravel, and the cover of loess, the exact altitudes of the old surfaces are hard to determine; some surfaces may also merge downslope with lower surfaces. The highest surface is about 600 to 620 ft above sea level, and small remnants of the surface, shown on the geologic map (Plate 1A–East), occur west of Cloverport on the divide north of Caney Creek near its headwaters. Several small remnants of this surface are also present, but not shown on the geologic map, on the north side of the Green River between Calhoun and Beech Grove, Ky. Gravel from this stratum, and perhaps from higher but now destroyed levels, has been reworked and redeposited on lower erosional surfaces.

Remnants of the next lower surface at 500 to 560 ft above sea level are present on stream divides adjacent to the Ohio River and on isolated hills adjacent to the lower valley of the Green River. There are extensive, though mostly loess-covered, gravel terrace remnants about 450 to 470 ft above sea level in the valleys of the Green and Pond Rivers; they are particularly well developed around Calhoun. The lowest gravel stratum at 400 to 420 ft is just above the valley bottoms. The deposit at the 400-ft level in the Ohio River Valley around Owensboro was called the Luce Gravel (Ray, 1965).

The gravel in all the deposits, which are as much as 25 ft thick locally, is predominantly yellowish- and reddish-brown, dense, porous, fossiliferous chert, but includes some white quartz, reddish-brown sandstone, silicified limestone, white to pink quartzite, and ironstone. It is subangular to subrounded and ranges in size from granules less than 0.01 ft in diameter to cobbles as much as 1 ft long. The gravel is interbedded with lenses of clayey silt and fine to coarse, clear quartz sand. Some deposits show low-angle crossbeds and locally are cemented by iron and manganese oxides to form tabular blocks of conglomerate.

The Pliocene and Pleistocene gravel-terrace remnants contain no igneous or carbonate rocks or heavy minerals characteristic of the glacial outwash in the Ohio River Valley, because the deposits predate Pleistocene glaciation. The chert gravel deposits are lithologically and genetically correlative with the Mounds Gravel of Illinois (Willman and Frye, 1970); with the brown chert gravel of the Jackson Purchase Region of western Kentucky, formerly called the Lafayette Gravel (Potter, 1955a); and with the unit, called continental deposits, in the Western Kentucky Fluorspar District.

The chert gravel deposits in the Rough Creek area were assigned a Pliocene and Pleistocene age, based primarily on their lack of glacially derived material. The age of the Mounds Gravel (continental deposits) apparently is not well constrained. In a number of quadrangles in the Western Kentucky Fluorspar District (Amos and Wolfe, 1966; Amos, 1967, 1974; Amos and Finch, 1968), the assigned age of the continental deposits is Pliocene(?) and Pleistocene, whereas Nelson and others (1997) assigned a late Miocene to early Pleistocene age to the Mound Gravel in southern Illinois. In the same report, however, Nelson and others (1997) assigned a Pliocene to early Pleistocene(?) age to the Mound Gravel in a narrow graben associated with the Lusk Creek Fault Zone in Illinois on the northern boundary of the fluorspar district.

Pleistocene Deposits

Glacial Outwash. The geomorphology and Quaternary geology of the Ohio River Valley around Owensboro were studied by Ray (1965), and he assigned the two major terraces cut on glacial outwash within the Ohio River Valley to the Tazewell and Cary substages of the Wisconsinan; these substage names have since been abandoned by the U.S. Geological Survey. In Illinois, the deposits formerly assigned to the Tazewell and Cary are included in the Woodfordian substage of the Wisconsinan (Frye and Willman, 1960); the nomenclature of Frye and Willman is used in this report.

Although the continental ice sheets did not invade the Rough Creek area, their intrusion into the Ohio River drainage system above Louisville, Ky., and the proximity of several sheets in southeastern Indiana and southern Illinois had a profound effect on the Ohio River Valley, which served as a major sluiceway for glacial meltwater and glaciofluvial debris. The Quaternary deposits in the Rough Creek area are related directly and indirectly to the alluviation. Glaciofluvial material was deposited in the Ohio River Valley as outwash trains of two pre-Illinoian and the Illinoian ice sheets that debauched directly into the valley above Louisville (Ray, 1974). The pre-Illinoian sheets were identified as Nebraskan and Kansan by Ray (1974); however, those names have now been abandoned in their type areas in the Central Plains Region (Hallberg, 1986) and have been replaced by the broader term "pre-Illinoian, undifferentiated." Although the last ice sheet, the Wisconsinan, failed to reach the Ohio River Valley, vast quantities of glacial outwash reached the Rough Creek area by moving down the valley. The Wabash River on the Illinois-Indiana state line also was a major meltwater spillway into the lower Ohio River Valley from the younger of the pre-Illinoian (Kansan of previous usage) ice sheets and from the Illinoian and Wisconsinan sheets. Although no major rivers in Indiana drain south into the Ohio River Valley from Louisville downstream to the mouth of the Wabash River, a small amount of outwash may have entered the Ohio River Valley through the small Blue River (Ray, 1965).

Although the two pre-Illinoian and the Illinoian ice sheets probably discharged vast quantities of outwash into the upper valley of the Ohio River, and the valley trains reached the Owensboro area, no alluvial deposits of those sheets can be identified, because they are now concealed by younger alluvium (Ray, 1965). The highest level of valley fill is of Wisconsinan (Woodfordian) age; the fill corresponds to the terrace remnants called "Tazewell" by Ray (1965), and is referred to as the lower Woodfordian deposits in this report. The outwash deposits of Wisconsinan age, termed "Cary" by Ray (1965), are herein called the upper Woodfordian deposits. The volume of deposits of the three earlier ice sheets may not have been sufficient to fill the valley above the level later reached by deposits of Wisconsinan age. Because of the lithologic similarity of the deposits of the various outwash trains, no major discontinuities can be recognized in the valley fill.

The oldest alluvial deposit of Quaternary age recognized within the Ohio River Valley in the Rough Creek area crops out in the river bank at Owensboro beneath deposits of the lower Woodfordian valley train. The deposit, termed "the Beds at Hubert Court" by Ray (1965), consists of 18 ft of dark-gray, clayey to finely sandy silt, clay, and fine sand. The unit has a carbon-14 date of 23,150 ± 500 BP (Rubin and Suess, 1956, sample W-270), which indicates a late Farmdale (middle Wisconsinan) or immediately post-Farmdale age (Ray, 1965). Because of its limited outcrop, this deposit is included with the alluvium and glacial outwash on the geologic map (Plate 1A).

The majority of the Wisconsinan glacial outwash in the Ohio River Valley in the Rough Creek area is represented by two widespread terrace remnants, both of Woodfordian age; the higher, more extensive, and older terrace is termed "the lower Woodfordian" (Tazewell terrace of Ray, 1965) and the lower and less extensive is the upper Woodfordian terrace (Cary terrace of Ray, 1965). The Wisconsinan glacial outwash deposits are combined with the alluvium on the geologic map of the Rough Creek area (Plate 1A). Both Woodfordian terraces are mantled by thick, fine-grained surficial sediment that masks underlying coarse sand and gravel, which are lithologically indistinguishable in the two terraces. The coarse deposits are rarely exposed and are known mainly from drillhole samples. The sand is fine to coarse, friable, generally well sorted, and mainly of subrounded quartz grains, but contains many grains of glacially derived igneous and metamorphic rocks. The sand is finer and more silty upward in the deposits. Gravel generally is composed of subangular to subrounded granules and pebbles of quartz, chert, limestone, sandstone, and ironstone, and lesser amounts of igneous and metamorphic rocks in a matrix of coarse sand. Lenses of gravel are more numerous in the lower part of the deposits. A few cobbles and small boulders generally of quartzite are found in most gravel pits and are reported to locally overlie bedrock on the valley bottom (Gallaher, 1963). Silty clay and silt constitute the upper part of the deposits, and lenses of clay, probably of lacustrine origin, commonly are interbedded with coarser sediments at the mouths of streams tributary to the Ohio River. The thickness of the Woodfordian glacial outwash is as much as 170 ft at Owensboro, and averages about 140 ft along the Ohio River Valley in the Rough Creek area.

Dune Sand. Sand dunes that are genetically related to the lower Woodfordian valley train are conspicuous topographic features on the terrace surface. The dunes, which are included with the outwash and alluvial deposits on the geologic map (Plate 1A), are low, irregular hummocks or in places well-defined ridges as much as 10 mi long, such as the prominent ridge that extends southwest through Owensboro. The material in the dunes was picked up by winds blowing across broad, alluvial flats within and north of the Ohio River Valley and deposited on the lower Woodfordian valley train deposits against the valley sides or on bluffs adjacent to the valley. The sand in the dunes is dominantly very fine to fine, subangular, and finely laminated. The silt is clayey, slightly micaceous, and in part weakly calcareous. Loess mantles all the dune deposits, and in places loess-like silt is intercalated with the dune sand. A maximum thickness of 55 ft of dune sand has been observed, but most deposits are likely of considerably less thickness. Exposures completely through the dune deposits, however, are rare.

Lacustrine Deposits. Extensive deposits of clay and silt underlie broad alluvial flats and low terrace remnants at an altitude comparable with that of the lower Woodfordian terrace along the Ohio River in the lower valleys of streams tributary to the river. These deposits developed as slack-water sediment in lakes formed when the aggrading valley trains in the Ohio River Valley blocked the mouths of the tributary streams. Ancient Green Lake, described by Shaw (1911), formerly occupied parts of the valleys of the Green and Pond Rivers, and several temporary spillways of the old lake are evident in bedrock ridges south of Beech Grove and southwest of Sebree. Shaw (1915) described beach ridges of chert gravel along the old lake, such as in places along the east side of the Pond River Valley in the Sacramento quadrangle (Hansen, 1976b), but Ray (1965, p. 41) believed that the gravels are not beach ridges, but are comparable to the chert-gravel deposit at the 400-ft level in the Ohio River Valley (Luce Gravel of Ray) near Owensboro. Large slack-water lakes occupied the lower valley of the Tradewater River and the valleys of other large streams on the east side of the Ohio River below the mouth of the Wabash River. The lacustrine deposits in these valleys are correlative with deposits included in the Equality Formation of Woodfordian age of Illinois (Willman and Frye, 1970) in old slack-water lakes, such as Lake Saline (Frye and others, 1972; Heinrich, 1982) on the west side of the Ohio River Valley opposite the Rough Creek area.

Several features in the Grove Center quadrangle (Palmer, 1976), at the western edge of the Rough Creek area, are apparently relicts of the Maumee Flood: namely, a spillway that temporarily connected the valley of Cypress Creek with the Ohio River Valley, as well as bar-like deposits (now loess-covered) along Cypress Creek. The Maumee Flood inundated the Ohio Valley below the mouth of the Wabash River about 14,000 years ago (Wayne and Zumberge, 1965). In places elsewhere in the Rough Creek area the valley mouths of streams tributary to the Ohio River are partially blocked by low alluvial ridges, termed "valley-mouth levees" by Ray (1965).

The lacustrine deposits consist of interlaminated olive-, greenish-, and yellowish-gray, silty, calcareous clay and yellowish-gray, clayey, in part finely sandy silt. Commonly, outcrops of lacustrine sediment are covered with abundant calcareous nodules that weather from the deposits. The deposits are interbedded with the Ohio Valley outwash at the mouths of tributary streams, and they merge upstream into alluvium above the former limits of the ancient lakes. Alluvial deposits in the lower Green River Valley, which are predominantly of lacustrine origin, are as much as 120 ft thick and of comparable thickness in the valley of the Tradewater River.

Loess. The northern part of the Rough Creek area is mantled by loess, derived by deflation of valley-train surfaces mainly in the Ohio River Valley, but also from alluvial flats to the north, on uplands adjacent to the Ohio Valley. The loess is thickest along the south side of the valley, where locally it is as much as 70 ft thick, but thins fairly abruptly away from the valley. The loess is composed predominantly of yellowish-brown silt, but includes minor amounts of clay and very fine sand. It is noncalcareous in the upper part and weakly calcareous below; the lower part also contains some small, irregular calcareous nodules. The loess in the Rough Creek area includes deposits of three loess sheets of Illinoian and Wisconsinan ages: the Loveland, Farmdale, and Peorian (Ray, 1965). Possible remnants of a fourth and older sheet, termed "the Kansan loess" by Ray (1965), may also be present, for Ray observed four loess deposits, the lowest a deposit of pre-Illinoian silt, in a roadcut in southern Indiana just north of the Ohio River near Yankeetown.

Fluvial Deposits

A fluvial deposit of silty, very fine quartz sand is present mostly in a cut-off meander over a limited area along the Rough River about 5.5 mi downstream from Rough River Reservoir in the Falls of Rough quadrangle (Johnson, 1977). The deposit rises from contact with the floodplain of the river to a height of about 60 ft, and in its higher part rests on bedrock. The sand is light reddish brown in the lower part and light grayish yellow in the upper part.

Alluvium

The alluvium underlying the floodplain of the Ohio River and the alluvium in the valleys of the other large streams in the Rough Creek area represent sediment deposited largely by lateral accretion of channel deposits along the shifting streams. The sediment in the Ohio Valley was mostly derived from reworked glacial outwash deposits within the valley, whereas that in tributary valleys was from eroded bedrock within the particular drainage basin and from adjacent loess-covered uplands. Because of lithologic similarity with the glacial outwash, the base of the Holocene alluvium generally cannot be defined, for fine sand and fine gravel constitute much of the lower part of the alluvium, as well as the upper part of the outwash deposits. The surface of the Ohio River floodplain is capped by a thick layer of silty clay and clayey silt, and locally sand forms bars along the river channel. Alluvium along the tributary streams is mainly silt, but contains gravel of yellowish-brown chert, derived in part from the Pliocene and Pleistocene terrace deposits, and sandstone, limestone, ironstone, shale, and fragments of coal from Mississippian and Pennsylvanian bedrock. In the valleys that contained slack-water lakes during the Pleistocene, the Holocene alluvium overlies fine lacustrine deposits and is not readily distinguishable from the older sediments.

Igneous Rocks

No outcrops of igneous rocks have been reported within the boundaries of the Rough Creek area, but lamprophyre dikes occur within the Western Kentucky Fluorspar District, both just south of and to the northwest of the southwestern corner of the area. All the mafic dikes and sills in Kentucky have been identified as mica peridotite or lamprophyre according to Koenig (1956), who has described the petrography of these intrusives; the lamprophyre is distinguishable by lack of olivine or olivine ghosts. Trace and Amos (1984) discussed in detail the distribution and stratigraphic and structural relations of the dikes and sills in the Western Kentucky Fluorspar District. Surface exposures are uncommon and difficult to find, because the mafic rock decomposes rapidly to form a clay residuum. The dikes are commonly 5 to 10 ft thick, dip from about 80° to vertical, and trend N20° to 30°W. In the fluorspar district, the dikes intruded rocks ranging from the Warsaw Limestone of Meramecian age to the Caseyville Formation of Early Pennsylvanian age. Cretaceous and Tertiary beds are present locally in the district, but no mafic dikes appear to have intruded those rocks. Although the principal faults in the fluorspar district are northeast-trending, most of the dikes are found along northwest-trending faults or fractures that have little vertical displacement but have horizontal displacement of an unknown amount, as indicated by slickensides. A few dikes trend to the north, but none are present along northeast-trending faults. The northeast-trending faults cut the mafic rock, so they are younger than the intrusives. Zartman and others (1967) dated mafic intrusives in the Illinois-Kentucky Fluorspar District, both in Kentucky and Illinois, by K-Ar or Rb-Sr methods (or both) and found an average Early Permian age of 267 m.y. The tectonic event during which the mafic rocks were emplaced certainly affected the nearby Rough Creek area.

Structure

The Rough Creek area is part of a very structurally complex area in the central craton of the United States at the head of the Mississippi Embayment. The embayment developed on a crustal rift of Precambrian age that was originally thought to branch into three distinct arms at its northern terminus in western Kentucky and southeastern Illinois (Braile and others, 1982a, b; Braile and others, 1982b). A later review of the evidence led Nelson (1990, 1991) to conclude that only the eastern arm, the Rough Creek Graben, is an integral extension of the rift structure. The craton in this area has been gently downwarped to form the southern end of the Illinois Basin. This part of the basin is broken by five major fault systems (Fig. 20): (1) the Rough Creek–Shawneetown system, which trends westward from western Kentucky into southeastern Illinois, (2) the Pennyrile system in western Kentucky, which trends generally parallel with but south of the Rough Creek system, (3) faults of the Illinois-Kentucky Fluorspar District, which extend southwestward and apparently join with faults along the axis of the northern Mississippi Embayment, which are concealed by alluvial deposits, (4) the Cottage Grove system, which is on trend to the west of the Shawneetown zone in southern Illinois, and (5) the Wabash Valley system, which trends from the Rough Creek–Shawneetown system northeastward along the Illinois-Indiana state boundary. These fault systems are mostly reactivated basement structural features on which movement occurred in late Precambrian and early Paleozoic, Middle Devonian, late Paleozoic, and Cretaceous times, but not necessarily along all zones in each geologic period, nor along all zones at the same time.

Rough Creek–Shawneetown Fault System

The Rough Creek–Shawneetown Fault System extends west-northwestward for about 130 mi from western Hart County in west-central Kentucky to southeastern Saline County, Ill. There, it bends sharply to the southwest and extends another 12 mi to a junction with the Lusk Creek Fault System in northern Pope County, Ill. The first reference to the Rough Creek structure was by Owen (1856); it was later named the Rough Creek Uplift by Norwood (1876). The Rough Creek–Shawneetown Fault System defines the northern flank of the Moorman–Eagle Valley Syncline, which occupies a broad area of western Kentucky and an adjacent but narrower area of Illinois. Although the fault system is a continuous structure, separate names have been applied to the Kentucky part (the Rough Creek Fault Zone) and to the Illinois part (the Shawneetown Fault Zone). In this report, the name "Rough Creek–Shawneetown Fault System" is applied to the structure as a whole, and the individual names are used when discussing the separate parts.

Rough Creek Fault Zone

The Rough Creek Fault Zone is a sinuous belt about 0.25 to about 5 mi wide of high-angle normal and reverse faults that extends from the Ohio River west of Morganfield, Ky., southeastward to western Hart County. In general, the zone is widest in its western part, particularly in northern McLean County, but diminishes in width eastward and dies out in a series of fault splays at the eastern end. In the western part, the structure is mostly steeply tilted, upthrown fault blocks; the eastern part is a faulted anticline.

The faults of the zone form an anastomosing pattern and break the zone into multiple, narrow, tilted horst and graben blocks. Horsts are more numerous,

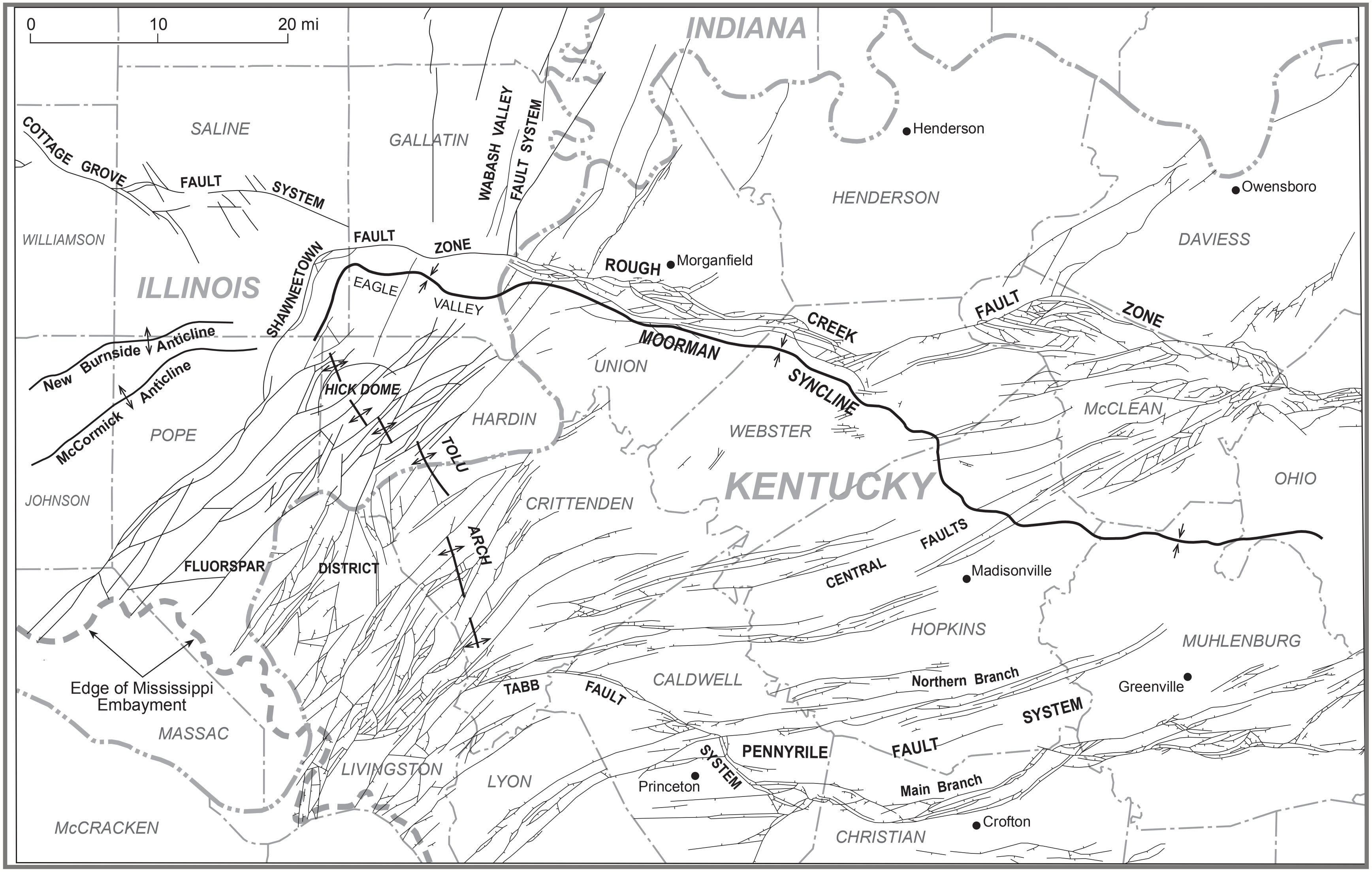

Figure 20. The main fault systems in the southern part of the Illinois Basin. Modified from Treworgy (1991), Nelson (1991, Fig. 16-21); used with permission of the American Association of Petroleum Geologists..

and those with the greatest displacement lie generally along the northern margin of the zone. In general, the amount of displacement between fault blocks decreases stepwise to the south.

The complex pattern of high-angle normal and reverse faults of the Rough Creek zone are well displayed on Plate 1B. The fault pattern, however, does not portray the true complexity of the zone. Many wells drilled in the zone cut faults that either do not come to the surface, do not offset the structure-contour horizon, or were not recognized at the surface because of poor exposure. Some wells drilled since completion of the geologic quadrangle maps have shown both the existence of additional faults and changes in the subsurface position of known faults at various stratigraphic horizons. The structure-contour map (Plate 1B) generally reflects the available well data as of November 1979; however, intensive drilling for oil and gas in the Glenville and Utica quadrangles, south of Owensboro, in the early 1980's revealed both additional faults and changes in the mapped position of known faults in the Rough Creek zone. So the structure on Plate 1B in those quadrangles reflects the more recent data.

As the north-bounding fault of the Rough Creek Graben (the Moorman Syncline at the surface), the Rough Creek Fault from Webster County, Ky., westward is expressed seismically as a single listric normal fault that splits above the top of Cambrian strata into a series of high-angle normal and reverse faults (Bertagne and Leising, 1991; Nelson, 1991). Vertical separation is 6,600 to 10,000 ft at the inferred top of Precambrian basement, but much less at the top of the Knox Group (Upper Cambrian and Lower Ordovician), and even less upward in the section. East of Webster County, the magnitude of offset on the top of basement diminishes, and several south-facing normal faults appear to be present.

