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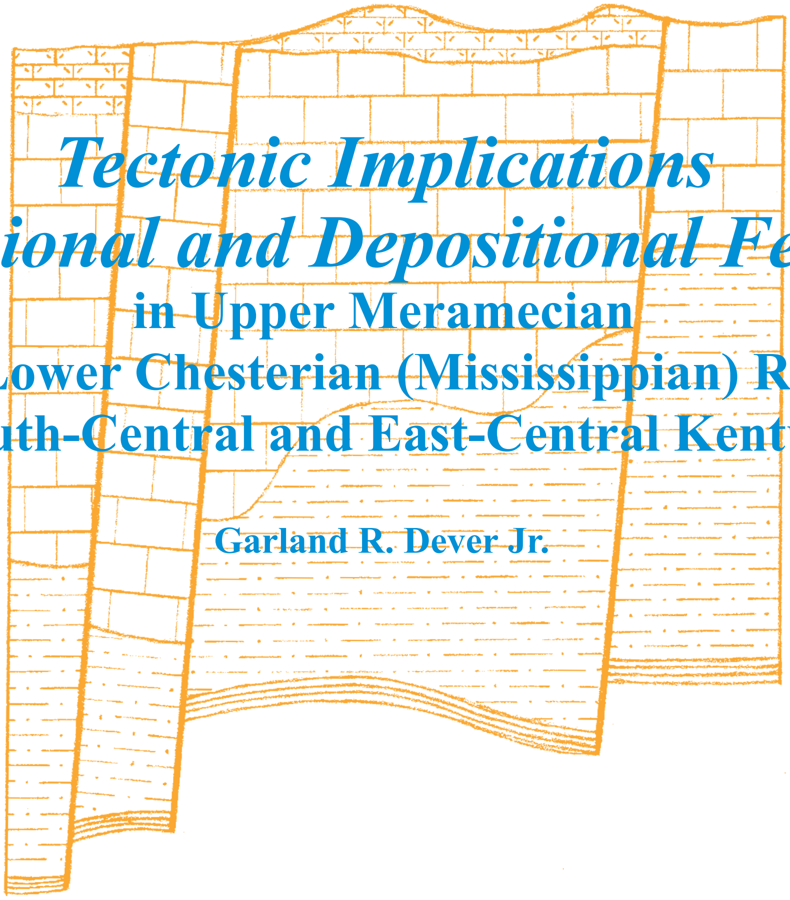

# *Tectonic Implications of Erosional and Depositional Features*
## in Upper Meramecian and Lower Chesterian (Mississippian) Rocks of South-Central and East-Central Kentucky

### Garland R. Dever Jr.

Bulletin 5

Series XI, 1999

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# Tectonic Implications of Erosional and Depositional Features in Upper Meramecian and Lower Chesterian (Mississippian) Rocks of South-Central and East-Central Kentucky

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# Tectonic Implications of Erosional and Depositional Features in Upper Meramecian and Lower Chesterian (Mississippian) Rocks of South-Central and East-Central Kentucky

Garland R. Dever Jr.

## ABSTRACT

Erosional and depositional features in upper Meramecian and lower Chesterian (Mississippian) carbonate rocks of south-central and east-central Kentucky suggest the influence of coeval structural activity. The study area, which extends from Pulaski County northeastward into Powell County, is underlain by (1) the Greenwood Anomaly, a large north-trending gravity anomaly, which probably represents part of a Precambrian rift system, and (2) the western part of the Rome Trough, an east-trending graben-like structure, which represents a Late Precambrian to Cambrian continental rift zone. The study focused on the St. Louis Limestone and lower Monteagle Limestone of south-central Kentucky and correlative carbonate rocks of the Slade Formation in east-central Kentucky.

Several lines of evidence suggest Mississippian reactivation of rift-related faults associated with the Greenwood Anomaly and the Grenville Front, which extends along the west side of the anomaly: (1) local subaerial exposure of St. Louis sediments, (2) local depositional thinning of lower Monteagle sediments, (3) relatively widespread erosion during early Monteagle time, and (4) thickness variation in Mississippian units across the anomaly.

In east-central Kentucky, erosional and depositional features suggest Mississippian movement along the Locust Branch and Glencairn Faults of the Irvine-Paint Creek Fault System in the interior of the Rome Trough during deposition of the Slade Formation. Reactivation along the projected trend of the Locust Branch Fault in Estill and Jackson Counties apparently resulted in (1) abrupt thinning of the Renfro Member, (2) penecontemporaneous soft-sediment deformation of Big Sinking bed deposits, and (3) extensive erosion of the Burnside member. Movement along the Glencairn Fault in Powell and Wolfe Counties is indicated by more pronounced erosion of the Burnside member along the border of the upthrown side.

Mississippian reactivation of faults apparently was caused by migration of lithospheric bulges through the area. Based on recent investigations that relate Mississippian depositional sequence to lithospheric flexure, passage of an east-migrating, relaxation-phase, Acadian bulge and a north-migrating Ouachita bulge seems to have been contemporaneous with the fault movements and may explain evidence of fault reactivation and its consequences on Mississippian carbonate deposition in the area.

## INTRODUCTION

Tectonic influence on patterns of sediment thickness and distribution is widely recognized in the geologic record. During the Acadian Orogeny, for example, continental collision and convergence along the eastern margin of North America produced uplifted terrains that were a source for terrigenous sediments of the Devonian Catskill Delta (Ettensohn, 1985). In the Black Warrior Basin of Alabama, fault movement influenced peat accumulation by modifying the topography of Pennsylvanian swamps (Weisenfluh and Ferm, 1984). Normal faulting contemporaneous with deposition, or growth faulting, in the Gulf Coast region has resulted in a thickening of Cenozoic sediments on the downthrown sides of faults (Hardin and Hardin, 1961).

Growth faulting dominated Paleozoic tectonic activity in the Rome Trough, a linear graben-like structure in the subsurface of eastern and central Kentucky and West Virginia. Units ranging in age from Cambrian to Pennsylvanian thicken on the downthrown sides of faults (Ammerman and Keller, 1979).

Investigations in the Mississippian outcrop belt of northeastern and northern east-central Kentucky have shown that fault movement along the northern boundary of the Rome Trough in Mississippian time not only resulted in depositional thickening, but also caused upward displacement, which was followed by extensive erosion of carbonate sediments (Dever, 1973, 1977; Ettensohn, 1975, 1977). Uplift along the Waverly Arch in the same area also affected sediment distribution and thickness.

Subsurface studies in the region have found additional evidence for tectonic influence during Mississippian deposition. In the subsurface of eastern Kentucky, Mississippian carbonate units thin across the axis of the Waverly Arch and across the southern axis of the Paint Creek Uplift; shallow-water carbonate lithologies are concentrated in the axial areas (Pear, 1980; MacQuown and Pear, 1983). Mississippian carbonate facies in the subsurface of north-central Tennessee were influenced by shoals occurring over the Greenwood and Wartburg gravity anomalies (Spalding, 1982). Furthermore, several Mississippian formations thicken away from the Greenwood Anomaly.

Geologic processes in orogenic belts along the eastern and southern margins of North America affected Mississippian deposition in eastern and south-central Kentucky (Ettensohn and Chesnut, 1989; Ettensohn, 1990, 1992d, 1993). Loading and unloading in the orogenic belts and the formation and migration of associated lithospheric flexural features resulted in deposition of sequences of both terrigenous-detrital and carbonate sediments across the region.

This publication reports the effects of Mississippian structural activity in south-central and east-central Kentucky, an area underlain by the Greenwood Anomaly and the western part of the Rome Trough. The project investigated relationships between structural and geophysical features in the area and variations in the thickness, areal distribution, and lithology of Upper Mississippian carbonate units.

The study was conducted in the belt of Mississippian rocks cropping out along the western border of the Appalachian Plateau in Kentucky, concentrating in the area extending from Pulaski County northeastward into Powell County (Fig. 1). The investigation focused on carbonate rocks in the St. Louis Limestone and lower Monteagle Limestone of south-central Kentucky and correlative rocks of the Slade Formation in east-central Kentucky (Fig. 2). Thickness, distribution, and lithology of carbonate units were determined by measuring and describing roadcut, quarry, and outcrop sections (Fig. 3, App. A).

## STRUCTURAL SETTING

The study area is on the eastern flank of the Cincinnati Arch and on the western border of the Appalachian Basin. It is underlain by the Rome Trough, a graben-like structure (Fig. 4). The southwestern part of the study area extends across the Greenwood Anomaly, a major gravity anomaly (Figs. 5–6). Previous subsurface and surface investigations have reported evidence indicating or suggesting the influence of Rome Trough faults, the Cincinnati Arch, the Waverly Arch, the Greenwood Anomaly, and migratory lithospheric flexural features on Paleozoic units in and near the study area.

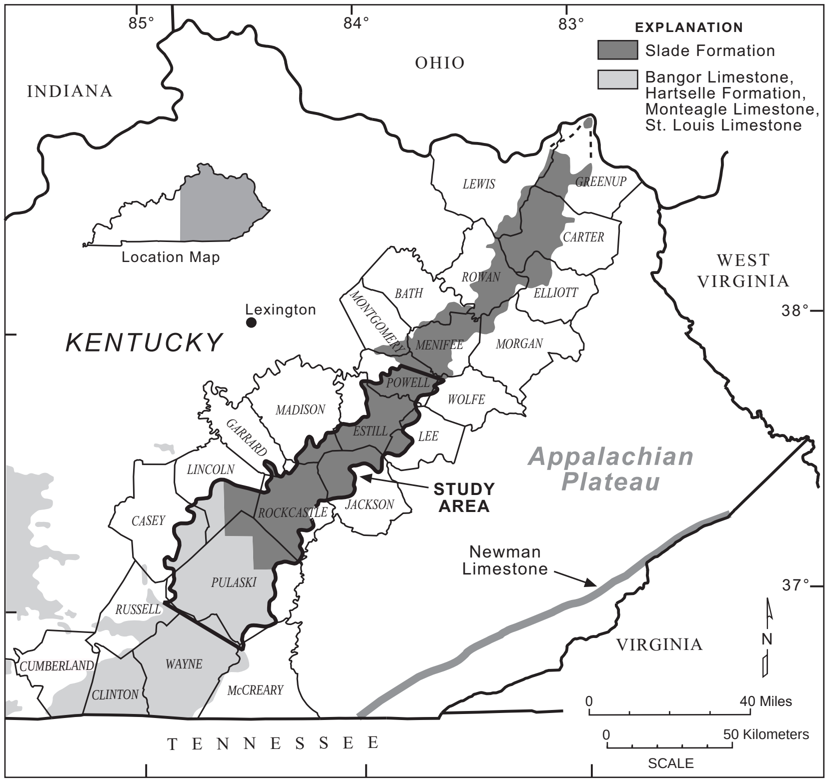


Figure 1. Central and eastern Kentucky, showing study area and the outcrop of Mississippian carbonate rocks assigned to the St. Louis, Monteagle, and Bangor Limestones, Slade Formation, and Newman Limestone.

### Rome Trough

The Rome Trough is a linear, asymmetrical, graben-like structure in the subsurface of eastern and central Kentucky and West Virginia. It is bounded on the north by the Kentucky River Fault System, on the west by the Lexington Fault System, and on the south by the Rockcastle River-Warfield Fault (Fig. 4) (Ammerman and Keller, 1979; Webb, 1980; Sutton, 1981; Cable, 1984; Maynor, 1984; Black, 1989).

The trough represents a Late Precambrian to Cambrian continental rift zone (Ammerman and Keller, 1979; Webb, 1980; Thomas, 1991; Ettensohn and Pashin, 1992a) that mainly formed contemporaneously with Cambrian Iapetan rifting (mid-ocean-ridge spreading) (Thomas, 1991; Goodmann, 1992). It has been interpreted to be part of a major graben or rift system extending from the Mississippi Valley Graben east-northeastward through the Rough Creek Graben and Rome Trough across Kentucky, West Virginia, and Pennsylvania, into

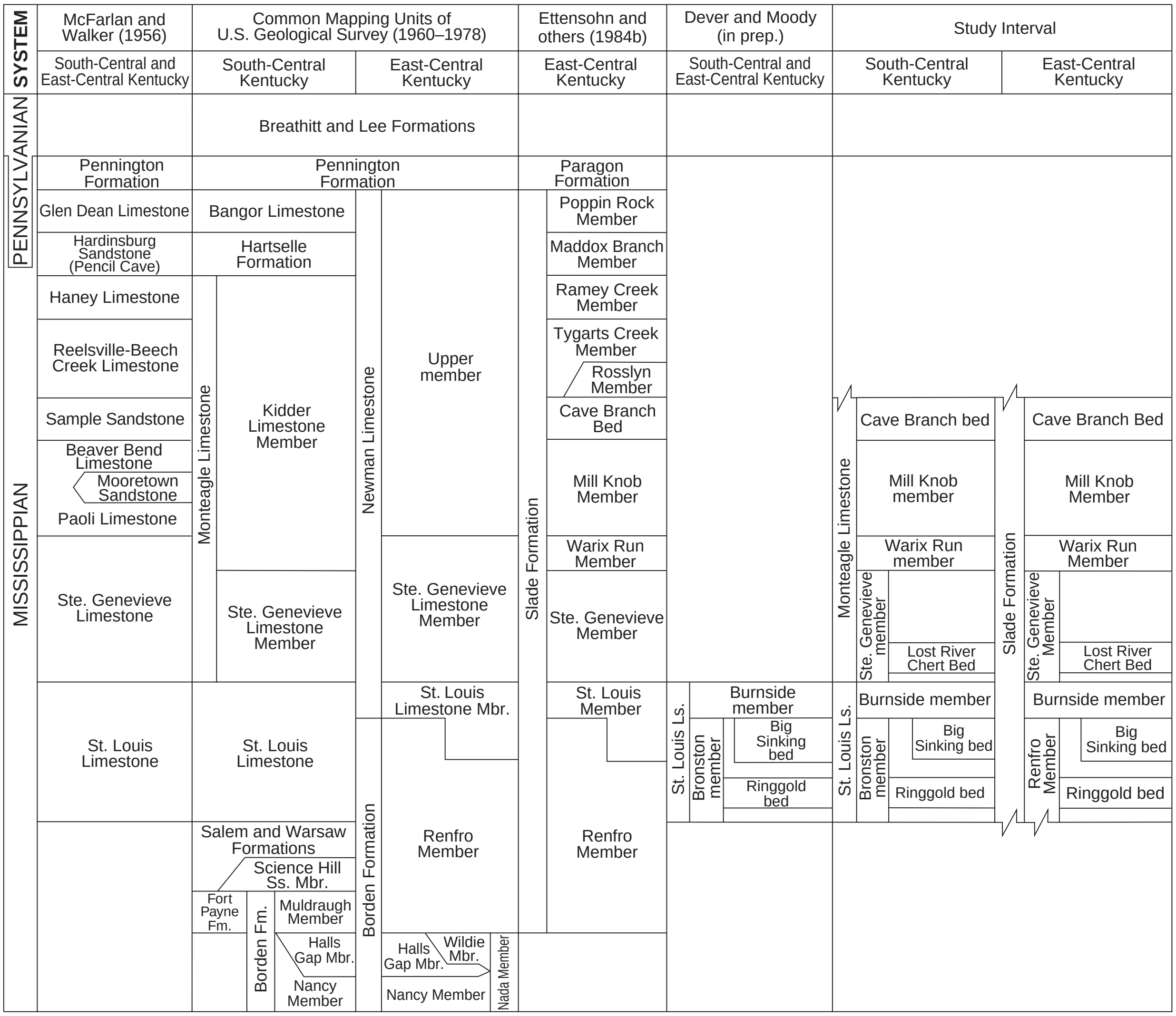


Figure 2. Stratigraphic nomenclature used for the study interval and by recent workers for Mississippian carbonate rocks and adjacent units of south-central and east-central Kentucky. Lost River Chert Bed after McGrain (1969).

south-central New York (Harris, 1978; Webb, 1980; Shumaker, 1986; Drahovzal, 1990; Thomas, 1991).

Ettensohn and Pashin (1992a) noted that the fault patterns in the Rome Trough of eastern Kentucky (dominantly down-to-the-south displacement) and Rough Creek Graben of western Kentucky (dominantly down-to-the-north displacement) have opposite fault polarity and, using East African Rift terminology (Rosendahl, 1987), represent nonoverlapping, opposing, half-graben systems. Ettensohn and Pashin (1992a) interpreted short, curvilinear faults associated with the intervening Jessamine Dome as being transfer faults of an isolation accommodation zone, which accommodates graben systems of opposite polarity.

Walker and others (1991, 1992) reported that structural mapping of the Rome Trough in eastern Kentucky and West Virginia suggested that Cambrian extension resulted in a series of half grabens of alternating polarity and variable displacement. The half grabens are bounded in the dip direction by west–southwest-trending normal faults that are laterally continuous only on the order of tens of kilometers. Along strike, the Rome Trough is laterally segmented by north–south-trending faults, commonly expressed as flexures in younger rocks, which show evidence of significant strike-slip displacement.

Surface faults in the study area mainly are interior faults of the Rome Trough and, at least in part, extend downward into the Precambrian basement (see Webb, 1980, Fig. 21). Complex patterns of basement faulting in the trough are shown on maps and cross sections by Goble (1972), Harris (1975), Webb (1980), Silberman (1981), Black (1986a, 1989), and Drahovzal and others (1992). Major basement faults, which apparently formed initially during Late Proterozoic time, were reactivated during the Paleozoic (Black, 1986a).

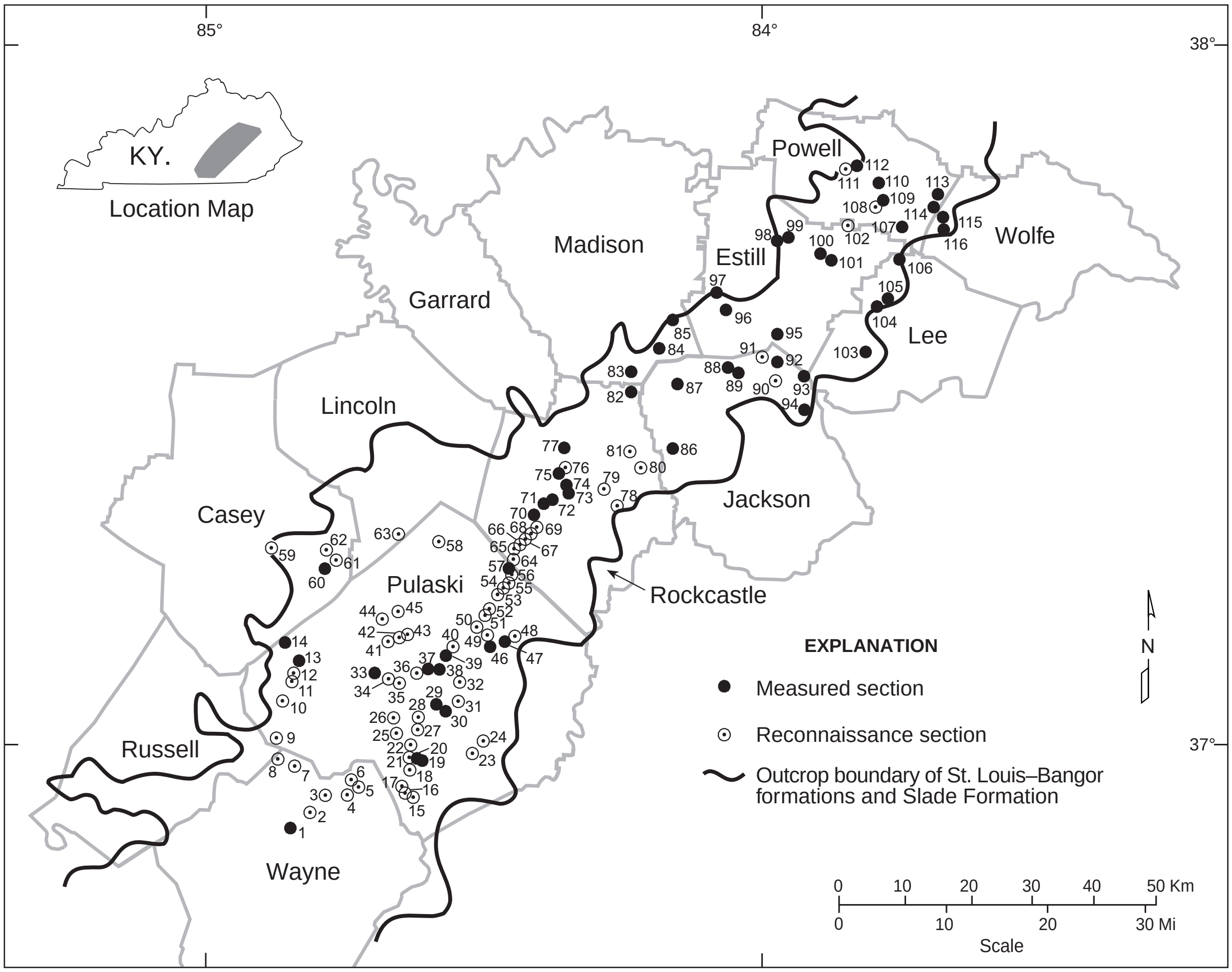


Figure 3. Locations of measured and reconnaissance sections in and adjacent to the study area, which extends from Pulaski County northeastward into Powell County.

The Rome Trough was formed mainly by Cambrian faulting, which may have been partly controlled by Precambrian zones of weakness or faults (Ammerman and Keller, 1979). Greatest subsidence occurred during Cambrian time (Thomas, 1960; Woodward, 1961; McGuire and Howell, 1963; Webb, 1969, 1980; Avila, 1971; Silberman, 1972; Cable, 1984; Cable and Beardsley, 1984; Thomas, 1991). Post-Cambrian growth faulting of decreased magnitude, compared to the Cambrian, occurred intermittently along bounding and interior faults, resulting in the thickening of Paleozoic sediments on the downthrown sides. Thickening has been reported for units in the Ordovician (Silberman, 1972; Black and Haney, 1975; Harris, 1978; Price, 1981; Cable, 1984; Cable and Beardsley, 1984; Maynor, 1984; Ettensohn and others, 1986; Jacobs, 1986; Ettensohn, 1992q), Silurian (Miles, 1972; Watson, 1983; Maynor, 1984; Lenhart, 1985), Silurian–Devonian (Weaver and McGuire, 1973; Scott, 1978; Currie, 1981; Currie and MacQuown, 1984; Maynor, 1984), Devonian (Scott, 1978; Dillman, 1980; Dillman and Ettensohn, 1980; Lenhart, 1985; Ettensohn and others, 1988b; Barnett and Ettensohn, 1992a, 1992b; Ettensohn, 1992c; Pashin and Ettensohn, 1992b), Mississippian (MacGill, 1973; Ettensohn, 1977, 1992p), and Pennsylvanian (Haney and others, 1975; Horne and Ferm, 1978; Sergeant, 1979; Sergeant and Haney, 1980; Haney and others, 1985; Chesnut, 1988).

Patterns in Ordovician lithofacies of central Kentucky suggest synsedimentary movement on the Kentucky River and Irvine-Paint Creek Fault Systems (Mackey, 1972; Cressman, 1973; Borella and Osborne, 1978; Weir and others, 1984; Ettensohn, 1992e, h, l, q). Greater thicknesses of Silurian rocks on the downthrown sides of northwest-trending faults in east-central Kentucky, observed by Jillson (1964), Simmons (1966), and Black (1975), may reflect growth faulting as well as the effects of pre-Middle Devonian uplift and erosion. Configuration of a fan-shaped body formed by the Farmers Member of the Borden Formation (Mississippian) in northeastern Kentucky was affected by the Kentucky River and Irvine-Paint Creek Fault Systems (Lierman and others, 1992). The areal distribution and thickness of Pennsylva-

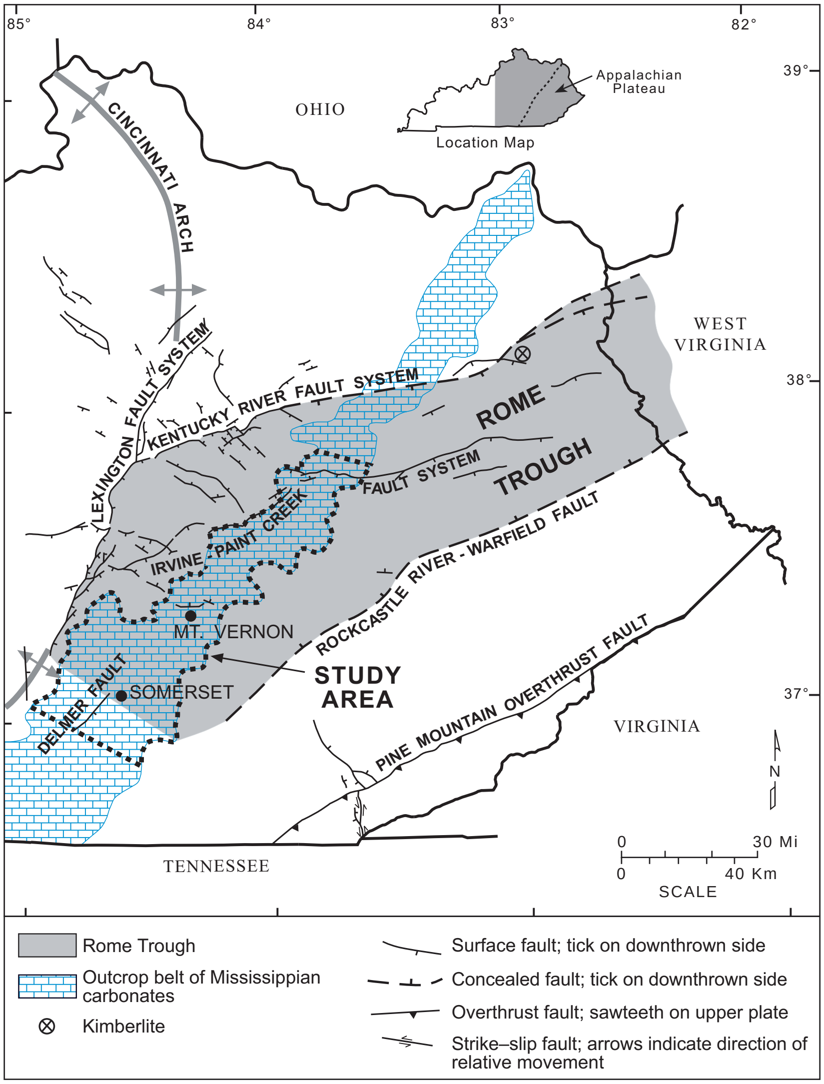


Figure 4. The Rome Trough in eastern and central Kentucky (modified from Dever, 1986). Surface faults from compilation by Roger B Potts. Concealed faults compiled from Ammerman and Keller (1979), Webb (1980), Sutton (1981), Maynor (1984), and data reported by Dever and others (1984). Study area outlined by dotted line.

nian and Mississippian sandstones in northeastern Kentucky were influenced by the fault system along the northern boundary of the trough (Short, 1978).