Reverse Faults. Over much of the area from the Ohio River eastward into western McLean County, a high-angle reverse fault, upthrown on its southern side, defines or lies close to the northern edge of the Rough Creek zone. The reverse fault is not continuous, but is broken into several long, arcuate segments separated by segments 4 to 5 mi wide bounded by high-angle normal faults, also downthrown to the south, that cut off the reverse fault at acute angles. The reverse fault terminates to the east against a northeast-trending normal fault in the northwestern quarter of the Calhoun quadrangle. Along the easternmost 6 mi, the reverse fault is present near the middle of the fault zone and is separated from the northern margin of the zone by a series of complex fault blocks bounded by normal faults. The reverse fault continues westward into Illinois, where it is the frontal fault of the Shawneetown zone.

Short segments of reverse faults, upthrown on the south, are also present at several localities farther east of the frontal reverse fault in the Rough Creek zone, both along the northern edge and within the zone; because loess and alluvium conceal much of the zone and because of the lack of well data, these reverse faults could be traced with certainty for only short distances. In fact, some of the faults near the northern edge of the zone, for example in the Dundee quadrangle (Goudarzi and Smith, 1968a), that were mapped as nearly vertical normal faults may actually be high-angle reverse faults. Northwest of Leitchfield, in Carter coordinate sec. 25-M-38 in the McDaniels quadrangle (Johnson, 1978b), a well in a fault block in the Rough Creek zone cuts a reverse fault with about 1,200 ft of stratigraphic throw (Freeman, 1951). Although the reverse fault could not be recognized at the surface and the bounding fault on the north side was mapped as a high-angle normal fault, the fault block is underlain by the Fort Payne Formation (Lower Mississippian, Osagean) upthrown against Chesterian (Upper Mississippian) rocks, which represents about 1,000 ft of stratigraphic offset.

Dip measurements on reverse faults in the Rough Creek zone are very limited, restricted mainly to areas of closely spaced wells where the dip of the fault plane could be calculated. Although the dip of most reverse faults could not be measured, the traces of the faults are nearly straight or broadly sinuous, an indication that the fault planes are very steeply dipping. Near the western end of the Rough Creek zone in the Grove Center quadrangle, the frontal reverse fault dips to the south about 65°, but to the east in the Morganfield quadrangle, in the Morganfield South Oil Field (Fig. 21), the dip ranges from 70° to as little as 25° (Smith and Palmer, 1981).

In their study of faulting in part of the Morganfield South Oil Field, Smith and Palmer (1981) showed that the dip of the reverse fault along the northern edge of the Rough Creek zone is variable. A wedge of the Fort Payne Formation (Lower Mississippian) as much as 450 ft thick has been transported along the reverse fault and juxtaposed against Lower Pennsylvanian and Lower Mississippian beds in the footwall and headwall of the fault. The Fort Payne strata are much above their normal stratigraphic position, and according to Smith and Palmer (1981) must have originally been thrust farther north along the reverse fault, and then later moved back to their present position. The south-dipping strata in the hanging-wall block of the thrust are broken into a series of narrow graben blocks by north-dipping normal faults that do not offset the thrust. The footwall block is also broken by numerous normal faults, but these dip mainly to the south.

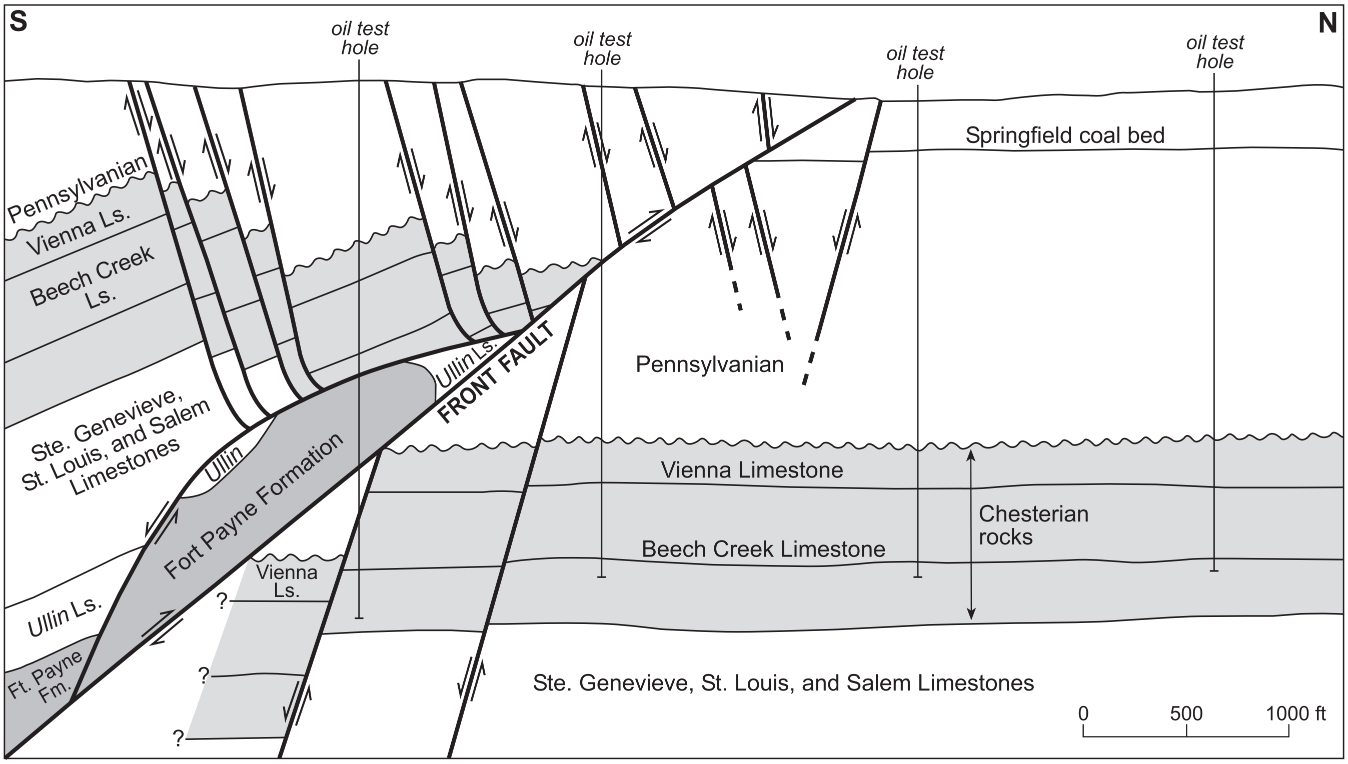

Figure 21. Section across the frontal fault of the Rough Creek Fault Zone, Morganfield South Oil Field, near Morganfield, Ky. Slightly modified from Smith and Palmer (1981).

Normal Faults. The normal faults of the Rough Creek zone generally are aligned subparallel to the trend of the zone and break the area into long, narrow blocks. In places, however, cross faults at high angles to the boundary faults break the blocks into subsidiary parts. Several of the normal faults that lie south of the frontal reverse fault near the Ohio River extend to the west into Illinois and join with the Ringold and Ringold South Faults of the Shawneetown Fault Zone, mapped by Nelson and Lumm (1984).

In the Rough Creek Fault Zone, dip measurements on normal faults are limited by poor exposures; they generally are 60° to about 90° and average about 72°. No data on slickensides or mullion were recorded by authors of the geologic quadrangle maps.

The most comprehensive view of structure of the Rough Creek Fault Zone is in a roadcut at milepost 53 on the Green River Parkway southeast of Owensboro. This locality in the Pleasant Ridge quadrangle (Goudarzi and Smith, 1968b), exposed after the quadrangle was mapped, reveals a limited part of the fault zone, which here is almost 3 mi wide. In this area the zone is an anticline complexly broken by high-angle faults into blocks containing south-dipping beds, ranging from the Tradewater Formation (Middle Pennsylvanian) and Caseyville Formation (Lower Pennsylvanian) to the Big Clifty Sandstone and Beech Creek Limestone Members of the Golconda Formation of Late Mississippian (Chesterian) age. The structure revealed in the roadcut (Figs. 22–23) has been called the “Clear Run Horst” by Krause and others (1979) in their detailed structural analysis. It was also described later by Nelson and Lumm in 1984; Nelson was closely involved in the study by Krause and others (1979). The following abbreviated description is based on both reports. At the core of the structure is a faulted asymmetrical anticlinal fold in interbedded shale and limestone of the Menard Limestone Member of the Buffalo Wallow Formation (Chesterian) that strikes N75°W and dips 70 to 75°NE. The axis of the fold is almost horizontal. The core and the limbs of the fold are fractured and sheared mainly by normal faults of small offset. The Mississippian beds are bounded on either side by Caseyville (Lower Pennsylvanian) strata along large, high-angle normal faults. The Pennsylvanian rocks are broken by numerous normal faults of moderate to steep dip, and the shale in both the Pennsylvanian and Mississippian units is intensely squeezed and deformed along the faults. In places, large blocks of limestone and sandstone are incorporated in a shear zone exposed in the western wall of the roadcut (Nelson and Lumm, 1984, Fig. 19). Slickensides and mullion are conspicuous, and indicate steep, oblique to dip-slip movement. As Krause and others (1979) concluded, the complex structure of the Clear Run Horst reflects sev-

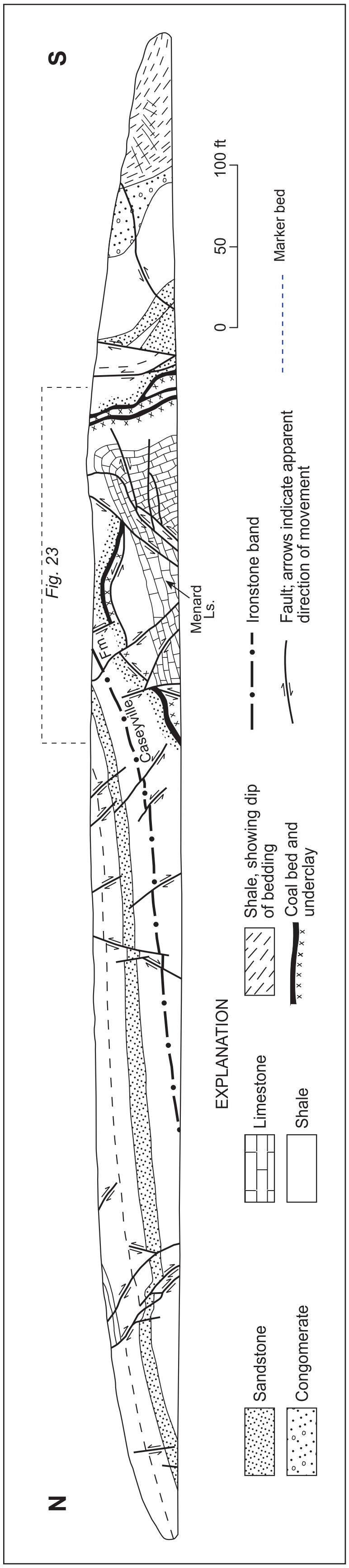

Figure 22. Sketch of part of the Rough Creek Fault Zone exposed in the eastern wall of roadcut (northbound lane) at milepost 53, Green River Parkway, Pleasant Ridge quadrangle, Ohio County, Ky. From Krause and others (1979, Fig. KY-18; used with permission of the Illinois State Geological Survey).

eral periods of major vertical movement. The central core of Menard limestone was folded, possibly by drag, as it was upthrusted against Pennsylvanian strata. The amount of vertical displacement could not be measured, but was estimated at 100 to 250 ft (Krause and others, 1979). There is no evidence at this locality of either regional lateral compressive stress or significant strike-slip movement (Krause and others, 1979).

To the northwest in this same segment of the Rough Creek Fault Zone, however, slickensides in Pennsylvanian sandstone, exposed at Hoover Hill along U.S. 231 (Fig. 24), indicate an unknown, but probably insignificant, amount of lateral movement (Thomas and Schwalb, 1973). Later examination of this outcrop area (Hester, 1988) revealed abundant horizontal slickensides oriented N20°E to N60°W.

Another description of structural detail associated with high-angle normal faults in the Rough Creek zone was given by Nelson and Lumm (1984, 1987), who examined a fault in the underground workings of the Peabody Coal Company No. 1 Camp Breckinridge Mine east of Morganfield in the Waverly quadrangle (Fairer, 1975). The fault forms the northwestern side of a broad graben that trends northeastward from an area of complex horsts and grabens immediately north of the frontal reverse fault of the Rough Creek zone. The fault in the mine has a throw of about 120 ft, and juxtaposes the Herrin (W. Ky. No. 11) coal bed at the top of the Carbondale Formation against the stratigraphically lower Springfield (W. Ky. No. 9) coal bed. In detail, the 6-ft-thick fault zone is a series of sheared and tilted blocks of the Herrin coal and the overlying Providence Limestone Member of the Sturgis Formation. At one locality along the fault, the Providence is strongly folded, and the Herrin bed is below its normal position on either side of the fault. Slickensides indicate dip-slip movement only, but the complexities of the fault zone point to one or more reversals of movement on the fault (Nelson and Lumm, 1984).

Shawneetown Fault Zone

The Shawneetown Fault Zone is the westward continuation into Illinois of the Rough Creek Fault Zone (Fig. 20). In 1984, Nelson and Lumm mapped in great detail all of the Shawneetown zone except the southern end; that part was mapped in 1967 by Baxter and others. The study by Nelson and Lumm supplanted earlier work on the fault zone by Butts (1925). The following brief summary of the study by Nelson and Lumm (1984) is intended to show the continuity of the pattern of faulting throughout the entire Rough Creek–Shawneetown system and to point out structural detail not observable in Kentucky that has a direct bearing on the origin and history of the entire fault system. The quality of surface exposures, the accessibility to open-pit coal mines at the time of mapping, and the availability of data from thousands of coal-test, oil and gas, and water wells allowed a greater degree of observation and knowledge of the Shawneetown zone and related structures than was possible during the geologic mapping of most of the quadrangles in western Kentucky.

The Shawneetown Fault Zone extends from the Ohio River westward for 15 mi, then bends sharply southwestward and continues for another 12 mi to a junction with the Lusk Creek Fault Zone (Klasner, 1982) on the western margin of the Illinois-Kentucky Fluorspar District. Mapping by Nelson and Lumm (1990) showed that the two fault zones do not actually join at the surface, but almost surely merge in the subsur-

Figure 23. Folded and faulted Menard Limestone Member of the Buffalo Wallow Formation (Chesterian) and overlying Caseyville Formation (Lower Pennsylvanian) in central part of the Clear Run Horst, milepost 53, Green River Parkway, Ohio County. See Figure 22 for site of the photograph in roadcut. Photograph courtesy of Ralph N. Thomas, Texas Gas Transmission Co.

face. The width of the Shawneetown zone ranges from several tens of feet to almost 1.5 mi; it is considerably narrower than most of the Rough Creek zone. Resistant Lower Pennsylvanian sandstone and subadjacent Upper Mississippian limestone form a prominent fault scarp along the northern and western margins of the structure. The Shawneetown zone is primarily composed of a single frontal fault on its northern and western margins, but a few secondary faults branch from the frontal fault and break the zone into individual blocks. The frontal fault throughout the entire zone is a high-angle reverse fault that has as much as 3,500 ft of reverse displacement, as measured in the John Dunhill No. 1 Margaret Karsch well (sec. 35, T. 9 S., R. 7 E., Saline County), near the area where the zone bends sharply to the southwest; the calculated dip of the fault plane is approximately 72° southward. Elsewhere, the stratigraphic throw on the frontal fault is 700 to 2,500 ft.

Most secondary faults in the Shawneetown zone are south of the frontal fault and have normal displacements generally of 100 to 800 ft, but a few are in excess of 1,000 ft. The fault blocks are about equal in the number of horsts and grabens; in the Rough Creek zone horsts are more numerous. In all but one fault block in the Shawneetown zone, the strata are tilted to the south or southeast at dips ranging from less than 10 to 90°, and some are even overturned; most dip 25 to 55°. The strike of the beds within the blocks is parallel to the major bounding faults, which indicates that the faults have primarily dip-slip displacement. In contrast to the Rough Creek zone, the Shawneetown zone has no sec-

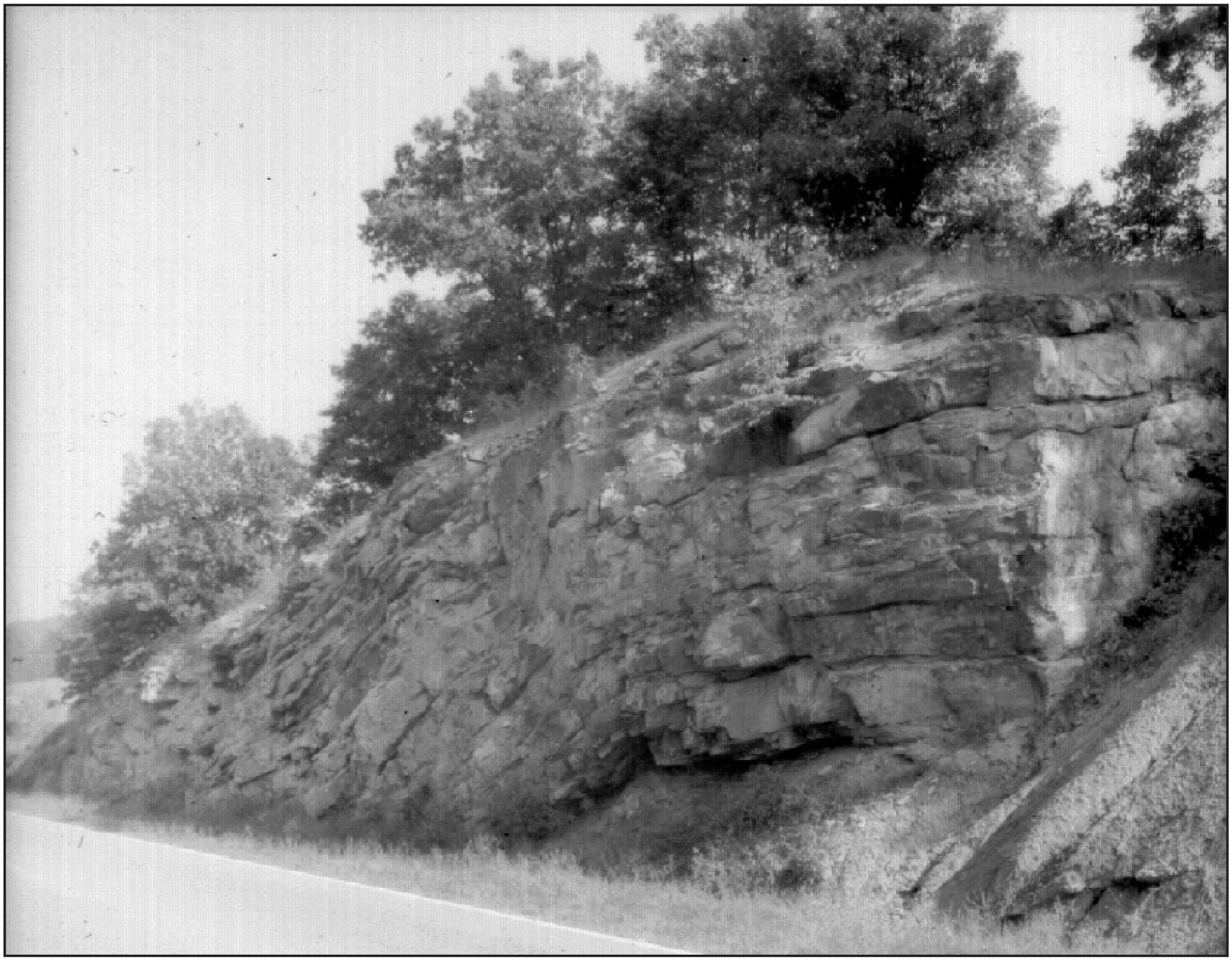

Figure 24. Faulted Pennsylvanian sandstone in the Rough Creek Fault Zone in roadcut at Hoover Hill on U.S. 231, Pleasant Ridge quadrangle, Ohio County, Ky. Photograph courtesy of Ralph N. Thomas, Texas Gas Transmission Co.

ondary reverse faults, at least none found by Nelson and Lumm (1984, 1987).

All large normal faults on the southern limb of the Shawneetown zone and many of the smaller secondary branching faults are downdropped on the side away from the frontal fault. The fault planes of both groups are vertical or steeply dipping; only in highly deformed areas were dips of less than 50° observed by Nelson and Lumm (1984). Slickensides and mullion plunge nearly vertically down the dip of the fault planes. Although some complex faults show several sets of slickensides of various orientations, the vertical ones are the most conspicuous. In support of their contention that the major movement in the Shawneetown zone was vertical, Nelson and Lumm (1984) also found that the axes of drag folds are horizontal and parallel with the adjacent faults; this indicates dip-slip rather than strike-slip movement.

In general, the southward regional dip of Pennsylvanian rocks in this part of the Illinois Basin is interrupted only by vertical offset along the Shawneetown Fault Zone, which forms the northern limb of the Eagle Valley Syncline. The strata south of the zone away from the steep limb of the syncline are at the same or lower elevation as the strata a few miles north of the fault zone. Vertical uplift is confined to the Shawneetown zone; Mississippian and Pennsylvanian strata in the zone are far above their normal stratigraphic positions.

Moorman–Eagle Valley Syncline

The Moorman Syncline and its western extension, the Eagle Valley Syncline, lie immediately south of the Rough Creek–Shawneetown Fault System, which forms the steep northern and western limbs of the Moorman–Eagle Valley Syncline. The syncline, which overlies the Rough Creek Graben in basement rocks, is asymmetrical; the axis lies close to the northern limb in Illinois and eastward into Union County, Ky. (Plates 1B). From there eastward, the syncline gradually widens, but initially the axis remains closely parallel with the Rough Creek Fault Zone. In Webster County, however, the axis bends sharply to the southeast, the trough flattens out and is less deep, and in places the axis is broken and offset along northeast-trending normal faults. In northeastern Hopkins County, the axis of the syncline extends south of the Rough Creek study area. South of the area, the axial trend is more easterly, and the syncline dies out in southwestern Ohio County, Ky. (Fig. 20). In the eastern two-thirds of the Rough Creek area, east of the axis of the Moorman Syncline and south of the Rough Creek Fault Zone, the regional dip is to the south and southwest. The deepest part of the Moorman–Eagle Valley Syncline is near the Ohio River in western Kentucky, where there is more than 30,000 ft of structural relief on the Precambrian basement (Fig. 2).

On the northern limb of the Moorman Syncline, beds in fault blocks in the Rough Creek Fault Zone generally dip from 10 to about 90° immediately adjacent to faults. Down the limb of the syncline away from the fault zone, the beds flatten rapidly, and dips of 1 to 2° are common. The southward dip is interrupted only where the beds are folded and more steeply tilted along northeast-trending normal faults.

Strata on the southern limb of the Moorman–Eagle Valley Syncline dip uniformly to the north away from the Pennyrile Fault System, which largely defines that limb in Kentucky, and to the northeast from structures of the Illinois-Kentucky Fluorspar District on the southern limb in Illinois. Only a small area in the northeastern part of the Western Kentucky Fluorspar District, mapped by Trace and Amos (1984), is included in the Rough Creek area. Most of the Pennyrile system lies south of the Rough Creek area; however, several faults in that system die out within the area. In Illinois, dips on the southern limb of the Eagle Valley Syncline range from about 6 to 9° (Nelson and Lumm, 1984). Dip is slightly lower immediately to the east in Kentucky along the Ohio River, and farther to the east the beds dip to the northeast at only 1 to 2°.

Toward its western end in both Illinois and Kentucky, the southern limb of the Moorman–Eagle Valley Syncline is broken at a few places into narrow horsts and grabens by northeast-trending normal faults. Displacement along these faults is a few feet to as much as 200 ft, both in Kentucky, particularly in the Dekoven quadrangle (Kehn, 1974), and in Illinois (Nelson and Lumm, 1984). The larger faults are northern extensions of faults of the Illinois-Kentucky Fluorspar District (Fig. 20). Where observed in Illinois (Nelson and Lumm, 1984), slickensides on the faults on the southern limb of the Eagle Valley Syncline indicate dip-slip movement and little or no strike-slip component, although at one locality in the Herod Fault Zone, Nelson and Lumm (1984) noted a suggestion of horizontal movement.

The axial part of the Moorman–Eagle Valley Syncline varies considerably in character from Illinois into Kentucky. In Illinois, the axis of the Eagle Valley Syncline is sinuous, and numerous large and small anticlinal and synclinal flexures interrupt the trough of the syncline (Nelson and Lumm, 1984). Most are small, having closures of 10 to 20 ft, but one anticline has at least 160 ft of closure on the Springfield (W. Ky. No. 9) coal bed, and the largest structure, the Pisgah Syncline, an arcuate south-bending depression along the axis of the Eagle Valley Syncline, has at least 300 ft of closure on the Springfield coal bed.

The Pisgah Syncline is broken by several northeast-trending faults near the northern end of the Grindstaff Fault Zone, which occurs largely south of the axial trough. The faults of the zone form the boundary of a single horst and a narrow graben; maximum offset in the fault zone is about 300 ft. Except for several very small faults, the only other faults in or close to the axial part of the Eagle Valley Syncline are those very low on the northern and western limbs of the structure; these were discussed above.

In western Kentucky, where the axis of the Moorman Syncline lies close to the northern limb of the syncline (Plate 1B), some faults of the Rough Creek zone far down on the northern limb apparently offset the axial trace; however, the axial area in the Grove Center, Morganfield, and Sturgis quadrangles is largely covered by loess and other surficial deposits, so the structural pattern is largely inferred from scattered drillholes. In those quadrangles, several inferred northeast-trending faults are thought to cut the axial trace and either abut at a high angle faults of the Rough Creek zone or bend eastward and merge with faults of the zone. The very deep graben that Palmer (1976) showed cutting the axis of the Moorman Syncline at the western edge of the Grove Center quadrangle, mostly within the alluviated Ohio River Valley, is based on highly speculative interpretation of a well log; the existence of the graben is questionable. Nevertheless, the deepest part of the Moorman Syncline is in this area of western Kentucky (Fig. 2). Palmer (1976) mapped a fault beneath the Ohio River in the easternmost part of the Shawneetown quadrangle; however, because Nelson and Lumm (1984) did not map an extension of the fault into Illinois, the fault is not shown on the geologic map of the Rough Creek area (Plate 1A). Farther eastward in the Rough Creek area, the Moorman Syncline flattens out, and the axis digresses southward from the steep northern limb. It then follows a sinuous, southeastern trend across southeastern Webster, northeastern Hopkins, and northernmost Muhlenberg Counties, and dies out in an area of low dip in southwestern Ohio County (Greb and others, 1992, Plate 1).

In northeastern Hopkins and southern McLean Counties (see Plate 1B), a broad, northeast-trending belt 8 to 10 mi wide, of north- and south-dipping normal faults, called the Central Faults by Mullins (1968, Fig. 3), is present mainly east and north of the Moorman synclinal axis; a few faults offset the axis, which is not well defined in northeastern Hopkins and southern McLean Counties. This part of the syncline is largely covered by alluvium, and the structural details are mostly inferred from data from wells drilled for oil and gas. Northwest-trending faults break the belt into a series of linear horst and graben blocks, which are less than 1,000 ft to more than 2 mi wide and as much as 13 mi long. Many of the faults at the northeastern end of the belt, particularly in the Glenville and Utica quadrangles, bend east and merge into the Rough Creek Fault Zone, but others cut off faults of the zone at high angles. A number of the fault blocks are broken by subsidiary cross-cutting faults into a series of mainly narrow grabens and variously tilted horsts, some in stairstep arrangement.

At the northeastern end of the central fault belt where it merges with the Rough Creek zone in the Glenville quadrangle, Johnson and Smith (1972b) recognized three short, cross-cutting reverse faults, largely on the basis of well data. Near the center of the Glenville quadrangle, a small reverse fault having about 60 to 90 ft of throw brings to the surface a small outcrop of the West Franklin Limestone Member (called the Madisonville Limestone Member on the geologic quadrangle map) of the Sturgis Formation. Two short reverse faults in the northwestern part of the southeastern quarter of the Glenville quadrangle bound on two sides a narrow wedge-shaped block, which is upthrown 300 to 400 ft. Well data and surface exposures are too limited to allow observation or calculation of the dip of the fault planes. The maximum offset across faults of the belt is about 850 ft at the horizon of the Vienna Limestone Member of the Buffalo Wallow Formation (upper Chesterian), and offsets of about 100 to 400 ft are not uncommon.

Pennyrile Fault System

The Pennyrile Fault System, which lies mostly south of the Rough Creek area (Fig. 25), largely defines the updip limit of the southern limb of the Moorman Syncline in Kentucky. The Pennyrile system runs roughly parallel to the Rough Creek Fault Zone. Near its western end, the northern part of the Pennyrile system lies about 25 to 30 mi south of the Rough Creek zone, but the eastern part of the system is as close as 14 mi to faults at the eastern end of the Rough Creek zone. The Pennyrile system interrupts the gentle, northern regional dip in this part of the Illinois Basin.

The name "Pennyrile" was applied by Schwalb (1975) to a narrow belt of faults in western Butler County that is part of a complex fault system that extends westward from western Edmonson County for about 90 mi to the vicinity of Princeton, Ky. The Pennyrile system has not been precisely defined, but most previous workers have limited it to the narrow band of faults described above. Geophysical data (Lumm and Stearns, 1989; Lumm and others, 1991b; Goldhaber and others, 1992), however, lend support to the view that the fault system marking the southern margin of the Rough Creek Graben at the Precambrian basement is wider and more complex, especially in the western part, than the zone expressed in surface exposures.

As defined in this report, the Pennyrile Fault System is composed of three east-trending branches that cover an irregular area with a maximum length of almost 90 mi and maximum width of about 22 mi. The northern branch extends eastward from north of Princeton and crosses southern Hopkins and southwestern Muhlenberg Counties. The main or central branch is the longest and structurally most complex. It splays off of the Tabb Fault System southeast of Princeton and extends as far east as western Edmonson County; this is the branch originally called the Pennyrile Fault Zone (Schwalb, 1975). The southern branch, the least well-defined branch, appears to begin in northern Trigg County and extends eastward across Christian County, just north of Hopkinsville, to Logan County. The western ends of both the southern and northern branches appear to be continuations of fault zones mostly concealed beneath Cretaceous and Tertiary deposits of the Mississippi Embayment.

Structural offset across the main or central branch of the Pennyrile system is down to the north; in its western part, offset is as much as 1,400 ft on surface faults. Total offset on surface faults that extend down to and cut pre-Knox Group strata (older than the Late Cambrian Elvins Formation) is less than 3,300 ft (Nelson, 1991). Offset of individual outcropping stratigraphic units across faults of the main Pennyrile branch is not nearly as pronounced as in the Rough Creek Fault Zone.

The faults of the Pennyrile system, which commonly are well exposed in open-pit coal mines, strike generally east-northeast in an en echelon pattern. In detail the longer faults are both straight and sinuous and bound narrow horsts and grabens. Where intersected by shorter subparallel fractures, the system is broken into a variety of fault blocks that give the system a braided appearance. Most of the faults are vertical or high-angle normal, but both scissor faults and one reverse fault were recognized at several localities in Muhlenberg County.

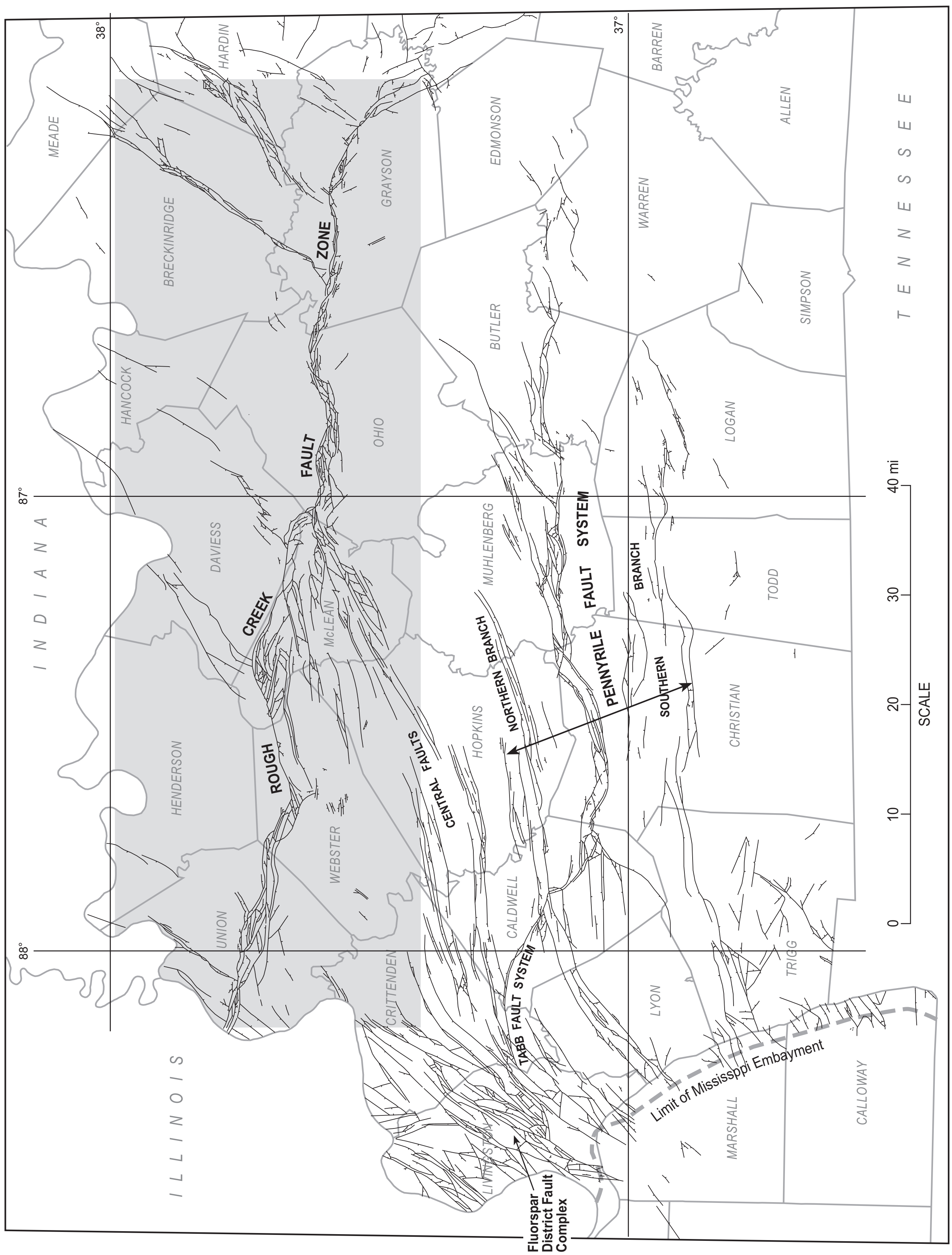

Figure 25. The Pennyrile Fault System and its relation to the Rough Creek area (outlined) and the Kentucky Fluorspar District Fault Complex. Compiled from Noger (1988).

The typical normal faults in the Pennyrile system, described from coal strip-pit exposures in the Saint Charles and Nortonville quadrangles by Palmer (1969), dip 54 to 90°; the average dip is about 72°, and he observed only one vertical fault. The fault planes are sharp, and the adjacent wallrock only slightly fractured. Brecciated zones are not common, but where present are only 1 to 2 ft wide. Drag folding is slight along most faults. Slickensides are smooth and uniform and indicate only one generation of vertical movement. Rose (1963) reported slickensides at several unidentified localities in Muhlenberg County, however, that he said indicated lateral movement. He also cited, as an example of lateral movement, the abrupt bend to the east over a distance of about 5,000 ft of a large, southwest-trending, pre-Pennsylvanian channel in the subsurface approximately at the eastern extension of the Sharbers–Twin Tunnels Fault System in southeastern Muhlenberg County.

Detailed analysis (Lumm and others, 1991a) of faults in the main Pennyrile zone in roadcuts and along the CSX Railroad track north of Crofton, Ky., revealed that nearly all faults exhibit dip-slip displacement, but two small normal faults that have striae that plunge 60° indicate a minor strike-slip component. Small thrust faults, high-angle reverse faults, and kink bands were ascribed to local compressional deformation (Lumm and others, 1991a), but lithologic discontinuities (as between thick sandstone lenses and shale) can result in small thrusts in an extensional regime. Overall, the Pennyrile Fault System formed in a dominantly tensional stress regime, but included some left-lateral shear (Nelson, 1991).

Displacement across the faults in the Pennyrile system at the surface commonly is 200 to 300 ft. Throws of more than 400 ft (Lumm and others, 1991b) are not uncommon, and along some faults in the western part of the system, where it merges with faults of the Western Kentucky Fluorspar District, throws are as much as 700 ft. Limited well data show that the throw on several of the large normal faults in the Saint Charles and Nortonville quadrangles decreases with depth (Palmer, 1969). This situation is also common on faults in the Rough Creek zone.

Scissor faulting in the Pennyrile system was recognized along the northeast-trending North Browder Fault in the Drakesboro (Hansen, 1972) and Rochester (Hansen, 1974) quadrangles. The fault is downthrown to the north near its western end and downthrown to the south along the remainder; the maximum displacement is 150 ft near the eastern end. Scissor faulting of less displacement was also recognized within the Sharbers–Twin Tunnels Fault Zone in the Pennyrile system in a series of quadrangles (Kehn, 1968, 1971; Hansen, 1972, 1974) mostly in Muhlenberg County.

A northwest-dipping reverse fault is present in the Sharbers Fault Zone in the Greenville quadrangle (Kehn, 1971) in Muhlenberg County. The fault is about 2.5 mi long, bounds an interior fault block, and has a maximum throw of about 400 ft.

In the area of the junction of the main branch of the Pennyrile system with the southeastern end of the Tabb Fault System of the Western Kentucky Fluorspar District in the Crider quadrangle (Rogers and Trace, 1976), two faults, identified on a seismic-reflection profile by Potter and others (1995, Plate 1), show reverse movement in Mississippian through Middle Cambrian strata. The larger of the faults (designated as D on Potter and others' Plate 1), however, shows probable normal displacement at the top of the Precambrian basement; this change in throw direction along the fault plane indicates reactivation of the Cambrian-age fault. The component of reverse movement on the fault is about 1,000 ft. The other fault (designated as C on Potter and others' Plate 1) shows much less reversal and merges with fault D within the Cambrian section.

Dip of the exposed Upper Mississippian (Chesterian) and Lower to Middle Pennsylvanian beds in the various blocks of the Pennyrile system generally is less than 2°, but locally, adjacent to some faults, is as high as 75°.

Faults North of the Rough Creek Fault Zone

In the area north of the Rough Creek Fault Zone, the sedimentary rocks dip gently westward in broad formational belts that are increasingly younger to the west; the Ste. Genevieve Limestone (Upper Mississippian, Meramecian) crops out along the eastern border of the area, and the Sturgis Formation (Upper Pennsylvanian, upper Desmoinesian through Virgilian) underlies the western border but is largely covered. The northern part of the Rough Creek area is broken at numerous localities by northeast-trending normal faults or by generally narrow zones of tilted horst and graben blocks bounded by normal faults. The fault zones range in width from less than 0.25 mi to about 4 mi in a zone at the eastern border of the Rough Creek area. Several fault zones in the northeastern part of the Rough Creek area extend beyond the area borders. In the eastern quarter of the area north of the Rough Creek Fault Zone, the faults offset outcropping Mississippian limestone units that alternate with units of sandstone and shale. The faults generally are easily located, although good exposures of the fault planes are limited. Dips generally are 60 to 80° on planes of the Locust Hill and Cave Hill faults and on subsidiary cross faults in the Garfield and Kingswood quadrangles (Amos, 1976, 1978, respectively, as recorded in his field notes). The remainder of the country north of the Rough

Creek Fault Zone is mostly covered by loess and alluvium, so the position of faults is mostly interpreted from data from oil wells and coal test holes; all of the faults are normal. The few slickensides observed confirm only dip-slip movement.

Most of the blocks in the fault zones north of the Rough Creek zone are grabens, and a considerable number of the blocks are tilted, generally either to the northwest or southeast. Beds within the blocks generally dip less than 10°, but locally as high as 40° on the downthrown side immediately adjacent to the faults. A few narrow horst blocks are conspicuous in the zone bounded by the Locust Hill and Cave Spring Faults in the eastern part of the Rough Creek area. Except for a very small horst block in the fault zone containing the Mount Olive and Pole Bridge Faults, near the eastern border of the area, in the Constantine quadrangle (Sable, 1964), in Carter coordinate sec. 16-O-41, the few other observed horsts are in the zone containing the Locust Hill Fault. Maximum uplift of the horst blocks is less than 100 ft. Throw on the faults north of the Rough Creek zone generally is about 20 to 100 ft, and rarely exceeds 200 ft.

Most of the faults north of the Rough Creek Fault Zone either do not appear at the surface to merge with the Rough Creek zone or abut it at a high angle. Only in the Utica quadrangle, south of Owensboro, and in the Morganfield quadrangle in the western part of the Rough Creek area, do some faults appear to merge into or have a genetic relationship with secondary faults that lie north of and closely parallel to the main frontal fault of the Rough Creek zone. In those quadrangles, the faults are not exposed, and the structural interpretation is based on drillhole data. In the Morganfield quadrangle, closely spaced wells in the Morganfield South Oil Field (Fig. 21), however, allowed detailed interpretation of the structure of the oil field (Smith and Palmer, 1981), but in the Utica quadrangle the relation of the northeast-trending faults to those of the Rough Creek zone is more speculative. Significantly, the fault zones north of the Rough Creek zone have no obvious correlatives immediately south of the zone.

Wabash Valley Fault System

The Wabash Valley Fault System in southeastern Illinois, southwestern Indiana, and Henderson and Union Counties, Ky., is entirely covered by surficial deposits, but because of the availability of considerable data from oil and gas wells and coal test holes and from exposures in underground coal mines, its structure is generally well known. Bristol and Treworgy (1979) made a detailed study of the Illinois part, and Tanner and others (1981a–f) mapped the Indiana part on a series of six maps. Ault and others (1980) discussed the Indiana part, and Nelson and Lumm (1984) summarized the structure of the entire fault system. The Wabash Valley system extends north-northeast from the Rough Creek–Shawneetown Fault System for a distance of about 55 mi along either side of the Ohio and Wabash Rivers (Fig. 3). The maximum width of the system of about 30 mi is in the area from northwestern Henderson County, Ky., across Indiana, into White County, Ill. The Wabash Valley system is characterized by generally parallel, high-angle normal faults that bound a series of broad, tilted grabens and horsts. The bounding faults are slightly arcuate segments that commonly overlap slightly, rather than one long, continuous fault. Displacement along individual faults in Illinois ranges from 25 ft to a maximum of 480 ft on the Inman East Fault, which continues into Indiana (Bristol and Treworgy, 1979, Table 1); in Kentucky, displacement is from less than 20 ft to about 500 ft on the Hovey Lake Fault (Plate 1B). The extensive Mount Carmel–New Harmony Fault that crosses meanders of the Wabash River back and forth from Illinois into Indiana has a maximum displacement of 300 ft (Bristol and Treworgy, 1979, Table 1), but other faults of the Wabash Valley system in Indiana have less displacement. Borehole data indicate that the Wabash Valley faults tend to split upward and merge downward, and seismic data show that the faults lose displacement downward and do not detectably offset the top of basement (Nelson, 1991).

Dip on the fault planes in the Wabash Valley system ranges from 50 to 85° (Bristol and Treworgy, 1979). Exposures in underground coal mines show only dip-slip movement on faults, which dip 60° to vertical; the observed slickensides are vertical or nearly so, and drag is normal (Nelson and Lumm, 1984). Some minor reverse flexures, which resulted from compressive wedging of narrow slices along large faults, were observed locally (Nelson and Lumm, 1984). Mine exposures show that many fractures are filled with minerals, evidence of horizontal extension normal to the fault surfaces (Nelson and Lumm, 1984). The dip of the faults in the Wabash Valley system in Kentucky was not calculated because well data are too sparse.

Several of the Wabash Valley faults in both Illinois and Kentucky extend south to intersect the Rough Creek–Shawneetown Fault System, but others lose displacement and die out before reaching the fault system. In Illinois, the Inman and Inman West Faults, which bound a graben, have nearly 200 ft of throw very close to the Shawneetown frontal fault (Nelson and Lumm, 1984). In Kentucky, the Hovey Lake Fault (Plate 1B) intersects the frontal fault of the Rough Creek zone and apparently offsets a secondary fault that lies slightly north of and parallel with the frontal fault. Offset on the Springfield (W. Ky. No. 9) coal bed at the junction with the Rough Creek zone is about 80 ft. The Wabash Island

Fault is interpreted in this report as intersecting the frontal fault; Nelson and Lumm (1984, Fig. 32), however, terminated the fault several miles north of the Rough Creek zone. None of the faults of the Wabash Valley system that intersect the Rough Creek–Shawneetown system continue south of the system. The dip of strata along the north side of the Rough Creek–Shawneetown system is northward into various fault blocks of the Wabash Valley System.

Hovey Lake Fault

The compound Hovey Lake Fault extends from the Rough Creek Fault Zone in western Union County, Ky., northeastward for about 17 mi, crosses the Ohio River back and forth between Kentucky and Indiana several times, and terminates northeast of Mount Vernon, Ind. The fault forms the southeastern side of a broad graben, termed the Mount Vernon Graben by Ault and others (1980); the Wabash Island Fault bounds the northwestern side of the graben. In Kentucky, the Hovey Lake is a normal fault that varies from a single fault near the Rough Creek zone to several faults that bound a graben and west-tilted fault blocks. At Uniontown on the Ohio River, the Hovey Lake Fault crosses the river into Indiana on a more northerly trend, but a northeast-trending branch of closely spaced, overlapping, subsidiary faults breaks the area into a series of narrow grabens and horsts over a distance of about 5.5 mi. Maximum displacement on the Hovey Lake Fault in Kentucky is about 500 ft in a large graben near its southern end (Plate 1B). In Indiana, the fault locally contains four closely spaced faults that together have a maximum vertical displacement of 310 ft (Ault and others, 1980). Fault planes dip 70° or more in Indiana (Ault and others, 1980). No dip calculations were made in Kentucky.

Wabash Island Fault

The Wabash Island Fault closely parallels the northeastern trend of the Hovey Lake Fault along the western side of the Mount Vernon Graben from the Rough Creek Fault Zone in Kentucky to the fault terminus about 4 mi north of Mount Vernon, Ind., a distance of about 25 mi. The fault forms the eastern boundary of a broad fault block that is tilted westward toward the Inman East Fault in the Wabash Valley system. The Wabash Island Fault is compound along much of its length. In Kentucky, where structural data on the Springfield (W. Ky. No. 9) coal bed is sparse, the fault is depicted on the structure map (Plate 1B) at its southern end as two subparallel branches about 3,300 ft apart at the Rough Creek Fault Zone, but they merge northward into a single fault in the vicinity of Wabash Island Fault, at the junction of the Wabash and Ohio Rivers. In Indiana just north of the Ohio River, the Wabash Island Fault has about 370 ft of displacement down on the eastern side (Ault and others, 1980, Table 1). In that area, two subsidiary faults parallel to the Wabash Island Fault bound either side of a narrow graben within the large Mount Vernon Graben (Ault and others, 1980, Fig. 2); these secondary faults may extend into Kentucky. Toward its northern end in Indiana, the Wabash Island Fault is more complex, composed of as many as four faults in a zone as much as 4,000 ft wide (Ault and others, 1980) that probably contains cross faults in an anastomosing pattern; dip on some fault planes is about 65°. In Kentucky, the maximum displacement on the Wabash Island Fault is about 280 ft near Wabash Island, but displacement diminishes southward to less than 50 ft near the Rough Creek Fault Zone. Dip on the fault plane in Kentucky has not been calculated.