Paleozoic episodes of uplift, accompanied by erosional and depositional thinning, and folding, also occurred along bounding and interior faults of the Rome Trough. Evidence for uplift has been found in deposits of pre-Middle Devonian age (Simmons, 1966; Black, 1986a), and of the Devonian (Harris, 1978; Dillman, 1980; Lenhart, 1985; Ettensohn and others, 1988b; Ettensohn and Bayan, 1990; Barnett and Ettensohn, 1992a, b; Ettensohn, 1992c), Mississippian (Dever, 1977; Ettensohn, 1977, 1992i, Ettensohn and Peppers, 1979), and Pennsylvanian (Chesnut, 1988, 1991; Ettensohn and others, 1992).

Deformed crossbedding in Mississippian calcarenites of east-central and northeastern Kentucky may reflect seismically induced gravity sliding resulting from contemporary tectonism (Woodward, 1983). The Upper Pennsylvanian Monongahela and Conemaugh Formations, the youngest Paleozoic sedimentary rocks in the Rome Trough of Kentucky, are folded above concealed faults of the Kentucky River Fault System in northeastern Kentucky (see Spencer, 1964).

Basement faults along the northern boundary of the trough provided a pathway for the intrusion of a Permian kimberlite (Fig. 4) (Silberman, 1972; Bolivar, 1982; Calandra, 1986). Radiometric age determinations for the kimberlite yielded an Early Permian age of 269 Ma (Zartman and others, 1967); paleomagnetic data indicated a Late Permian to Early Triassic age (Harvey, 1980).

In the complex structural terrain along the southern boundary of the Rome Trough, Paleozoic units thin across uplifts (Perry County, Pike County, and Rockcastle River Uplifts) and thicken in adjoining embayments, partly in response to growth faulting. Thickness variations occur in units of the Cambrian (Ammerman, 1976; Weaver and McGuire, 1977; Ammerman and Keller, 1979; Webb, 1980; Sutton, 1981; Cable, 1984), Silurian (Currie, 1981; Currie and MacQuown, 1984; Maynor, 1984), Devonian (Dillman, 1980; Currie, 1981; Nicholson, 1983; Maynor, 1984; Ettensohn and others, 1988b), Mississippian (Pear, 1980; Hetherington, 1981; MacQuown and Pear, 1983; Maynor, 1984), and Pennsylvanian (Chesnut, 1988). Both facies and thickness patterns in the Stoney Fork Member of the Breathitt Formation (Pennsylvanian) suggest synsedimentary tectonic activity on the Perry County Uplift (Ping, 1978).

Recognition of post-Paleozoic tectonic activity in the Rome Trough has been limited by the common absence of post-Paleozoic deposits in central and eastern Kentucky. However, in central Kentucky, Tertiary(?) and Quaternary high-level fluvial deposits and Quaternary alluvium locally rest on surface faults of the Kentucky River and Lexington Fault Systems. Local faulting and folding in the high-level fluvial deposits above faults of the Kentucky River Fault System indicate that displacement has occurred less than 5 Ma and

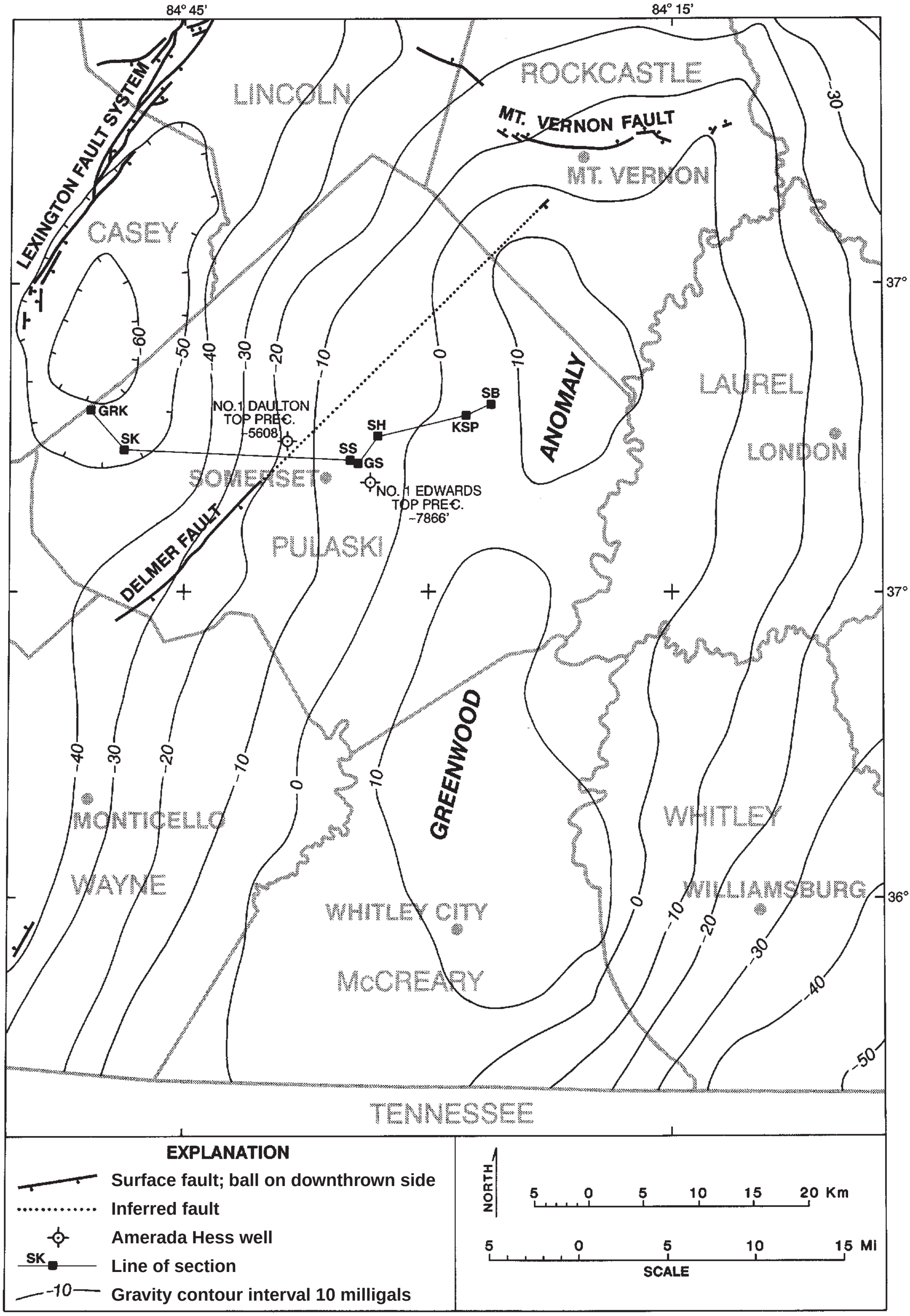


Figure 5. Part of Greenwood Anomaly, surface faults, Amerada Hess wells with top-of-basement elevations, and line of cross section shown in Figures 26 through 29 (from Dever, 1990). Gravity contours from Ammerman (1976). Surface faults adapted from McDowell and others (1981) and Schlanger (1965).

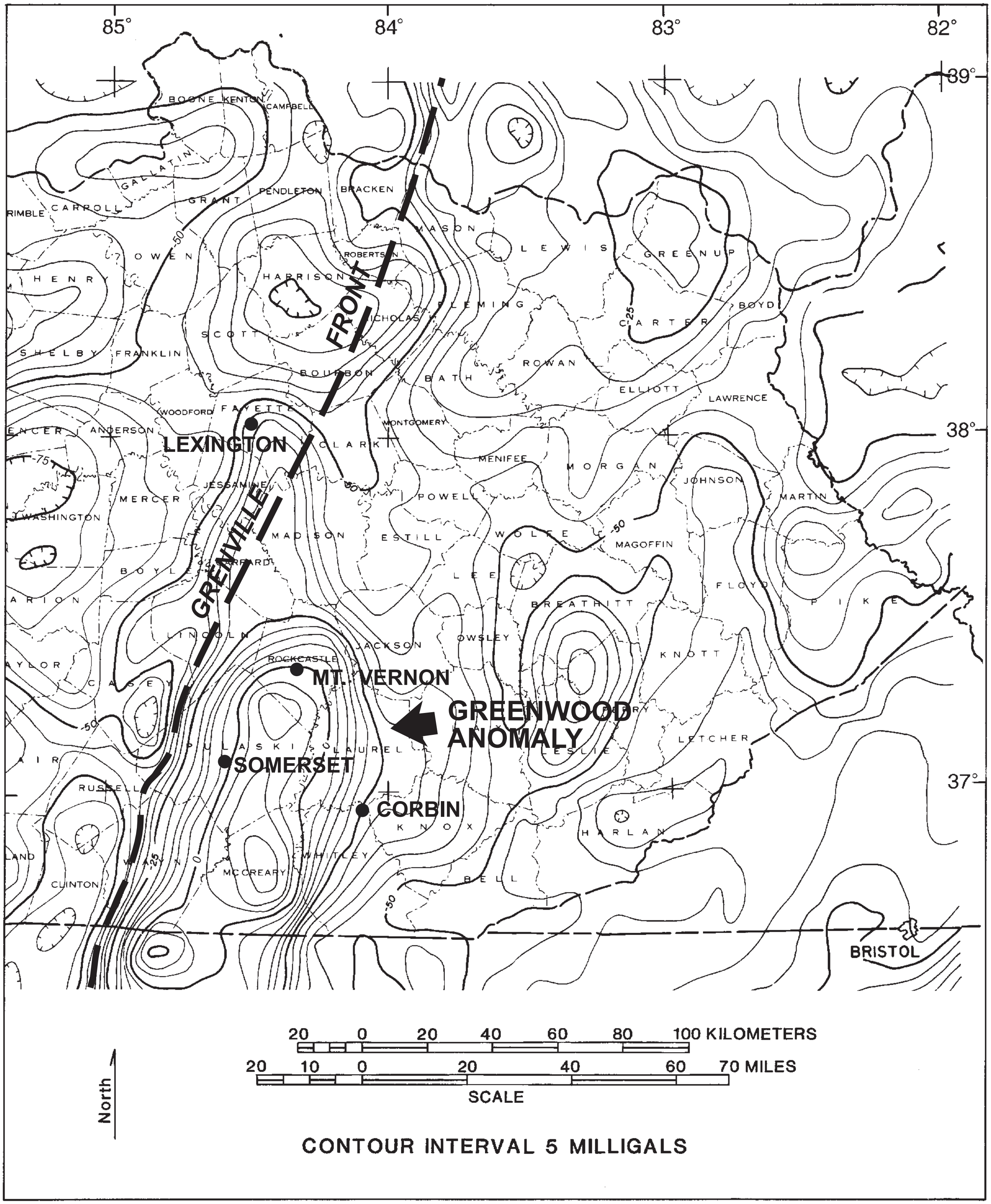


Figure 6. Bouguer gravity for eastern and central Kentucky (from Keller and others, 1980), showing Greenwood Anomaly and projected trend of Grenville Front (from Keller and others, 1982). Modified from Dever (1990).

probably less than 1 Ma ago (VanArsdale, 1986; VanArsdale and Sergeant, 1987). Along the Lexington Fault System, a fluvial cobble was found embedded and crushed in the plane of a surface fault (Black, 1986b). Instrument-determined and estimated epicenters for several historic (1854–1987) earthquakes were within the boundaries of the Rome Trough (Stover and others, 1979; Braile and others, 1983; Mueller, 1987).

In addition to multiple episodes of recurrent movement on faults of the Rome Trough, multiple components of fault movement (normal, reverse, left-lateral, right-lateral, scissorlike, and combinations of movement) have been identified along the Kentucky River and Lexington Fault Systems, where they are exposed in Ordovician rocks of central Kentucky (Haney, 1974; Black and Haney, 1975; Phillips and Haney, 1976; Black and others, 1979; Gustafson, 1986). Several lines of evidence indicate right-lateral movement on the Kentucky River Fault System along the northern boundary of the Rome Trough: (1) patterns in subsidiary faults and folds (Heyl, 1972; Black, 1986b; Gustafson, 1986), (2) offset gravity and magnetic anomalies (Heyl, 1972; Lidiak and Zietz, 1976), (3) offset of the Grenville Front (Heyl, 1972; Lidiak and Zietz, 1976; Denison and others, 1984), (4) offset of the Waverly Arch (Ettensohn, 1975), and (5) offset mineral veins (Black, 1986b).

However, Black and others (1976, 1979) have disputed the occurrence of 80 km of right-lateral displacement between basement gravity anomalies in central and northeastern Kentucky that was suggested by Heyl (1972). Black and others (1976, 1979) reported that no large-scale lateral movement has occurred along either the Kentucky River Fault System or the Irvine-Paint Creek Fault System since emplacement of a Precambrian igneous mass, which is the source of the central Kentucky anomaly, because both fault systems cross, but do not offset, the anomaly.

Left-lateral displacement along the Lexington Fault System, which forms the western boundary of the Rome Trough, is indicated by fault, lineament, and joint patterns, and by the apparent offset of dolomite belts (Black and Haney, 1975; Black and others, 1979). Fault segments of the Irvine-Paint Creek Fault System in the interior of the trough are offset, suggesting lateral movement along northwest-trending concealed faults (Black and others, 1979). Lineament patterns indicate left-lateral offset of the Kentucky River and Irvine-Paint Creek Fault Systems, and the Warfield Fault in northeastern and eastern Kentucky (Black, 1986a, b).

The location of the southwestern boundary of the Rome Trough, beneath the southern part of the study area, is uncertain, partly because of masking by the strong gravity signature of the Greenwood Anomaly (Ammerman, 1976; Ammerman and Keller, 1979). The trough may be bounded by a west- or west–southwest-trending extension of the Rockcastle River-Warfield Fault (Ammerman, 1976; Keller and others, 1981); or, either the Rome Trough or an embayment of the trough may extend southward into Tennessee (Weaver and McGuire, 1977; Sutton, 1981; Cable, 1984). A southwestern extension of the Rome Trough cutting across the Greenwood Anomaly is suggested by the presence of lower velocity basement in the center of the anomaly in Pulaski County (Preziosi, 1985).

Results from drilling the Amerada Hess No. 1 Daulton and No. 1 Edwards wells, two basement tests in central Pulaski County, showed that the top of the Precambrian basement is downthrown 688 m to the east or southeast, and 637 m of thickening occurs in the Cambrian Maynardsville-Conasauga-Rome interval on the downthrown side (Fig. 5). A northeast- or north-trending basement fault has been projected between the two wells (Weaver and McGuire, 1977; Silberman, 1981; Sutton, 1981), and was interpreted by Weaver and McGuire (1977) and Silberman (1981) as a western bounding fault of the Rome Trough in south-central Kentucky. The northeast-trending Delmer Fault may be a surface expression of this basement faulting (Figs. 4–5). Magnetic gradients and offset margins of magnetic anomalies in eastern Pulaski County and adjacent counties were inferred by Black (1989) to reflect the presence of two northeast-trending, right-lateral basement faults, the Burnside and Alpine Lineaments, which parallel the trend of the Delmer Fault. A subparallel fault, indicated by a sharp declivity in east–west magnetic and gravity surveys, occurs along the Pulaski-Laurel County line (Greb and others, 1990). Pennsylvanian movement on the fault is suggested by the presence of mass-flow deposits and deformed bedding (ball-and-pillow structures) on the downthrown (east) side (Greb and Chesnut, 1989, 1990a, b; Greb and others, 1990).

### Greenwood Anomaly

The Greenwood Anomaly is a large linear gravity anomaly that extends northward from Tennessee into central Kentucky (Fig. 6) (Watkins, 1963; Bryan, 1975; Ammerman, 1976; Keller and others, 1980). The gravity anomaly coincides with a series of high-amplitude magnetic anomalies (Fig. 7) (Lidiak and Zietz, 1976; Johnson and others, 1980a, b; Mayhew and others, 1982; Zietz and Bond, 1984). Based on gravity, magnetic, seismic, and lithologic data, the source of the geophysical anomaly commonly has been interpreted to be a body of mafic igneous rocks, representing the core of a Proterozoic (Keweenawan) rift zone (Bryan, 1975; Keller and others, 1975, 1981, 1982; Mayhew and others, 1982; Owens and others, 1984; Preziosi, 1985). In north-central Tennessee, the Greenwood Anomaly influenced facies and thickness patterns in Mississippian units (Spalding, 1982).

The anomaly is part of the East Continent Gravity High (Bryan, 1975), a series of gravity-magnetic anomalies, partly offset, that are considered to represent a Keweenawan rift system extending northward across Tennessee, Kentucky, Ohio, and Indiana, into Michigan (McGuire and Howell, 1963; Rudman and others, 1965; Lyons, 1970; Heyl, 1972;

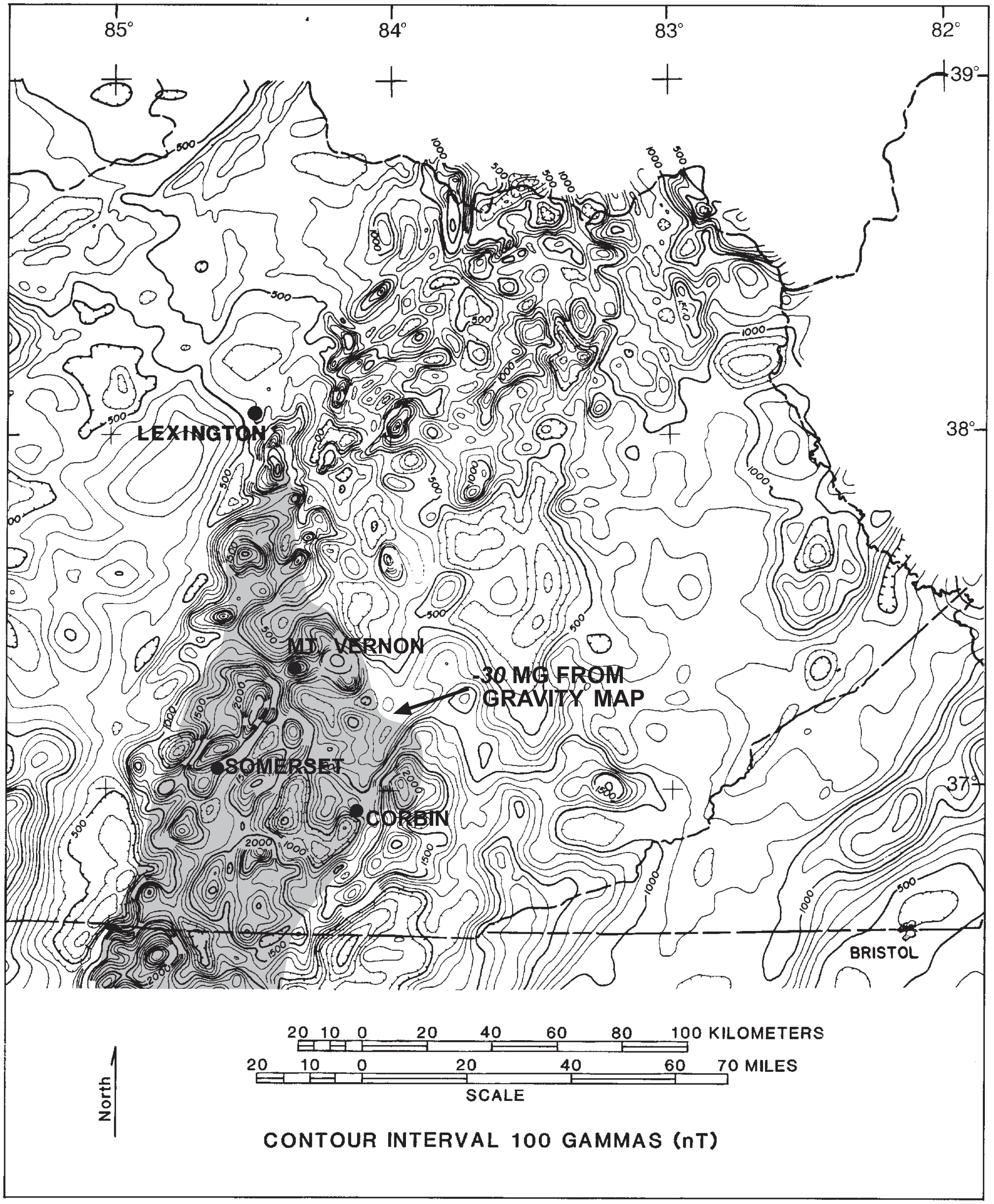


Figure 7. Total magnetic intensity for eastern and central Kentucky (from Johnson and others, 1980a), showing relationship between magnetic anomalies and Greenwood gravity anomaly, which is outlined by –30 milligal contour (from Dever, 1990).

Mayhew and others, 1982; Keller and others, 1982, 1983; Owens and others, 1984). The East Continent Gravity High and the adjacent East Continent Rift Basin, a Precambrian fault-bounded, sedimentary basin, are interpreted to be an extension of the Midcontinent Rift System, or Midcontinent Gravity High, a similar geophysical feature that also is considered to be a Keweenawan rift system (Drahovzal and others, 1992). The Midcontinent Rift System extends from Kansas northeastward through Nebraska, Iowa, Minnesota, and Wisconsin, across the Lake Superior region, and into southeastern Michigan. In Kentucky, the East Continent Rift Basin, which is filled with Proterozoic sediments and volcanic rocks, extends along the west side of the East Continent Gravity High (Drahovzal and others, 1992).

The Grenville Front, the western boundary of the Proterozoic metamorphic Grenville Province, has been projected southward from Canada into Kentucky, and commonly is shown as extending southward along the western border of the Greenwood Anomaly in south-central Kentucky (Fig. 6) (Lidiak and Zietz, 1976; Keller and others, 1981, 1982; Mayhew and others, 1982; Gordon and Hempton, 1986; Drahovzal and others, 1992). Recent investigation has shown that the Grenville Front is a structural contact between allochthonous Grenville Province metamorphic rocks to the east and East Continent Rift Basin sedimentary and igneous rocks to the west (Drahovzal and others, 1992). In Kentucky and southern Ohio, the Grenville allochthon was thrust across rocks of the East Continent Gravity High and onto deposits of the East Continent Rift Basin, as a result of continent-continent collision during the Grenville Orogeny. Seismic lines in Kentucky and Ohio show that extensive strike-slip faulting occurred along and near the Grenville Front during the Late Proterozoic and that Proterozoic faults were reactivated during the Paleozoic (Drahovzal and others, 1992).

A model for forming the extensional features of the Midcontinent Rift System and East Continent Gravity High in the dominantly compressive tectonic setting of the Grenville continent-continent collision was proposed by Gordon and Hempton (1986), but, based on structural relationships and age determinations, Drahovzal and others (1992) have concluded that the East Continent Rift Basin and East Continent Gravity High predate the Grenville Orogeny and that these rift features were subsequently overridden by allochthonous Grenville rocks. The Grenville Province, dated at 0.9 to 1.0 Ga, is younger than the Midcontinent Rift System and East Continent Rift Basin, dated at 1.0 to 1.2 Ga, and the East Continent Gravity High, dated at 1.2 to 1.3 Ga (Drahovzal and others, 1992; Drahovzal and Harris, 1993).