Structure of the Illinois-Kentucky Fluorspar District

The Illinois-Kentucky Fluorspar District, as used in this report, encompasses a somewhat larger area than that of fluorspar and metallic mineral production centered in the area shown on Figures 3 and 5; it includes structures, especially on the northwest in Illinois, that appear genetically related to those of the Western Kentucky Fluorspar District. The district and its mineral deposits have been mapped and described in many studies, including for the Illinois part those by Weller and others (1920), Bastin (1931), Currier (1944), Brown and others (1954), Baxter and others (1963, 1967), Baxter and Desborough (1965), and Grogan and Bradbury (1968). For the Kentucky part, Trace and Amos (1984) gave an extensive reference list in their summary paper on the stratigraphy and structure of the Western Kentucky Fluorspar District. The following brief summary of the entire district incorporates data for Kentucky mostly from Trace and Amos (1984) and for Illinois from Nelson and Lumm (1984) and some authors listed above.

The Illinois-Kentucky Fluorspar District is an area of complex structure that lies south and southwest of the Moorman–Eagle Valley Syncline, mainly in Hardin and Pope Counties, Ill., and Crittenden and Livingston Counties, Ky.; only the northeastern extremity is within the Rough Creek area. On the northwest in Illinois, the Herod Fault Zone and its southwestern continuation, the Lusk Creek Fault System, mark that margin of the district. The southwestern end of the Shawneetown Fault Zone bends west to merge with the Lusk Creek Fault; this indicates that the faults were formed by the same tectonic force. The southern limit of structures in the Western Kentucky Fluorspar District is south and west of Princeton, Ky., across northern Lyon and western Caldwell Counties. The area of mineralization lies farther to the north in both Kentucky and Illinois. The structural elements of the Illinois-Kentucky Fluorspar District reflect several periods of tectonism.

The Illinois-Kentucky Fluorspar District is underlain in part by a broad structural arch, named the Tolu Arch by Trace (1974) to replace the name "Kuttawa" (Heyl and Brock, 1961), that extends from about 6 mi south of the Ohio River in Kentucky northwestward into Illinois and terminates against the southwestern part of the Shawneetown Fault Zone (Baxter and others, 1967) (Fig. 20). The high point of the arch is Hicks Dome, near the northern end. The arch, together with most of the Illinois-Kentucky Fluorspar District, is broken by an extensive system of steeply dipping normal faults that strike dominantly northeast and divide the district into elongate, northeast-trending grabens and horsts. The axis of the Tolu Arch is offset as much as 3 mi, both to the left and right, from one fault block to another. The southern terminus of the axis apparently is at the northeast-trending Griffith Bluff Graben (Trace and Amos, 1984), but several small structural highs in fault blocks farther to the south and southwest may be possible extensions of the Tolu Arch (Trace and Amos, 1984, Fig. 3).

Hicks Dome is a nearly circular uplift about 10 mi in diameter that has about 4,000 ft of structural relief; it is extensively faulted and modified on the southeast. Middle Devonian limestone crops out at the apex of the dome, where dips are 15 to 20°. Upper Devonian, Mississippian, and Lower Pennsylvanian strata crop out in successive belts outward on the flanks, and dips decrease progressively outward to about 5°.

A series of concentric and radial faults at a distance of 3 to 4 mi from the apex of the dome surround and radiate from the dome, particularly from the southwestern to the northeastern quadrants. The concentric faults are downthrown away from the center of Hicks Dome, but one on the north and northeast shows reverse throw along several segments of the fault (Baxter and Desborough, 1965, Plate 2). Throw direction on the radial faults is not consistent. The pattern of concentric and radial faults has been completely disrupted on the southeast by a complex of northeast-trending normal faults that cut the Tolu Arch. The displacement on both the concentric and radial faults ranges from less than 50 ft to as much as 500 ft (Baxter and Desborough, 1965, Plate 2; Baxter and others, 1967, Plate 2).

Seismic data (Potter and others, 1995) allowed new insight as to the origin of Hicks Dome and the nature of the subsurface rocks (and processes) in the vicinity of the dome. The data clearly show that the entire Paleozoic section under the structure has been domed and that the doming originated in the Precambrian basement, not just within the Paleozoic section. Hicks Dome is situated on the southwestern flank of a northwest-trending magnetic anomaly, the maximum intensity of which is about 5.5 mi northeast of the center of the dome (McGinnis and Bradbury, 1964). McGinnis and Bradbury (1964) interpreted the anomaly as the reflection of a mafic intrusive body at a depth of 11,000 ft or more in lower Paleozoic rocks or in the Precambrian basement. No major potential-field anomaly is centered on Hicks Dome, but the dome is clearly a product of explosive magmatism fed by the intrusive body to the northeast (Potter and others, 1995).

Previous workers (Brown and others, 1954; Heyl and others, 1965; Hook, 1974; Trace, 1974; and Nelson and Lumm, 1984) have generally considered Hicks Dome to be a cryptovolcanic structure, based mostly on the many diatremes (explosion breccias) present in the area, although these same features have also been ascribed to igneous activity. Weller and others (1920) thought that the uplift of Hicks Dome was the result of intrusion of magma. Currier (1944) called the intrusion a laccolith, but the lack of a magnetic anomaly beneath Hicks Dome (McGinnis and Bradbury, 1964) is evidence against a magmatic body at depth.

The breccias, which were studied in detail by Bradbury and Baxter (1992), are mostly vertical or steeply dipping dike-like bodies, oriented along northeast and northwest strikes, but some are bodies of indeterminate shape. Bradbury and Baxter (1992) defined the breccias on the basis of geometry and composition into three types: shatter, vent, and carbonatitic. Shatter breccias are essentially vertical bodies composed of fragments of the immediate wall rocks; they lack vertical displacement of the included rock fragments. Vent breccias are composed of rock fragments from the host sedimentary strata. Fragments that have undergone vertical transport of as much as 1,000 ft were probably caused by explosively released gases (Bradbury and Baxter, 1992). Carbonatitic breccias contain displaced sedimentary rocks and mineral fragments of igneous origin in a carbonate matrix. Although the origin of the carbonatitic breccia is unclear, the presence of reaction rims on rock fragments indicates an explosive volcanic origin and transport by fluidization with the entraining agent, a CO_2-rich gas, from a solidifying alkaline magma (Bradbury and Baxter, 1992). All the breccias occur in Illinois, some at the apex of Hicks Dome and others within 7 mi of the apex (Baxter and Desborough, 1965, Plate 1; Grogan and Bradbury, 1968). Some breccias are mineralized with fluorspar, barite, and metallic minerals.

Well-defined, northeast-trending grabens and horsts dominate the structural pattern of the Illinois-Kentucky Fluorspar District. In general, the grabens and horsts are wider and longer in Kentucky than in Illinois, where they tend to be broken into small segments by antithetic and cross faults. Trace and Amos (1984) pointed out that the internal structure of the grabens is quite different from that of the horsts. In the grabens, most of the beds dip inward as a result of tilt and associated dragfolding parallel to the bounding faults, but in the horsts the beds commonly retain their regional northeast dip into the Moorman–Eagle Valley Syncline.

Along the eastern side of the Illinois-Kentucky Fluorspar District, the faults bounding the structural blocks terminate in the Moorman–Eagle Valley Syncline, but the major Tabb Fault System in the southeastern part of the district bends southeastward and merges into faults of the Pennyrile Fault System of western Kentucky. On the western side of the district the faults trend southwest, pass beneath the cover of Cretaceous and Tertiary rocks, and cut Paleozoic rocks that underlie the upper Mississippi Embayment. In a number of quadrangles in the Western Kentucky Fluorspar District (Amos and Wolfe, 1966; Amos, 1967, 1974; Amos and Finch, 1968), Upper Cretaceous rocks (Tuscaloosa and McNairy Formations) and the Tertiary and Quaternary Mounds Gravel are faulted and in places juxtapose Paleozoic rocks.

The northeast-trending faults of the Western Kentucky Fluorspar District vary from a single fault to complex zones of subparallel and sinuously intersecting fractures composed of step, antithetic, and cross faults, especially along the edges of many of the larger grabens (Hook, 1974, Fig. 3; Trace and Amos, 1984). The fault zones commonly are a few hundred feet wide, although at places they are as much as 1,500 ft wide (Hook, 1974). The majority are normal faults that dip from 70 to nearly 90°; a few small antithetic and large faults have relatively low dips of 45 to 65° (Weller and others, 1920; Baxter and others, 1967; Hook, 1974; Trace and Amos, 1984).

Along the major northeast-trending faults, the dip-slip component of displacement is dominant. Stratigraphic displacement ranges from a few feet to as much as 3,000 ft in the Lockhart Bluff Graben in the Smithland quadrangle in Kentucky (Amos, 1967), where the Fort Payne Formation (Lower Mississippian, Osagean) lies adjacent to the Caseyville Formation (Lower Pennsylvanian, Morrowan). Hook (1974) estimated that the cumulative northwest-southeast have component of the normal faults in the district is roughly 5,000 ft.

Many of the northeast-trending faults in underground mine exposures in the Illinois part of the district show grooves and slickensides indicative of strike-slip or oblique-slip movement (Nelson and Lumm, 1984). Because the recorded direction of movement is variable, movement on some faults must have occurred at several different times. Some slickensides indicate right-lateral movement, others left lateral, but wrench faulting is subordinate to dip-slip normal faulting (Hook, 1974; Nelson and Lumm, 1984). The amount of strike-slip movement is difficult to determine, because most of the strata are nearly horizontal or low dipping. Nelson and others (1997), however, noted apparent right-lateral offset of about 500 ft of the Mounds Gravel relative to older units along a fault in the Lockhart Bluff Graben in the Little Cypress quadrangle (Amos and Wolfe, 1966). Hook (1974) believed that strike-slip movement on the northeast-trending faults was minor, and Trace and Amos (1984) supported that view by pointing out that although the presence of horizontal slickensides indicates some horizontal movement, no positive evidence is known for major strike-slip displacement.

A set of widely scattered north- to northwest-trending faults is present mainly near the crest and to the west of the Tolu Arch in the Illinois-Kentucky Fluorspar District. The faults are straight, clean cut, and generally much shorter than the northeast-trending faults. They are steeply dipping to vertical, but have very little vertical displacement, rarely more than a few feet. Slickensides show that the fault movement was primarily strike-slip (Hook, 1974). At many places these faults contain dikes, mostly 3 to 10 ft wide, of mica peridotite and lamprophyre (Koenig, 1956). Mafic dikes along both the north-trending and northeast-trending faults and a few bedding-plane replacement deposits contain the ore bodies of the fluorspar-zinc-lead-barite ores in the district. The mineral deposits are not discussed in this report, but papers by Grogan and Bradbury (1968) and Trace (1974) have excellent summaries of the many detailed studies of the various deposits and the mineralogy of the ores.

Cottage Grove Fault System

The Cottage Grove Fault System of Illinois was mapped in detail by Nelson and others (1981); later work by Nelson and Lumm (1984) further defined the eastern end of the system. The following brief discussion is a summary of their observations. The Cottage Grove Fault System lies generally to the west-northwest of the Shawneetown Fault Zone (Fig. 3), and extends from west-central Gallatin County westward to Jackson County, a distance of about 70 mi. The eastern 4 mi of the system overlaps the Shawneetown zone, but lies about 2.5 mi to the north. Although some early workers (Clark and Royds, 1948) thought that the Cottage Grove system probably was an extension of the Shawneetown Fault Zone, Nelson and others (1981) found no link with the Shawneetown to the east or with the Ste. Genevieve Fault Zone to the west. Furthermore, based on geophysical data, Strunk (1984) concluded that although the Rough Creek–Shawneetown and Cottage Grove systems are intimately related to the 38th Parallel Lineament, a discontinuity in the Precambrian basement (Heyl, 1972), the faults are separate and do not directly connect. The

Cottage Grove system is largely known from exposures in underground coal mines; surface expression is obscured by a thick cover of glacial and alluvial deposits.

The Cottage Grove Fault System is a nearly continuous single fault or a narrow, braided zone of subparallel faults that shows dominant right-lateral movement. Vertical offset on the fault is no more than 200 ft. In the eastern half of the system, braided segments of the main fault are downthrown alternately on the north and south sides, but in the western half the fault is downthrown uniformly on the north side.

Exposures of the main fault in open-pit coal mines show conspicuous horizontal to subhorizontal slickensides and mullions (Nelson and Lumm, 1984). Right-lateral movement was not more than 1 mi (Nelson and others, 1981). Subsidiary northwest-trending, high-angle normal and oblique-slip faults diverge from the master fault at angles of 45 to 75°, which is consistent with second-order, right- and left-lateral shearing in a right-lateral wrench. A subsidiary fault, examined in a surface mine by Nelson and Lumm (1984), shows horizontal slickensides and left-lateral offset of about 50 ft. The fault plane is nearly vertical and intersects the main fault at an angle of about 65°. This is a good example of second-order, conjugate, left-lateral wrenching in a right-lateral system. A few small anticlines are subparallel to the main fault or oriented northeastward in en echelon pattern oblique to the fault. Most of these anticlines are on the south side of the Cottage Grove system. Many of the northwest-trending subsidiary faults in the eastern part of the system contain dikes of mafic rocks that are a northern continuation of the system of mafic dikes of the Illinois-Kentucky Fluorspar District. Nelson and Lumm (1984) also reported that an oil well in this part of the system penetrated a 60-ft-thick sill of peridotite in Upper Mississippian strata.

Geologic and Tectonic History

In the late Precambrian to Cambrian, the North American craton (Laurentia) rifted along trends later followed by the Appalachian-Ouachita orogenic belt in the late Paleozoic, and the Iapetus Ocean opened along the newly formed continental margins. The zigzag trace of the Appalachian-Ouachita rifted margins outlines large-scale promontories and embayments in the edge of the North American continental crust (Thomas, 1991, Fig. 2). The shape is attributed to transform offset of a northeast-trending rift system (Cebull and others, 1976; Thomas, 1976, 1977, 1989, 1991). An alternative interpretation attributes the shape of the continental margin to triple junctions at which failed arms (aulacogens) intrude into the continent. Along the southern continental margin these are represented by the Mississippi Valley (Reelfoot) Graben (Burke and Dewey, 1973; Ervin and McGinnis, 1975; Keller and others, 1983) and by the Southern Oklahoma Aulocogen (Burke and Dewey, 1973; Hoffman and others, 1974; Rankin, 1976).

In their discussion of the Reelfoot–Rough Creek Rift System, Potter and others (1995) pointed out that Thomas (1991) considered the Reelfoot Rift, Rough Creek Graben, and Rome Trough (a Cambrian basin that extended from central and eastern Kentucky northeast to western Pennsylvania) as linked segments of a failed intracratonic rift system of Early and Middle Cambrian age that was contemporaneous with and compatible with the Alabama-Oklahoma Transform, which coupled Ouachita rifting with mid-Iapetus spreading. Although conceding that the proposed Rough Creek Graben–Rome Trough connection was not well understood, Thomas (1991) suggested that the Rough Creek Graben served as an "oblique transfer zone" between the Reelfoot Rift and the Rome Trough. Drahovzal and others (1992) concluded, however, that during the Early and Middle Cambrian a structurally stable area, which was a component of the pre-Grenville East Continent Rift Basin, separated the two structural features. Potter and others (1995) observed that the geometry of the postulated Reelfoot–Rough Creek–Rome rift conforms to a right-stepping rift offset, as defined by Nelson and others (1992), and that an oblique rift offset segment (in this case the Rough Creek Graben) would be a zone of complex strain and that the bounding faults (Rough Creek–Shawneetown and Pennyrile Fault Systems) would have undergone oblique displacement with a significant strike-slip component during Cambrian time. Apparently, no estimate of the amount of Cambrian strike-slip on either of the bounding fault systems has been made. Goetz and others (1992) postulated, but cited no data, that the Rough Creek Graben and Rome Trough originated in the Precambrian before development of the Reelfoot Rift, and that the Reelfoot Rift linked up with the older structures during the Cambrian.

Tectonic evolution of a rift system along the upper Mississippi Embayment, composed of the Reelfoot Rift graben under the embayment and an east-trending arm (the Rough Creek Graben), was the primary control on the origin and structural evolution of the Illinois Basin (Fig. 4). Activity within the rift complex influenced sedimentation, development of ancient and modern river systems, formation of younger structures, and contemporary earthquake activity (Braile and others, 1986). But, as pointed out by Kolata and Nelson (1991b), tectonic activity in the Illinois Basin apparently unrelated to the rift complex also resulted in some major anticlines and synclines (i.e., the LaSalle Anticlinal Belt) and certain fault zones, such as the Sandwich Fault Zone in the northern part of the basin and the Centralia Fault Zone in the central part that parallels part of the DuQuoin

Monocline (Fig. 3). Proposed mechanisms, models, and chronology of events in the formation and evolution of the rift complex and the Illinois Basin have been summarized by Kolata and Nelson (1991a, b); they did not, however, discuss the tectonic model for the evolution of the Ouachita Mountains structural system to the south in Arkansas and the Mississippi Valley Graben (Reelfoot Rift graben) proposed by Hendricks (1988), which incorporated the suggestion by Hildenbrand and others (1982) that the rift formed along a suture in the North American continent (the Grenville Front) that separates crustal blocks of different lithology and age. The character of the crust underlying the Illinois Basin has been described by Heigold (1991). The mechanisms and models for evolution of the rift complex are only lightly touched on in subsequent discussion in this paper. For more detailed information, see the extensive references in Hendricks (1988), Heigold (1991), Kolata and Nelson (1991a, b), and Potter and others (1995).

Burke and Dewey (1973) suggested that the upper Mississippi Embayment was a failed arm of a triple junction, and Ervin and McGinnis (1975), using geophysical and geologic data, confirmed the presence of the structure, which they called the Reelfoot Rift. The Reelfoot Rift extends beneath the Mississippi Embayment from east-central Arkansas northeastward to southern Illinois. At its southern end, the rift abuts the ancestral cratonic margin that was deformed during the late Paleozoic Ouachita Orogeny. At its northern end the rift bends gradually eastward and merges with the east-trending Rough Creek Graben of western Kentucky, which was named and described by Soderberg and Keller (1981). Two additional arms or extensions have been postulated at the northern end of the Reelfoot Rift, based on magnetic and gravity anomalies. One extension postulated to the northeast beneath the Wabash Valley Fault System (Fig. 3), along the Illinois-Indiana state line: the so-called Southern Indiana Arm (Braile and others, 1982a, b, 1984; Sexton and others, 1986); the other extension, the St. Louis Arm, postulated to the northwest along the Mississippi Valley as far as St. Louis (Braile and others, 1982b, 1984). The composite structural feature was termed the "New Madrid Rift Complex" (Braile and others, 1982b). A review of evidence for rifting along the Southern Indiana and St. Louis Arms led Nelson (1990, 1991) to discount both features; Pratt and others (1990) concurred with Nelson's conclusions about the Southern Indiana Arm.

The Wabash Valley Fault System undoubtedly reflects west-northwest crustal extension (Nelson, 1991), but evidence for the proposal by Braile and others (1984) and Sexton and others (1986) that the fault system is caused by post-Pennsylvanian reactivation of Precambrian basement faults associated with northeast extension of the Reelfoot Rift is not convincing (Pratt and others, 1989, 1990; Nelson, 1990, 1991). A Consortium for Continental Reflection Profiling (COCORP) seismic profile (Pratt and others, 1989) across southern Illinois and adjacent Indiana, near seismic profiles cited by Sexton and others (1986) as evidence for the Southern Indiana Arm of the Reelfoot Rift, revealed a thick and widespread sequence of layered strata within the Precambrian basement that is contemporaneous with, or predates, the 1,510 to 1,450 Ma granite and rhyolite forming the basement throughout the eastern Midcontinent region (Pratt and others, 1990). The layering that is recorded by strong, subhorizontal seismic reflectors commonly is truncated and appears to reflect small, graben-like features (Sexton and others, 1986). Sexton and others thought that the grabens were filled with pre-Mount Simon (Upper Cambrian) layered rocks, but Pratt and others (1990) interpreted the structures and layered rocks as part of the Middle Proterozoic sequence itself and not part of a late Precambrian rift basin. Furthermore, Pratt and others (1990) found no significant thickening of lower Paleozoic strata similar to the thickening in the Reelfoot Rift (Howe and Thompson, 1984) and Rough Creek Graben (Bertagne and Leising, 1991).

In discounting the postulated rifting in the Wabash Valley area, Nelson (1991) pointed out that the Wabash Valley faults tend to split upward and merge downward, and on seismic sections show no detectable offset at the top of basement; that some Wabash faults do not overlie inferred older faults; and that renewal of movement on old faults in the Phanerozoic sedimentary cover should induce drape folding rather than the horst-and-graben structures of the Wabash Valley system. As an alternative for the origin of the Wabash Valley Fault System, Nelson (1991) proposed that the system is the product of post-Pennsylvanian crustal arching and cited Sanford's work (1959) on arching in clay models to demonstrate development of features consistent with those of the Wabash Valley system. Of particular note are the longitudinal, normal faults that have maximum throw at the surface and die out with depth, and faults that outline a central collapsed area. A later magnetic and gravity study by Hildenbrand and others (1996) suggests that the northwestern margin of the Reelfoot Rift does not continue northward beyond the Rough Creek–Shawneetown Fault System, but bends to the east and merges with the basement fault along the northern margin of the Rough Creek Graben.

The postulated St. Louis Arm of the New Madrid Rift Complex is also not supported by compelling evidence (Nelson, 1990, 1991). COCORP seismic profiles (Pratt and others, 1989) from the St. Francois Mountains of southeastern Missouri eastward across the proposed rift arm into southwestern Illinois revealed "relatively transparent crust" (Pratt and others, 1989) and no rifts or grabens. Numerous drillholes in the area show that the Upper Cambrian Lamotte Sandstone, not graben-fill sediments, unconformably overlies rocks of the eastern granite and rhyolite terrane, which is exposed in the St. Francois Mountains. The northwestern alignment of magnetic and gravity anomalies near the junction of the proposed St. Louis Arm and the northwestern margin of the Reelfoot Rift (near the junction of the Mississippi and Ohio Rivers) have been ascribed by Hildenbrand and others (1996) to strike-slip faulting in the basement rather than to structural features marking the margins of a rift. In fact, Hildenbrand and others (1996) thought that the zone of high gravity that is generally aligned along the postulated St. Louis Arm is uncharacteristically restricted in length and width for a rift structure.

The faults within the outcropping Paleozoic rocks in the area of the St. Louis arm are post-Ordovician in age (Nelson, 1990, 1991), but some may have Precambrian precursors related to the 1.6-b.y. gneissic metamorphic basement (Hildenbrand and others, 1996) that in places forms a reentrant into the younger granite-rhyolite terrane of southern Missouri (Guiness and others, 1982). Consequently, because the rift apparently is a two-arm rather than a four-arm rift, as envisioned by Braile and others (1982b), Nelson (1990) suggested that the name "New Madrid Rift Complex" is inappropriate and should be discarded. Discarding the name would also eliminate the confusion between the New Madrid Rift Complex and the New Madrid Seismic Zone.

During the active rifting that occurred from the latest Precambrian to the Middle Cambrian, the rift area underwent crustal stretching, extensional faulting, subsidence, and infilling of the basin that developed along the Reelfoot Rift and Rough Creek Graben. The Reelfoot Rift is bounded by sets of listric normal faults that parallel the trend of the rift, and total displacement down to the center probably is in excess of 5,000 ft (Schwalb, 1982b). There is a pronounced upwarp of Paleozoic strata along the axis of the rift, which Howe and Thompson (1984) attributed to an early normal fault that was later reactivated by compression, but Crone and others (1985) ascribed the upwarp to intrusion of felsic igneous rocks.