Projection of the Grenville Front through central Kentucky along the western border of the Greenwood Anomaly was questioned by Black (1989) because metamorphic rocks dated as old as 0.95 Ga are present 160 km to the west in Kentucky, Tennessee, and Ohio. He also suggested that the unaltered extrusive rocks west of the commonly projected position of the Grenville Front appear to be coeval with similar unaltered igneous rocks that overlie Grenville metamorphics in the east. Other workers have projected the Grenville Front southward across far western Kentucky near Paducah (Rudman and others, 1965) and through south-central and west-central Kentucky near Bowling Green (Bayley and Muehlberger, 1968).

### Cincinnati Arch

The Cincinnati Arch is a broad anticlinal structure that extends northeastward from central Tennessee through central Kentucky toward Cincinnati, Ohio (Fig. 8). In northern Kentucky (McFarlan, 1943) or Ohio (McDowell, 1986), it splits into the Kankakee and Findlay Arches, which extend across Indiana and Ohio, respectively. Principal features on the Cincinnati Arch are the Jessamine Dome (or Lexington Dome) of central Kentucky, Cumberland Saddle of south-central Kentucky, and Nashville Dome of central Tennessee.

The arch was a positive structural feature as early as Silurian time, but the presence of an earlier Ordovician arch in Kentucky has been questioned (McDowell, 1986). McFarlan (1943) cautioned that indications of Ordovician upwarping in central Kentucky did not necessarily imply the beginning of the Jessamine Dome. Mappers with the U.S. Geological Survey-Kentucky Geological Survey cooperative mapping program (1960–78) reported that lithofacies and thickness trends in Ordovician units of central Kentucky show no influence of the Cincinnati Arch (Wolcott and others, 1972; Cressman, 1973; Weir and others, 1984). Results from other studies of Ordovician units in central and south-central Kentucky, however, suggest that the Jessamine Dome and Cincinnati Arch, or their precursors, were present in Ordovician time. In central Kentucky, the distribution of Ordovician shoal deposits (versus deeper water facies) indicates the presence of an uplifted area approximately coincident with the Jessamine Dome (Borella and Osborne, 1978; Grossnickle, 1985; Ettensohn and others, 1986; Ettensohn, 1992e, h, l). Lithofacies trends in uppermost Ordovician rocks, shown by Weir and others (1984), parallel the present axis of the arch, and together with deepening trends away from the axis suggest development of a continuous Cincinnati Arch (Ettensohn, 1992e, r; Ettensohn and Pashin, 1992a). An Ordovician arch in south-central Kentucky is indicated by thickness and facies variations in Lower, Middle, and Upper Ordovician units across an axis essentially coincident with the present Cincinnati Arch (McGuire and Howell, 1963; Mackey, 1972; Jacobs, 1983; Anderson, 1989, 1991).

An Early Silurian arch is indicated by eastward depositional thickening of Silurian strata (McDowell, 1983, 1986) and is suggested by depositional and diagenetic features in the Lower Silurian Brassfield Formation (Gordon and Ettensohn, 1984). The arch increasingly influenced sedimentation during Middle and Late Silurian time, gradually lim-

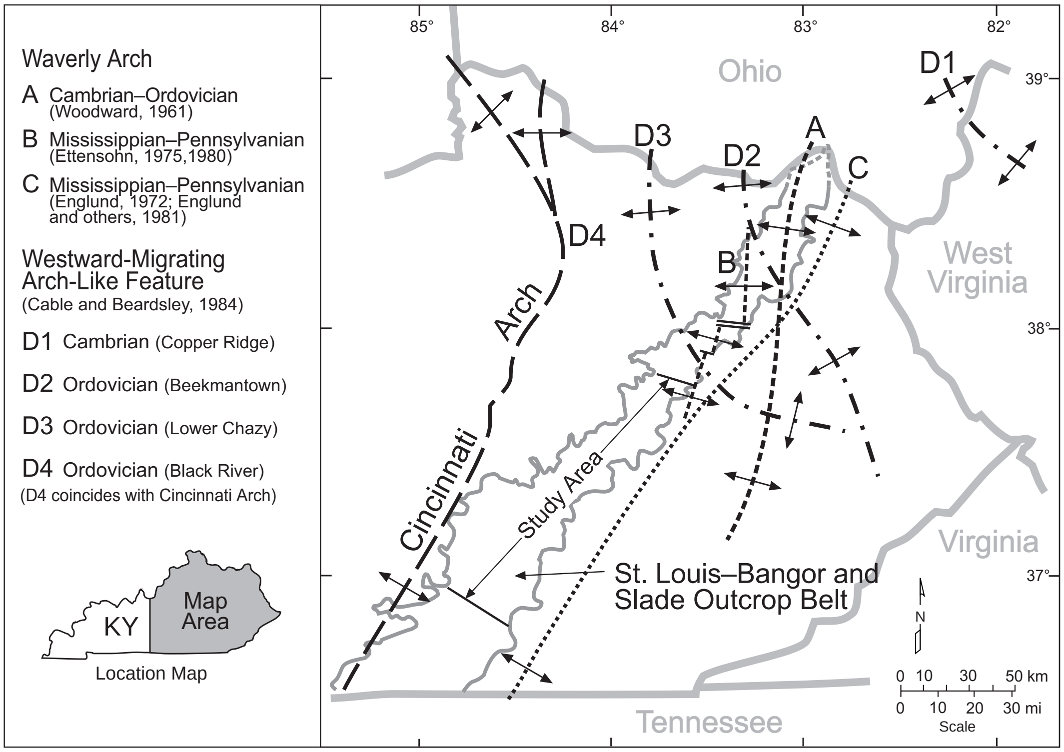


Figure 8. Approximate axis of Cincinnati Arch (adapted from McFarlan, 1943; Wolcott and others, 1972; Weir and others, 1984), axes of Waverly Arch (A–C) (Woodward, 1961; Ettensohn, 1975, 1980; Englund, 1972; Englund and others, 1981), and axes of west-migrating arch-like feature (D1–D4) (Cable and Beardsley, 1984).

iting westward movement of terrigenous-detrital sediments and later forming a barrier to open-marine circulation, resulting in evaporite deposition in eastern Kentucky (Freeman, 1951; Currie, 1981). This uplift and basin isolation more recently have been attributed to lithospheric flexure in response to the Salinic disturbance (Ettensohn, 1992f, 1994).

Pre-Middle Devonian emergence resulted in extensive erosion of Silurian and Upper Ordovician units along the Cincinnati Arch; Middle and Upper Devonian carbonate rocks and black shales deposited during subsequent transgression generally rest on progressively older Silurian and Ordovician rocks toward the axis of the arch (McFarlan, 1943; Freeman, 1951; Kepferle, 1986). Progressive onlap of the arch by units of the Devonian black shale sequence and their thinning toward the axis indicate that the arch was a positive, but submerged feature during Late Devonian time (Dillman, 1980; Ettensohn and others, 1988b). Only the youngest units of the black shale sequence crossed the arch (Dillman, 1980). Devonian black shale is preserved in a graben near the apex of the Jessamine Dome and crest of the arch in central Kentucky (McFarlan, 1943; Wolcott and Cressman, 1971). Devonian subsidence on the arch was related to migratory lithospheric flexure in response to Acadian tectonism (Ettensohn and others, 1988b; Ettensohn, 1992m).

During Mississippian time, the Cincinnati Arch was alternately submergent and emergent (Pryor and Sable, 1974; Sable, 1979; Sable and Dever, 1990). An anomalous rubidium-strontium age for authigenic glauconite from the Lower Silurian Belfast Member of the Brassfield Formation in south-central Ohio has been attributed to Mississippian uplift on the arch (Laskowski and others, 1980). The glauconite yielded a rubidium-strontium isochron age of 337 ± 27 Ma, 20 to 25 percent younger than the depositional age of the Belfast. Laskowski and others (1980) suggested that uplift produced fluid movement through the deposits, resulting in isotopic equilibration of the glauconite's strontium with that in the fluid.

Pepper and others (1954) suggested that the arch was a positive feature during earliest Mississippian (Kinderhookian) time, with emerging lowlands that may have been a source for small amounts of sediment during deposition of the Bedford Shale and Berea Sandstone on the east side of the arch (Pepper and others, 1954; Elam, 1981) and during Rockford Limestone deposition west of the arch (Pryor and Sable, 1974; Sable, 1979). Pashin and Ettensohn (1992b), however, have concluded that sediments for the Bedford-Berea sequence were derived entirely from the east, from both the Appalachian orogen and from Catskill sediments that were eroded and reworked during a eustatic lowstand. The Cincinnati Arch was a positive, but mainly submerged, feature in late Kinderhookian time, as indicated by thinning of the Sunbury Shale and its southern equivalent toward and onto the arch (Ettensohn and Elam, 1985).

In Osagian time, the arch was submerged and apparently covered by distal sediments of a west-prograding deltaic sequence, the clays and silts of the Borden Formation. A graben in central Kentucky, near the apex of the Jessamine Dome and crest of the arch, contains 33 m of Borden shale and siltstone (McFarlan, 1943; Wolcott and Cressman, 1971). Two turbidite deposits occur in the Borden east of the arch: the Farmers Member (Moore and Clarke, 1970) and the beds locally known as "Rockcastle freestone" in the Wildie Member (Weir, 1970). A third turbidite is present west of the arch, the Kenwood Siltstone Member (Kepferle, 1977). Paleocurrent directions, generally west in the eastern turbidites and west–southwest in the Kenwood, show no influence of an arch in central Kentucky and indicate the presence of a west- to west–southwest-trending paleoslope across the region (Moore and Clarke, 1970; Kepferle, 1977). The Cincinnati Arch was interpreted to have been an emergent source for Osagian sandy detrital sediment (Walker, 1962) and red mudstones (Sable, 1970), but these deposits probably were derived from more distant source areas (Pryor and Sable, 1974; Sable and Dever, 1990).

Meramecian deposits in the Eastern Interior Basin of western Kentucky commonly thin eastward, suggesting that the Cincinnati Arch was a positive feature during Mississippian time (Sable, 1979; Sable and Dever, 1990). In middle Meramecian time, uplift of the Cincinnati Arch and other positive structures, combined with regression, restricted circulation in the Eastern Interior Basin, resulting in evaporite deposition in the St. Louis (Craig and Varnes, 1979; De Witt and others, 1979). Subsequent transgression during deposition of upper St. Louis limestones probably inundated the arch (Sable, 1979). Paleocurrent patterns in the northern Appalachian Basin, based on crossbedding in late Meramecian (and early Chesterian[?]) limestones, indicate the presence of an elongate embayment that probably was constricted on the west by emergence or shoaling of the Cincinnati Arch in Ohio and north-central Kentucky (Woodward, 1983).

In Late Mississippian (Chesterian) time, the northern part of the Cincinnati Arch is considered to have been an emergent lowland or shoal, which contributed little sediment, but formed a partial barrier between the Appalachian and Eastern Interior Basins, and influenced the Michigan River drainage (Swann, 1963; Pryor and Sable, 1974; Craig and Varnes, 1979; Sable, 1979; Sable and Dever, 1990). Depositional thinning and erosion of Upper Mississippian units in northeastern Kentucky in part reflect Late Mississippian uplift on the arch (Ettensohn, 1975). Erosion of older Mississippian rocks on the east flank of the Cincinnati Arch was suggested as a probable source for the quartz sand and pebbles in the Carter Caves Sandstone (Chesterian) of northeastern Kentucky (Englund and Windolph, 1971), but petrographic and paleocurrent data indicate a sedimentary source to the east and north (Martin, 1975). The Cumberland Saddle in south-central Kentucky was submerged during much or all of Meramecian and Chesterian time and may have served as a passageway for the westward transport of detrital sediments (Sable, 1979; Sable and Dever, 1990).

Basal Pennsylvanian deposits in both west-central and eastern Kentucky rest on progressively older Mississippian units toward the axis of the Cincinnati Arch, indicating uplift and erosion along the arch in Late Mississippian to Early Pennsylvanian time (Englund and others, 1981; Englund and Randall, 1981; Sable and Dever, 1990). Beveling of Mississippian rocks in northeastern Kentucky, however, may mainly reflect penecontemporaneous uplift on the Waverly Arch (Englund, 1972). Apparent southward stream deflection and radial streams in an inferred Late Mississippian–Early Pennsylvanian drainage system across Kentucky suggest that the Jessamine Dome was a positive feature (Rice, 1984; Rice and Schwietering, 1988). Influence of the Cincinnati Arch during Pennsylvanian time is indicated by eastward thinning of Pennsylvanian strata in the Eastern Interior Basin of western Kentucky (Rice and others, 1979), and by westward thinning of Pennsylvanian rocks in the Appalachian Basin of eastern Kentucky (Tankard, 1986; Chesnut, 1991). Present structural relief on the arch mainly resulted from latest Paleozoic or post-Paleozoic movement (McDowell, 1986).

Based on models for lithospheric flexural response to geologic processes in orogenic belts, outlined in a following section, several recent workers have suggested that episodes of Paleozoic uplift on the Cincinnati Arch were related to movement of peripheral bulges across the region during the Ordovician (Beaumont and others, 1988; Ettensohn and Pashin, 1992a), Devonian (Quinlan and Beaumont, 1984; Beaumont and others, 1988; Barnett and others, 1989; Ettensohn and Pashin, 1992a), Mississippian (Quinlan and Beaumont, 1984; Tankard, 1986; Chesnut, 1991), and Pennsylvanian (Tankard, 1986; Chesnut, 1991, 1992; Ettensohn and Pashin, 1992a). The formation and movement of a peripheral bulge are related to deformational loading in an orogen and to lithospheric relaxation after active loading ceased.

According to Quinlan and Beaumont (1984), the Cincinnati Arch was formed by flexural interaction between the Appalachian and Illinois Basins. In Late Ordovician time, an Appalachian Basin bulge, associated with the Taconic Orogeny, had migrated far enough west to interact constructively with an Illinois Basin bulge, producing the arch (Quinlan and Beaumont, 1984; Ettensohn and Pashin, 1992a). Subsequent phases of bulge interaction in response to the Acadian and Alleghenian Orogenies enhanced uplift of the arch. Domes along the Cincinnati Arch may reflect regions of maximum constructive bulge interference (Quinlan and Beaumont, 1984), but Ettensohn and Pashin (1992a) have suggested that the domes may represent isolated fault-bounded structures where stress was localized and uplift was focused.

The East Continent Rift Basin generally coincides with the axis of the Cincinnati Arch across central Kentucky. This coincidence suggests that the basin and its associated faults influenced the location of the arch (Drahovzal and others, 1992).

### Waverly Arch

Woodward (1961) reported that depositional and erosional thinning of early Paleozoic formations indicated the presence of a broad, low, concealed arch, which he named the Waverly Arch, extending from north-central Ohio southward into eastern Kentucky (Fig. 8). The arch was described as an axis of low and persistent relief or an axis of resistance to subsidence from Middle Cambrian through Early Ordovician time. Principal episodes of uplift and erosion occurred after deposition of the Lower Ordovician Beekmantown Dolomite of the Knox Group and the Middle Ordovician Black River Limestone (Woodward, 1961; McGuire and Howell, 1963). The Cambrian basal sandstone in northeastern Kentucky thins across the arch (Goble, 1972).

According to Calvert (1974), use of the erosional surface at the top of the Knox as a datum by Woodward (1961) resulted in the mistaken identification of a nonexistent Waverly Arch. Isopach and structure maps prepared by Calvert (1974) for Cambrian and Ordovician units in the subsurface of Ohio showed no evidence for the arch. In a later study of Upper Cambrian and Lower Ordovician units in the subsurface of eastern Kentucky and adjacent states, Cable and Beardsley (1984) mapped a west-migrating arch-like feature, which represented areas of less active subsidence (Fig. 8). The location of the arch-like feature in Early Ordovician Beekmantown time corresponded to the position of the Waverly Arch of Woodward (1961).

The Silurian Clinton Sandstone, a reservoir for natural gas in northeastern Kentucky, thins westward toward the Waverly Arch; the western limit of Clinton natural gas production in Boyd and Lawrence Counties, Ky., and in Ohio parallels the axis of the arch (Watson, 1983). During deposition of Middle Silurian–Lower Devonian “Corniferous” carbonate and sandstone units in eastern Kentucky, a north–south-trending hinge line in the vicinity of the Waverly Arch separated a western shelf from an eastern subsiding basin (Currie, 1981; Currie and MacQuown, 1984). The hinge line, as plotted by Currie (1981), is a north–south-trending belt, about 13 to 14 km wide, with the axis of the Waverly Arch of Woodward (1961) as its eastern border.

Isopach mapping of Upper Devonian black shales in eastern Kentucky indicated the presence of a north–south-trending hinge line, extending from western Lewis County southward to eastern Bell County, that separated relatively thin black shales on a platform near the Cincinnati Arch from an area of abruptly thickening black shales to the east (Dillman, 1980; Dillman and Ettensohn, 1980). The Upper Devonian hinge line is about 13 to 16 km west of the Middle Silurian–Lower Devonian hinge line identified by Currie (1981); its relationship, if any, to the Waverly Arch is not clear. Local thinning of the Devonian black shale along the east flank of the Waverly Arch in northeastern Kentucky may represent precursory movement along the trend of the arch prior to renewed uplift in Mississippian time (Scott, 1978).

Development of a steep break in slope between an eastern shelf and western basin that affected sedimentation and facies patterns during deposition of the Upper Devonian Bedford Shale-Berea Sandstone sequence was related by Pashin and Ettensohn (1987, 1992a, b) to syndepositional movement on a basement fault mapped in northeastern Kentucky by Goble (1972). Pashin and Ettensohn (1987) designated the fault as the Waverly Arch Basement Fault because its trend generally coincides with the position of the Waverly Arch. It may have controlled the location of the arch (Pashin and Ettensohn, 1987; Ettensohn, 1992k, p). The fault also influenced the thickness of the Henley Bed of the Farmers Member of the Borden Formation (Mississippian) (Mason and Lierman, 1992), and controlled the eastern boundary of a fan-shaped body formed by the Farmers Member in northeastern Kentucky (Lierman and others, 1992).

Vertical movement along the Paint Creek Uplift resulted in pronounced thinning of Lower Mississippian rocks across its axis in northeastern Kentucky; recurrent movement along the parallel and proximal Waverly Arch of Woodward (1961) was suggested as a dominant force in Early Mississippian development of the Paint Creek structure (Dohm, 1963). Uplift on the Waverly Arch during deposition of the Lower Mississippian Borden Formation was also suggested as having caused (1) cessation of deeper water sedimentation by diversion of the distributary system, (2) local exposure of the Cowbell Member to erosion, and (3) formation of a platform upon which succeeding shallow-water sediments were deposited (Kearby, 1971).

Deposition of the St. Louis Member of the Slade Formation across northeastern and east-central Kentucky was interrupted by Middle Mississippian uplift along the Waverly Arch, resulting in subaerial exposure of the carbonate sediments (Dever, 1973). The succeeding Ste. Genevieve, Warix Run, and Mill Knob Members in east-central Kentucky (northernmost part of present study area) show progressive easterly overlapping and depositional thinning toward the axis of the arch, indicating that the Waverly Arch remained a positive feature after the uplift.

Topographic highs along the crest of the arch in northeastern Kentucky were sites of high-energy environments during deposition of Carboniferous carbonate and terrigenous-clastic sediments (Horne and Ferm, 1978). In the subsurface of eastern Kentucky, Mississippian carbonate units thin across the axis of the Waverly Arch of Woodward (1961), with shallow-water carbonate lithologies concentrated in the axial area (Pear, 1980; MacQuown and Pear, 1983).

Isopach mapping of Upper Mississippian units in northeastern and east-central Kentucky indicated that the Mississippian axis of the Waverly Arch was 11.7 to 13.3 km west of the Cambrian–Ordovician axis identified by Woodward (1961), with right-lateral offset of the arch along the Kentucky River Fault System (Ettensohn, 1975, 1980) (Fig. 8). The apparent absence of synsedimentary effects suggests a post-Mississippian age for the right-lateral movement (Ettensohn, 1975). Tankard (1986) attributed the offset to reactivation of basement faults during Alleghenian compression, and also concluded that uplift and development of unconformities on the arch during Mississippian time were caused by eastward migration of a peripheral bulge in response to lithospheric relaxation, a process outlined in the following section. Ettensohn (1992p) suggested that uplift and erosion in the region of the arch after Ste. Genevieve deposition may represent flexural response to Ouachita tectonism along the southern margin of the continent.

Following Middle Mississippian uplift, the arch remained a positive and partly emergent feature, influencing the pattern of Late Mississippian depositional environments and the thickness and distribution of units; uplift was renewed in Late Mississippian time and continued intermittently into Pennsylvanian time, resulting in erosional disconformities and influencing the deposition and diagenesis of both Mississippian and Pennsylvanian units in northeastern Kentucky (Ettensohn, 1975, 1977, 1980, 1981, 1992j, k, n, p; Martin, 1975; Short, 1978; Ettensohn and Dever, 1979a–c; Rice, 1984; Tankard, 1986; Ettensohn and Cecil, 1992). The linear Carter Caves Sandstone (Mississippian), for example, was deposited as a tidal-channel sand, paralleling the arch.

Erosion associated with Late Mississippian to Early Pennsylvanian uplift on the Waverly Arch resulted in basal Pennsylvanian deposits of eastern Kentucky resting on older Mississippian units toward the axis of the arch (Englund, 1972; Englund and others, 1981; Englund and Randall, 1981; Ettensohn, 1992k, p). According to Englund (1972), distribution patterns of rock units indicate that the arch extends southwestward across eastern Kentucky into northern Tennessee, approximately paralleling the Cincinnati Arch (Englund and others, 1981, Fig. 6) (Fig. 8).

## Migratory Lithospheric Flexural Features

Recent studies indicate that Paleozoic deposition and structural features in Kentucky were affected by bulges and basins migrating across the region in response to loading and unloading in orogenic belts along the eastern and southern margins of North America. Models for lithospheric flexural response to geologic processes in orogenic belts, including the resultant formation and migrations of a foreland basin and peripheral bulge, have been presented by Quinlan and Beaumont (1984) and Beaumont and others (1988), and summarized by Ettensohn and Chesnut (1989) and Ettensohn (1990, 1991, 1992o, 1993, 1994).

The following outline of the lithospheric flexural models of Quinlan and Beaumont (1984) and Beaumont and others (1988) is adapted from the summaries by Ettensohn and Chesnut (1989) and Ettensohn (1990, 1991, 1993). Deformational loading in an orogen produces a downwarped flexural foreland basin immediately cratonward of the orogen and a peripheral bulge on the cratonward margin of the foreland basin. As orogeny proceeds and the thrust load migrates cratonward, the foreland basin and peripheral bulge migrate away from the load. When orogeny and thrusting cease, lithospheric relaxation causes the peripheral bulge to be uplifted and to migrate back toward the orogen, while the foreland basin narrows and deepens. Erosional unloading in the orogen results in rebound of the orogen, progressive uplift adjacent to the unloaded area, and formation of an "antiperipheral bulge" that deepens and migrates toward the former load.

In response to loading and unloading in the Taconic, Salinic, Acadian, Ouachita, and Alleghenian orogens, lithospheric flexure in Kentucky influenced sedimentation during the Ordovician (Ettensohn, 1991, 1992b, e, g, l, q; Goodmann, 1992; Schumacher, 1992), Silurian (Ettensohn, 1992f, r, 1994; Ettensohn and Pashin, 1992b; Goodmann, 1992; Mason and others, 1992a, b), Devonian (Ettensohn and others, 1988b; Barnett and others, 1989; Barnett and Ettensohn, 1992a, b; Ettensohn, 1992a, c, m, 1994; Goodmann, 1992; Lierman and others, 1992), Mississippian (Tankard, 1986; Ettensohn and others, 1988b; Ettensohn and Chesnut, 1989; Ettensohn, 1990, 1992a, d, p, 1993, 1994; Ettensohn and others, 1992; Lierman and others, 1992), and Pennsylvanian (Tankard, 1986; Ettensohn and Chesnut, 1989; Chesnut, 1991; Chesnut and others, 1992a, b; Goodmann, 1992; Ettensohn, 1994). Flexural response to geologic processes in the orogenic belts also affected structural features in Kentucky during the Paleozoic and caused uplift of the Cincinnati Arch (Quinlan and Beaumont, 1984; Tankard, 1986; Beaumont and others, 1988; Barnett and others, 1989; Chesnut, 1991, 1992; Ettensohn and Pashin, 1992a), uplift of the Waverly Arch (Tankard, 1986; Ettensohn, 1992p), reactivation of faults (Tankard, 1986; Barnett and others, 1989; Ettensohn and Chesnut, 1989; Barnett and Ettensohn, 1992a, b; Ettensohn, 1992c, d, e, l, p, q, 1994; Ettensohn and others, 1992; Ettensohn and Pashin, 1992a, b), and development of unconformities (Quinlan and Beaumont, 1984; Tankard, 1986; Beaumont and others, 1988; Barnett and others, 1989; Ettensohn and Chesnut, 1989; Chesnut, 1991, 1992; Ettensohn, 1991, 1992c, f, p, 1993, 1994; Ettensohn and others, 1992; Goodmann, 1992; Mason and others, 1992a).

In eastern and south-central Kentucky, deposition of Mississippian rocks, the focus of this study, was influenced by lithospheric flexural structures (Ettensohn and Chesnut, 1989; Ettensohn, 1990, 1993). Deformational loading during the last phase of the Acadian Orogeny along the eastern margin of North America was accompanied by deposition of terrigenous-detrital sediments (Borden and Grainger Formations) in a foreland basin cratonward of the orogen. As active loading ceased, lithospheric relaxation caused migration of the peripheral bulge back toward the orogen. Eastward bulge migration toward the Acadian orogen and nearly coeval northward bulge migration from the Ouachita orogen together produced shallow-water environments suitable for carbonate deposition (Muldraugh Member of Borden Formation, Salem and Warsaw Formations, St. Louis Limestone, Monteagle Limestone, Slade Formation, and lower member of Newman Limestone). Erosional unloading and rebound in the eastern orogen resulted in renewed deposition of terrigenous-detrital sediments (upper member of Newman Limestone, Paragon Formation, and Pennington Formation).

## STRATIGRAPHIC AND LITHOLOGIC FRAMEWORK

The St. Louis and Monteagle Limestones and correlative rocks in the Slade Formation, the focus of this study, are part of a major sequence of carbonate rocks that were deposited across a large part of the eastern United States during Mississippian time. In the Appalachian Basin of eastern Kentucky, carbonate deposition occurred between Early and Late Mississippian episodes of terrigenous-detrital sedimentation.

### Pre-St. Louis Units of Mississippian Age

Early Mississippian sedimentation in Kentucky was dominated by the deposition of terrigenous-detrital sediments, principally clays and silts of the Borden Formation and the correlative Grainger Formation of eastern Kentucky. Deep-water prodelta clays of the basal Borden coarsen upward into delta-front silts (Peterson and Kepferle, 1970; Kearby, 1971). These sediments were the distal marine edge of a west-prograding detrital wedge associated with the final stages of the Acadian Orogeny along the eastern margin of North America (Kepferle, 1977; Ettensohn, 1985; Ettensohn and Chesnut, 1989). In the study area, the Borden overlies black, organic-rich shales of the Chattanooga Shale of Devonian and Mississippian age (Ettensohn and Elam, 1985), which accumulated in the anaerobic bottom layer of a restricted inland sea (Ettensohn and Barron, 1983; Ettensohn, 1992a).

The deltaic deposits, as much as 200 m thick in eastern Kentucky, progressively thin southwestward and westward into the central part of the State, where they abruptly thin across the Borden Delta Front, a southwest-facing foreset slope about 2 to 12 km wide (Peterson and Kepferle, 1970). The belt of abrupt thinning trends southeast across central and southeastern Kentucky, passing through southwestern Pulaski County (Lewis and Potter, 1978). Except for a thin accumulation of prodelta clays, commonly less than 10 m thick, starved-basin conditions existed southwest of the front.

Following a sharp decrease in detrital sedimentation, a thin, widespread glauconitic unit, the Floyds Knob Bed, accumulated across the platform formed by the deltaic wedge, on the slope of the delta front, and in the basin (Sedimentation Seminar, 1972; Whitehead, 1984). The hiatus represented by the Floyds Knob Bed marks a change from terrigenous-detrital sedimentation to carbonate deposition in late Early Mississippian time. Development of these shallow-water environments across the region suitable for carbonate deposition was influenced by peripheral bulges migrating east toward the Acadian orogen and north from the Ouachita orogen (Ettensohn and Chesnut, 1989; Ettensohn, 1990, 1992d, 1993).

Deposition of carbonate sediments continued into Late Mississippian time, resulting in the accumulation of as much as 145 m of limestone and dolomite on the platform before the renewal of terrigenous-detrital sedimentation.

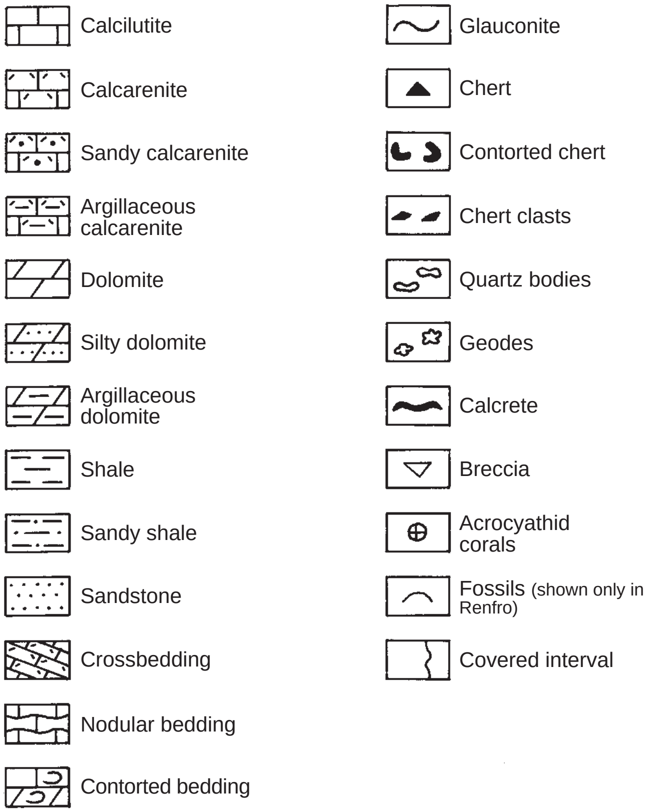
In south-central Kentucky, basal deposits of the carbonate sequence, assigned to the Muldraugh Member of the Borden, mainly consist of dolomite and bioclastic limestone, which have been interpreted to represent, respectively, supratidal-peritidal and subtidal sediments (Klein, 1974; Hannan, 1975; Benson, 1976). Chert occurs in lenses and beds, replacing bioclastic limestone. Small geodes are relatively common.

Muldraugh sediments originating on the Borden platform in part were transported to the platform margin, onto the foreset slope, and into the basin, forming clinoform deposits and building a southwest-prograding carbonate platform (Sedimentation Seminar, 1972; Klein, 1974; Hannan, 1975; Benson, 1976). Progradation of the platform contributed to infilling of the previously sediment-starved basin in south-central Kentucky. The Muldraugh deposits abruptly thicken to the southwest across the Borden Delta Front, from 11 to 18 m on the platform to more than 90 m in the basin southwest of the front, where rocks correlative with the Muldraugh are assigned to the Fort Payne Formation.

The Salem and Warsaw Formations, treated as a single mapping unit by the U.S. Geological Survey (see Lewis and Taylor, 1975), overlie the Muldraugh and Fort Payne in south-central Kentucky. The unit, 12 to 27 m thick, consists of shallow, subtidal, crossbedded, bioclastic calcarenite; peritidal, argillaceous dolomite; subtidal, fossiliferous shale; and intertidal-subtidal, quartzose sandstone (Benson, 1976). It contains geodes, from 5 to 60 cm in diameter, and chert. The sandstone is the Science Hill Sandstone Member, a shallow-marine deltaic deposit derived from an eastern source area (Lewis and Taylor, 1975, 1979). The Science Hill contains distinctive quartz granules and pebbles, and reaches a thickness of more than 13 m in the outcrop of northern Pulaski County and eastern Casey County.

The Muldraugh and Salem-Warsaw thin northeastward, and in east-central Kentucky correlative rocks, composed principally of dolomite, are included in the basal part of the

Renfro Member of the Slade Formation (Figs. 9–10) (Dever and others, 1979b; Dever and Moody, 1979a; Lewis and Taylor, 1979; Ettensohn and others, 1984b). In central Rockcastle County, Muldraugh and Salem-Warsaw correlatives consist of 8.2 to 9.4 m of dolomite, shale, sandstone, and bioclastic calcarenite, with chert and geodes (section 74—Renfro Valley South; section 75—Lake Linville). Cherty and geodiferous dolomite, 1.5 to 5 m thick, is present in the basal Renfro at least as far north as southeastern Madison County (section 83—Bighill), northwestern Jackson County (section 87—Owsley Fork), and western Estill County (Stockdale, 1939; Moser, 1960; Greene, 1968).



SECTION IDENTIFICATION

| | |
|---|---|
| BH | 83—Bighill |
| BI | 20—Burnside |
| BQ | 110—Bowen Quarry |
| LL | 75—Lake Linville |
| MP | 113—Mountain Parkway |
| RVS | 74—Renfro Valley South |
| SCC | 93—Station Camp Creek |
| SS | 37—Somerset Stone Quarry |
| TB | 73—Town Branch |
| TR | 100—Tipton Ridge |
| WB | 25—Waitsboro |

Figure 9. Symbol explanation and section identification for Figures 10, 18, and 34.

## St. Louis Limestone and Correlative Rocks of the Slade Formation

The St. Louis Limestone of south-central Kentucky is divided into two members; they are, in ascending order, the Bronston member and Burnside member (Dever and Moody, in preparation). The Bronston is composed of dolomite and limestone; the Burnside is mainly limestone (Fig. 10). The St. Louis and correlative rocks in the Slade Formation of east-central Kentucky generally thin northeastward across the study area (Fig. 11).

During the U.S. Geological Survey-Kentucky Geological Survey cooperative mapping program (1960–78), carbonate rocks in east-central Kentucky that are correlative with the St. Louis Limestone of south-central Kentucky were assigned in part to the Renfro Member of the Borden Formation and in part to the St. Louis Limestone Member of the Newman Limestone (Fig. 2) (Hatch, 1964; Cohee and West, 1965; Weir and others, 1966; Dever and others, 1979b; Dever and Moody, 1979a). This division of St. Louis-correlative rocks was retained in the Slade Formation, which was established in east-central and northeastern Kentucky by Ettensohn and others (1984b) (Fig. 2). They assigned Bronston-correlative dolomite and limestone to the Renfro Member of the Slade and Burnside-correlative limestone was designated as the St. Louis Member of the Slade.

To facilitate the discussion of this study, rocks of the St. Louis Member of the Slade in east-central Kentucky are herein informally redesignated as the Burnside member of the Slade Formation (Fig. 2). This may prevent any confusion that might arise from using "St. Louis" both for a formation in south-central Kentucky and for a restricted interval of rocks in east-central Kentucky that is correlative with only part of the formation. The nomenclature for the dolomite-dominated Renfro Member is retained because in parts of east-central Kentucky, Bronston-correlative dolomites are not readily distinguished from dolomitic correlatives of the Muldraugh and Salem-Warsaw occurring in the basal Renfro.

***Bronston Member.*** The Bronston member of the St. Louis and correlative rocks in the Renfro Member of the Slade thin northeastward across the study area, from a thickness of 21 to 23 m in southern and western Pulaski County to a thickness of 6.0 to 10.5 m in Powell County (Fig. 10). The unit is mainly composed of very finely crystalline dolomite, commonly in alternating intervals of burrowed (mainly subhorizontal burrows) and finely laminated dolomite. The dolomite is silty, slightly argillaceous, generally unfossiliferous, partly brecciated, and thick to thin bedded (Fig. 12). In fresh exposures, it is very light gray to olive gray and greenish gray, but weathers to yellowish-gray, yellowish- to grayish-orange, and yellowish-brown colors. Intervals of sandy dolomite and calcarenite, up to 2.7 m thick, occur in the lower to middle Renfro in parts of Estill, Jackson, and Lee Counties (Eyl, 1927; Eyl and Hudnall, 1927).

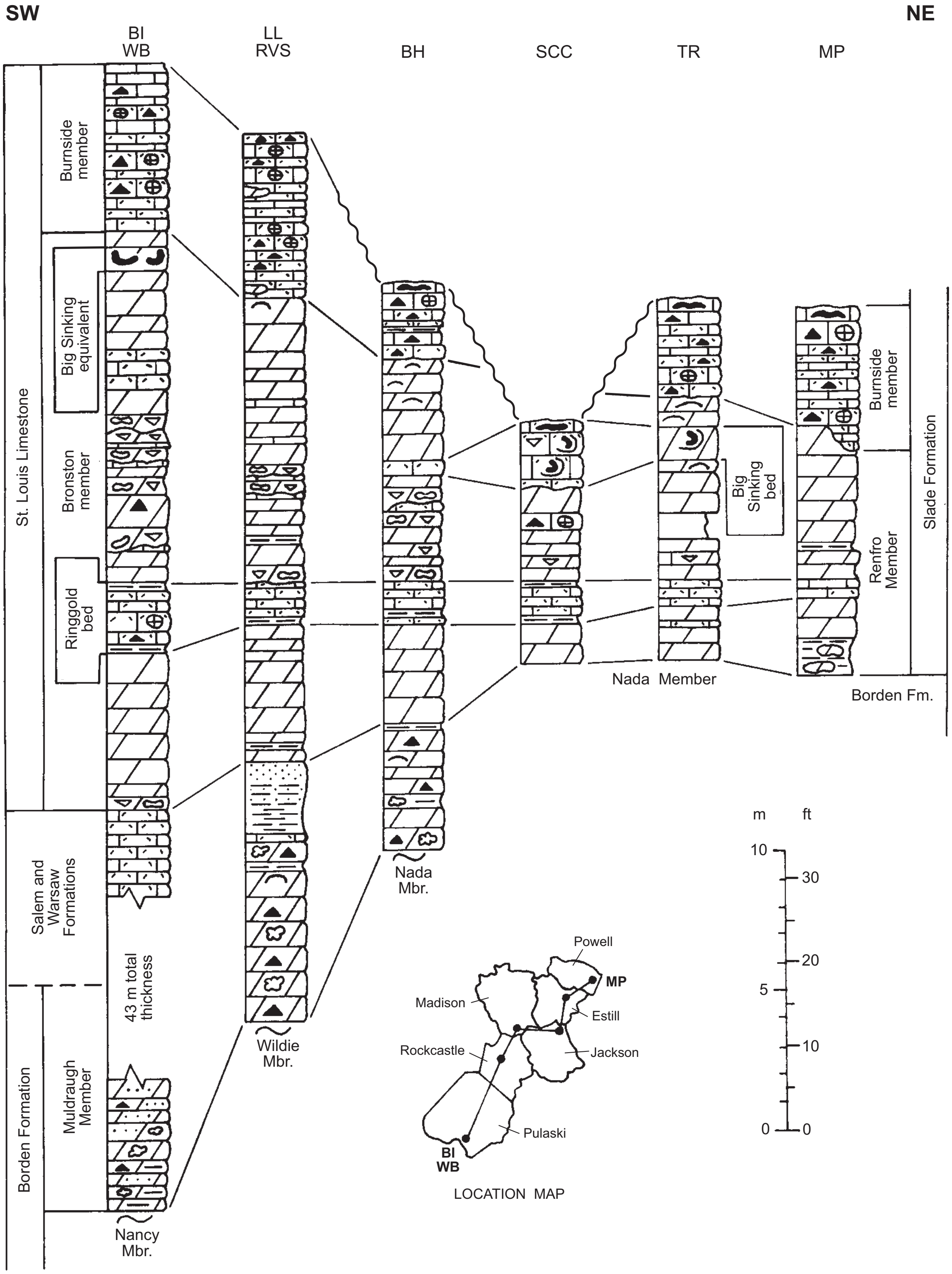


Figure 10. Southwest–northeast cross section showing principal lithologies of St. Louis Limestone, Salem and Warsaw Formations, and Muldraugh Member of Borden Formation in south-central Kentucky and of correlative rocks in Renfro and Burnside members of Slade Formation in east-central Kentucky. Glauconite symbol below Muldraugh and Renfro Members represents Floyds Knob Bed. See Figure 9 for symbol explanation and section identification. Datum is top of Ringgold bed.

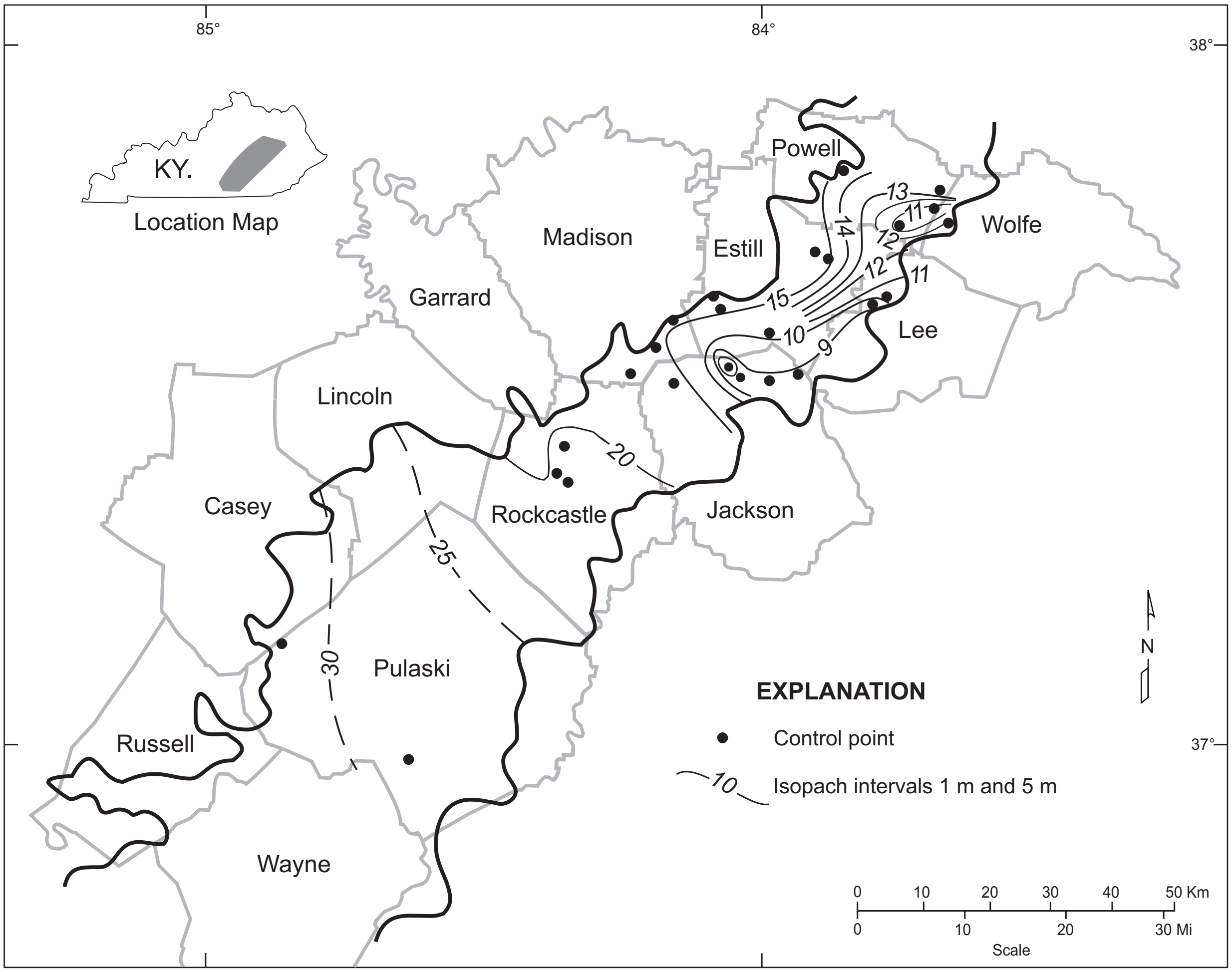


Figure 11. Thickness of St. Louis Limestone and correlative rocks of Slade Formation in study area.

As many as six limestone units, from 5 cm to 4 m thick, are present in the Bronston and correlative rocks of the Renfro (Fig. 10). Most of the limestones apparently were relatively widespread, but dolomitization and dissolution have obscured their original thickness and areal extent in parts of the area.

The Ringgold bed (Dever and Moody, in preparation) in the lower Bronston is the most widespread limestone unit, extending across the entire study area (Fig. 10). In south-central Kentucky, where it is as much as 2.7 m thick, the Ringgold is composed of medium-olive-gray to dark-olive-gray, very fine- to very coarse-grained, bioclastic calcarenite, with nodules and discontinuous stringers of chert. The unit is very thin to thick bedded, with interbedded greenish-gray shale and argillaceous partings. Fossils are abundant in the Ringgold of Pulaski and Rockcastle Counties, and include brachiopods, bryozoans, echinoids, solitary corals, colonial corals (*Acrocyathus proliferus* and *Syringopora*), gastropods, blastoids, and pelecypods. Horizontal burrows commonly cover bedding planes. The top limestone bed in western and southern Pulaski County contains abundant algal oncolites. In the northern part of the study area, where the Ringgold is up to 1.2 m thick, the limestone is lighter in color and varies from calcilutite with scattered bioclastic grains to bioclastic calcarenite. It is highly burrowed, sparsely fossiliferous, and very thin to medium bedded, with interbedded shale and argillaceous partings.

Three thin limestones, 5 cm to 0.5 m thick, composed of dark-yellowish-brown and light-olive-gray to olive-gray, sparsely fossiliferous calcilutite and bioclastic calcarenite, are present near the middle of the Bronston and in the correlative interval of the Renfro. The limestone beds commonly are scalloped and thinned by solution, resulting in local removal of the limestone units (Fig. 10). Each limestone is overlain by an interval of brecciated dolomite, from 2 cm to 0.9 m thick, composed of dolomite clasts in a very finely crystalline, dolomitic matrix, with irregular and nodular bodies of quartz in the lower part of the brecciated intervals (Fig. 12). The quartz bodies contain celestite, anhydrite laths, and rare gypsum ghosts. One to two additional intervals of dolomite breccia and quartz bodies, but without evidence of an underlying limestone, are present in this part of the Bronston and Renfro. Brecciated dolomite with quartz bod-

Figure 12. Dolomite in Bronston member of St. Louis Limestone (from Sable and Dever, 1990). Christopher Dever points to zone of nodular quartz associated with dissolution and replacements of evaporites. Section 20—Burnside Island, Pulaski County.

ies occurs in the Renfro as far to the northeast as Estill County (section 95—Drip Rock).

The breccias and quartz are considered to have formed during dissolution and replacement of evaporites (Dever and others, 1978). These vanished evaporites would be correlative with subsurface deposits of gypsum and anhydrite in the St. Louis of west-central and western Kentucky, southwestern Indiana, and south-central Illinois (McGregor, 1954; Saxby and Lamar, 1957; McGrain and Helton, 1964). Limestones underlying the breccias may correspond to the limestones in cyclic evaporite deposits of the St. Louis in southwestern Indiana, described by Jorgensen and Carr (1973).

One to two limestones are present in the upper 2 to 6 m of the Bronston and Renfro, from Pulaski County northeastward into Estill and Lee Counties. The limestones, 5 cm to 4 m thick, are composed of light-olive-gray to olive-gray and light-gray calcilutite and bioclastic calcarenite (in part containing micrite-enveloped bioclastic grains and sparse ooids), locally with nodules and thin beds of chert. In contrast to the underlying limestones associated with the dolomite breccias, which are only sparsely fossiliferous, the upper limestones commonly are fossiliferous, containing crinoid plates, brachiopods, bryozoans, and colonies of *Syringopora* and *Acrocyathus proliferus*.

***The Big Sinking Bed.*** The Big Sinking bed (Dever and Moody, in preparation) is a distinct limestone unit, as much as 3 m thick, that is present at or near the top of the Renfro Member of the Slade in parts of east-central Kentucky (Figs. 10 and 13). A Big Sinking equivalent, up to 1.8 m thick, also occurs at or near the top of the Bronston member of the St. Louis in parts of south-central Kentucky. Big Sinking limestone is mainly composed of well-sorted, finely laminated, very fine-grained, bioclastic, pelletal calcarenite. These characteristics distinguish it from the relatively poorly sorted, coarser grained, bioclastic calcarenite in the lower part of the overlying Burnside.

In more detail, the Big Sinking and its equivalent principally consist of very light-olive-gray to light-olive-gray, very fine-grained, bioclastic, pelletal calcarenite, with calcilutite occurring locally in the basal part of the unit. The calcarenite, commonly finely laminated, is mainly composed of micritic pellets (slightly elongate to round) with bioclasts, including fragmented and whole ostracodes and calcareous sponge spicules. Carbonate particles mainly range from coarse silt to very fine and fine sand. The unit contains detrital quartz silt and very fine- to fine-grained quartz sand. It is sparsely fossiliferous (brachiopods, bryozoans, gastropods, and crinoid plates), but orthotetid and productoid brachiopods are locally abundant. Light-brown to reddish-brown and light-gray to light-olive-gray chert occurs in discontinuous stringers (in part with relict laminae), irregular bodies, nodules, and, locally, in beds as much as 0.4 m thick. Discrete, elongate bodies of dolomite, up to 0.5 m thick, are present locally (section 57—Mount Pleasant Church). The limestone is thin to thick bedded, with very thin to thin interbeds of greenish-gray shale, mainly in the lower part.