Initial deposits in the rift basin were red and gray arkose (Crone and others, 1985), possibly derived from topographically high areas in the granite-rhyolite terrane on the flanks of the rift. The arkose may represent alluvial-fan deposits (Houseknecht and Viele, 1984). Overlying the arkose are basinal shale and carbonate rocks deposited along the trough of the rift during marine transgression. The carbonate rocks grade into arkose or arkosic sandstone in the northern part of the rift (Houseknecht and Weaverling, 1983; Houseknecht and Viele, 1984). Great variation in the thickness of the pre-Knox (older than Late Cambrian) fill, from 2,500 ft to as much as 20,000 ft in the rift south of the Pascola Arch, reflects differential, intrafit, normal faulting in the basement (Howe and Thompson, 1984). On the basis of lithology, the basal clastic sequence is correlated with the Rome Formation (Lower Cambrian) and the carbonate sequence with the Middle Cambrian Conasauga Formation of the southern Appalachians (Houseknecht and Weaverling, 1983).

In the Rough Creek Graben, the basal Paleozoic section, described by Harris (1994) from the only well in the area to penetrate Precambrian basement, consists of more than 3,000 ft of synrift marine sandstone, green shale, and some oolitic limestone; the section contains no datable fossils. Overlying this sequence are post-rift deposits more than 1,000 ft thick dominantly of marine shale containing in the upper part the diagnostic Middle Cambrian trilobite *Baltagnostus,* which confirms correlation with the Conasauga Shale. Seismic reflection data (Drahovzal, 1994) indicate that as much as 18,000 ft of pre-Knox Group strata (below the top of the Upper Cambrian Eau Claire Formation) overlies the Precambrian basement within the Rough Creek Graben. The maximum thickness of pre-Knox strata in the graben adjacent to the south side of the Rough Creek–Shawneetown Fault System reflects growth faulting during deposition. Strata of the succeeding Knox Group and younger units, however, exhibit much more uniform thickness across the graben, although periodic fault movement over time did affect deposition across the system.

By the end of the Middle Cambrian, most faulting within the rift complex had ceased, except perhaps for local movement on the rift-bounding faults, and the tectonic setting evolved from that of a rift basin to a broad, slowly subsiding cratonic embayment (Fig. 4). Regional subsidence of both the rift complex and the adjacent craton continued with only periodic interruption throughout most of the Paleozoic. The proto-Illinois Basin opened southward to the Black Warrior and Arkoma Basins (Thomas, 1985, Fig. 2) and to the open ocean. The embayment remained open to the south until the rise of the Pascola Arch across the embayment in possibly the Late Permian or early Mesozoic (Kolata and Nelson, 1991a) structurally closed the basin and created the present basin configuration.

Beginning in the Late Cambrian, a major marine transgression spread across the eroded Precambrian surface of the Midcontinent and onto the Canadian Shield. Arkose and quartzarenite of the Mount Simon and Lamotte Sandstones filled the relief on the surface and inundated all but the higher hills. By the end of Cambrian time, however, all of the Precambrian topography was covered. The Mount Simon (Lamotte) Sandstone and overlying Eau Claire (Bonneterre) Formation grade southward into thick basin shale in the Reelfoot Rift (Houseknecht and Weaverling, 1983), an indication that the rift was continuing to subside. The presence of coarse clastics interspersed in the shale may suggest episodic deposition of submarine fans (Houseknecht and Weaverling, 1983).

During the Late Cambrian, a short-lived basin developed in northeastern Illinois (Buschbach, 1964) and was filled with more than 2,800 ft of Mount Simon Sandstone. This basin did not subside significantly after the Late Cambrian; the overlying Eau Claire was deposited uniformly across the area.

The southern boundary of the Rough Creek Graben is marked by a zone of down-to-the-north normal faults in the Precambrian basement that coincides approximately at the surface with faults bounding the south side of the Western Kentucky Fluorspar District and the Pennyrile Fault System of western Kentucky (Bertagne and Leising, 1991, Fig. 15-5; Goldhaber and others, 1992). The zone of basement faults on the south side of the graben functioned like a hinge and allowed greater deposition of pre-Knox strata on the north side of the graben than on the south.

Near the western end of the Pennyrile Fault System, however, where the fault system and the Rough Creek Graben merge into the Reelfoot Rift, the sense of rift asymmetry is opposite to that farther east in the graben. A seismic section (Goldhaber and others, 1992; Potter and others, 1995) from north of the Shawneetown Fault Zone in Illinois southeastward across Hicks Dome, then along the Tabb Fault Zone in the Western Kentucky Fluorspar District to the western part of the Pennyrile Fault System, shows southeastward thickening of the Lower and Middle Cambrian synrift clastic sequence (the pre-Knox sequence of Bertagne and Leising [1991]) from 3,600 ft on the south side of the Shawneetown zone to 10,200 ft on the north side of the Pennyrile system. The thickness of the pre-Knox sequence along the north side of the Pennyrile increases to the west and southwest within the Rough Creek Graben. The sequence south of the fault system is poorly known, because most published seismic sections terminate near the northern edge of the system. These seismic sections (Bertagne and Leising, 1991; Goldhaber and others, 1992; Potter and others, 1995) show that the pre-Knox section thins, but not abruptly, across the Pennyrile system.

The units of the Knox Group (Upper Cambrian and Lower Ordovician) record the northward transgression of a marine environment over the entire proto-Illinois Basin and far onto the craton. Paleomagnetic data for the Ordovician of North American (Laurentia) indicate that the craton was in the equatorial paleolatitudes throughout the Ordovician and that the craton rotated in a counterclockwise sense by about 45° (Van der Voo, 1988). In general, clastic units were deposited in the northern part of the basin and graded southward into shale and carbonate rocks. The center of Knox deposition was in the present Jackson Purchase Region of western Kentucky near the junction of the Reelfoot Rift and the Rough Creek Graben. The trend of depositional thickening southward down the rift is unknown because of the erosion of Knox units with later uplift of the Pascola Arch across the rift.

Although subsidence rates during Knox deposition were generally higher in the Reelfoot Rift and Rough Creek Graben south of the Rough Creek–Shawneetown Fault System, as evidenced by the isopach map of the Eau Claire Formation and underlying Knox Group (Fig. 7), seismic cross sections (Bertagne and Leising, 1991, Figs. 15-2 and 15-4) show anomalous thicknesses of Knox strata immediately north of the fault system locally in Illinois and western Kentucky. Yet nearby areas show no appreciable differences in thickness of the Knox across the system. Because the regional depositional pattern of the Knox reflects downwarping of the Rough Creek Graben and the northern end of the Reelfoot Rift, and therefore down-to-the-south movement on the ancestral Rough Creek–Shawneetown Fault System, local thickening on the north side of the system is difficult to explain.

Seismic data show that growth faulting on basement faults on the southern margin of the Rough Creek Graben continued, but was less pronounced, during deposition of the Knox Group than it was before the Knox was deposited (Bertagne and Leising, 1991, Fig. 15-5). The thickness of the Knox Group on the north side of the southern marginal faults is not appreciably greater than on the south side.

Tectonic activity during Knox deposition was not confined to the Reelfoot Rift Complex, for abrupt thickening of Knox strata east of the DuQuoin Monocline (in Figure 7, the zone of very tight contours in south-central Illinois) shows that the flexure served as a hingeline during Knox time (Kolata and Nelson, 1991a). Farther to the northeast, the Kankakee Arch began to form near the end of Canadian (Early Ordovician) time and its eventual emergence separated the Illinois Basin area from the Michigan Basin (Atherton, 1971). Evidence of the rise of the Kankakee Arch is the truncation of about 600 ft of upper Knox strata across the axis of the arch in northern Indiana (Atherton, 1971, Fig. 3). Thinning of the St. Peter Sandstone across the arch indicates its influence during later Middle Ordovician deposition. In western Kentucky, there is little evidence of structural deformation at this time, but the presence of about 145 ft of igneous rock in the bottom of the Exxon No. 1 Jimmy Bell well in Webster County (Plate 2C, well 15), which has a K-Ar age of 478 ± 25 Ma (Ralph Thomas, Texas Gas Transmission Co., written commun., 1975), suggests some tectonic activity in the Early to Middle Ordovician.

At the end of Knox deposition, the sea withdrew from the Midcontinent, and much of the region was subjected to a long period of erosion that resulted in the major post-Sauk sequence unconformity (Sloss, 1963). Erosion, particularly of the Knox, was greatest toward the northern flanks of the basin and diminished toward the depositional center. In southern Illinois and extreme southwestern Indiana, the Everton Dolomite (lower Middle Ordovician, Whiterockian) rests unconformably on strata of the Lower Ordovician (Canadian) part of the Knox Group. Conodont faunas from cores in southern Illinois (Norby and others, 1986) and southwestern Indiana (Rexroad and others, 1982) confirm the Whiterockian age of the Everton. The fauna from Illinois also indicate an apparent short hiatus prior to Everton deposition; however, later faunal study (R.D. Norby, Illinois State Geological Survey, written commun., 1992) shows that the true length of the hiatus is undetermined. In deeper parts of the rift complex, especially in the Rough Creek Graben, deposition may even have been continuous from the Canadian into the Champlainian.

A relative rise in sea level in the Middle Ordovician resulted in northward transgression onto the post-Canadian erosion surface. The initial deposits—sandy carbonate rocks, sandstone, shale, and locally anhydrite of the Everton Dolomite (lower Middle Ordovician)—are thickest in the southern part of the proto-Illinois Basin and pinch out northward, although quartzarenite of the Everton may have filled shallow embayments on the eroded surface toward the margins and now is not readily distinguishable from the overlying St. Peter Sandstone (Droste and Shaver, 1983).

Minor erosion followed deposition of the Everton Dolomite, except perhaps south of the Rough Creek–Shawneetown Fault System in the Rough Creek Graben, where the contact with the overlying St. Peter Sandstone appears to be gradational. The St. Peter spread north as a time-transgressive (Chazyan to lower Blackriverian) sand sheet (Dapples, 1955) over the Midcontinent, including the proto-Illinois Basin, and filled in karst features and valleys on the underlying erosion surface (Buschbach, 1964). Deposition of both the Dutchtown Limestone and Joachim Dolomite was in part contemporaneous with that of the St. Peter. These carbonate units accumulated east of and in part interfinger with the St. Peter in southern Illinois, western Kentucky, and western Indiana.

The succeeding late Champlainian carbonate rocks spread rather uniformly over the Illinois Basin, although subsidence was continuous and greatest, but not significantly so, in the rift complex. On the flanks of the basin, the Ozark Uplift and the Wisconsin Arch were emergent at the end of Blackriverian time, and there was local erosion and nondeposition of some late Middle Ordovician units (Kolata and others, 1986).

By late Champlainian and Cincinnatian time, extensive volcanic activity associated with the Taconic Orogeny spread volcanic ash (now preserved as K-bentonite beds) westward over a wide area of the Midcontinent. At least 18 K-bentonite beds are known from Middle and Late Ordovician rocks cropping out in the Mississippi Valley above the junction with the Ohio River Valley (Kolata and others, 1986). Only a few of these bentonite beds are recognized in the subsurface of western Kentucky.

Uplift of the Appalachian orogen was reflected in the westward distribution of fine siliciclastic material, such as that incorporated in the argillaceous Lexington Limestone, but more evident in the Upper Ordovician Maquoketa Shale, which was widely distributed in the epeiric seas covering the craton. A broad, submarine trough or valley (Sebree Valley), flanked by carbonate bank-like areas, extended southward from Ohio across Indiana and western Kentucky into western Tennessee. An eastward-thinning wedge of terrigenous sediments (Maquoketa) largely filled the trough, and flanking carbonate banks formed the Lexington and Kimmswick Limestones. Thickening of the Maquoketa Shale over the Rough Creek Graben indicates that the Reelfoot Rift was subsiding slightly during this time (Whitaker, 1988). The Ozark Uplift was emergent and shed some clastic wedges into the Maquoketa sea, but the Cincinnati Arch was not evident at this time (Atherton, 1971). By the end of the Late Ordovician, the terrigenous sediments had spread to the limits of the proto-basin. Except for minor uplift over the LaSalle Anticline and possible uplift of the Wisconsin Arch (Fig. 3) (Kolata and Graese, 1983), the craton was stable in the Late Ordovician.

A nearly worldwide glacio-eustatic drop in sea level during latest Ordovician and earliest Silurian time (Dennison, 1976; Lenz, 1976), as a response to glaciation in North Africa, resulted in extensive erosion and development of a pronounced unconformity on the Ordovician rocks over much of the Midcontinent. In northeastern Illinois, there is as much as 150 ft of relief on the unconformity (Kolata and Graese, 1983), and farther north, Ordovician rocks were stripped from the Wisconsin Arch area. On the east side of the proto-Illinois Basin, Upper Ordovician rocks were eroded from the Cincinnati Arch in Kentucky and over a broad belt from southern Illinois across Indiana into northwestern Ohio (Droste and Shaver, 1983).

Transgression of the Silurian sea initially flooded low areas on the eroded Ordovician surface and reworked the shaly Maquoketa strata, which contributed argillaceous material to Silurian units that filled deep channels. Initially, a narrow land bridge separated the proto-Illinois Basin into north and south segments, and much of Indiana and western Kentucky were emergent (Droste and Shaver, 1983, Fig. 30). Characteristically, the Silurian was a time of carbonate deposition in a broad embayment that connected southward through the Reelfoot Rift to the open sea. With uplift of the areas of the present Kankakee and Cincinnati Arches during the early Niagaran, the Wabash Platform (Droste and others, 1975)—a broad, shallow-water shelf—formed and separated the proto-Illinois Basin from the proto-Michigan Basin to the northeast and the proto-Appalachian Basin to the east (Fig. 26). The Terre Haute reef-bank complex developed on the southern flank of the platform, while the Fort Wayne bank (not identified on Figure 26) formed on the northern flank adjacent to the Michigan Basin. These banks separated platform from basinal sedimentary environments, and apparently influenced deposition in both areas. Reef development on the southern flank of the Wabash Platform continued for the remainder of the Silurian, the most extensive growth of both platform and peripheral reef systems being in the late Cayugan (Late Silurian).

Figure 26. Carbonate bank and reef systems (stippled), including the Terre Haute bank, in relation to the proto-Illinois, proto-Michigan, and proto-Appalachian Basins. Modified slightly from Droste and Shaver (1987, Fig. 3; used with permission of the Indiana Geological Survey).

Regression of the seas in the Late Silurian or Early Devonian terminated reef development. Droste and Shaver (1980, 1987) envisioned the Terre Haute bank as marking a structural hingeline peripheral to a relatively deep, subsiding basin called the Vincennes Basin by Droste and others (1975) in southern Illinois, southwestern Indiana, and adjacent Kentucky. A different model, proposed by Coburn (1986) and Whitaker (1988) for Silurian deposition in the proto-Illinois Basin, was of a ramp that deepened southward with no break between the shelf platform and the basinal slope. The area of greatest subsidence and thickness of Silurian strata was in the northern part of the Reelfoot Rift and adjoining Rough Creek Graben. In the Late Silurian and Early Devonian the proto-Illinois Basin connected southward through a broad, shallow seaway between the Ozark Uplift and the Nashville Dome (Broadhead and others, 1989) to the open ocean along the margin of the craton.

At the beginning of the Devonian, the position of the equator relative to the North American plate (Laurentia) was across the western end of present Alaska and north of Greenland (Kent and Van der Voo, 1990, Fig. 4). At this time, the southern part of the proto-Illinois Basin (western Kentucky) was at latitude 44°S, and by the Late Devonian that area had shifted north to latitude 18°S (paleolatitude calculations by M.R. Hudson, U.S. Geological Survey, 1992, from data by Kent and Van der Voo, 1990, Table 2).

Deposition from the Silurian into the Early Devonian was continuous in the deeper parts of the proto-basin. If the seas encroached onto the Wabash Platform, the resulting strata were later removed by post-Early Devonian erosion. The widespread argillaceous carbonate strata of the Moccasin Springs Formation (Upper Silurian) give way upward to the conformable Lower Devonian sequence of cherty carbonate units of the Bailey, Flat Gap, Grassy Knob, Backbone, and Clear Creek Limestones that attains a maximum thickness of more than 1,200 ft (Kolata and Nelson, 1991a).

Near the end of the Early Devonian, the Cincinnati, Kankakee, Sangamon, and Northeast Missouri Arches and the Ozark Uplift, all on the flanks of the basin, were uplifted. Lower Devonian strata are absent from these structures, either through erosion or nondeposition, and Silurian rocks generally underlie a pre-Middle Devonian unconformity. On the structures along the west side of the basin, the depth of erosion was to Ordovician and locally Cambrian rocks. In the Rough Creek area of western Kentucky, the Clear Creek Limestone (uppermost Lower Devonian) is missing over the eastern half of the area. Eastward, Middle Devonian limestone progressively overlies Silurian rocks and rests on Upper Ordovician strata on the flanks of the Cincinnati Arch.

Tectonism in the proto-Illinois Basin and the eustatic drop in sea level at the end of the Early Devonian probably were responses to the Silurian–Early Devonian convergence and collision between North America (Laurentia) and Gondwana that resulted in the Caledonian-Acadian Orogeny (Van der Voo, 1988). With retreat of the seas from much of the Midcontinent, a pronounced unconformity developed before deposition of Middle Devonian rocks. In the deeper parts of the basin, however, in southeastern Illinois, southwestern Indiana, and western Kentucky, sedimentation was continuous from the Early into the Middle Devonian, and as a consequence, there is no pre-Middle Devonian unconformity in these areas (Droste and Shaver, 1975).

Northward transgression of the sea over the pre-Middle Devonian surface began in late Early Devonian time (Devera and Fraunfelter, 1988). The timing of the transgression is supported by faunal evidence (Collinson, 1967; Oliver, 1967). At this time there was no closed Illinois Basin; instead, the southern part of the future basin served as an inlet, allowing open circulation and a supply of nutrients from the sea to the south (Devera and Fraunfelter, 1988). The sea transgressed over successively truncated belts of Lower Devonian and Upper Silurian strata onto an eroded surface of generally subdued topography.

Many Silurian reefs were exhumed during the post-Early Devonian erosion, and these may have formed shoals or even islands in the encroaching sea (Droste and Shaver, 1975). Channels as much as 50 ft deep are present in Lower Devonian and Silurian rocks in western Illinois (Devera and Hasenmueller, 1991) and also in the northern part of the basin in Indiana and Illinois. In western Illinois, solution fissures filled with Middle Devonian rocks (mostly sandstone) penetrate at least 70 ft into Silurian rocks (Meents and Swann, 1965), and in northern Indiana, clastic dikes and solution cavities filled with Devonian sandstone and shale are common in Upper Silurian strata (Sunderman, 1988).

Erosion of the Ozark Uplift to the west and the Wisconsin Arch to the north of the proto-basin contributed sand, which was irregularly distributed as the initial deposit of the Middle Devonian sea in Kentucky. In southern Illinois, the sand was deposited by tides over a shallow carbonate shelf (Tissue, 1977). The overlying bioclastic Middle Devonian limestones represent deposition in a deeper, open-marine environment restricted to the adjoining areas of Illinois, Kentucky, and Indiana (Droste and Shaver, 1975, Fig. 11). Bordering the open-marine area on the north and northeast was a shoal area on the very broad Wabash Platform, which extended over much of Illinois and Indiana and probably part of northern Kentucky (Droste and others, 1975, Fig. 1). The shoal area covered the Silurian Terre Haute reef bank and profoundly affected the distribution and character of the Middle Devonian limestones.

Near the end of the early Middle Devonian, the Tioga K-bentonite bed was deposited in the upper part of the limestone sequence over southeastern Indiana and eastern Illinois. The only known occurrence of the Tioga in western Kentucky is in a well in Union County on the north side of the Rough Creek Fault Zone. The ash bed originated from a vent source in the Piedmont of central Virginia (Dennison, 1961), and is evidence of volcanic activity associated with the Acadian Orogeny. Activity in the orogen was coincident with tectonic activity in the proto-Illinois Basin area.

At the close of the early Middle Devonian, the north side of the Rough Creek–Shawneetown Fault System was uplifted, including parts of present Grayson, Breckinridge, and Meade Counties, Ky., and the Devonian strata were partly or entirely eroded (Devera and Hasenmueller, 1991). Elsewhere, the seas regressed from the flanks of the basin and exposed the lower Middle Devonian units to minor erosion before deposition of the upper Middle Devonian strata. Deposition was continuous, however, in the deeper parts of the basin.

Re-advance of the sea in the late Middle Devonian covered the eroded lower Middle Devonian strata, inundated areas far beyond the limits of the older Middle Devonian units, and onlapped the Sparta Shelf and Sangamon Arch in western Illinois (the arch is no longer in existence) and the Kankakee and Cincinnati Arches in Indiana and Kentucky. The three arches were very subdued features on the Wabash Platform, which continued to control sedimentation mainly by separating highly saline water in the interconnected Michigan and Central Iowa Basins on the north from normal marine water to the south (Atherton, 1971).

During the late Middle Devonian, the proto-basin area was largely an open-marine environment, but very shallow-marine conditions on the northern and western fringes of the basin reflected the influence of slightly emergent structural features, such as the Sangamon Arch (Whiting and Stevenson, 1965) and coastal flats in the area of the present Wisconsin Arch (Droste and Shaver, 1983, Figs. 44–45). The Ozark Uplift was also emergent, together with a southeastern extension of those highlands in southwestern Illinois called the Sparta Peninsula (Devera and Fraunfelter, 1988). The Sparta Shelf (Meents and Swann, 1965) was a shallow-water area peripheral to the peninsula (Fig. 3); the shelf was bordered on the south by the Ste. Genevieve Fault Zone. Uplift along the Ste. Genevieve Fault, beginning in the late Middle Devonian, tilted and raised the Sparta

Shelf (Nelson and others, 1985). Most of the eroded sediment was deposited in a restricted basin on the south side of the fault, but some was carried farther offshore and incorporated in the uppermost Middle Devonian sediments.

Continued advance of the sea deepened marine water over the Wabash Platform, inundated the structural features on the platform, and by the latter half of the Middle Devonian a connection between the proto-Illinois and Michigan Basins was well established.

At a time comparable with the structural movement on the Ste. Genevieve Fault Zone, movement on the Rough Creek Fault Zone in western Kentucky uplifted a small area on the north side, the McDaniels Island of Devera and Fraunfelter (1988), mostly in northern Grayson and southern Breckinridge Counties. The Sellersburg Limestone (late Middle Devonian) and the underlying Jeffersonville Limestone (early Middle Devonian) are unusually thin over this area (Freeman, 1951, Fig. 9); McDaniels Island probably functioned as a submarine sill (Devera and Fraunfelter, 1988). The Jeffersonville was partly or totally eroded from the uplifted side of the fault zone, and the eroded sediment was reworked into thicker Sellersburg deposits south of the fault.

At the end of Middle Devonian deposition, regression of the sea from the flanks of the proto-basin resulted in minor erosion. Uplift along the Rough Creek–Shawneetown Fault System exposed the Sellersburg Limestone to erosion prior to deposition of the New Albany Shale (uppermost Middle Devonian to Lower Mississippian). But in the deeper parts of the basin, sedimentation was continuous from the argillaceous carbonate rocks of the upper Middle Devonian to the basal, calcareous, carbon-rich shale of the New Albany. In Kentucky and Indiana, however, the New Albany is disconformable on the Middle Devonian limestones.

By late Middle Devonian time, a basinal-shale facies of the Catskill delta complex, which resulted from uplift in the Acadian orogen, spread west from the Appalachian Basin into the central Midcontinent (Devera and Hasenmueller, 1991). The New Albany Shale, part of that depositional facies, overlapped the Cincinnati, Kankakee, and Sangamon Arches, and during deposition of its most extensive member, the Grassy Creek (early Late Devonian to Early Mississippian [Kinderhookian]), covered most, if not all, of the basin and spread northwestward into Iowa (Cluff and others, 1981). The principal depocenter was in western Kentucky and southeastern Illinois on the south side of the Rough Creek–Shawneetown Fault System, but a second depocenter was in southeastern Iowa and adjacent west-central Illinois (Cluff and others, 1981). All members of the New Albany Shale (the Blocher at the base, the Selmier in the middle, the Grassy Creek in the upper part, and at the top, the thin, undifferentiated Saverton and Hannibal Shales) are present in the deepest part of the basin in western Kentucky and adjacent Illinois. Eastward in Kentucky, the Selmier overlaps the Blocher, and the Grassy Creek in turn overlaps the Selmier (Schwalb and Norris, 1980a); no lithic equivalent of the Saverton and Hannibal Shales has been reported in the New Albany outcrop belt in Kentucky. The Grassy Creek Member constitutes the majority of the New Albany on outcrop in Kentucky, as well as in Indiana.