Contorted bedding is a prominent feature of the Big Sinking bed in the northeastern part of the study area (parts of

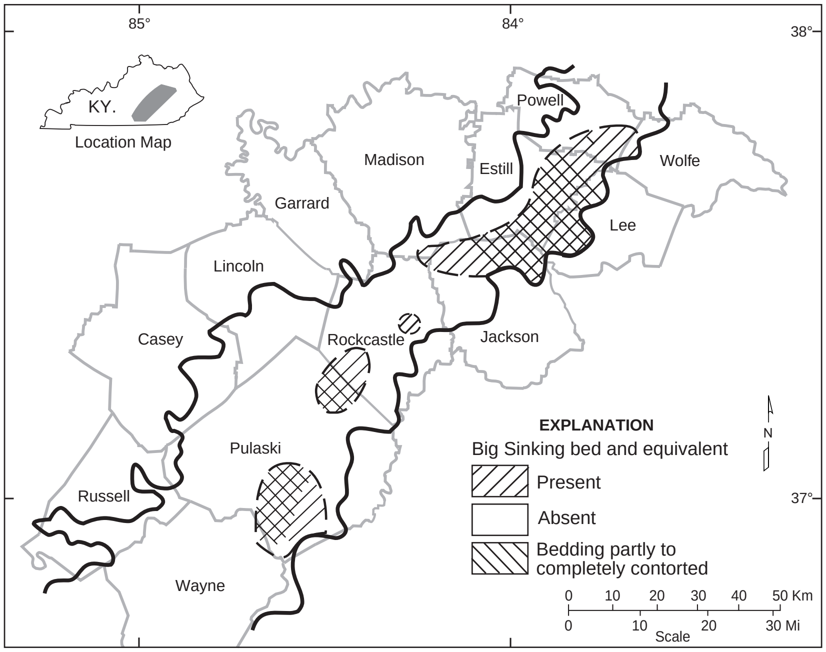


Figure 13. Areal distribution of Big Sinking bed of Slade Formation in east-central Kentucky, its equivalent in St. Louis Limestone of south-central Kentucky, and occurrence of contorted bedding.

Jackson, Estill, Lee, and Powell counties) and in equivalent rocks to the south in Pulaski County (Figs. 13–15). The contorted bedding had been noted by previous workers in the northeastern counties, who mainly identified the rocks as St. Louis limestone (Butts, 1922; McFarlan and Walker, 1956; Rice, 1972; Haney, 1976; Black, 1977, 1978; Haney and Rice, 1978). Curvilinear patterns of deformed laminae and chert stringers outline bodies of rolled-up sediment. Original laminae in the calcarenite and chert, though highly contorted, commonly are preserved, an indication of deformation by plastic flow during subaqueous movement (Dott, 1963). Bedding in the Big Sinking ranges from totally deformed to wholly planar, but more commonly it is only partly deformed, the interval of contorted bedding being either underlain by, overlain by, or within undeformed planar-bedded Big Sinking limestone.

Partial to complete dolomitization of Big Sinking limestone is common. At several localities, relict chert stringers and curvilinear structures in the dolomite are the only evidence for the presence of the unit (Fig. 10). The ap-

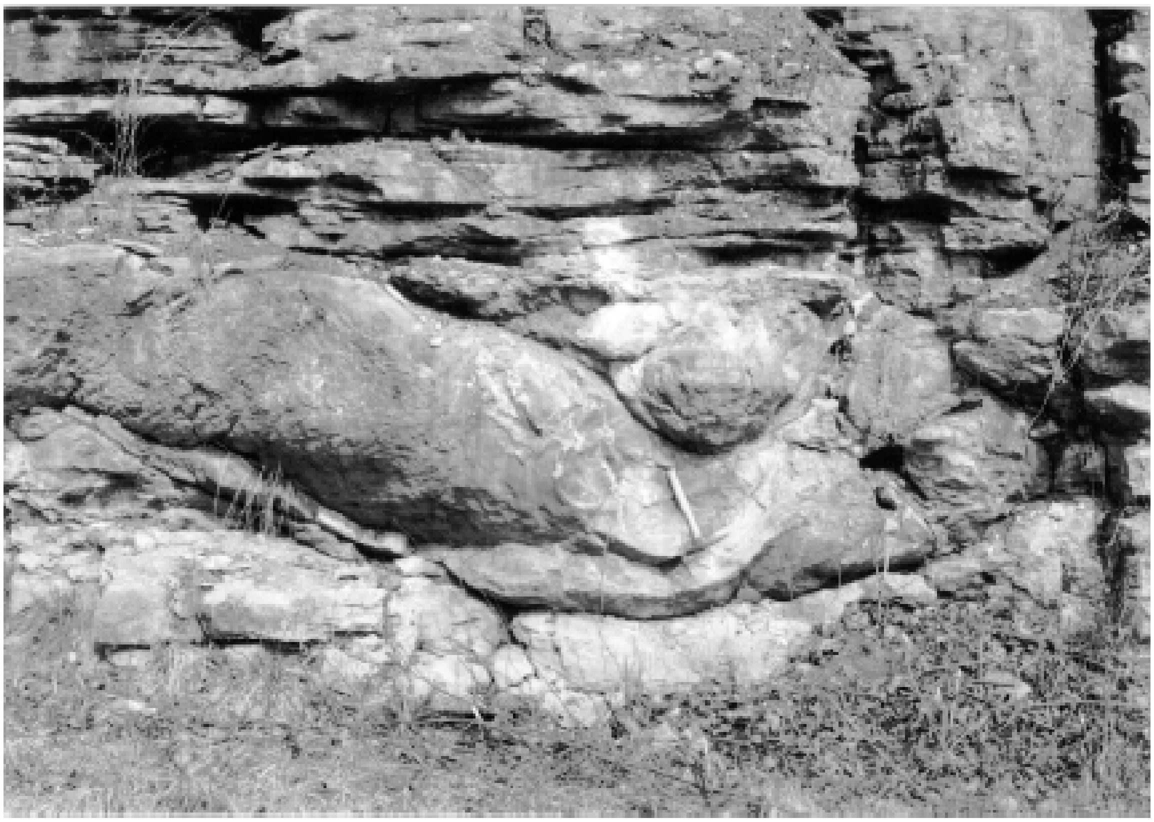


Figure 14. Contorted bedding in Big Sinking bed, section 92—Pond School, Jackson County.

Figure 15. Contorted-bedded limestone of Big Sinking bed overlying dolomite of Renfro Member, viewed from base of vertical outcrop. Section 104—Hatton Hollow, Lee County.

parent absence of the Big Sinking in parts of the study area may be the result of masking by dolomitization.

The contact between the Big Sinking bed and overlying limestone or dolomite commonly is sharp. Locally in Powell, Pulaski, and Rockcastle Counties, Big Sinking and Burnside limestones intertongue through intervals less than 1 m thick. The Burnside is absent in parts of Estill, Jackson, and Lee Counties, and Ste. Genevieve calcarenite rests on the Big Sinking bed (Fig. 16). In the area where the Burnside is absent, pedogenic features (micritic calcrete, brecciated limestone, and melanization, or darkening, of the limestone) occur at the top of the Big Sinking bed (Fig. 10). These features in other units of the Slade Formation have been interpreted to represent the C horizon of an erosionally truncated caliche paleosol (Ettensohn and others, 1984a, 1988a).

***Burnside Member.*** The Burnside member of the St. Louis and Slade formations, 0.7 to 9.0 m thick, consists of cherty, fossiliferous limestones. The lower part is composed of very light-olive-gray to medium-olive-gray, very

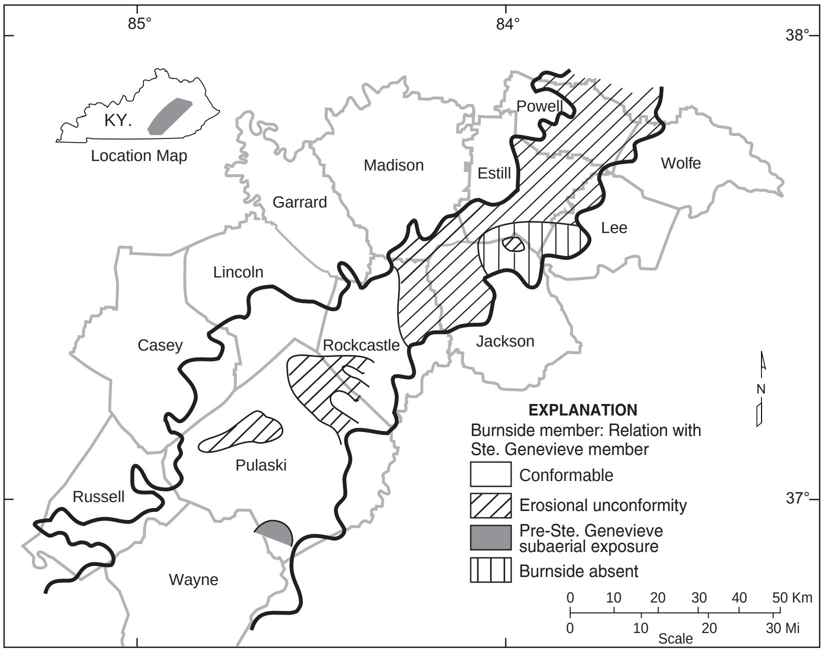


Figure 16. Distribution of Burnside member and its relationship with Ste. Genevieve member.

fine- to very coarse-grained, bioclastic calcarenite, locally with interbeds and lenses of calcilutite. The upper part mainly consists of light-olive-gray to dark-olive-gray and dark-brownish-gray to dusky-yellowish-brown calcilutite and calcisiltite, with interbeds and lenses of bioclastic calcarenite. Burnside limestones are thin to thick bedded, with very thin to thin interbeds of greenish-gray shale, more commonly in the lower part. Discrete bodies of very finely crystalline dolomite, up to 1.5 m thick, occur locally in the member.

In the northern part of the study area, a distinctive subunit, 0.4 to 1.8 m thick, consisting of interbedded calcarenite, calcilutite, and greenish-gray argillaceous limestone, occurs near the middle of the Burnside. Limestone in the subunit is thin to medium bedded, with interbedded shale.

Broken and whole fossils are abundant in the Burnside and include corals, brachiopods, bryozoans, crinoids, echinoids, and gastropods. Colonies of acrocyathid and syringoporid corals (*Acrocyathus proliferus, A. floriformis,* and *Syringopora* sp.), partly in growth position, are the most prominent fossils. The corals occur concentrated in zones and as scattered, isolated colonies, both in the lower calcarenite and upper calcilutite. In earlier geologic reports, *A. proliferus* and *A. floriformis* commonly were identified, respectively, as *"Lithostrotion" proliferum* and *Lithostrotionella castelnaui* (see Sando, 1983).

Chert in the form of nodules, irregular bodies, and discontinuous beds and stringers is common to abundant, occurring both scattered through the member and concentrated in intervals as much as 1 m thick. In the southern part of the study area, the chert is mainly dark colored (dark gray to grayish black and olive gray to olive black), but in the northern part of the area, it commonly is red, brown, light-colored, and green (moderate red, pale reddish brown to dark reddish brown, moderate reddish brown, light brown to moderate brown, very light gray to yellowish gray, and dark greenish gray). A limestone containing abundant nodules and irregular bodies of chert at the top of the Burnside on weathering yields a bedded chert, up to 0.3 m thick, in parts of Pulaski and Rockcastle Counties.

The lithologic contact between the Burnside and the overlying Ste. Genevieve member of the Monteagle and Slade formations is sharp, but apparently conformable in much of the southern part of the study area (Fig. 16). Planar-bedded, cherty, micrograined to very fine-grained limestone of the Burnside is overlain by cross-laminated, very fine- to coarse-grained calcarenite of the basal Ste. Genevieve (Fig. 17). Exposure and erosion of the Burnside, however, occurred locally in Pulaski County prior to Ste. Genevieve deposition. Remnants of a caliche paleosol cap the Burnside in part of southern Pulaski County (Fig. 16). Small-scale erosion in southern and eastern parts of the county resulted in 0.8 to 1.2 m of erosional relief on the top of the member, but no pedogenic features have been recognized at these sites (section 19—Burnside South, section 46—Pulaski Quarry).

The thickness of the Burnside, where conformable with the Ste. Genevieve, averages about 6 m, commonly ranging from 5.9 to 7.0 m. The member thickens to 9 m in western Pulaski County. An episode of intra-Ste. Genevieve erosion, described in a following section on the Ste. Genevieve member, cut down through the lower Ste. Genevieve into the upper Burnside in parts of Pulaski and Rockcastle Counties (Fig. 16). The eroded Burnside ranges from 4.0 to 5.6 m in thickness.

Northeast of central Rockcastle County, remnants of a caliche paleosol, described by Ettensohn and others (1984a, 1988a), cap the Burnside throughout its outcrop belt across the northern part of the study area and also northeast of the study area, throughout the Burnside outcrop belt across northern east-central and northeastern Kentucky (Fig. 10). Subaerial exposure of Burnside carbonate sediments in this region has been attributed to Mississippian uplift along the

Figure 17. Contact (at base of hammer) between planar-bedded, cherty, micrograined to very fine-grained limestone of St. Louis Limestone and overlying cross-laminated, very fine- to coarse-grained calcarenite of Ste. Genevieve member of Monteagle Limestone. Section 39—Sugar Hill, Pulaski County.

Waverly Arch (Dever, 1973). The Burnside in the northern part of the study area ranges from 0.7 to 5.2 m in thickness, and is unconformably overlain by the Ste. Genevieve Member and, locally, by the Warix Run Member of the Slade (section 87—Owsley Fork). Thinning of the Burnside member across this part of the study area resulted from subaerial erosion. Dolomitization of basal limestones in the member locally has resulted in thinner sections of limestone (Moody, 1982; Dever, 1986). Local fossiliferous dolomite in the uppermost Renfro apparently represents dolomitized Burnside limestone (Fig. 10). The Burnside, as noted in the previous Big Sinking section, is absent in parts of Estill, Jackson, and Lee Counties (Fig. 16).

### Monteagle Limestone and Correlative Rocks of the Slade Formation

The Monteagle Limestone of south-central Kentucky, 44 to 76 m thick in Pulaski County, consists of, in ascending order, the Ste. Genevieve Limestone Member and the Kidder Limestone Member (Lewis, 1971) (Fig. 2). The Ste. Genevieve and Kidder are composed of bioclastic and oolitic calcarenite, and calcilutite, with lesser amounts of dolomite and shale.

In south-central Kentucky, the study interval includes all of the Ste. Genevieve Limestone Member, but only part of the Kidder Limestone Member of the Monteagle Limestone. Correlative rocks of the study interval in east-central Kentucky are assigned, in ascending order, to the Ste. Genevieve Member, Warix Run Member, Mill Knob Member, and Cave Branch Bed of the Slade Formation. To facilitate discussion, Monteagle rocks included in the study interval herein are informally designated as the Ste. Genevieve member, Warix Run member, Mill Knob member, and Cave Branch bed of the Monteagle Limestone (Fig. 2).

Caliche paleosols are common features in the carbonate-dominated Ste. Genevieve, Warix Run, and Mill Knob members of the Monteagle and Slade, occurring at multiple positions in each member (Fig. 18). Several are widespread; others have very limited areal extent. Most of the paleosols have been truncated and commonly only the C horizon is preserved (Ettensohn and others, 1988a). Pedogenic features include (1) melanization of the limestone, (2) laminar micritic calcrete, in part silicified, and (3) brecciated calcilutite, in part dolomitized. Subaerial exposure of the carbonate sediments resulted from several causes: (1) tectonic uplift, (2) shoaling of calcareous sand bodies, (3) progradation of supratidal deposits, and (4) eustasy (Ettensohn and others, 1988a, 1992).

***Ste. Genevieve Member.*** The Ste. Genevieve member of the Monteagle and Slade ranges from 0.3 to 23.9 m in thickness. It generally thins northeastward across the study area, from an average thickness of 14.6 m in Pulaski County to an average thickness of 3.0 m in Powell and Wolfe Counties (Fig. 19). The member is less than 1 m thick across parts of Estill and Lee Counties, and is absent locally in northwestern Jackson County (section 87—Owsley Fork).

Initial Ste. Genevieve deposition in south-central Kentucky produced a widespread, relatively uniform sequence of carbonate sediments, as much as 8.2 m thick, which currently extends along the outcrop belt from Clinton County northeastward into Rockcastle County. Principal lithologies of the sequence, in ascending order, are (1) cross-laminated bioclastic calcarenite, (2) calcilutite (locally absent), (3) bioclastic calcarenite with numerous fossils, and (4) calcarenite and calcilutite containing thin beds of chert. The thickness of individual subunits is varied.

The basal cross-laminated calcarenite, up to 3.6 m thick, is light olive gray, very fine to coarse grained, bioclastic (commonly with micrite-enveloped grains), and sparsely oolitic, with very thin chert stringers in the lower meter. Alternating concentrations of very fine to fine grains and medium to coarse grains form the laminae (Fig. 17). The second subunit, as much as 1.9 m thick, but absent locally, is composed of light-olive-gray to medium-olive-gray calcilutite containing varied amounts of very fine to coarse bioclastic grains. The third subunit, up to 2 m thick, consists of light-olive-gray to medium-olive-gray, very fine- to very coarse-grained, bioclastic calcarenite (in part with micrite-enveloped grains), which contains abundant broken and fewer whole fossils, including brachiopods, crinoids, bryozoans, echinoids, solitary corals, gastropods, and colonial corals (*Syringopora* sp.). Silicified brachiopods and irregular bodies of dark-colored chert are common.

The upper subunit, as much as 2.6 m thick, is composed of light-olive-gray to medium-light-olive-gray, very fine- to medium-grained, bioclastic calcarenite and calcilutite, which commonly are unfossiliferous. Rare fossils include echinoids, crinoids, brachiopods, and bryozoans. The limestone contains numerous beds of chert, ranging from 2.5 to 30.5 cm in thickness. The chert is light olive gray to light gray, with medium-gray to dark-gray mottling. Upon weathering, the subunit yields a bedded chert, up to 1.5 m thick, which McGrain (1969) identified as the equivalent of the Lost River Chert of west-central Kentucky and southern Indiana. The Indiana rock-unit name, Lost River Chert Bed (Shaver and others, 1986), is herein adopted for the chert-bearing limestone unit in Kentucky (Dever, 1990).

The lower three subunits in the basal sequence are abnormally thin in part of south-central Pulaski County (Fig. 20). There they have a total thickness of 0.7 to 2.0 m where they are overlain by the Lost River Chert Bed (section 24—Hound Hollow, section 29—Rush Branch Church, section 30—Alcalde). Elsewhere in Pulaski County, both to the north and south, total thickness of the three subunits, where overlain by the Lost River, is 3.9 to 4.1 m.

The basal lithologic sequence of the Ste. Genevieve is conformable with overlying deposits of the member in the

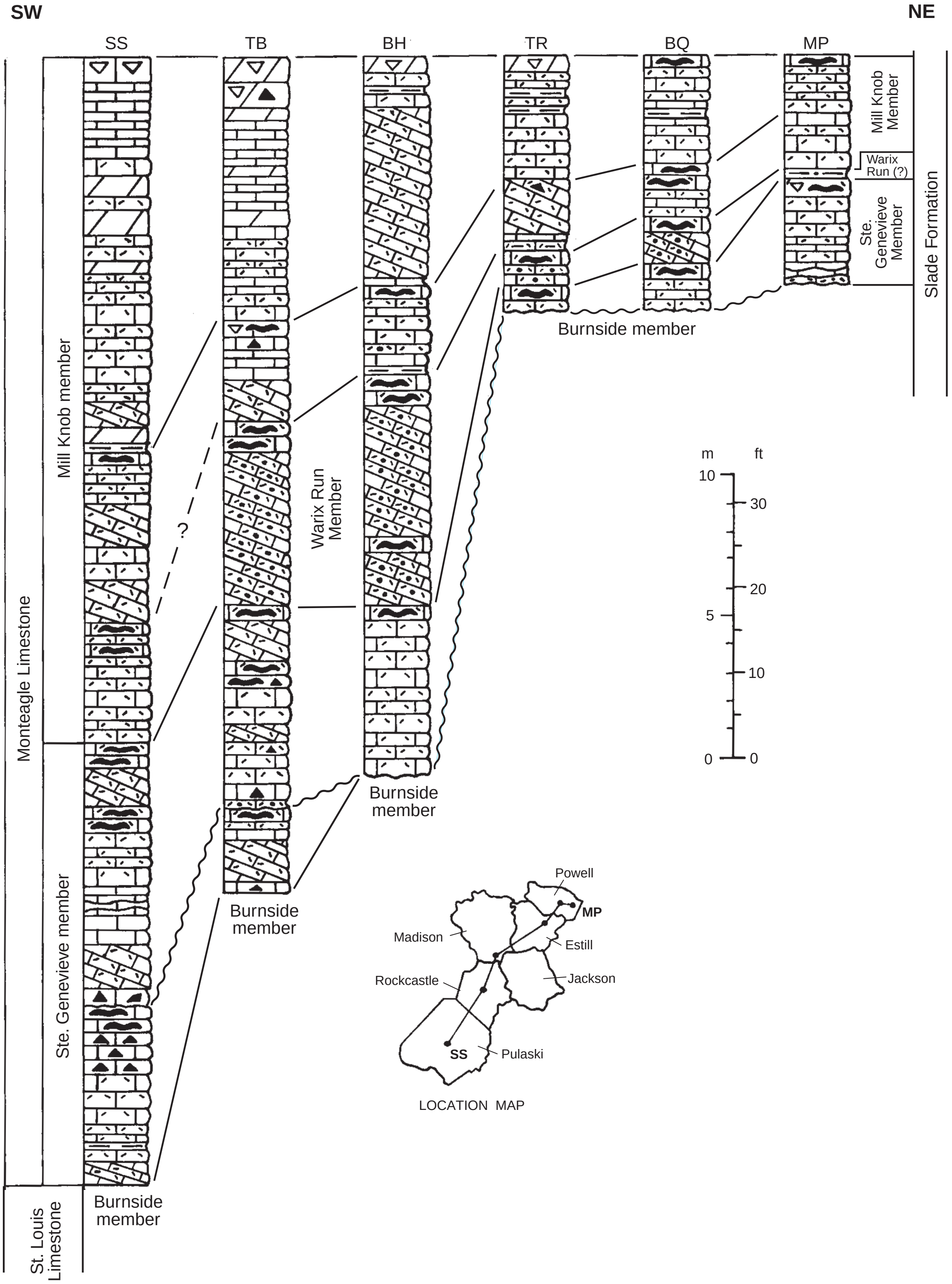


Figure 18. Southwest–northeast cross section showing principal lithologies of Ste. Genevieve, Warix Run, and Mill Knob members of Monteagle Limestone and Slade Formation. In lower Ste. Genevieve at section SS, interval of cherty calcilutite, capped by calcrete, represents Lost River Chert Bed. See Figure 9 for symbol explanation and section identification. Datum is top of Mill Knob member.

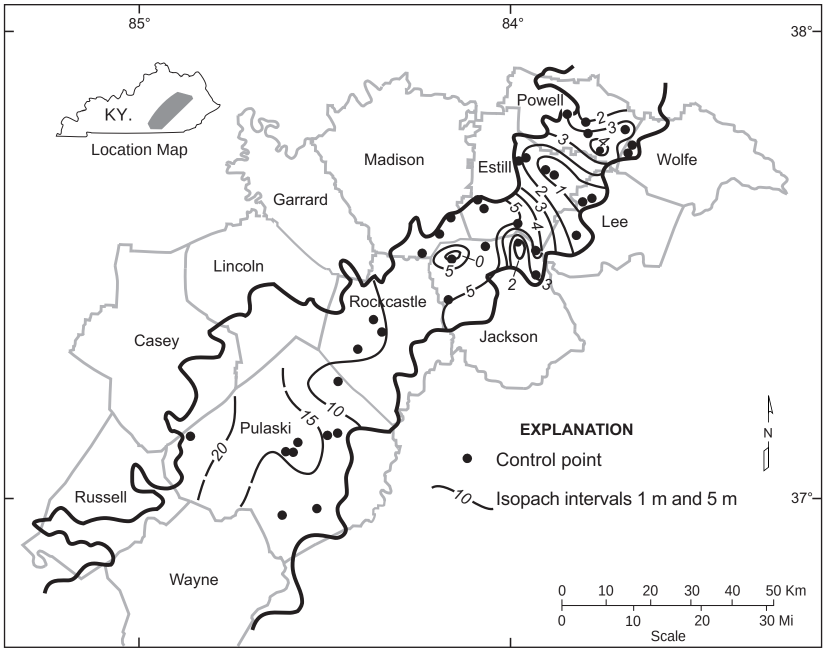


Figure 19. Thickness of Ste. Genevieve member of Monteagle Limestone and Slade Formation in study area.

westernmost part of the study area (parts of Pulaski and Casey Counties) and in the outcrop belt to the southwest (Clinton County and parts of Wayne County) (Fig. 20). Across the study area to the east and northeast, sedimentation was interrupted after deposition of the Lost River Chert Bed, resulting in (1) exposure of the Lost River bed, (2) extensive erosion of the basal Ste. Genevieve deposits and upper part of the underlying Burnside member of the St. Louis, and (3) development of a caliche soil on the erosional surface (Figs. 18, 20–21).

A conglomerate, 2.5 cm to 3.4 m thick, rests on the erosional surface in the lower Ste. Genevieve and upper Burnside of Pulaski, Rockcastle, Casey, and Lincoln Counties, and northeastern Wayne County, as noted by Butts (1922), McFarlan and Walker (1956), Lewis (1971), Malott and McGrain (1977), and Lewis and Potter (1978), and on U.S. Geological Survey geologic quadrangle maps covering the area. The conglomerate consists of abundant angular to subrounded chert clasts and a lesser amount of subangular to subrounded limestone clasts (principally calcilutite) in a calcarenitic matrix composed of very fine to coarse, bioclastic (commonly micrite-enveloped grains) and oolitic grains. Clasts also include fossils (bryozoans, brachiopods, and acrocyathid corallites) and calcrete. Locally, the matrix is argillaceous and dolomitic.

Chert and limestone clasts in the conglomerate are partly sorted by size, and commonly are concentrated into subhorizontal layers and laminae. The unit contains varied amounts of detrital quartz sand. Locally, thin, discontinuous stringers and small patches of pedogenic micritic calcrete are present in the conglomerate.

Succeeding Ste. Genevieve sediments, deposited after the intraformational episode of erosion, principally consist of calcarenite, with lesser amounts of calcilutite (Fig. 18). The calcarenite is light olive gray, very fine to very coarse grained, bioclastic (commonly micrite-enveloped grains), oolitic, peloidal, sparsely fossiliferous (crinoids, brachiopods, bryozoans, blastoids, gastropods, and solitary and colonial corals), commonly crossbedded, and partly cross-laminated. Bodies of fine- to very coarse-grained, crinoidal calcarenite, up to 0.6 m thick, occur locally in the member.

Insoluble residues from post-Lost River limestones, principally calcarenites, at two sites in Pulaski and Rockcastle Counties were studied by Ford (1956) (section 36—Colyer Quarry, section 72—Mount Vernon Quarry).

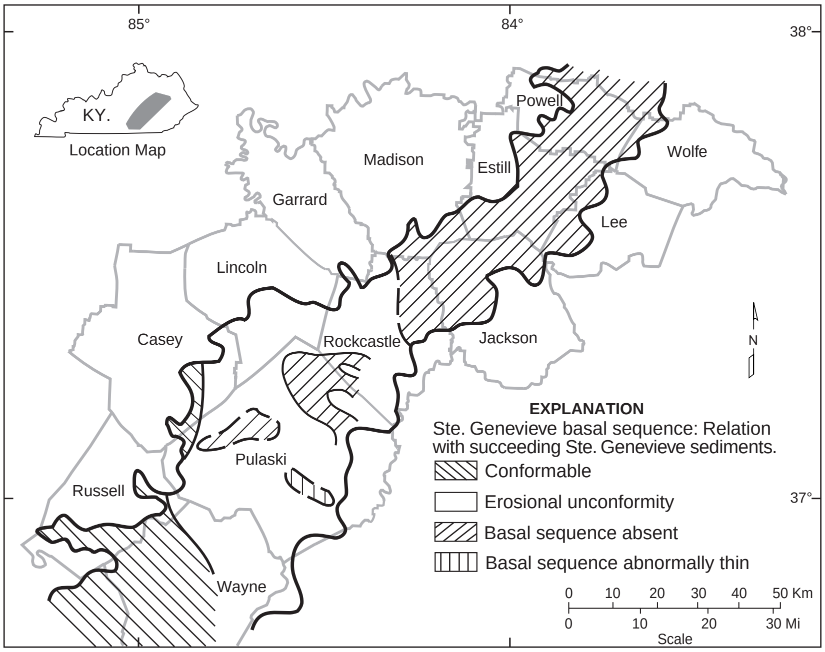


Figure 20. Areal distribution of basal lithologic sequence in Ste. Genevieve member of Monteagle Limestone and Slade Formation, and its relationship with succeeding Ste. Genevieve sediments deposited after an intraformational episode of erosion.

Figure 21. Pedogenic breccia (limestone and chert) in upper part of Lost River Chert Bed in Ste. Genevieve member of Monteagle Limestone. Subhorizontal stringer of micritic calcrete is at pickhead of hammer. Section 37—Somerset Stone Co. Quarry, Pulaski County.

Ste. Genevieve residues included (1) varied amounts of very fine to fine, subangular to subrounded quartz grains, (2) few coarser, frosted quartz grains, (3) few very fine, well-rounded zircon grains, (4) very sparse amounts of very fine-grained tourmaline and silt-size rutile, both well-rounded, and (5) rare very fine to fine, subangular to subrounded feldspar grains.

Intervals of planar-bedded, light-olive-gray to medium-olive-gray calcilutite, as much as 1.2 m thick, are interlayered with the bioclastic and oolitic calcarenite. The calcilutite contains varied amounts of very fine to coarse bioclastic grains. Birdseye calcilutite is rare, but, where present, commonly grades upward into brecciated calcilutite.

In Pulaski, Rockcastle, and Casey Counties, a widespread calcilutite facies, 0.3 to 8.0 m thick, distinguished by its thin to medium, wavy and irregular bedding, occurs at or near the base of the sedimentary sequence overlying the erosional surface that was cut into the lower Ste. Genevieve and upper Burnside. The facies contains scattered brachiopods and bryozoans. Bodies of light-gray to very light-olive-gray, very finely crystalline dolomite occur in the lower part of the wavy-bedded calcilutite in northeastern Pulaski County and southwestern Rockcastle County (section 57—Mount Pleasant Church, section 64—Friendship South). The dolomite bodies, up to 1.6 m thick, have an irregular domal shape with a flat base. Contacts with the enclosing limestone range from sharp to apparently gradational.

Dolomite is only sparsely present elsewhere in the Ste. Genevieve. Light-gray to very light-olive-gray, very finely crystalline to microcrystalline dolomite, in part with relict bioclastic grains, mainly occurs in beds 0.2 to 0.9 m thick. A massive bed, up to 3.5 m thick, with scattered brachiopods in the lower part, occurs near the middle of the member in western Pulaski County (section 13—Siever Knob, section 14—Green River Knob).

Two widespread paleosols are present in the uppermost Ste. Genevieve of Pulaski and Rockcastle Counties (Fig. 18). The upper one caps the member. The thickness of the interval between the tops of the two paleosols commonly ranges from 1.2 to 3.3 m in Pulaski County and from 1.2 to 1.9 m in Rockcastle County. These paleosols may be correlative with two paleosols in the uppermost Ste. Genevieve of west-central Kentucky on the west side of the Cincinnati Arch (Dever and others, 1979a).

Rocks of the basal lithologic sequence (cross-laminated calcarenite, calcilutite, bioclastic calcarenite, and Lost River Chert Bed) in the Ste. Genevieve of Pulaski, Casey, Lincoln, and Rockcastle Counties, are absent in the study area northeast of central Rockcastle County (Figs. 18 and 20). The post-Lost River erosional surface, cut into the lower Ste. Genevieve and upper Burnside in the southwestern counties, apparently coincides with an erosional surface cut into the Burnside across the outcrop belt to the northeast. A conglomerate, 2.5 to 30.0 cm thick, containing abundant clasts of Burnside chert, limestone, and silicified fossil fragments, with varied amounts of detrital quartz silt and sand, commonly is present at the base of the Ste. Genevieve in the northeastern counties.

The Ste. Genevieve northeast of Rockcastle County, as in the post-Lost River interval of Pulaski, Rockcastle, and Casey Counties, mainly consists of calcarenite, with lesser amounts of calcilutite (Fig. 18). The calcarenite is very light olive gray to medium olive gray, very fine to very coarse grained, bioclastic (commonly micrite-enveloped grains), oolitic, peloidal, locally cherty, rarely fossiliferous (crinoids, bryozoans, and solitary corals), commonly crossbedded, and partly cross-laminated.

Calcilutite, light olive gray to olive gray and in part with varied amounts of bioclastic grains, is present in the northeastern counties in (1) thin to medium, wavy to irregular beds, similar to the wavy-bedded calcilutite facies of Pulaski, Rockcastle, and Casey Counties, (2) very thin to medium beds interlayered with calcarenite, and (3) medium to thick beds at the top of the Ste. Genevieve. The wavy-bedded facies, 0.2 to 2.9 m thick, occurs discontinuously in the basal and middle parts of the member. Locally, in Lee and Wolfe Counties, the Ste. Genevieve, 0.5 and 2.9 m thick, is mainly to entirely composed of calcilutite (section 105—Big Sinking Creek, section 116—Middle Fork).

Remnants of a caliche paleosol, described by Ettensohn and others (1984a, 1988a), cap the Ste. Genevieve in the northeastern counties of the study area. In contrast with the presence of multiple paleosols in the member to the southwest, the capping paleosol commonly is the only one in the Ste. Genevieve of the northeastern counties (Fig. 18). Locally, in northern Jackson County, a second paleosol occurs 2.1 and 2.7 m below the top of the member (section 88—Cane Branch, section 93—Station Camp Creek).

Means of vectors for Ste. Genevieve crossbedding in south-central Kentucky mainly trend northwest (Woodward, 1983). In the outcrop belt north of central Pulaski County, crossbedding is principally oriented to the northeast. Data reported for the Ste. Genevieve in east-central and northeastern Kentucky include measurements of both Ste. Genevieve and Warix Run crossbeds (S.C. Woodward, oral commun., 1982).

The traditional boundary between the Chesterian and Meramecian Series in Kentucky is marked by a change in crinoid fauna. Late Meramecian strata are characterized by the presence of *Platycrinites penicillus,* and Early Chesterian rocks by species of *Talarocrinus* (Swann, 1963). Calyx cups of *Talarocrinus* sp. are relatively common in the Mill Knob member of the Monteagle in Pulaski County, but are rare in the outcrop belt to the northeast (see King, 1950; Stokley and Walker, 1953; McFarlan and Walker, 1956). Spiny, elliptical stem plates of *Platycrinites penicillus* occur in the Ste. Genevieve of Pulaski, Rockcastle, and Jackson Counties, but are present to the northeast only rarely (Dever, 1973). Specimens of *P. penicillus* also have been found in the St. Louis Limestone and Salem and Warsaw Formations of Pulaski County (Dever and Moody, 1979b). The colonial coral, *Schoenophyllum aggregatum* (*Lithostrotion harmodites* or *Siphonodendron* aff. *S. genevievensis* of earlier reports), a form restricted to the Ste. Genevieve in Kentucky, is present in the Ste. Genevieve across Pulaski County, occurring both in calcarenite and calcilutite.

The boundary between the Chesterian and Meramecian Series was redefined at the contact between the Ste. Genevieve and St. Louis limestones in the type Mississippian region by Maples and Waters (1987), mainly based on foraminifera zones. In this study, following the current usage of the Kentucky Geological Survey, the Ste. Genevieve is retained in the Meramecian Series.

Neither *Platycrinites penicillus* nor *Talarocrinus* sp. has been found in the Warix Run member, which intervenes between the Ste. Genevieve and Mill Knob in much of the study area. Its possible Meramecian or Chesterian age has not been resolved (Dever, 1973), but lithologic relationships in northeastern Kentucky suggest a possible Chesterian age (Ettensohn and others, 1984b).

***Warix Run Member.*** The Warix Run Member of the Slade principally consists of crossbedded quartzose calcarenite, with lesser amounts of calcilutite. In northeastern and northern east-central Kentucky, the Warix Run accumulated in low areas on a post-Ste. Genevieve erosional surface developed on the upthrown side of the Kentucky River Fault System (Dever, 1973; Ettensohn and others, 1984b). It commonly reaches its maximum thickness, as much as 31 m, near the middle of the erosional lows, and thins and pinches out along the margins, forming a series of isolated bodies in the present outcrop. To the southwest, in the area of this study, the Warix Run is a widespread unit, resting unconformably on the Ste. Genevieve and, locally in western Jackson County (section 87—Owsley Fork), on the Burnside. It ranges from 0.1 to 13.2 m in thickness and is absent locally in southeastern Powell County (section 107—Stump Cave Branch) (Fig. 22).

The distinctive, dominant lithology of the Warix Run, a crossbedded quartzose calcarenite, has not been recognized in the Monteagle of central and western Pulaski County (Figs. 18 and 22). Speculative correlation of a paleosol in the lower Mill Knob member of the Monteagle in central Pulaski County with a paleosol capping the Warix Run Member of the Slade in northeastern Pulaski County and Rockcastle County, as shown in Figure 18, suggests that the nonquartzose calcarenite, dolomite, and calcilutite in the lowermost Mill Knob of central Pulaski County might be correlative with

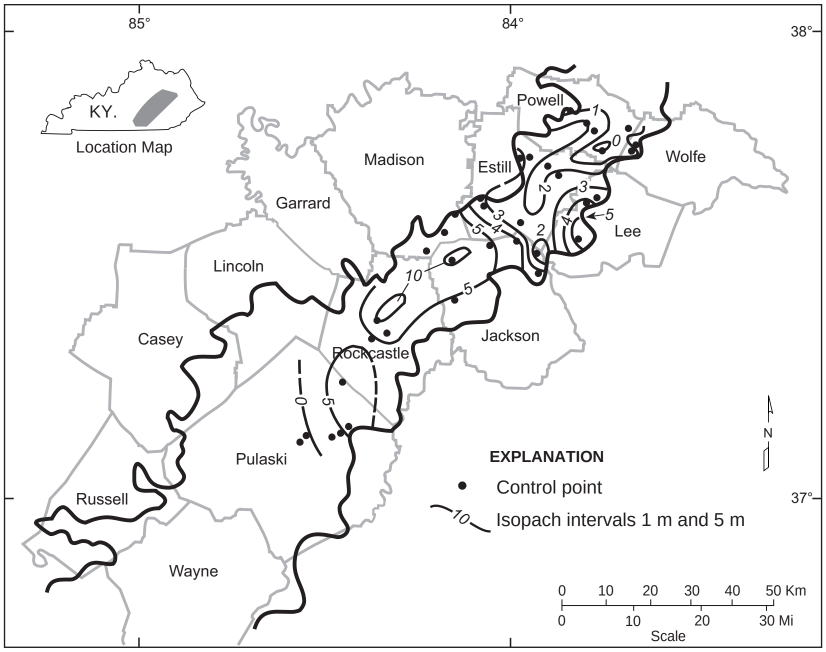


Figure 22. Thickness of Warix Run member of Slade Formation and Monteagle Limestone in study area.

Warix Run quartzose calcarenite to the northeast, but this possible correlation remains to be resolved.

Warix Run calcarenite is very light olive gray to medium light olive gray, very fine to very coarse grained, bioclastic (in part micrite-enveloped grains), peloidal, oolitic, rarely cherty, rarely fossiliferous (crinoids and brachiopods), and commonly crossbedded and cross-laminated. It contains varied amounts of detrital quartz silt and very fine- to very coarse-grained quartz sand. Commonly, detrital quartz, particularly the coarser fraction, is more abundant in the lower part of the member and decreases upward. Quartz silt and very fine-grained sand are concentrated in finer grained laminae of the calcarenite and along very thin argillaceous partings. The lower part of the unit locally contains intervals of greenish-gray, argillaceous calcarenite, up to 0.4 m thick. Clasts of melanized limestone, calcrete, and chert occur in the basal part of the member.

The Warix Run locally contains intervals of calcilutite that occur variously in lower, middle, and upper parts of the member. They generally are less than 1 m thick, but a calcilutite body in central Rockcastle County reaches a thickness of 3.7 m (section 72—Mount Vernon Quarry). Warix Run calcilutite is light olive gray to yellowish brown, locally contains bioclastic grains, and is rarely fossiliferous (gastropods). Intervals of birdseye calcilutite, present in Rockcastle and Pulaski Counties, are brecciated in the upper part. Rare bodies of dolomite occur within calcilutite at the top of the member in northeastern Pulaski County (section 54—Sunnyside Church South).

Remnants of caliche paleosol cap the Warix Run across the study area and occur in the lower part of the unit in northeastern Pulaski County and southeastern Madison County (section 57—Mount Pleasant Church, section 83—Bighill) (Fig. 18). They principally consist of melanized calcarenite or calcilutite with stringers and small circular bodies of calcrete, which, in part, are silicified. In the northeastern part of the study area (parts of Powell, Wolfe, Estill, Lee, and Jackson Counties), the melanized, calcrete-bearing limestone is overlain by 5 to 20 cm of greenish-gray, silty and sandy shale, containing both clasts and stringers of calcrete and melanized limestone, and lenses and nodules of light-colored calcilutite and calcarenite. It locally grades into argillaceous, sandy calcarenite, containing clasts of melanized limestone and calcrete (Fig. 18). The shale and argillaceous limestone may represent a leached unit in the caliche profile. Locally, in eastern Powell County, 15 cm of the silty and sandy shale apparently constitute the entire Warix Run (section 113—Mountain Parkway) (Fig. 18).

Warix Run crossbedding in east-central and northeastern Kentucky was measured as part of a study of Ste. Genevieve paleocurrents (Woodward, 1983; S.C. Woodward, oral commun., 1982). In that part of the outcrop belt, both Warix Run and Ste. Genevieve crossbeds are mainly oriented to the northeast.

***Mill Knob Member.*** The Mill Knob member of the Monteagle and Slade ranges from 2.9 to 33.4 m in thickness. It thins northeastward across the study area, from an average thickness of 23.7 m in Pulaski County to an average thickness of 4.8 m in Powell and Wolfe Counties (Fig. 23).

Carbonate rocks of the Mill Knob were deposited in two major sequences composed of calcarenite with interbeds of calcilutite and dolomite. Each sequence commonly is capped by calcilutite and a paleosol, but in parts of the area they have been partly to completely replaced by dolomite, mainly those capping the upper sequence (Fig. 18).

The two sequences thin to the northeast across the area, paralleling the thinning trend of the Mill Knob member (Fig. 18). The thickness of the lower sequence ranges from at least 13.1 to 1.8 m. The upper sequence ranges from at least 15.5 to 1.8 m in thickness. Sequence thicknesses were not determined for the thickest Mill Knob section in the study area because of discontinuous exposures (section 19—Burnside South).

Calcarenite, the principal lithology of the Mill Knob, is very light olive gray to medium olive gray, very fine to very coarse grained, bioclastic (commonly micrite-enveloped grains), with lesser amounts of ooids and peloids. It is partly

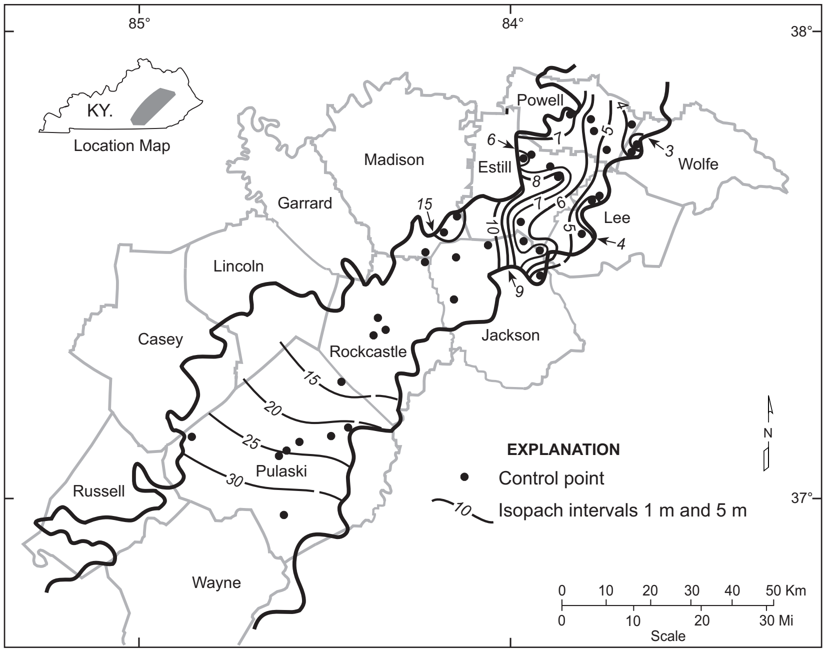


Figure 23. Thickness of Mill Knob member of Monteagle Limestone and Slade Formation in study area.

crossbedded and cross-laminated. Fining-upward cycles are relatively common in the calcarenites of Jackson, Estill, Powell, and Wolfe Counties. Calcarenite of the uppermost cycle in the northeastern counties fines upward into calcisiltite and calcilutite capping the upper sequence. Coarsening-upward calcarenites occur locally in Pulaski and Powell Counties. Calcarenite grades laterally into dolomite in parts of Pulaski, Rockcastle, and Jackson Counties, and it locally contains bodies of dolomite, which have sharp lithologic contacts between the dolomite and limestone. Carbonate microfacies in the Mill Knob of east-central Kentucky were described by Szymanski (1975) as mainly consisting of biosparites, oosparites, pelsparites, and biomicrites, generally capped by micrite and brecciated micrite. The microfacies, except for the capping micrites, were found to be highly varied in their lateral distribution and to fine upward toward the top of the member.

Calcilutite and dolomite, in addition to capping the two sequences, are interlayered with the calcarenite of each sequence, and form the basal unit in parts of the study area. They are more abundant in the upper sequence.

The calcilutite is light olive gray to olive gray and greenish gray, and in part contains varied amounts of very fine to coarse bioclastic grains. Birdseye texture occurs locally. The thickness of calcilutite interlayers ranges from 2 cm to 1.5 m. In the northeastern part of the study area, calcilutite, ranging from 1 cm to 2 m in thickness, commonly is present at the base of the Mill Knob.

The dolomite is very light olive gray to medium olive gray, yellowish gray, and greenish gray, microcrystalline to very finely crystalline. The interlayers of dolomite, which range from 0.1 to 2.2 m in thickness, in part contain varied amounts of bioclastic grains and, rarely, birdseye texture. The upper sequence in Pulaski County locally also contains finely laminated dolomite, in part with slightly wavy laminations, and a basal bed of dolomite, 0.6 to 1.5 m thick.

Chert in the Mill Knob is more common in the northern part of the study area. The occurrences mainly are associated with paleosols.

Calcilutite and a paleosol, with a combined thickness of 0.2 to 2.1 m, commonly cap the lower sequence (Fig. 18). The calcilutite locally contains varied amounts of bioclastic grains and interlayers of calcarenite and calcisiltite. Birdseye texture is rarely present. Pedogenic features include brecciated calcilutite, calcrete, and melanization. Very light-olive-gray to medium-olive-gray calcilutite darkens upward into pale-yellowish-brown to dusky-yellowish-brown colors. Tepee structures and vadoids occur locally in the paleosol. In parts of Jackson County, brecciated dolomite, 0.6 to 0.7 m thick, caps the lower sequence (section 92—Pond School, section 93—Station Camp Creek). Pedogenic features are absent in the calcilutite of eastern Powell and Wolfe Counties, which locally contains gastropods (section 113—Mountain Parkway) (Fig. 18). At several sites in Estill, Lee, and Powell Counties, the calcilutite and paleosol that would mark the top of the lower sequence apparently are absent. Pedogenic calcrete occurs in calcarenite in the lower part of the Mill Knob in parts of Pulaski, Estill, and Jackson Counties.

The upper sequence also commonly is capped by calcilutite and a paleosol, but in parts of the study area they are partly to completely replaced by dolomite (Fig. 18). Thickness of the interval of calcilutite, dolomite, and paleosol ranges from 0.1 to 3.6 m. The calcilutite locally contains varied amounts of bioclastic grains. Fossils and birdseye texture are rarely present. In the northeastern part of the study area, calcisiltite and very fine-grained calcarenite are interlaminated with the calcilutite. Pedogenic features in the paleosol capping the upper sequence are similar to those in the paleosol at the top of the lower sequence (Fig. 24). Locally in Jackson, Lee, and Pulaski Counties, two paleosols occur in the upper 1 to 2 m of the upper sequence (section 93—Station Camp Creek, section 104—Hatton Hollow, section 56—Plato-Vanhook).

Mill Knob limestones commonly are only sparsely fossiliferous. Fossils include crinoids, brachiopods, bryozoans, gastropods, blastoids, solitary corals, echinoids, and a colonial coral resembling *“Campophyllum gasperense.”* They are more common in calcarenites than in calcilutites, and occur both as scattered specimens and in roughly layered

Figure 24. Pedogenic breccia (calcilutite) at top of Mill Knob Member of Slade Formation. Section 73—Town Branch, Rockcastle County.

concentrations, the latter principally in calcarenites. In Pulaski County, calcarenites contain layered concentrations of *Talarocrinus* calyx cups. *Agassizocrinus*, a Chesterian crinoid, occurs in the Mill Knob of Rockcastle County (F.R. Ettensohn, oral commun., 1995). Dolomites are unfossiliferous, except for rare occurrences of brachiopods and gastropods.

Very thin greenish-gray shales and argillaceous partings are interlayered with calcarenite and calcilutite of the upper sequence in the northeastern part of the study area (Fig. 18). Lesser amounts of shale occur in the lower sequence. Insoluble residues from Mill Knob limestones, apparently mainly calcarenites, at two sites in Pulaski and Rockcastle Counties include (1) varied amounts of very fine to fine, subangular to subrounded quartz grains, (2) very few coarser, frosted quartz grains, (3) few very fine, well-rounded zircon grains, (4) very sparse amounts of silt-size tourmaline and rutile, both well rounded, and (5) one silt-size, rounded garnet (Ford, 1956) (section 36—Colyer Quarry, section 72—Mount Vernon Quarry).