Growth faulting on the Rough Creek–Shawneetown Fault System during deposition of the New Albany is reflected in particular by the variation in thickness of the Blocher and Selmier Members across the system. Both members have a greater thickness on the south side of the fault system than on the north (Schwalb and Norris, 1980d, e), which suggests some uplift of the north side. The change in thickness of the Grassy Creek Member across the system is much less pronounced (Schwalb and Norris, 1980g).

The Pennyrile Fault System on the south side of the Rough Creek Graben was also active during New Albany time. An isopach map (Schwalb and Potter, 1978) shows that the New Albany along the western part of the system in Lyon and Caldwell Counties, Ky., abruptly thickens by 60 to about 100 ft on the north (downthrown) side, but to the east the amount of thickening is considerably less. In fact, in southwestern Muhlenberg County, there may have even been some reversal of fault movement, for locally there is thickening of the New Albany on the south rather than on the north side of the Pennyrile system.

In Illinois, the New Albany sea spread to the north and west from the southern depocenter, described by Cluff and others (1981) as a deep anoxic basin, up a gentle ramp onto a shallow shelf that occupied the area of the Sangamon Arch and Sparta Shelf in western Illinois (Fig. 3). The facies relationships and thicknesses of the formations of the New Albany Group reflect the interplay of oxygen content, wave energy, and basin topography on depositional environments within the New Albany sea (Cluff and others, 1981).

In the deeper parts of the basin, the members of the New Albany are conformable on older Devonian rocks, but in some shallower shelf areas they unconformably overlie Silurian and locally even Ordovician strata. Deposition of the New Albany in Illinois was continuous from the Late Devonian into the Kinderhookian (Early Mississippian), except for limited areas in western Illinois on the flank of the Lincoln Fold, an anticlinal feature in northeastern Missouri that extends northwest from the Mississippi River (Fig. 3).

The presence of limited gray and green shale and thin limestone in the latest Devonian and earliest Mississippian (Kinderhookian) deposits attests to transition to shallower and better-oxygenated environments in the basin. There was local minor erosion in Illinois and Indiana before deposition of Osagean strata (Lineback, 1970; Treworgy, 1991), and in north-central Kentucky, a thin zone of phosphatic nodules in basal Mississippian beds represents a depositional hiatus before Osagean time (Kepferle, 1977).

Near the beginning of the Osagean, the rate of subsidence in the southern part of the proto-Illinois Basin became greater than the rate of sedimentation, and this resulted in a deep-water, sediment-starved basin (Lineback, 1969). A carbonate shelf bounded the northern and western margins of the basin, but to the south the basin apparently deepened toward the Ouachita Trough.

By the Early Mississippian, the final stages of the Acadian Orogeny in and east of present New England facilitated the maximum westward advance of a vast delta complex that stretched from southern Canada down into the Appalachians. In the early Osagean, the time of maximum deltaic deposition, the prograding front of the Borden delta reached Kentucky (but east of the Rough Creek area) and southern Indiana sometime before a distinctive, submarine, tongue-shaped, siltstone delta filled the western part of the basin in Illinois (Swann and others, 1965). In Kentucky, sediment transport during at least the early phase of delta deposition was from the east; the source of several large siltstone units is postulated as a granite-cored Appalachia to the east and southeast (Kepferle, 1977).

Various sources for the mostly subgraywacke of the deltaic detrital units (Potter and Pryor, 1961) have been interpreted as north and east of the Appalachian Basin (Potter and Pryor, 1961; Walker, 1962), in the Canadian Shield (Potter and Pryor, 1961), and possibly in northernmost Canada (Franklin Mountains) (Swann and others, 1965). The volume and thickness trends of detrital sediments and paleocurrent data (Whitehead, 1976, Fig. 16) suggest eastern sources, perhaps located in or east of the present Piedmont Belt or the New England Acadian Mountain system (Sable and Dever, 1990). The Canadian Shield was not an important source. Only the finer detritus of the great volume of clastic sediments from these source areas reach Kentucky.

The Cincinnati Arch was submergent during most or all of Early Mississippian time. A low-lying landmass, "Cincinnatia," was postulated by Pepper and others (1954) along the axis of the arch at this time, but a comparison of the due-west paleocurrents recorded in a siltstone unit in the delta sequence east of the arch with the southwesterly paleocurrents of a similar unit west of the arch shows no deflection, as would be expected if there had been a land mass along the arch (Whitehead, 1976). Also, the presence of phosphatic-nodule accumulations both east and west of the arch, likely caused by upwelling along a single shelf (R.C. Kepferle, written commun., 1985, *in* Sable and Dever, 1990), argues against extensive emergence of the arch at this time.

After active delta growth ceased near the end of Osagean time, siliceous carbonate rocks of the Fort Payne Formation were deposited in the adjoining deep-water basin and on foreset slopes of the Borden delta front, thereby partly filling depressions adjacent to the delta (Lineback, 1966; Sable and Dever, 1990). Irregular topography on the top of the Fort Payne was later filled by the Ullin Limestone in Illinois and by the Muldraugh Member of the Borden Formation in Kentucky. These shallower-water carbonate deposits filled much of the remaining basin and eventually overlapped terrigenous clastics of the Borden delta. A discrete, depositional, delta-front interface separated the west-thinning delta clastics from the east-thinning carbonate rocks (Peterson and Kepferle, 1970). A shallow-water carbonate platform developed on top of the Borden delta as the sea transgressed across the delta platform, and the carbonate platform persisted through deposition of the overlying Meramecian carbonate units.

The Cincinnati and Kankakee Arches and the Ozark Uplift were intermittently emergent and restricted circulation of marine waters in the proto-Illinois Basin during Meramecian time (Sable and Dever, 1990); seaway connections were mainly to the south and to the Appalachian Basin through the Cumberland Saddle (Fig. 3). During the Meramecian, the proto-basin continued as a major negative feature, as shown by the accumulation of more than 1,100 ft of sediment in western Kentucky (Sable and Dever, 1990); all units thinned eastward toward the Cincinnati and Kankakee Arches. Maximum subsidence in western Kentucky occurred near the middle of the Meramecian. A little later, during deposition of the St. Louis Limestone, uplift of the arches and fluctuation of sea level resulted in cyclic deposition of evaporites and shallow-marine carbonate rocks over a broad tidal flat from western Kentucky across southwestern Indiana to western Illinois (Saxby and Lamar, 1957; Jorgensen and Carr, 1973) and into southeastern Iowa (Carlson, 1979). Normal-marine, shallow-water conditions returned near the end of the Meramecian, but the incursion of terrigenous clastics in the youngest Meramecian limestone in western Kentucky and adjacent Illinois signaled the onset of cyclic deposition, which characterizes the overlying Chesterian section.

Although there apparently was no significant time break between the youngest Meramecian limestone (Ste. Genevieve) and overlying Chesterian units, there was a break in deposition and some emergence that allowed for development of two widespread paleosols (Bryantsville Breccia Bed) in the upper part or at the top of the

Ste. Genevieve Limestone (G.R. Dever Jr., Kentucky Geological Survey, *in* Treworgy, 1991). The Bryantsville is recognized on both sides of the Cincinnati Arch in Kentucky and northward across Indiana and in some areas of Illinois.

By Chesterian time, the proto-Illinois Basin area was a shallow epeiric sea, with low sea-floor relief on a low-angle, southwest-dipping paleoslope, in which deposition was strongly influenced by fluctuation in the supply of terrigenous clastics to the basin through the Michigan River system (Swann, 1964, Fig. 2) (Fig. 16). The river flowed southwest in a shallow trough across the present state of Michigan from sources primarily in eastern Canada, and established a bird-foot delta in the sea beyond a northwest-trending shoreline in the area of the Illinois-Indiana state line. Major lateral, northwest-southeast shifts of the course of the Michigan River distributed deltaic sediments over different parts of the region at different times, and major northeast-southwest oscillations of the shoreline produced numerous marine transgressions of carbonate deposits (Swann, 1964). The wide distribution of sedimentary units of uniform thickness shows that there was a close balance between the rate of sediment accumulation and of subsidence, and that subsidence was relatively uniform over broad areas. The repetitive interplay of marine, marginal, and continental environments is reflected in the cyclic deposits that characterize the Chesterian (Sable, 1979a).

During the Chesterian, the Cincinnati and Wisconsin Arches were emergent. The northern part of the Cincinnati Arch in Ohio and possibly in adjacent northern Kentucky was a low-lying peninsula or shoal area that contributed little sediment, but may have served as a partial barrier between the proto-Illinois Basin and the Appalachian Basin (Sable and Dever, 1990).

Beginning in the Chesterian, deformation was widespread throughout the proto-Illinois Basin in response to compressive stresses created by the collision of Laurentia, Africa, and South America to form the supercontinent Pangea. The compressive stresses resulted in uplift of crustal blocks within the basin, the reactivation of some existing faults or creation of new faults, and drape folding in the Paleozoic sequence (Kolata and Nelson, 1991a). Deformation was widespread along the western margin of the basin from the Ste. Genevieve Fault Zone on the south to the Mississippi River Arch on the north (Fig. 3). In addition, several major structural features in the interior of the basin, the DuQuoin Monocline and associated Salem and Louden Anticlines (not shown on Figure 3), and the LaSalle Anticlinal Belt, began or had renewed uplift in the Late Mississippian, and movement continued into the Pennsylvanian. Those features in the southern part of the basin closest to the Rough Creek area that influenced sedimentation and tectonics in the late Paleozoic were the Ste. Genevieve Fault Zone and the DuQuoin Monocline.

Renewed movement on the Ste. Genevieve Fault Zone in latest Mississippian and Early Pennsylvanian time (Nelson and others, 1985) reversed the direction of the earliest movements on the fault zone, which had occurred in the late Middle Devonian. Also during this second period of tectonic activity, the Ozark Uplift rose more than 3,000 ft along preexisting fractures relative to the Sparta Shelf and the adjoining basin. The Late Mississippian faults developed mostly southwest of the Devonian faults and extended laterally beyond the limits of the earlier faults (Nelson and others, 1985).

The DuQuoin Monocline in the south-central part of the Illinois Basin served as a hingeline between the Sparta Shelf and the area to the east of greater subsidence, initially from the Late Cambrian to the Early Ordovician (Kolata and Nelson, 1991a). Renewed but minor movement along the monocline during middle Chesterian time is reflected in the lithofacies distribution of the units of the Golconda Group of Illinois (Formation in Kentucky). Deposition west of the monocline was under shallow-shelf conditions, whereas deposition to the east reflected somewhat deeper water (Treworgy, 1988). Maximum development of the monocline occurred in the Early Pennsylvanian (Siever, 1951; Brownfield, 1954).

In the southern part of the basin, the ancestral Rough Creek lineament, also termed the 38th Parallel Lineament (Heyl, 1972), along the trend of the present Rough Creek–Shawneetown and Cottage Grove Fault Systems, also served as a structural hingeline during the middle Chesterian (Treworgy, 1988). On its south side lay a broad shelf over which the sea was shallower than north of the lineament. Lithofacies of various units of the Golconda show that the feature influenced the lithology and probably unit thicknesses at this time. The consistent offset and bending of isopachs along the Rough Creek Fault Zone (Fig. 15) suggest tectonic instability during all of Mississippian time, not just during the Chesterian. Although structural hingelines focused the center of deposition to the north of the Rough Creek lineament during the middle Chesterian, the area of maximum deposition for the entire Chesterian was south of the lineament, near or south of the present limits of the Illinois Basin (Treworgy, 1991, Fig. 9-8).

At the end of the Chesterian, the seas withdrew from the proto-Illinois Basin. A major erosional hiatus between Mississippian and Pennsylvanian rocks developed throughout the basin, and the erosional event was even worldwide (Saunders and Ramsbottom, 1986). The amount of time represented by the unconformity in the Illinois Basin is hard to determine.

Droste and Keller (1989) suggested that in northern Indiana the Mississippian-Pennsylvanian unconformity may represent as much as 8 million years of erosion, but in southern Indiana the unconformity may represent less than 3 million years. In fact, Rexroad and Merrill (1985) even proposed that locally in the deep basin in southern Illinois there was uninterrupted marine deposition from the Mississippian into the Pennsylvanian, because fossils in shale and sandstone conformably overlying the Grove Church Shale (the youngest Mississippian strata in the basin, based on conodont assemblages) are of earliest Pennsylvanian age. Damberger (1989), however, interpreted data by Ross and Ross (1985), postulating six worldwide transgressive and regressive episodes covering the time of the unconformity, to suggest a potentially large hiatus in the Illinois Basin. Whatever the actual span of the Mississippian-Pennsylvanian hiatus, it was least in the southeastern part of the basin, where Morrowan (Lower Pennsylvanian) rocks rest on Chesterian strata, and greatest on the northern and western flanks, where locally Desmoinesian (Middle Pennsylvanian) rocks overlie the erosional surface.

In the eastern part of the Appalachian Basin (southwestern and eastern West Virginia), a thick succession of strata, the oldest Pennsylvanian rocks in the eastern United States (Englund and others, 1977), was deposited during the interval of the Mississippian-Pennsylvanian unconformity in the Illinois Basin. These Early Pennsylvanian strata wedge out northwestward across the Appalachian Basin (Rice and Weir, 1984), and no representative of this sequence is recognized farther west in the Illinois Basin.

In the Illinois Basin, the hiatus is marked by progressively deeper beveling of pre-Pennsylvanian strata toward the flanks of the basin in Kentucky and in northern Illinois and Indiana, where as much as 1,500 ft of the Mississippian section may have been removed (Sable, 1979a). A linear drainage system was entrenched on a gently rolling, southwest-dipping paleoslope, and in southeastern Illinois valleys as much as 20 mi wide and 450 ft deep were cut into the surface (Siever, 1951; Bristol and Howard, 1971). In western Kentucky, as much as 900 ft of Mississippian rocks is believed to have been removed, and channels incised as deeply as 250 ft into the erosional surface (Rice and others, 1979). In Indiana, in the upper reaches of the drainage system on the pre-Pennsylvanian surface, known from detailed studies by Droste and Keller (1989) and Keller (1990), topographic relief on the Mississippian strata is locally as much as 200 ft, but generally less than 100 ft. Howard (1979) proposed that the pre-Pennsylvanian drainage pattern in the basin evolved through a succession of erosional periods, each marked by development of a drainage pattern followed by aggradation.

Several major features in the southern part of the basin began or continued to undergo structural movement in post-Mississippian time, but except for the DuQuoin Monocline, none appear to have served as topographic barriers to development of the prominent southwest-draining system in the basin prior to Early Pennsylvanian deposition. Near the southern end of the LaSalle Anticlinal Belt in Clark and Crawford Counties, Ill., several major paleovalleys cross the anticlinal structures without diversion (Howard, 1979; Howard and Whitaker, 1988). But southwestward in the basin, diversion of major paleovalleys east of the DuQuoin Monocline suggests that the western shelf, including the DuQuoin Monocline on its eastern edge, was rising at this time and deflected southwest-flowing streams to the south (Bristol and Howard, 1971).

In western Kentucky, several paleochannels cross the Rough Creek Fault Zone, but no significant offset is evident. In the vicinity of Sebree, Ky., however, a segment of a channel may have been deflected from a southwesterly to a more westerly trend by pre-Pennsylvanian movement on the fault (Davis and others, 1974). Although the Rough Creek zone apparently did not markedly influence the location of paleochannels, Greb (1989a) concluded that in the subsurface east of Owensboro a fault-bounded valley was the locus of a basal Pennsylvanian channel network that was tributary to the extensive Evansville channel system (Bristol and Howard, 1971, Fig. 4), which crosses the western part of the Rough Creek area.

On the southwestern flank of the proto-Illinois Basin in latest Mississippian and Early Pennsylvanian time, movement on the Ste. Genevieve Fault Zone folded and faulted Chesterian and older rocks, but superjacent Lower Pennsylvanian strata show only gentle tilting and minor faulting (Nelson and others, 1985). Paleocurrent directions in basal Pennsylvanian sandstones also indicate movement along the Ste. Genevieve zone. An upthrown block along a segment of the fault zone served as a barrier at this time to southwest regional sediment transport and caused local stream diversion to the southeast (Desborough, 1961).

With the gradual return of the sea into the basin in the Early Pennsylvanian, the valleys on the old erosional surface were filled with fluvial, deltaic, and shallow-marine sediments (Glick, 1963; Koeninger and Mansfield, 1979; Pryor and Potter, 1979). The Pennsylvanian strata in the Illinois Basin, as well as worldwide, are characterized by repetitive sedimentary sequences, or cyclothems, that resulted from alternate advances and retreats of the seas. A hypothesis of eustatic sea-level changes, primarily caused by waxing and waning of glaciation in the southern hemisphere, or Gondwanaland, most readily explains the contemporaneous and widespread nature of the cyclic deposition (Wanless and Shepard, 1936; Crowell, 1978; Heckel, 1980, 1986; Boardman and Malinky, 1985; Ross and Ross, 1985).

The earliest determined structural movement during the Pennsylvanian that involved the Rough Creek–Shawneetown Fault System and adjacent areas was minor movement in the late Desmoinesian and early Missourian. In the Eagle Valley Syncline in southeastern Illinois immediately south of the fault system, the Herrin coal bed and overlying Brereton Limestone Member of the Modesto Formation were apparently faulted prior to deposition of the slightly younger Gimlet Sandstone Member (Nelson and Lumm, 1984, Fig. 28); the strata of the Modesto Formation are now included in the Shelburn Formation. In western Kentucky, faulting of about the same age along the north side of the Rough Creek Fault Zone displaced strata from the Springfield (W. Ky. No. 9) coal bed in the upper part of the Carbondale Formation up to the West Franklin (formerly the Madisonville) Limestone Member of the Sturgis Formation in and near the Peabody Coal Company Camp Breckenridge No. 11 underground coal mine southeast of Morganfield (Nelson and Lumm, 1984, Fig. 17).

To the south along the main branch of the Pennyrile Fault System north of Crofton, Ky., even earlier episodes of structural movement involving Pennsylvanian strata were detected by Lumm and others (1991a). They were: (1) movement in Morrowan time that caused slumping in the Caseyville Formation, (2) movement during the Atokan that resulted in angular unconformities and controlled the direction of sediment transport, and (3) major faulting during post-Atokan time along the main branch of the fault system.

Elsewhere in the southern part of the proto-Illinois Basin, continued uplift during the Pennsylvanian and probably into the Early Permian on the LaSalle Anticlinal Belt (Kolata and Nelson, 1991a, Fig. 18-1), DuQuoin Monocline (Brownfield, 1954), and Louden Anticline (DuBois, 1951) further differentiated the Fairfield Basin (Fig. 3). The rising structures acted as hingelines and contributed to the abrupt basinward thickening of Pennsylvanian strata, especially near the LaSalle and DuQuoin structures (Atherton, 1971).

Apparently, Strunk (1984) was the first to propose a two-phase stress model for the tectonic evolution of the southern part of the Illinois Basin: first, a compressional phase and then an extensional phase, both tied to major tectonic events involving continental collision and rifting from the late Paleozoic to possibly the Jurassic. This hypothesis was generally accepted by Kolata and Nelson (1991a). Earlier, Weller (1940) had recognized the compressive origin of many of the structures in southern Illinois and their relation to the Appalachian Orogeny. In his tectonic scenario, Strunk (1984) incorporated many of the ideas put forth in the structural study of southeastern Illinois of Nelson and Lumm (1984, 1987); Strunk was a participant in Nelson and Lumm's 1984 study. He agreed with Nelson and Lumm's ideas on the origin of the Rough Creek–Shawneetown Fault System, but differed on the sequence and timing of several major structural events. It should be emphasized, however, that geologic evidence to firmly establish the sequence of structural development in the southern part of the Illinois Basin is obscure.

The late Paleozoic continental collision that began in the Chesterian and continued through the Early Permian assembled North America, Africa, and South America into the supercontinent of Pangea (Braile and others, 1986, Fig. 9D). Along the southern margin of the North American craton, a deep marginal basin, between the north-facing subduction complex and the continental margin around the Ouachita Embayment (Fig. 27), remained open through the Late Mississippian and

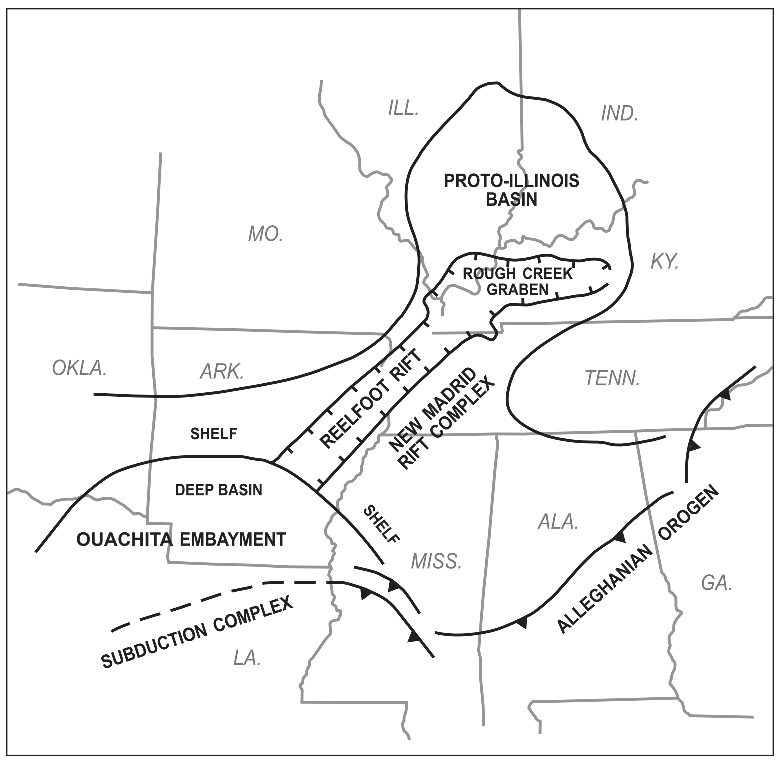

Figure 27. Late Paleozoic tectonic setting along the southern margin of the North American craton. Tectonic events greatly simplified and condensed. Modified from Thomas (1985; used with permission of Annual Review of Earth and Planetary Sciences), Kolata and Nelson (1991a; used with permission of the American Association of Petroleum Geologists), Hildenbrand and Hendricks (1995).

Early Pennsylvanian simultaneously with arc-continent collision at the southern end of the Alleghanian orogen (southern Appalachians) (Thomas, 1985). During the Pennsylvanian, the drainage from the proto-Illinois Basin was southwestward into the margin basin. Orogenesis migrated westward along the continental margin through time, and the remnant ocean closed and filled (Thomas, 1985). On the west, the collision that resulted in the Ouachita Foldbelt of Arkansas and Oklahoma began in the Early Pennsylvanian and was over by the Early Permian (Wickham and others, 1976).

As noted by Kolata and Nelson (1991a), precise dating of the tectonic deformation that is reflected in the variety of structural features in southern Illinois and western Kentucky is difficult, because of the lack of near-contemporaneous sedimentary strata to bracket periods of deformation. Most structures can only be dated as post-Pennsylvanian to pre-Late Cretaceous. Nelson and others (1997), however, demonstrated that tectonic faulting in the Illinois-Kentucky Fluorspar District, although not spectacular, was of post-Late Cretaceous age, involving Upper Cretaceous, Tertiary and Quaternary, and Quaternary sediments. Also, ultramafic intrusions associated with several structural features in southeastern Illinois and adjacent Kentucky that have been radiometrically dated as Early Permian (Zartman and others, 1967) allow more precise age assignments.