***Cave Branch Bed.*** The Cave Branch bed of the Monteagle and Slade is a widespread shale that overlies the Mill Knob across the study area, except where removed by postdepositional erosion. It ranges from about 1 cm to 1 m in thickness. The shale generally is greenish gray to dark greenish gray and contains detrital quartz (principally silt to very fine sand). In Powell County, grayish-red shale occurs locally in the upper part (section 110—Bowen Quarry) and locally near the middle of the unit (Ky. Highway 15 roadcut paralleling and immediately south of section 113—Mountain Parkway) (Dever, 1973).

## EVIDENCE FOR STRUCTURAL ACTIVITY

Structural activity in south-central and east-central Kentucky suggests the influence of regional tectonism during Mississippian time. Evidence for structural activity is associated with several features in the study area, which are, from south to north, (1) the Greenwood Anomaly and Grenville Front, (2) Locust Branch Fault of the Irvine-Paint Creek Fault System, and (3) Glencairn Fault of the Irvine-Paint Creek Fault System.

### Greenwood Anomaly and Grenville Front

The Greenwood Anomaly, as noted in a previous section, is a large linear gravity anomaly, which coincides with a series of high-amplitude magnetic anomalies. A body of mafic igneous rocks, representing the core of a Proterozoic (Keweenawan) rift zone, is considered to be the source of the geophysical anomaly (Keller and others, 1982; Mayhew and others, 1982; Owens and others, 1984). Intrarift areas generally are complexly faulted terrains, as exemplified by the Upper Rhine Rift (De Sitter, 1964), Rio Grande Rift (Brown and others, 1980), and East African Rift (Rosendahl, 1987).

During the Grenville Orogeny, later in the Proterozoic, metamorphic rocks of the Grenville Province were thrust westward across the Keweenawan rift (Drahovzal and others, 1992). The Grenville Front, which is the western boundary of the Grenville allochthon, extends along the west side of the Greenwood Anomaly. Seismic lines in Kentucky and Ohio show that extensive strike-slip faulting occurred along and near the Grenville Front during the Late Proterozoic and that Proterozoic faults were reactivated during the Paleozoic (Drahovzal and others, 1992).

Keweenawan rifts in the central United States apparently have affected Paleozoic and younger sedimentary deposits (King and Zietz, 1971; Spalding, 1982). The Greenwood Anomaly is part of the East Continent Gravity High, a series of gravity-magnetic anomalies considered to represent a Keweenawan rift system extending north from Tennessee across Kentucky and Ohio (Keller and others, 1982). The East Continent Gravity High has been interpreted to be an extension of the Midcontinent Gravity High, also considered to be a Keweenawan rift system extending from eastern Kansas into Michigan (Keller and others, 1982, 1983; Drahovzal and others, 1992). Faults or zones of weakness along the margin of the Midcontinent Gravity High apparently controlled later, largely vertical movement in the overlying Paleozoic and younger sedimentary rocks (King and Zietz, 1971). In north-central Tennessee, the Greenwood Anomaly influenced facies and thickness patterns in Mississippian units (Spalding, 1982).

In a nonrift structural setting, deep structures associated with positive magnetic and gravity anomalies may have affected sea-floor topography and Mississippian carbonate deposition in southwestern Kansas (Parham and Sutterlin, 1993). A St. Louis oolite shoal, the source of oil in the Ingalls Field, developed at a site above coincident positive magnetic and gravity anomalies.

In the subsurface of eastern Kentucky, the Mississippian “Big Lime” generally is thinner above positive gravity features, and thicker above negative features (Pear, 1980). The “Big Lime” is a drillers’ term for a subsurface carbonate unit, which is correlative with the Renfro through Ramey Creek Members of the Slade Formation.

Several lines of evidence suggest that fault movement occurred near the crest and on the margin of the Greenwood Anomaly and along the Grenville Front in Kentucky during Mississippian time: (1) local subaerial exposure of the St. Louis, (2) local depositional thinning of lower Ste. Genevieve sediments, (3) relatively widespread erosion during early Ste. Genevieve time, (4) thickness variations in Mississippian units across the anomaly, as shown by the east–west cross section, and, possibly, (5) local thickening of Mississippian rocks in the subsurface east of the present outcrop belt (Fig. 25). Mississippian fault movement may have been caused by reactivation of rift-related faults of the Greenwood Anomaly, both interior and bounding faults, and faults associated with the Grenville Front.

***Local Subaerial Exposure of the St. Louis.*** Pre-Ste. Genevieve exposure of St. Louis sediments in south-central Kentucky occurred locally near the crest of the Greenwood Anomaly (Figs. 16 and 25). The Burnside member of the St. Louis is capped by remnants of a caliche paleosol (with calcrete, melanization, and brecciation) in southern Pulaski County (section 15—Garland Road, section 16—Mayfield Branch, section 17—Cedar Sinking Creek). Cross-laminated calcarenite of the basal Ste. Genevieve overlies the Burnside paleosol. Subaerial exposure of the St. Louis sediments and subsequent development of a caliche soil resulted from local uplift, and may be related to movement on a fault block associated with the Greenwood Anomaly.

***Local Depositional Thinning of Lower Ste. Genevieve Sediments.*** Lower Ste. Genevieve deposits are abnormally thin locally on the crest of the Greenwood Anomaly (Figs. 20 and 25). The lower three subunits in the basal sequence of the Ste. Genevieve have a total thickness of 0.7 to 2.0 m at three sites in south-central Pulaski County (section 24—Hound Hollow, section 29—Rush Branch Church, section 30—Alcalde). Elsewhere in Pulaski County, both to the north and south, total thickness of the three subunits is 3.9 to 4.1 m.

Thinning in the basal sequence apparently was caused by depositional thinning across a local area of uplift, associated with movement on a fault block. At each of the three sites, the lower subunits are overlain by rocks of the Lost River Chert Bed, indicating that thinning did not result from the intra-Ste. Genevieve episode of erosion described below.

***Widespread Erosion During Early Ste. Genevieve Time.*** Sedimentation in part of south-central Kentucky was interrupted after deposition of the Lost River Chert Bed in the Ste. Genevieve member, resulting in (1) exposure of the Lost River bed, (2) extensive erosion of the basal Ste. Genevieve deposits and upper part of the underlying St. Louis, and (3) development of a caliche soil on the erosional surface (Figs. 20 and 25). Ste. Genevieve deposition was not interrupted in the westernmost part of the study area (parts of Pulaski and Casey Counties) and in the outcrop belt to the southwest (Clinton County and parts of Wayne County). There, the basal lithologic sequence of the Ste. Genevieve, capped by the Lost River bed, is conformable with overlying deposits of the member.

The area of erosion coincides with the position of the Greenwood Anomaly, suggesting uplift over the anomaly (Fig. 25). The western boundary of the eroded area generally par-

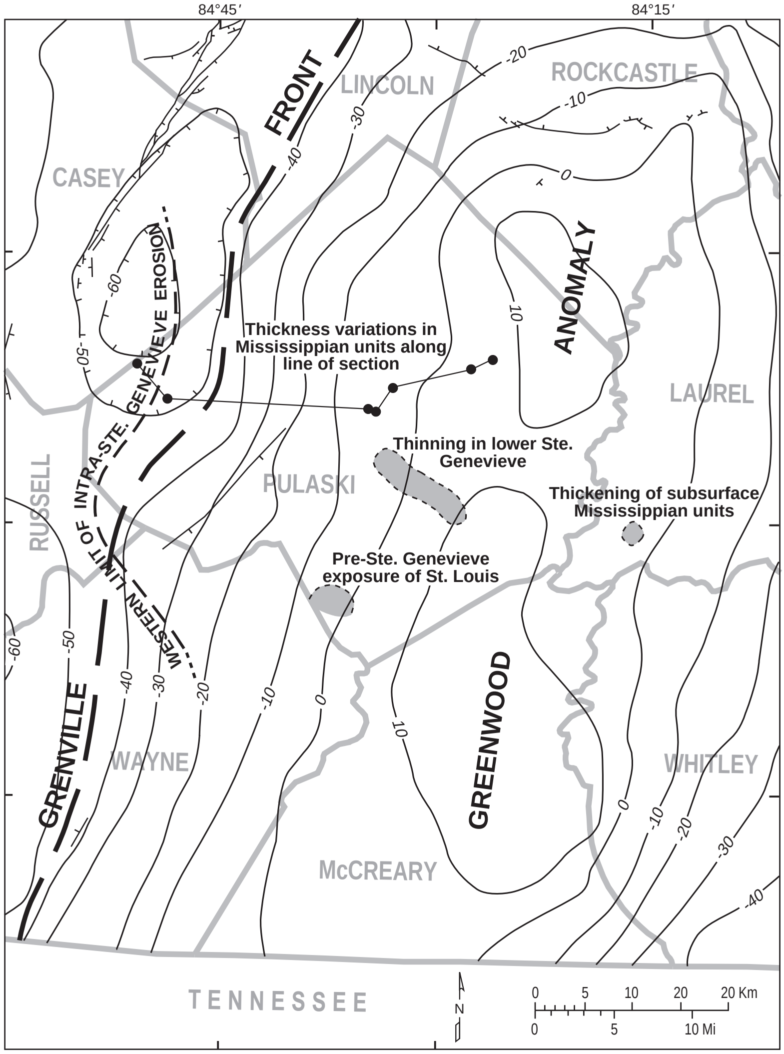


Figure 25. Relationship in south-central Kentucky between Greenwood Anomaly and Grenville Front, and (1) area of pre-Ste. Genevieve exposure of St. Louis, (2) area of thinning in lower Ste. Genevieve, (3) western limit of intra-Ste. Genevieve erosion, (4) line of cross section shown in Figures 26 through 29, and (5) area of thickening in subsurface Mississippian units.

allels the western margin of the gravity anomaly and the projected trace of the Grenville Front, suggesting the presence of one or more faults along the west side of the anomaly. Thickness variations in Mississippian units across the Greenwood Anomaly, outlined below, also indicate faulting on the western margin of the anomaly.

***Thickness Variations in Mississippian Units Across the Greenwood Anomaly.*** Faulting on the margin and crest of the Greenwood Anomaly is inferred from thickness variations found in post-Chattanooga Mississippian units across the Greenwood Anomaly, as shown in an east–west cross section through Pulaski County (Figs. 26–29). Growth faulting is suggested by the thickening of three carbonate units (Burnside member of the St. Louis; Ste. Genevieve and Mill Knob members of the Monteagle) at Green River Knob, off the western flank of the gravity anomaly.

The Burnside member of the St. Louis thickens to 9 m off the western flank of the Greenwood Anomaly in western Pulaski County. Its thickness overlying the gravity anomaly averages about 6 m, ranging from 5.9 to 7.0 m in parts of Pulaski and Rockcastle Counties where the member is conformable with the Ste. Genevieve. The thickness of the Ste. Genevieve in the outcrop belt above the gravity anomaly is highly varied, ranging from 7.3 to 17.5 m in eastern and central Pulaski County, but it increases to 23.9 m off the flank of the anomaly in the western part of the county. The Mill Knob overlying the Greenwood Anomaly is 23.6 to 24.9 m thick, but thickens to 28.4 m off its western flank.

The thicknesses of the Mississippian carbonate sequence and the underlying terrigenous-detrital deposits of the Borden, or correlative Grainger Formation, commonly are reciprocal, both in the outcrop belt (Fig. 30) and in the subsurface of eastern Kentucky, east of the study area (Pear, 1980; Hetherington, 1981; Nicholson, 1983; Maynor, 1984). An isopach map of Borden terrigenous-detrital rocks was compiled to determine if the thicker carbonate deposits at Green River Knob were underlain by a relatively thin interval of Borden (Fig. 31). The isopach map, however, shows that Green River Knob is underlain by a relatively thick lobe of Borden terrigenous-detrital rocks, indirectly supporting an interpretation for growth faulting causing the thicker accumulation of Burnside, Ste. Genevieve, and Mill Knob sediments.

***Local Thickening of Mississippian Rocks in the Subsurface.*** Subsurface Mississippian rocks thicken locally near the crest of the Greenwood Anomaly (Fig. 32). Well data from Nicholson (1983) for Knox, Laurel, and Whitley Counties were used to map the thickness of subsurface Mississippian rocks over the eastern part of the gravity anomaly to determine if any anomalous deposits are present. Because thicknesses of the Mississippian Big Lime and Borden in the three counties are reciprocal (Nicholson, 1983), a combined Big Lime-Borden unit, rather than just the Big Lime, was used for isopach mapping.

Several interpretations may explain the anomalous thickening of the Big Lime-Borden unit in southwestern Laurel County (Fig. 32). The increased thickness may reflect depo-

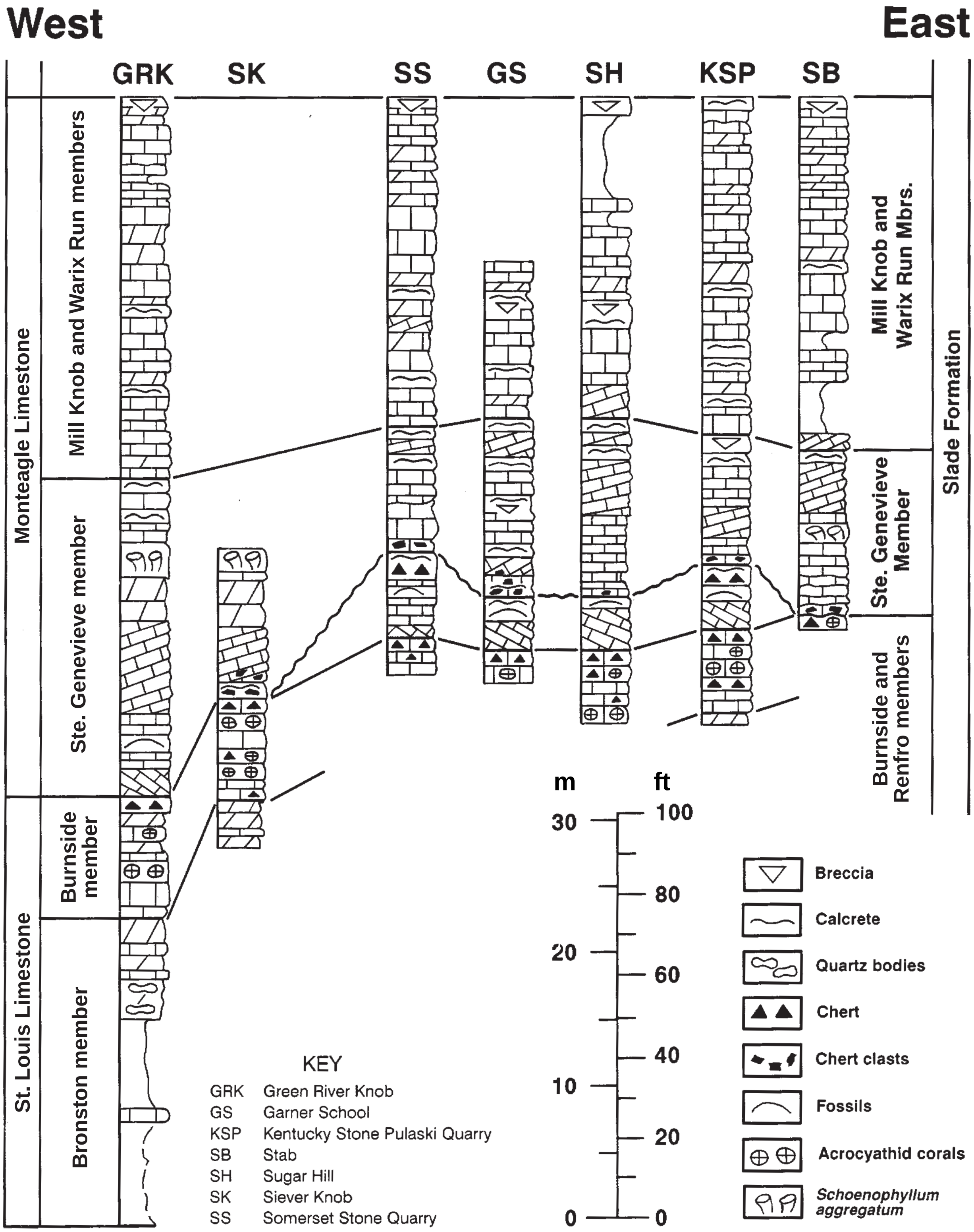


Figure 26. East–west cross section showing carbonate rocks of St. Louis and Monteagle Limestones, and correlative rocks of Slade Formation in Pulaski County, off the western flank of the Greenwood Anomaly onto the anomaly (modified from Dever, 1990). Intra-Ste. Genevieve erosional unconformity indicated by wavy line. Datum is top of Mill Knob member. Line of section shown in Figures 5, 25, 27–29, and 31.

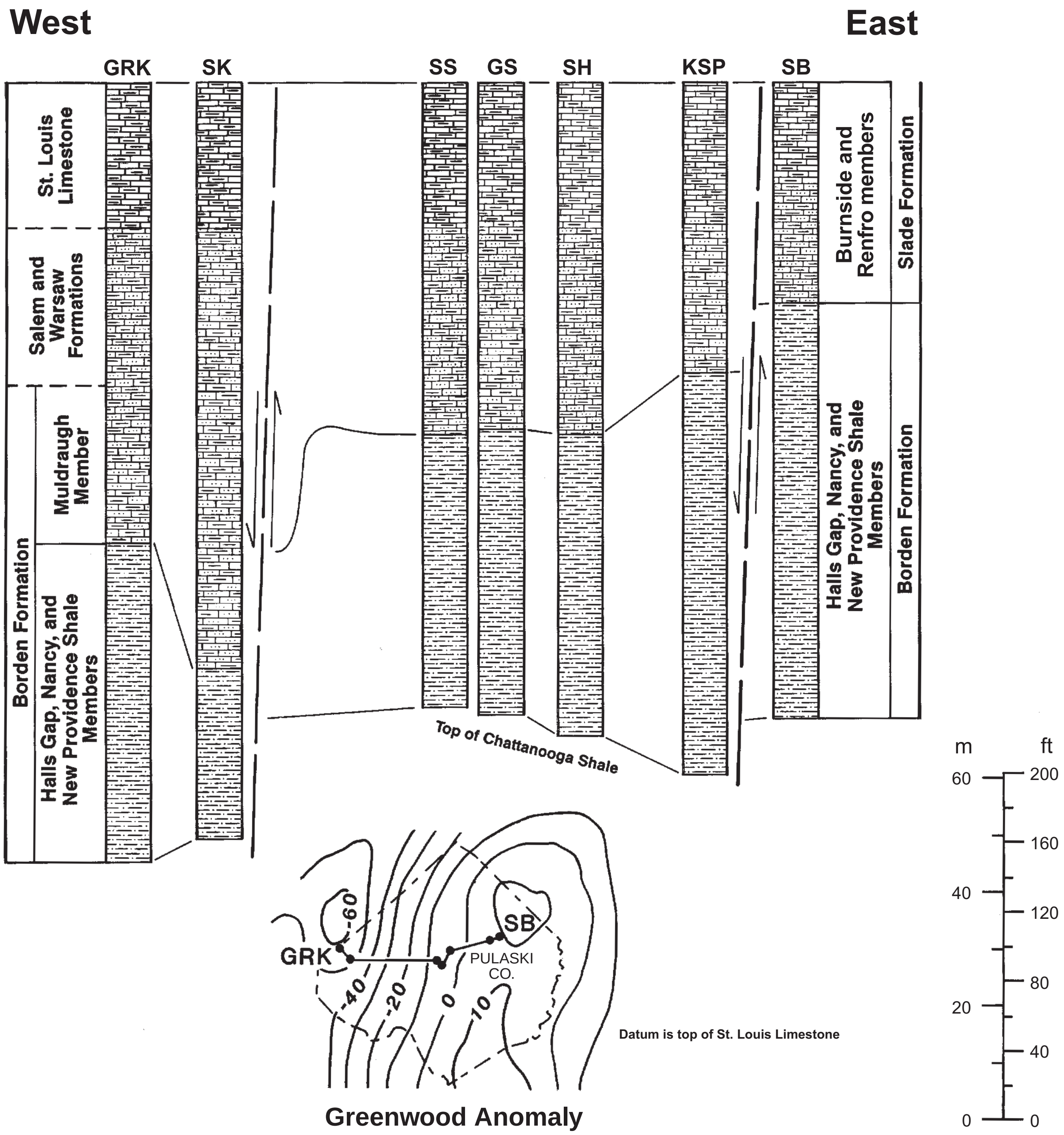


Figure 27. Faulting on flank and crest of Greenwood Anomaly, inferred from thickness variations in post-Chattanooga Mississippian rocks after deposition of St. Louis and correlative rocks of the Slade (modified from Dever, 1990). Line of section also shown in Figures 5, 25, and 31.

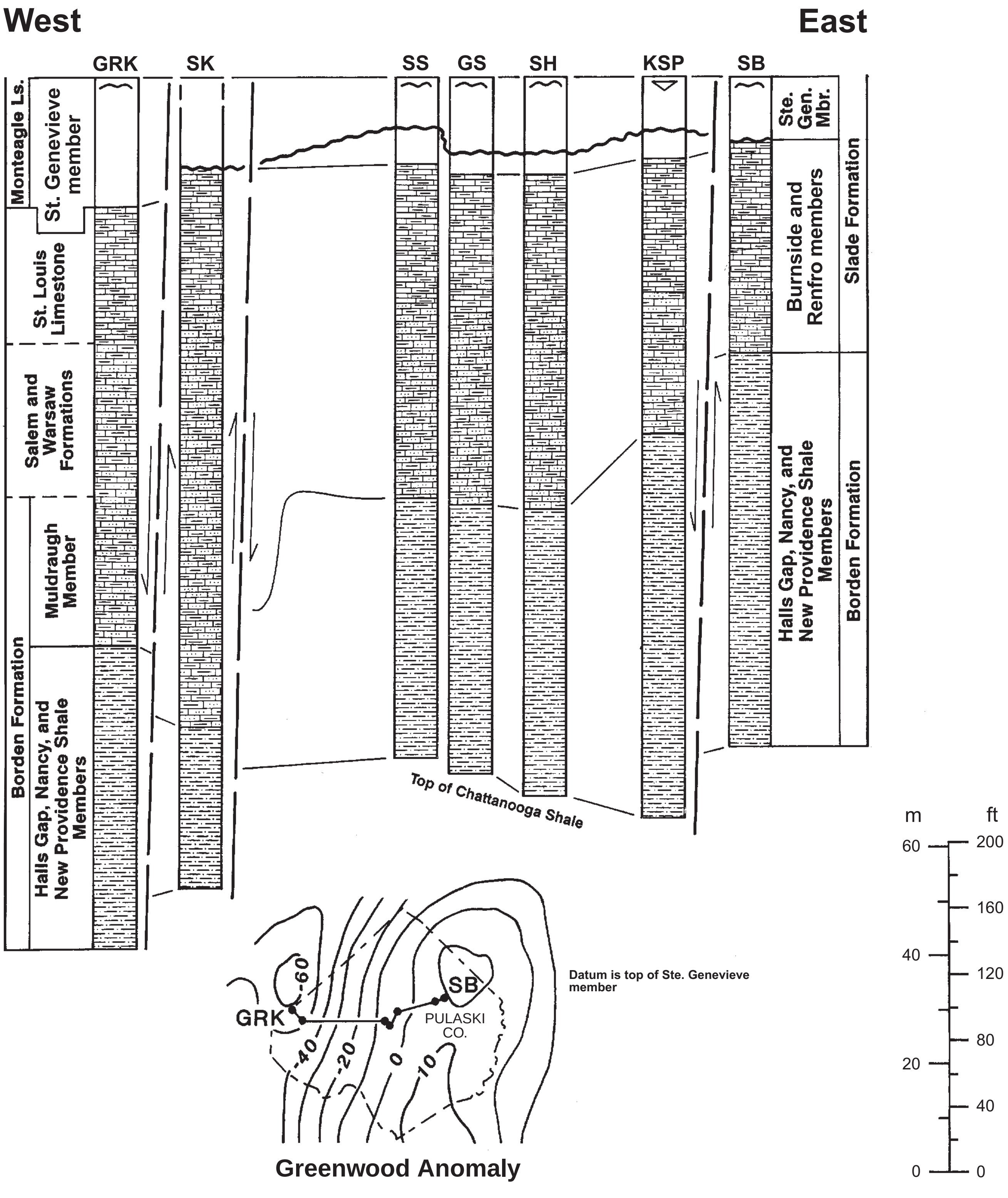


Figure 28. Faulting on flank and crest of Greenwood Anomaly, inferred from thickness variations in post-Chattanooga Mississippian rocks after deposition of Ste. Genevieve member of Monteagle and Slade (modified from Dever, 1990). Symbols in Ste. Genevieve same as in Figure 26. Line of section also shown in Figures 5, 25, and 31.