The northwest-directed compression associated with the Alleghanian Orogeny reactivated boundary faults of the Rough Creek Graben and the Reelfoot Rift and resulted in reverse faulting that elevated crustal blocks south of the Rough Creek–Shawneetown Fault System and also southeast of the Lusk Creek Fault System (Kolata and Nelson, 1991a), which is about 12 mi inboard from the northwest margin of the rift. The Rough Creek–Shawneetown system has as much as 3,500 ft of vertical separation near the abrupt bend in the Shawneetown Fault Zone in southeastern Illinois (Nelson and Lumm, 1987). From the bend, both eastward along the fault system and southwestward along the Lusk Creek Fault, the magnitude of displacement is less. On the boundary faults on the south side of the graben and southeast side of the rift, there evidently was relatively little displacement—the faults acted as hinge zones for the much greater displacements to the north and northwest, respectively (Kolata and Nelson, 1991a). Nelson and Lumm (1987) compared the uplifted block of the Rough Creek Graben to an obliquely hung trap door hinged at the southeastern corner.

A seismic-reflection section (Potter and others, 1995) across the western end of the Rough Creek Graben in the vicinity of the dogleg bend at its junction with the Reelfoot Rift reveals data on the configuration of the Precambrian basement and the distribution of the sedimentary fill, particularly the Cambrian (pre-Knox) sequence, that raise questions about the efficacy of the trap-door model. The seismic section shows that in the junction area, the geometry of the Cambrian rift system is that of a half-graben that is tilted to the southeast. The Cambrian synrift sequence is thickest against basement-cutting normal faults in the area of the junction of the Tabb Fault System of the Western Kentucky Fluorspar District and the main (central) branch of the Pennyrile Fault System. This contrasts with the northward tilt of the graben floor farther to the east and the location of the maximum thickness of fill against the northern margin of the graben along the Rough Creek Fault Zone. The asymmetry of the Rough Creek Graben also contrasts with the more symmetrical graben that composes the main part of the Reelfoot Rift to the south beneath the upper Mississippi Embayment.

In other parts of the rift basin during the compressional phase in the late Paleozoic, right-lateral movement occurred along the Cottage Grove Fault System (Nelson and others, 1981). Although both the Cottage Grove and the Rough Creek–Shawneetown systems were undergoing compression at about the same time and the two systems are en echelon to one another, they are not connected at or near the surface; but Strunk (1984) believed that they are directly related at depth to the 38th Parallel Lineament, a major crustal discontinuity. To the south of the Cottage Grove system, the northwest-directed compression also created the McCormick and New Burnside Anticlines (Kolata and Nelson, 1991a) (Fig. 20). Farther north in the Illinois Basin, the late Paleozoic compression caused renewed movement along the DuQuoin Monocline, and the LaSalle Anticlinal Belt achieved its present form.

Igneous activity accompanied the late Paleozoic deformation in the southern part of the Illinois Basin. The Tolu Arch in the Illinois-Kentucky Fluorspar District (Fig. 20) was uplifted, possibly by intrusion of an ultramafic body, a remnant of which is present 5.5 mi northeast of Hicks Dome at a depth of 11,000 ft or more (McGinnis and Bradbury, 1964; Kolata and Nelson, 1991a); Hicks Dome is the northern terminus of the arch. The magma intruded as dikes along northwest- and some north-trending faults in the district and as dikes, pipes, and small stocks in the tensional fractures associated with Hicks Dome (Nelson, 1991). Nearby in Illinois, ultramafic magma also intruded faults in the Cottage Grove system and in the Albion-Ridgway Fault, the bounding fault along the west side of the Wabash Valley Fault System, and in the subsurface of the Omaha Dome. Ultramafic rocks from Hicks Dome and the Cottage Grove Fault System are radiometrically dated as Early Permian (Zartman and others, 1967).

Following Alleghanian-Ouachita orogenesis, extensional opening of the Gulf of Mexico in the Late Triassic to Jurassic (Winkler and Buffler, 1988) initiated extensional faulting in the southern part of the Illinois Basin. In the northwest-southeast tensional regime, the crustal blocks in the Rough Creek Graben and Reelfoot Rift, previously upthrown along the Rough Creek–Shawneetown and Lusk Creek Fault Systems, sank back to their approximate pre-Pennsylvanian positions (Kolata and Nelson, 1991a). Along the southern margin of the Rough Creek Graben, normal faulting along all three branches of the Pennyrile system was activated. Pronounced dip-slip movement on the faults and sharp flexure of the beds along the Rough Creek–Shawneetown system contrast markedly with the same, but more subdued, features of the Pennyrile system. The character of the bounding fault systems, together with northeast-trending normal faults called the Central Faults (Fig. 20) near its middle, define the structural pattern of the Moorman–Eagle Valley Syncline, much of which is a reflection of the structure of the graben below.

In the Illinois-Kentucky Fluorspar District, the dominant northeast-trending system of normal faults developed contemporaneously with the Central Faults of the Moorman–Eagle Valley Syncline. In Kentucky, faults in the southern part of the district merge gently eastward with faults of the Pennyrile system. The faults of the Western Kentucky Fluorspar District probably were active over a long period from post-Middle Pennsylvanian to post-Early Permian, as demonstrated by offset of peridotite dikes of Early Permian age (Trace and Amos, 1984); locally, faulting may even have begun during the Early Pennsylvanian (Trace and Amos, 1984). Evidence of Cretaceous or younger movement on the faults of the district is commonly ambiguous, because of the poor quality of outcrops and the slumping of material. Most faults extend southwestward and are concealed beneath Cretaceous and Tertiary alluvial deposits in the Mississippi Embayment.

Faults offsetting Upper Cretaceous strata (Tuscaloosa and McNairy Formations) and the late Miocene to early Pleistocene Mounds Gravel (continental deposits) have been mapped by several geologists (Amos and Wolfe, 1966; Amos, 1967, 1974; Amos and Finch, 1968), but in places the poor quality of the outcrops raises doubt as to the certainty of faulting. The faults are apparently steeply dipping, many are offset less than 100 ft, and some juxtapose Paleozoic bedrock with Cretaceous units and locally Mounds Gravel; others have Cretaceous strata on both sides; and at numerous localities the Mounds Gravel overlies the faults. So there is evidence of several periods of tectonic faulting.

In his studies of faulting in southernmost Illinois, Ross (1963, 1964) cited evidence for Cretaceous, Eocene, and younger movement on some Illinois-Kentucky Fluorspar District faults. Kolata and others (1981) reexamined the subsurface data, as well as surface localities, cited by Ross, and could find no evidence of any stratigraphic change or structural movement that could be attributed to post-Paleozoic tectonism. But later geologic mapping by Nelson and others (1997) did find tectonic faults in the Illinois-Kentucky Fluorspar District, as well as in other parts of southern Illinois, that clearly offset Upper Cretaceous, Tertiary to Quaternary, and locally Quaternary deposits. Tectonic faulting of the late Miocene to early Pleistocene Mounds Gravel is widespread in southeastern Illinois and adjacent Kentucky. The youngest faulted unit in the Illinois-Kentucky Fluorspar District is the Metropolis Gravel, which underlies a broad terrace bordering the Ohio River in Illinois. The age of the Metropolis is poorly constrained, but probably is Illinoian or older (Nelson and others, 1997).

As discussed in detail earlier, the origin and timing of the Wabash Valley Fault System are ambiguous. Kolata and Nelson (1991a) speculated that an arch developed during late Paleozoic compression, and that later during Mesozoic extension it collapsed and formed the tension fractures of the Wabash Valley system. Sexton and others (1986) suggested, however, that the fault system represents post-Pennsylvanian reactivation of a Precambrian rift system. But based on later seismic data, Nelson (1990) contended, and Pratt and others (1990) agreed, that there is no rift structure under the Wabash Valley area.

Since its inception as a rift basin in the late Precambrian and Early Cambrian, the proto-Illinois Basin was open southward to the continental margin, but during the Mesozoic extensional phase of tectonism (Kolata and Nelson, 1991a), the Pascola Arch was uplifted in the area of the Bootheel of Missouri, thus structurally closing the southern end of the basin and giving the basin its present configuration. Kolata and Nelson (1991a) theorized that uplift of the arch reflected thermotectonic doming in conjunction with reactivation of the Reelfoot Rift during the early Mesozoic. Subsequent cooling and isostatic adjustment in the crust led to subsidence and beveling of the arch before Late Cretaceous inundation of the Mississippi Embayment.

Houseknecht and Kacena (1983, Fig. 10), however, suggested that the Pascola Arch began its rise in the early Desmoinesian (Middle Pennsylvanian), and by Missourian (Late Pennsylvanian) time the structure was extensive enough to divert sediment dispersal from the Illinois Basin around the northern flank of the Ozark Uplift. Kolata and Nelson (1991a) pointed out that late Paleozoic depositional, environmental, and structural considerations restrict the most likely period of uplift of the arch to the Permian or early Mesozoic. Such a period would be sufficient for the arch to be beveled before subsidence of the Mississippi Embayment in the Late Cretaceous. The concealed and eroded arch has Cambrian rocks in the core, surrounded by broad, concentric belts of Ordovician, Silurian, and Devonian rocks (Marcher and Stearns, 1962). An estimated 8,000 ft to as much as 15,000 ft of Paleozoic strata was eroded from the crest of the arch (Marcher and Stearns, 1962) before it was concealed beneath Late Cretaceous sediments.

Although tectonism in the Illinois Basin largely ceased in post-Cretaceous time, the area has undergone a change in the stress regime from tension to the present horizontal compression. The basin itself, together with the New Madrid Seismic Zone in the northern part of the Mississippi Embayment, are now subject to horizontal compression that is oriented east-west to northeast-southwest (Sbar and Sykes, 1973; Zoback and Zoback, 1980). Small north-trending thrust faults observed in coal mines in southern Illinois and western Kentucky probably are the result of this compression (Nelson and Lumm, 1984; Nelson and Bauer, 1987). The New Madrid Seismic Zone, the site of the devastating 1811–1812 sequence of earthquakes, is the most active earthquake area in eastern North America. Southeastern Illinois and vicinity continue to be subject to small to moderate earthquakes, but none have been reported along the Rough Creek–Shawneetown or Pennyrile Fault Systems, and few have been detected along faults within the Illinois-Kentucky Fluorspar District (Nelson and Lumm, 1987). Just to the north in the lower Wabash River Valley, a liquefaction study of Holocene sediments (Obermeier and others, 1991) indicated that an earthquake of magnitude 6.2 or larger occurred 1,500 to 7,500 years ago.

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The lithologic descriptions of the outcropping stratigraphic units in this report is a summary of the descriptive material from the many geologic quadrangle maps covering the area, and their authors are listed in the References Cited and the quadrangle locations are shown on Figure 1; the authors generally are not cited in the text, however, except when reference is made to specific data from a particular quadrangle map.

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Appendix A:
U.S. Geological Survey Geologic Quadrangle (GQ) Maps Covering the Rough Creek Area (See Figure 1 for Locations of Quadrangles)

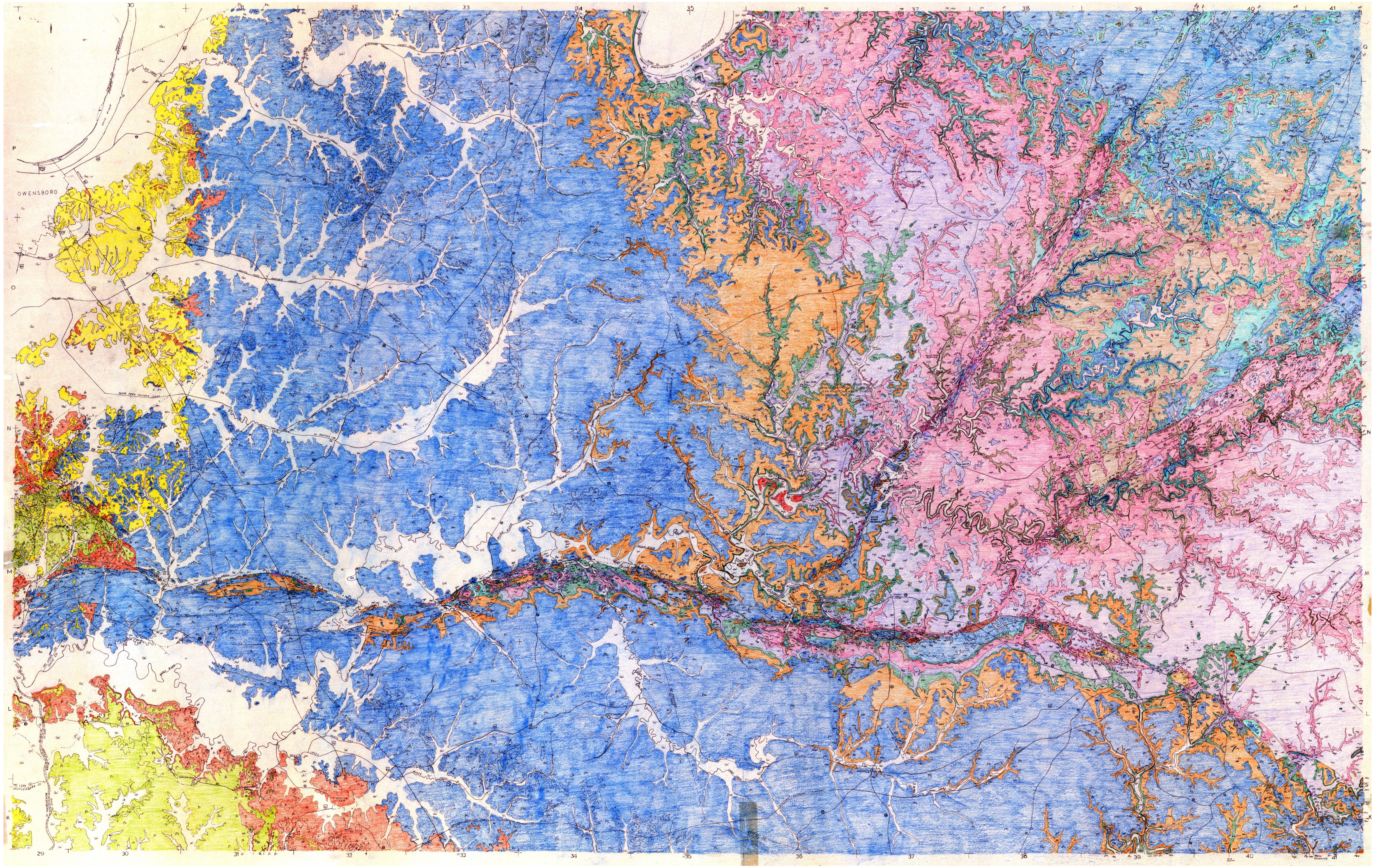
GQ	*Reference*
Beech Grove	Fairer, G.M., Norris, R.L., and Johnson, W.D., Jr., 1975, Geologic map of the Beech Grove quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1230, scale 1:24,000.
Big Clifty	Swadley, W C, 1962, Geology of the Big Clifty quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-192, scale 1:24,000.
Big Spring	Peterson, W.L., 1964, Geology of the Big Spring quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-261, scale 1:24,000.
Blackford	Amos, D.H., 1970, Geologic map of the Blackey quadrangle, Letcher and Knott Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-873, scale 1:24,000.
Bordley	Kehn, T.M., 1975, Geologic map of the Bordley quadrangle, Union and Webster Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1275, scale 1:24,000.
Calhoun	Johnson, W.D., Jr., and Smith, A.E., 1975, Geologic map of the Calhoun quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1239, scale 1:24,000.
Caneyville	Gildersleeve, B., and Johnson, W.D., Jr., 1978, Geologic map of the Caneyville quadrangle, Grayson County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1472, scale 1:24,000.
Clarkson	Glick, E.E., 1963, Geology of the Clarkson quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-278, scale 1:24,000.
Cloverport-Cannelton	Bergendahl, M.H., 1965, Geology of the Cloverport quadrangle, Kentucky-Indiana, and the Kentucky part of the Cannelton quadrangle: U.S. Geological Survey Geologic Quadrangle Map GQ-273, scale 1:24,000.
Constantine	Sable, E.G., 1964, Geology of the Constantine quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-302, scale 1:24,000.
Curdsville	Fairer, G.M., and Norris, R.L., 1972, Geologic map of the Curdsville quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1039, scale 1:24,000.
Custer	Amos, D.H., 1977, Geologic map of the Custer quadrangle, Breckinridge and Hardin Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1367, scale 1:24,000.
Dekoven–Saline Mines	Kehn, T.M., 1974, Geologic map of the Dekoven and Saline Mines quadrangles, Crittenden and Union Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1147, scale 1:24,000.
Delaware	Johnson, W.D., Jr., 1973, Geologic map of the Delaware quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1087, scale 1:24,000.
Dixon	Hansen, D.E., 1976, Geologic map of the Dixon quadrangle, Webster County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1293, scale 1:24,000.
Dundee	Goudarzi, G.H., and Smith, A.E., 1968, Geologic map of the Dundee quadrangle, Ohio County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-688, scale 1:24,000.
Equality	Goudarzi, G.H., 1969, Geologic map of the Equality quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-815, scale 1:24,000.
Falls of Rough	Johnson, W.D., Jr., 1977, Geologic map of Falls of Rough quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1360, scale 1:24,000.
Fordsville	Bergendahl, M.H., and Smith, A.E., 1964, Geology of the Fordsville quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-295, scale 1:24,000.
Garfield	Amos, D.H., 1976, Geologic map of the Garfield quadrangle, Breckinridge County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1278, scale 1:24,000.
Glen Dean	Goudarzi, G.H., 1970, Geologic map of the Glen Dean quadrangle, Breckinridge and Hancock Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-836, scale 1:24,000.
Glenville	Johnson, W.D., Jr., and Smith, A.E., 1972, Geologic map of the Glenville quadrangle, McLean and Daviess Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1046, scale 1:24,000.

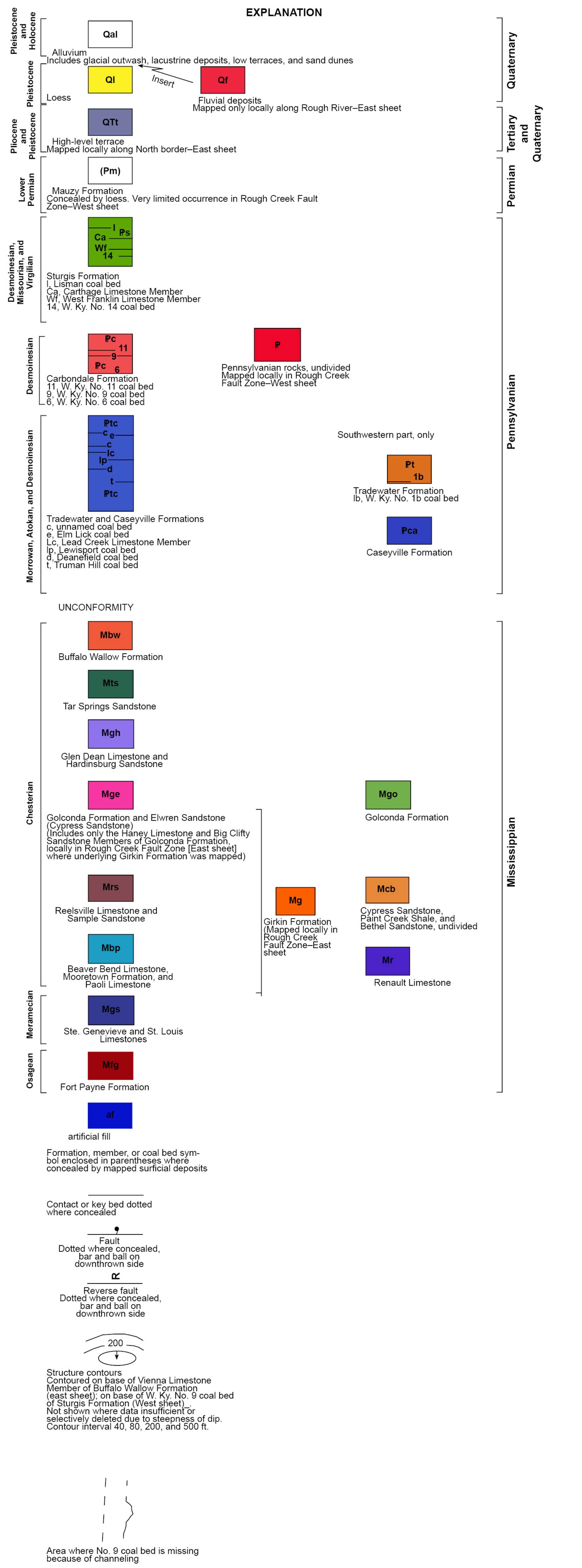
GQ	*Reference*
Grove Center–Shawneetown	Palmer, J.E., 1976, Geologic map of the Grove Center quadrangle, Kentucky-Illinois, and part of the Shawneetown quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1314, scale 1:24,000.
Hanson	Franklin, G.J., 1965, Geology of the Hanson quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-365, scale 1:24,000.
Hardinsburg	Amos, D.H., 1975, Geologic map of the Hardinsburg quadrangle, Breckinridge County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1232, scale 1:24,000.
Hartford	Goudarzi, G.H., 1968, Geologic map of the Hartford quadrangle, Ohio County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-741, scale 1:24,000.
Henderson	Johnson, W.D., Jr., 1973, Geologic map of the Henderson quadrangle, Henderson County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1074, scale 1:24,000.
Horton	Johnson, W.D., Jr., 1971, Geologic map of the Horton quadrangle, Ohio County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-915, scale 1:24,000.
Kingswood	Amos, D.H., 1978, Geologic map of the Kingswood quadrangle, Breckinridge County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1447, scale 1:24,000.
Leitchfield	Gildersleeve, B., 1978, Geologic map of the Leitchfield quadrangle, Grayson County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1316, scale 1:24,000.
Livermore	Hanson, D.E., and Smith, A.E., 1978, Geologic map of the Livermore quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1467, scale 1:24,000.
Maceo	Calvert, R.H., 1966, Geologic map of the Maceo quadrangle, Daviess and Hancock Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-570, scale 1:24,000.
Madrid	Johnson, W.D., Jr., 1978, Geologic map of the Madrid quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1482, scale 1:24,000.
Mattingly	Clark, L.D., and Crittenden, M.D., Jr., 1965, Geology of the Mattingly quadrangle, Kentucky-Indiana: U.S. Geological Survey Geologic Quadrangle Map GQ-361, scale 1:24,000.
McDaniels	Johnson, W.D., Jr., 1978, Geologic map of the McDaniels quadrangle, Grayson and Breckinridge Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1473, scale 1:24,000.
Morganfield	Johnson, W.D., Jr., Smith, A.E., and Fairer, G.M., 1975, Geologic map of the Morganfield quadrangle, Union County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1269, scale 1:24,000.
Nebo	Franklin, G.J., 1969, Geologic map of the Nebo quadrangle, Webster and Hopkins Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-777, scale 1:24,000.
Olaton	Johnson, W.D., Jr., and Smith, A.E., 1968, Geologic map of the Olaton quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-687, scale 1:24,000.
Owensboro East	Johnson, W.D., Jr., and Smith, A.E., 1968, Geologic map of the Owensboro East quadrangle, Daviess County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-751, scale 1:24,000.
Owensboro West	Goudarzi, G.H., and Smith, A.E., 1971, Geologic map of the Owensboro West quadrangle, Daviess County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-890, scale 1:24,000.
Panther	Goudarzi, G.H., 1971, Geologic map of the Panther quadrangle, Daviess County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-866, scale 1:24,000.
Pellville	Spencer, F.D., 1963, Geology of the Pellville quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-284, scale 1:24,000.
Philpot	Calvert, R.H., 1964, Geology of the Philpot quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-297, scale 1:24,000.
Pleasant Ridge	Goudarzi, G.H., and Smith, A.E., 1968, Geologic map of the Pleasant Ridge quadrangle, Ohio and Daviess Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-766, scale 1:24,000.

GQ	*Reference*
Poole	Fairer, G.M., 1973, Geologic map of the Poole quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1088, scale 1:24,000.
Providence	Kehn, T.M., 1966, Geologic map of the Providence quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-491, scale 1:24,000.
Reed	Johnson, W.D., Jr., 1972, Geologic map of the Reed quadrangle, Kentucky-Indiana: U.S. Geological Survey Geologic Quadrangle Map GQ-1038, scale 1:24,000.
Repton	Seeland, D.A., 1968, Geologic map of the Repton quadrangle, Crittenden County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-754, scale 1:24,000.
Robards	Fairer, G.M., 1973, Geologic map of the Robards quadrangle, Henderson and Webster Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1084, scale 1:24,000.
Rosine	Johnson, W.D., Jr., 1971, Geologic map of the Rosine quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-928, scale 1:24,000.
Sacramento	Hansen, D.E., 1976, Geologic map of the Sacramento quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1306, scale 1:24,000.
Sebree	Hansen, D.E., 1975, Geologic map of the Sebree quadrangle, Webster County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1238, scale 1:24,000.
Slaughters	Kehn, T.M., 1964, Geology of the Slaughters quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-360, scale 1:24,000.
Smith Mills	Johnson, W.D., Jr., and Norris, R.L., 1974, Geologic map of the Smith Mills quadrangle, Henderson and Union Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1215, scale 1:24,000.
Spottsville	Johnson, W.D., Jr., 1973, Geologic map of the Spottsville quadrangle, Henderson County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1090, scale 1:24,000.
Spring Lick	Gildersleeve, B., and Johnson, W.D., Jr., 1978, Geologic map of the Spring Lick quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1475, scale 1:24,000.
Sturgis	Kehn, T.M., 1975, Geologic map of the Sturgis quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1273, scale 1:24,000.
Sutherland	Johnson, W.D., Jr., and Smith, A.E., 1969, Geologic map of the Sutherland quadrangle, Daviess County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-839, scale 1:24,000.
Uniontown–Wabash Island	Johnson, W.D., Jr., and Norris, R.L., 1976, Geologic map of the Uniontown and Wabash Island quadrangles, Union and Henderson Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1291, scale 1:24,000.
Utica	Johnson, W.D., Jr., and Smith, A.E., 1972, Geologic map of the Utica quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-995, scale 1:24,000.
Waverly	Fairer, G.M., 1975, Geologic map of the Waverly quadrangle, Union and Henderson Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1220, scale 1:24,000.
Whitesville	Calvert, R.H., 1965, Geology of the Whitesville quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-419, scale 1:24,000.
Wilson	Johnson, W.D., Jr., 1973, Geologic map of the Wilson quadrangle, Henderson County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1136, scale 1:24,000.

Appendix B. Nomenclature of the Paleozoic units (exposed and unexposed) in the Rough Creek area, western Kentucky. (Nomenclature does not necessarily conform to U.S. Geological Survey or Kentucky Geological Survey standards.)

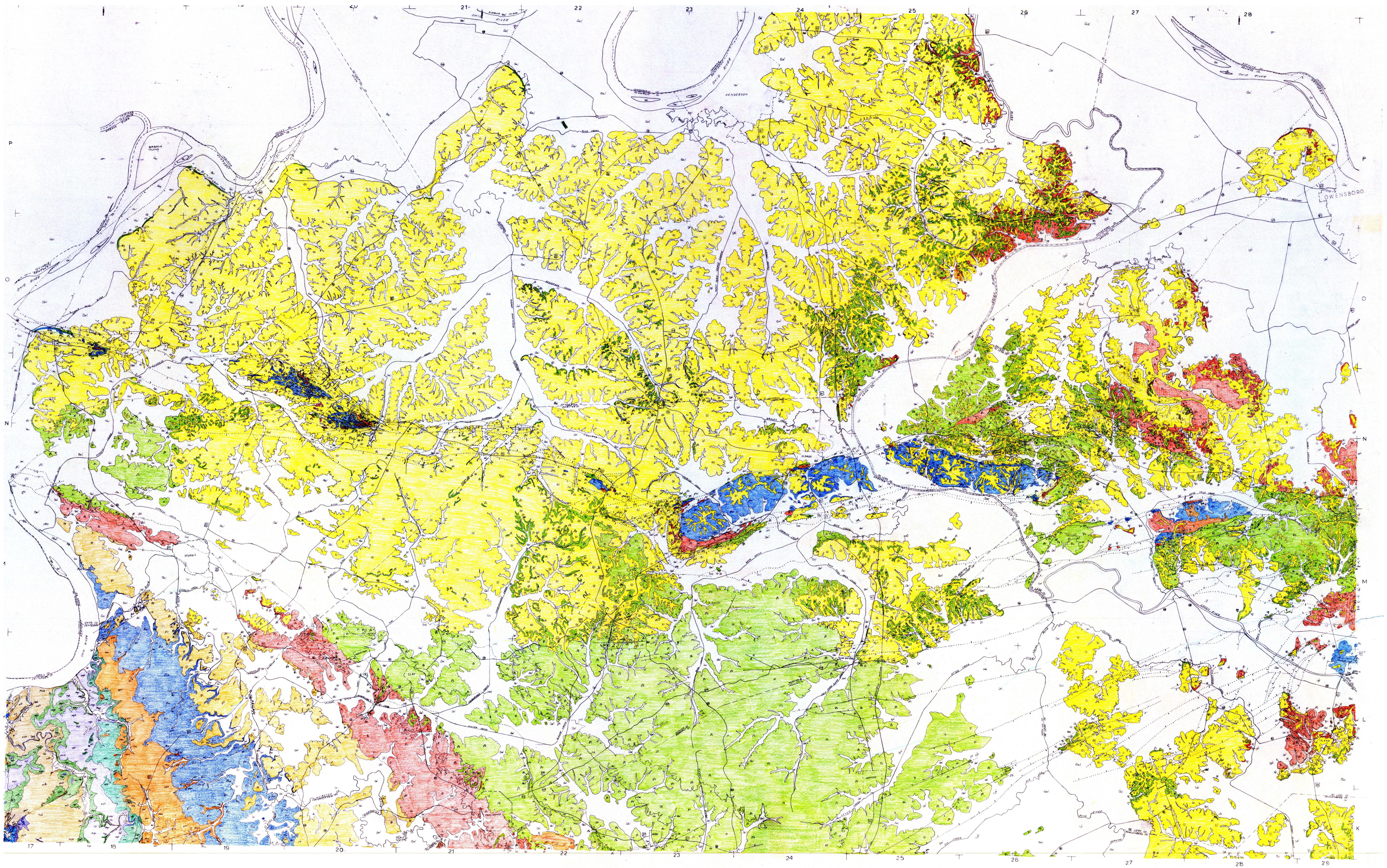
System	Series/Stage		Western Part		Eastern Part		
PERMIAN	Upper	Wolfcampian	Mauzy Formation				
PENNSYLVANIAN		Virgilian		Sturgis Formation		Sturgis Formation	
		Missourian	Carthage Limestone Mbr.				
		Desmoinesian	West Franklin Limestone Mbr.		West Franklin Limestone Mbr.		
			Anvil Rock Ss. Mbr.				
			Providence Limestone Mbr.		Providence Limestone Mbr.		
			Carbondale Formation		Carbondale Formation		
			Yeargins Chapel Limestone Mbr.	Tradewater Formation	Yeargins Chapel Limestone Mbr.	Tradewater Formation	
		Atokan	Curlew Limestone Mbr.		Lewisport Limestone Mbr.		
					Lead Creek Limestone Mbr.		
		Morrowan	Caseyville Formation		Caseyville Formation		
MISSISSIPPIAN	Upper	Chesterian	Kinkaid Limestone		Kinkaid Limestone Member	Buffalo Wallow Formation	Leitchfield Formation
			Degonia Sandstone				
			Clore Limestone				
			Palestine Sandstone				
			Menard Limestone		Menard Limestone Member		
			Waltersburg Sandstone		Waltersburg Sandstone Member		
			Vienna Limestone		Vienna Limestone Member		
			Tar Springs Sandstone		Tar Springs Sandstone		
			Glen Dean Limestone		Glen Dean Limestone		
			Hardinsburg Sandstone		Hardinsburg Sandstone		
			Haney Limestone Member	Golconda Formation	Haney Limestone Member	Golconda Formation	Girkin Formation
			Frailey Shale Member		Big Clifty Sandstone Member		
			Beech Creek Limestone Member		Beech Creek Limestone Member		
			Cypress Sandstone		Elwren Formation		
			Paint Creek Shale		Reelsville Limestone		
					Sample Sandstone		
					Beaver Creek Limestone		
			Bethel Sandstone		Mooretown Formation		
			Renault Limestone		Paoli Limestone		
		Meramecian	Levias Limestone Member	Ste. Genevieve Limestone	Bryantsville Breccia Bed	Ste. Genevieve Limestone	
			Rosiclare Sandstone Member				
			Fredonia Limestone Member		Lost River Chert Bed		
			St. Louis Limestone		St. Louis Limestone		
			Salem Limestone		Salem Limestone		
			Warsaw Limestone		Warsaw Limestone		
	Lower	Osagean	Fort Payne Formation		Fort Payne Formation		
			New Providence Shale		New Providence Shale		
		Kinderhookian	Rockford Limestone		Rockford Limestone		
			Undifferentiated Saverton and Hannibal Shales (Hannibal Shale Mbr.)	New Albany Shale	Undifferentiated Saverton and Hannibal Shales (Hannibal Shale Mbr.)	New Albany Shale	
DEVONIAN	Upper		Grassy Creek Member		Grassy Creek Member		
			Selmier Shale Member		Selmier Shale Member		
			Blocher Shale Member		Blocher Shale Member		
	Middle		Sellersburg Limestone		Sellersburg Limestone		
			Tioga Bentonite Bed Jeffersonville Limestone		Jeffersonville Limestone		
			Dutch Creek Sandstone		Dutch Creek Sandstone		
	Lower		Clear Creek Limestone		Clear Creek Limestone		
			Backbone Limestone		Backbone Limestone		
			Grassy Knob Limestone		Grassy Knob Limestone		
			Flat Gap Limestone		Flat Gap Limestone		
			Bailey Limestone		Bailey Limestone		
SILURIAN	Upper	Cayugan	Moccasin Springs Formation		Lobelville Shale Member	Brownsport Formation	
	Middle	Niagaran			Bob Limestone Member		
					Beech River Limestone Member		
			St. Clair Limestone		Dixon Limestone		
					Louisville Limestone	Reef-detritus facies	
					Waldron Shale		
					Laurel Limestone		
					Osgood Limestone		
	Lower	Alexandrian	Sexton Creek Limestone		Brassfield Dolomite		
ORDOVICIAN	Cincinnatian	Richmondian	Maquoketa Shale		Drakes Formation(?)		
		Maysvillian			Calloway Creek Limestone		
		Edenian			Clays Ferry Formation		
	Champlainian	Shermanian	Kimmswick Limestone		Lexington Limestone		
		Kirkfieldian					
		Rocklandian					
			Plattin Limestone		Plattin Limestone	High Bridge Group	Tyrone and Camp Nelson Limestones, undifferentiated
			Pecatonica Formation		Pecatonica Formation		
			Joachim Dolomite		Joachim Dolomite		
			Dutchtown Formation		Dutchtown Formation		Wells Creek Dolomite(?)
			St. Peter Sandstone		St. Peter Sandstone		
			Everton Dolomite		Everton Dolomite		
	Canadian		Cotter Dolomite	Knox Group	Cotter Dolomite	Knox Group	
			Jefferson City Dolomite		Jefferson City Dolomite		
			Roubidoux Formation		Roubidoux Formation		
			Gasconade Dolomite		Gasconade Dolomite		
			Gunter Sandstone		Gunter Sandstone		
CAMBRIAN	Upper		Eminence Dolomite		Eminence Dolomite		
			Potosi Dolomite		Potosi Dolomite		
			Elvins Formation		Elvins Formation		
			Eau Claire Formation		Eau Claire Formation		
			Mount Simon Sandstone		Mount Simon Sandstone		
	Middle		Conasauga Shale		Conasauga Shale		
	Middle and Lower(?)		Unnamed and uncorrelated marine sedimentary rocks		Unnamed and uncorrelated marine sedimentary rocks		

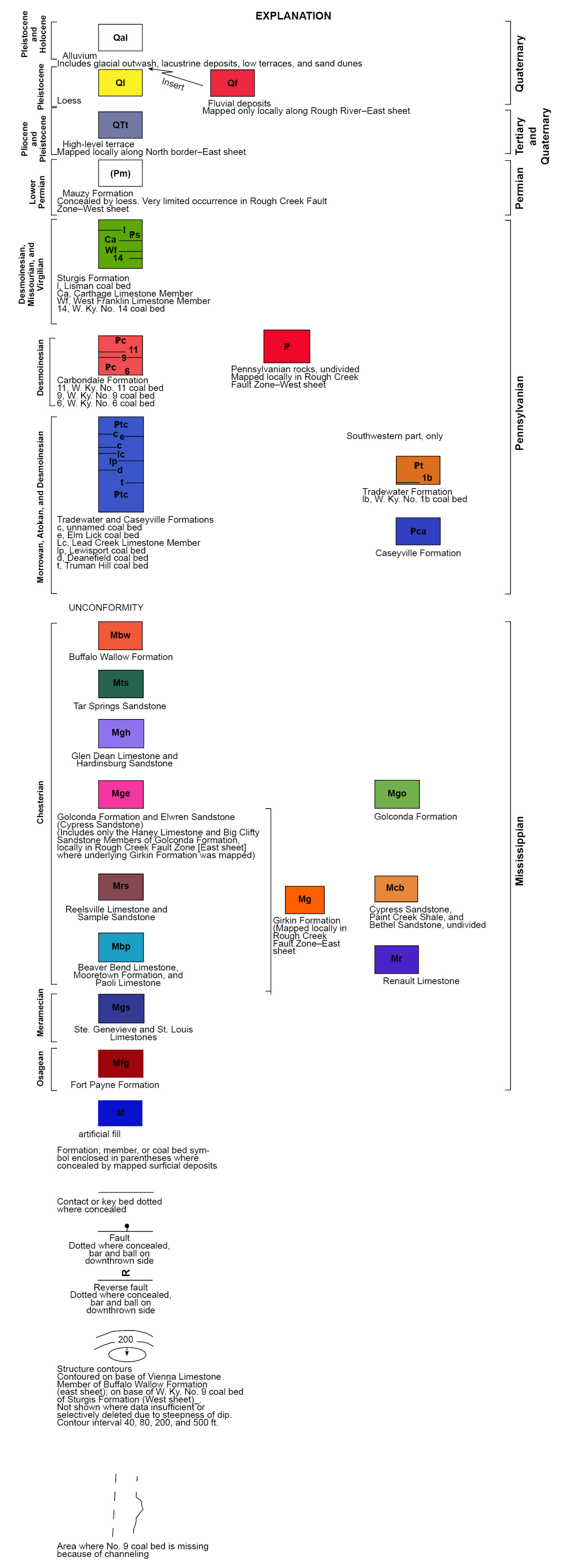




Note:
Not all geologic map units shown above occur on both the eastern part (Plate 1A–East) and western part (Plate 1A–West) of this map.

Plate 1A. Geology of the Rough Creek area, western Kentucky—West sheet.





Note:
Not all geologic map units shown above occur on both the eastern part (Plate 1A–East) and western part (Plate 1A–West) of this map.

Plate 1B. Structure of the Rough Creek area, western Kentucky—East sheet.

Drawn on the base of the Vienna Limestone Member of the Buffalo Wallow Formation (Upper Mississippian)

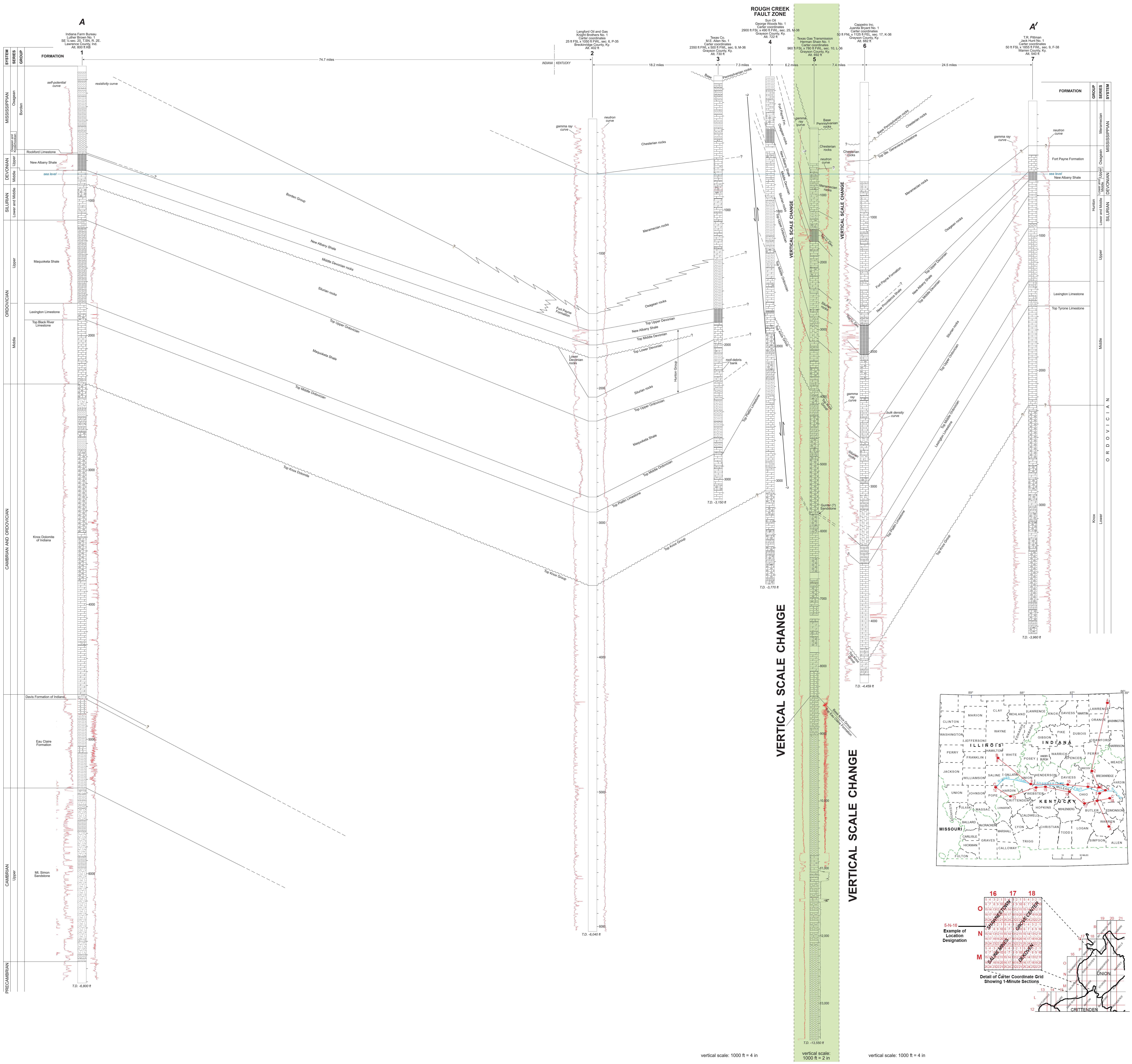
No symbols are shown on the structure maps (Plates 1B–East and 1B–West) to designate direction of movement on the fault.

Plate 1B. Structure of the Rough Creek area, western Kentucky—West sheet.

Drawn on the base of the Springfield (W. Ky. No. 9) coal bed in the Carbondale Formation (Middle Pennsylvanian)

No symbols are shown on the structure maps (Plates 1B–East and 1B–West) to designate direction of movement on the fault.

Plate 2. Stratigraphic relations of Paleozoic rocks in and adjacent to the Rough Creek area. A. Cross section from Lawrence County, Ind., to Warren County, Ky.



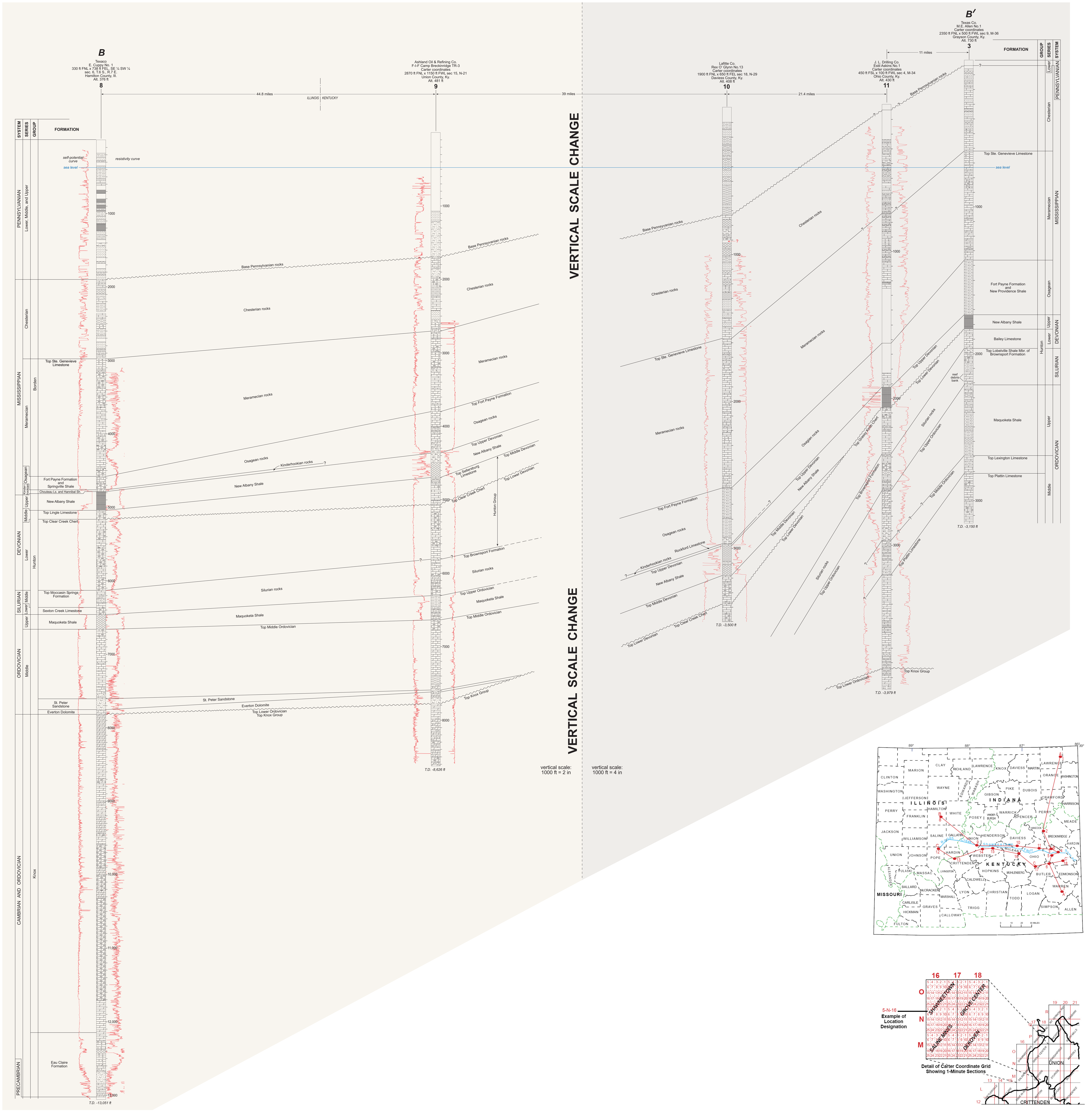


Plate 2. Stratigraphic relations of Paleozoic rocks in and adjacent to the Rough Creek area. B. Cross section from Hamilton County, Ill., to Grayson County, Ky.

Plate 2. Stratigraphic relations of Paleozoic rocks in and adjacent to the Rough Creek area. C. Cross section from Pope County, Ill., to Grayson County, Ky.