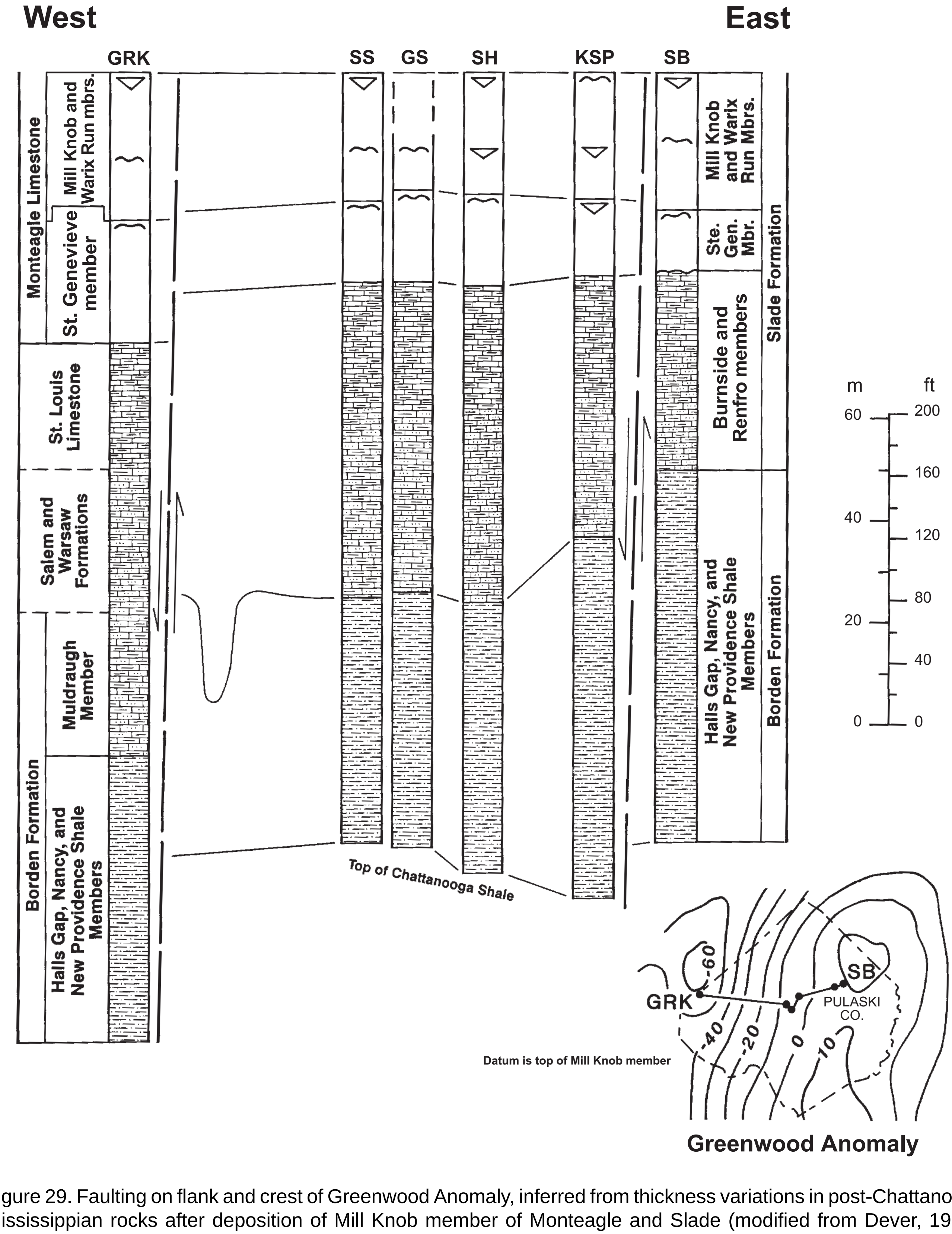


Figure 29. Faulting on flank and crest of Greenwood Anomaly, inferred from thickness variations in post-Chattanooga Mississippian rocks after deposition of Mill Knob member of Monteagle and Slade (modified from Dever, 1990). Symbols in Ste. Genevieve, Warix Run, and Mill Knob same as in Figure 26. Line of section also shown in Figures 5, 25, and 31.

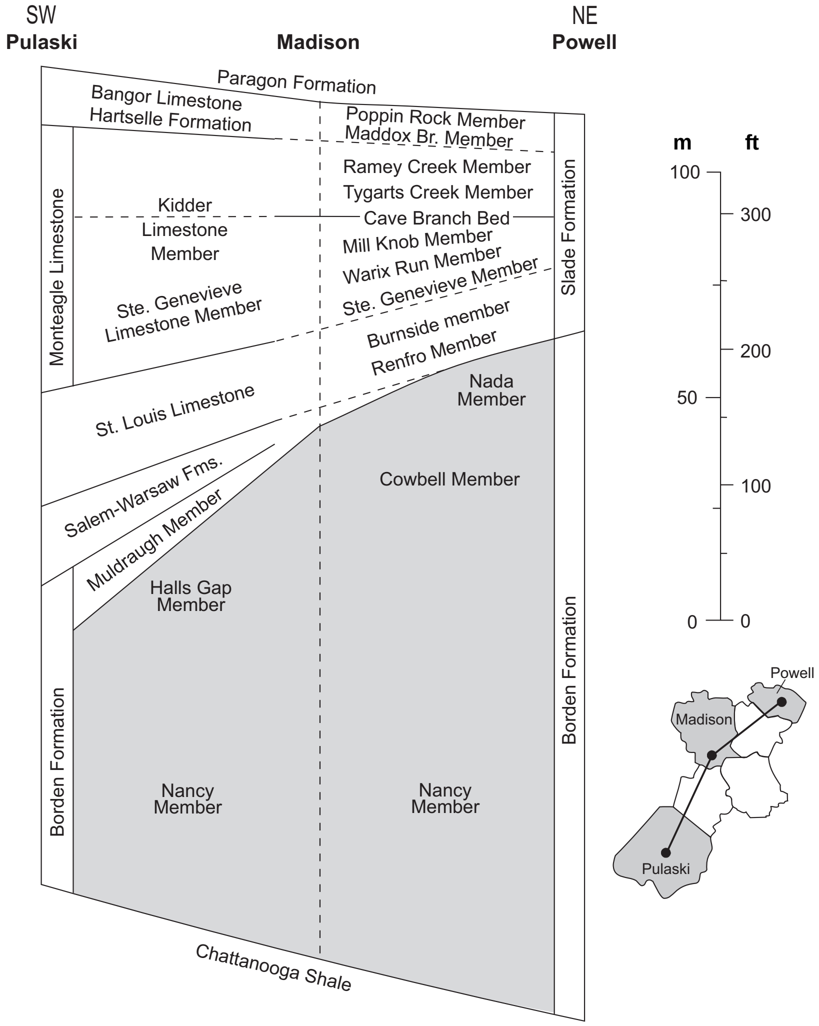


Figure 30. Northeast–southwest cross section across study area showing general relationship between Mississippian carbonate sequence and terrigenous-detrital rocks of Borden (shaded). Datum is Cave Branch Bed.

sition in a downfaulted block associated with the Greenwood Anomaly. The site is also on the downthrown side of the projected trace of the subsurface Rockcastle River-Warfield Fault, and thickening may have resulted from growth faulting during Big Lime-Borden deposition. Greater thicknesses of carbonate sediments may accumulate on positive areas or positive linear trends (e.g., edges of fault blocks), depending upon factors such as water depth (Wilson, 1975).

## Locust Branch Fault of the Irvine-Paint Creek Fault System

The Irvine-Paint Creek Fault System in the interior of the Rome Trough apparently was formed initially during the Late Proterozoic (Fig. 4) (Black, 1986a). Reactivation during the Paleozoic is indicated by thickening of Paleozoic units on the downthrown side during the Cambrian (Webb, 1980), Silurian (Miles, 1972; Lenhart, 1985), Silurian–Devonian (Weaver and McGuire, 1973), Devonian (Dillman, 1980; Lenhart, 1985; Ettensohn, 1992c), and Pennsylvanian (Horne and Ferm, 1978; Haney and others, 1985).

The Locust Branch Fault branches off to the southeast from the main fault system in southwestern Estill County (Figs. 4 and 33) (Rice, 1972). It is exposed at the surface in the valley of Locust Branch and was mapped for a distance of 2.4 km by Rice (1972). Displacement along the southeast-striking fault is downthrown to the southwest. The Locust Branch Fault diverges from the main fault system at the point where the general trend of the major fault system changes from east to northeast.

Lateral offsets in the Irvine-Paint Creek Fault System suggest the presence of northwest-trending, buried faults (Figs. 4 and 33) (Black and others, 1979). The northwest–southeast-trending Locust Branch Fault may be a surface expression of one of these zones of weakness. Northwest-trending surface faults, subparallel to the trend of the Locust Branch Fault, also are present north of the Irvine-Paint Creek system (Figs. 4 and 33).

Several lines of evidence suggest that multiple movements occurred along the projected trend of the Locust Branch Fault during Mississippian time: (1) thinning of the Renfro Member of the Slade, (2) erosion of the Burnside member of the Slade, and possibly, (3) contorted bedding in the Big Sinking bed of the Slade. Sphalerite and galena in the Renfro of northern Jackson County (section 89—Rock Lick Creek) apparently were deposited from hydrothermal fluids that moved upward through a fault or fracture along the projected Locust Branch Fault trend.

***Thinning of the Renfro Member of the Slade.*** The Renfro Member of the Slade thins abruptly across northern Jackson County in the vicinity of the projected trend of the Locust Branch Fault (Fig. 34). The unit is thinner on the upthrown side of the projected fault. West of the projected fault trend, in northwestern Jackson County and adjacent southeastern Madison County, the thickness of the Renfro ranges from 16.7 to 17.5 m (section 83—Bighill, section 87—Owsley Fork). Along and east of the projected trend, in north-central and northeastern Jackson County and southern Estill County, thicknesses range from 6.3 to 9.7 m (section 88—Cane Branch, section 89—Rock Lick Creek, section 90—Cavanaugh Creek, section 93—Station Camp Creek, section 95—Driprock). The abrupt westward thickening of the Renfro was also noted by MacGill (1973), who suggested that basement-controlled growth faults were a possible explanation.

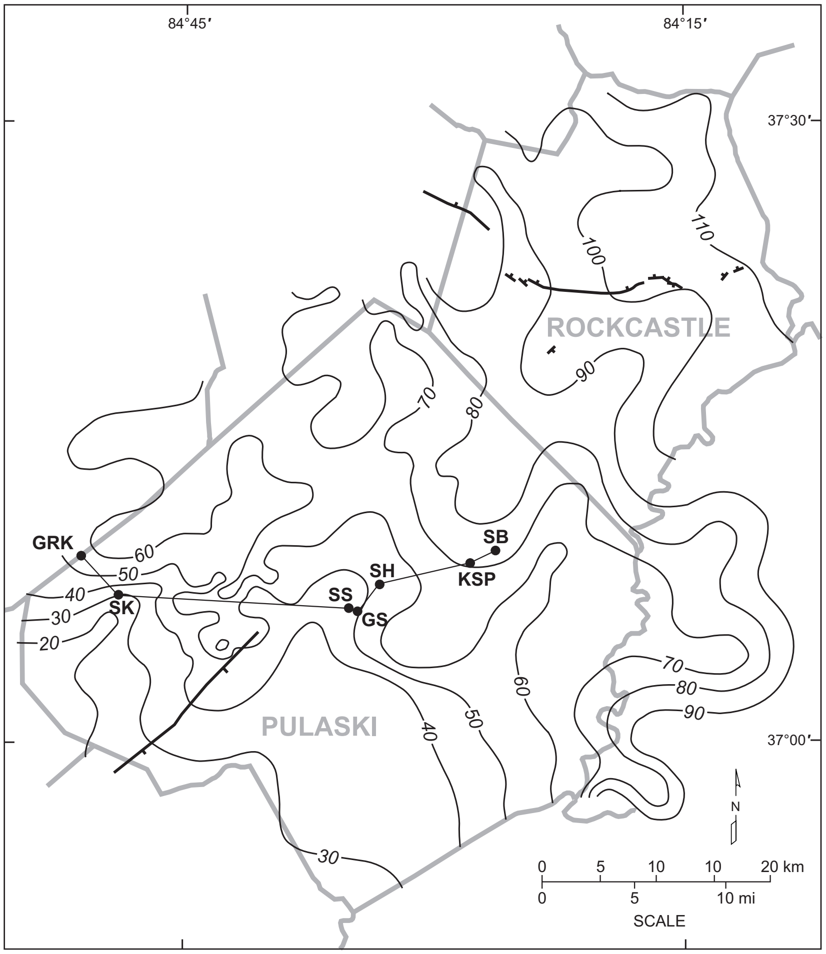


Figure 31. Thickness of terrigenous-detrital rocks of Borden in Pulaski and Rockcastle Counties. Contour interval=10 m. Line of cross section shown in Figures 26 through 29.

The change in thickness apparently mainly involves the lower part of the Renfro (Fig. 34). In the vicinity of the projected trend of the Locust Branch Fault, Renfro rocks correlative with the Muldraugh Member of the Borden and Salem and Warsaw Formations of south-central Kentucky are restricted to the downthrown side of the trend. Geodes and chert, lithologic constituents characteristic of the Muldraugh and Salem and Warsaw, commonly are absent from the Renfro northeast of the fault trend. Intertonguing of lower Renfro carbonate rocks (Muldraugh and Salem and Warsaw correlatives) with shale of the Nada Member of the Borden in the vicinity of the projected fault trend was not noted during field studies, but further investigation may be warranted.

***Erosion of the Burnside Member.*** The Burnside member of the Slade and Monteagle is present across the length of the Slade-Monteagle outcrop belt, with the exception of (1) parts of northeastern Kentucky and (2) an area in east-central Kentucky. In northeastern Kentucky, the Burnside was eroded from parts of the area on the upthrown side of the Kentucky River Fault System, following post-Ste. Genevieve uplift along the fault system (Dever, 1973, 1977). In east-central Kentucky, the Burnside is absent from an area encompassing parts of Estill, Jackson, and Lee Counties, along and on the upthrown side of the projected trend of the Locust Branch Fault (Figs. 33–34).

Erosional removal of the Burnside in east-central Kentucky followed pre-Ste. Genevieve uplift along the Locust Branch Fault trend. The contact between the Burnside and overlying Ste. Genevieve in the adjacent part of the outcrop belt is an erosional unconformity, with remnants of a caliche paleosol capping the Burnside (Figs. 16, 34). In the area where the Burnside is absent, Ste. Genevieve calcarenite rests on the Big Sinking bed, which is capped by a paleosol. Erosional remnants of Burnside, 1.1 to 1.5 m thick, containing pedogenic features (micritic calcrete and melanization), are present locally (section 91—South Fork, section 92—Pond School).

***Contorted Bedding in the Big Sinking Bed.*** Contorted bedding is a prominent feature in the Big Sinking bed of the Slade along and on the northeast (upthrown) side of the projected Locust Branch Fault trend (Fig. 35). The areal distribution of contorted bedding suggests that in-place sediment deformation was probably triggered by recurrent seismic activity along the Locust Branch trend. The specific reactivation that resulted in Big Sinking deformation probably represented a major episode of movement and attendant seismicity on the fault. Earlier activity along the trend, which affected Renfro deposition, was relatively slow growth-fault movement. Uplift accompanying later (post-Big Sinking) movement was followed by erosional removal of the Burnside.

The Big Sinking is mainly a very fine-grained, bioclastic, pelletal calcarenite. Carbonate particles principally range from coarse silt to very fine to fine sand. The limestone is finely laminated and commonly contains stringers of laminated chert. In the interval of contorted bedding, curvilinear patterns of deformed laminae and chert stringers outline bodies of rolled-up sediment (Figs. 14–15). Original laminae in the calcarenite and chert, though highly contorted, commonly are preserved, indicating that the sediment was semilithified and was deformed by plastic flow during subaqueous movement (Dott, 1963).

Bedding in the Big Sinking ranges from totally deformed to wholly planar, but more commonly it is only partly deformed. In sections where it is partly deformed, only one interval of contorted bedding is present, suggesting that only

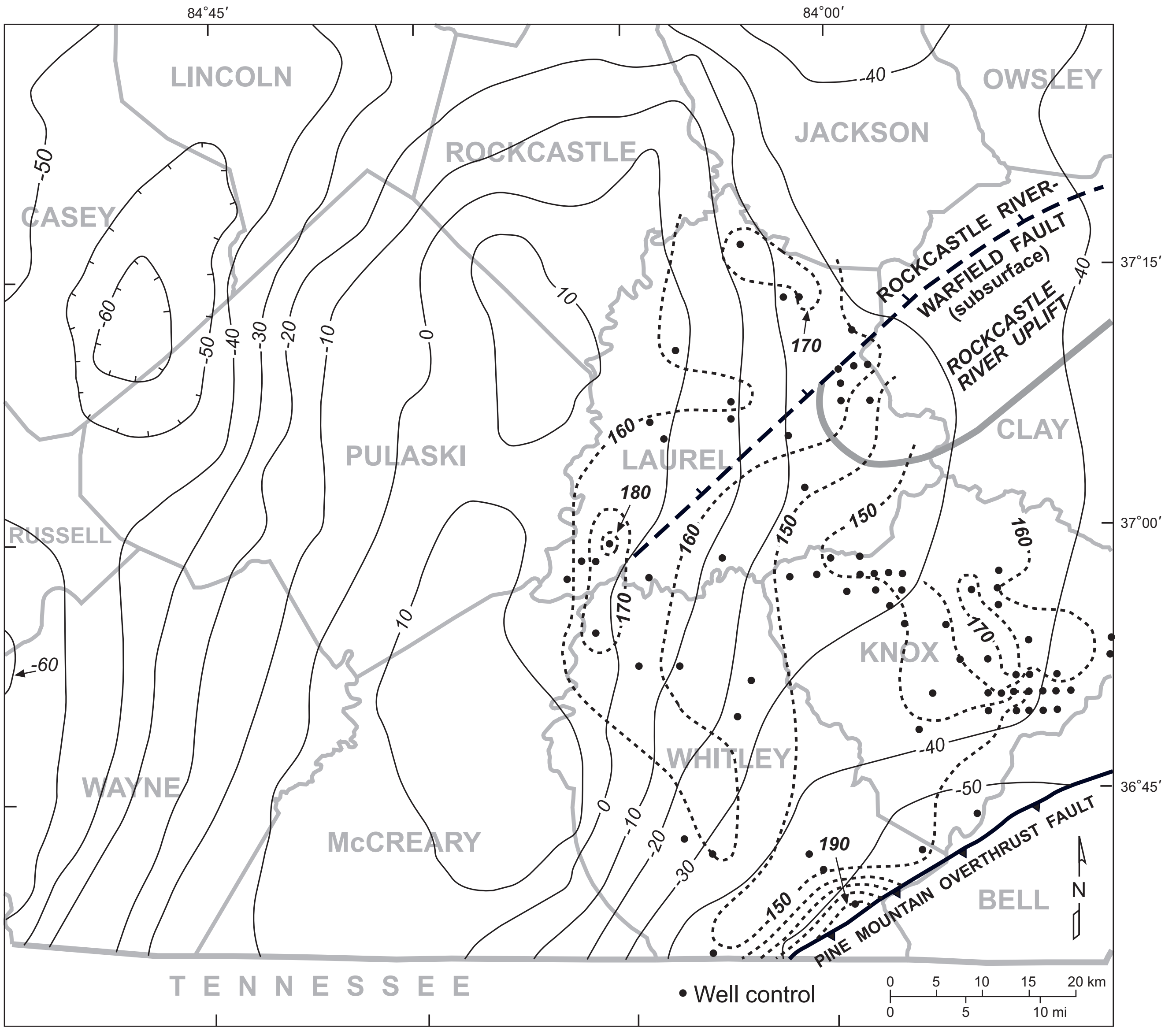


Figure 32. Thickness of Big Lime-Borden unit (dashed line) in subsurface over eastern part of Greenwood Anomaly. Contour interval=10 m. Subsurface data adapted from Nicholson (1983). Rockcastle River-Warfield Fault and Rockcastle River Uplift from Sutton (1981) and Maynor (1984).

one episode of fault movement occurred or that only one episode was sufficiently strong to trigger sediment movement.

In the northeastern part of the study area, Big Sinking limestone along the Irvine-Paint Creek Fault System generally is planar bedded. At one site, south of the Glencairn Fault, contorted bedding occurs locally in the basal 0.3 to 0.7 m of the unit; laterally along the same roadcut, the entire unit, 0.9 to 1.2 m thick, is planar bedded (section 108—Rogers Chapel).

Contorted bedding also occurs in the Big Sinking equivalent of Pulaski County in the outcrop above the Greenwood Anomaly (Fig. 13). This suggests that the uplift exposing Burnside sediments, noted above, was not the earliest Meramecian structural activity in south-central Kentucky.

The possible presence of a zone of faulting and fracturing extending southeastward from the Locust Branch Fault mapped by Rice (1972) is supported by the occurrence of epigenetic sphalerite and galena in northern Jackson County (section 89—Rock Lick Creek) (Fig. 33). In the Central Kentucky Mineral District, about 35 km northwest of Rock Lick Creek, structural control of the ore is related to faults and fractures (Jolly and Heyl, 1964). The central Kentucky deposits (barite, calcite, fluorite, galena, and sphalerite) are mainly veins associated with faults and fractures (Robinson, 1931; Jolly and Heyl, 1964; Anderson and others, 1982). Small deposits of galena, sphalerite, and calcite have been recog-

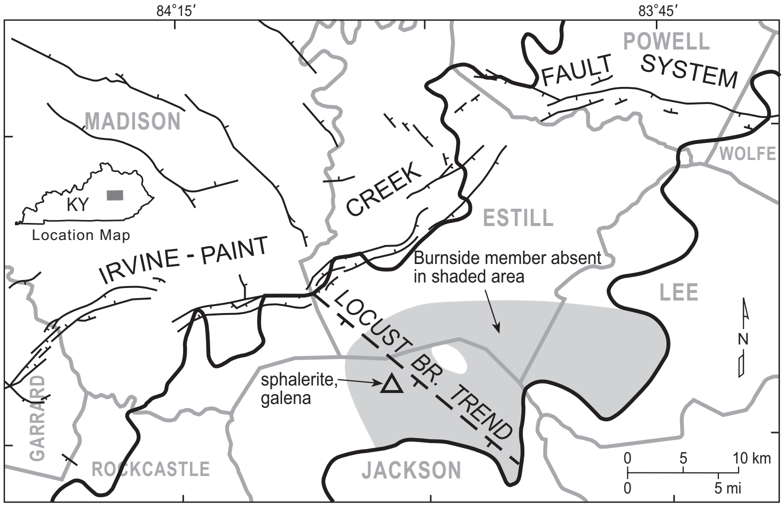


Figure 33. Areal relationship between projected trend of Locust Branch Fault and (1) absence of Burnside member and (2) site of sphalerite and galena mineralization in Renfro Member.

nized along the Irvine-Paint Creek Fault System in Johnson County, about 100 km northeast of Rock Lick Creek (Jillson, 1928). Barite and calcite occur along and near faults associated with the Irvine-Paint Creek system in eastern Lincoln County, about 45 km to the west (Robinson, 1931; Weir, 1971; Anderson and others, 1982).

Mineralization at the Rock Lick Creek section is exposed in the base of a vertical, bulldozed-cut face of a prospect (locally known as the "Platinum Mine") in the Renfro Member of the Slade. The mineralized interval is 1.2 m thick. In the upper part, calcite, sphalerite, and galena are scattered through the very finely crystalline, dolomitic matrix of a breccia composed of fragmented micrograined limestone. The lower part of the interval is a massive, saccharoidal dolomite with numerous vertical to inclined, 0.6- to 1.2-cm-wide veinlets, bearing calcite, sphalerite, and galena.

At Rock Lick Creek, the Renfro is 7.8 m thick. The 1.2-m-thick mineralized zone occurs 2.6 m below the top of the member, which is overlain by cherty limestone of the Big Sinking bed. Dolomite crops out discontinuously on the slope below the base of the prospect. The Renfro is underlain by shale of the Nada Member of the Borden.

### Glencairn Fault of the Irvine-Paint Creek Fault System

Mississippian movement along the Glencairn Fault of the Irvine-Paint Creek Fault System, 35 km northeast of the Locust Branch Fault trend, is indicated by differential erosion of the Burnside Member of the Slade. Erosional thinning of the Burnside is more pronounced adjacent to the Glencairn Fault, along the border of the upthrown (north) side, suggesting pre-Ste. Genevieve upward displacement on the fault. As noted in the previous section on the Locust Branch Fault, earlier Paleozoic movement along the Irvine-Paint Creek Fault System had resulted in the thickening of units on the downthrown side during the Cambrian (Webb, 1980), Silurian (Miles, 1972; Lenhart, 1985), Silurian–Devonian (Weaver and McGuire, 1973), and Devonian (Dillman, 1980; Lenhart, 1985; Ettensohn, 1992c).

The contact between limestone of the Burnside and dolomite of the underlying Renfro Member in the area is marked by a sharp but slightly wavy to very irregular surface, and a thin clay parting along the surface separates limestone from dolomite (Figs. 36–37). The surface has been interpreted to be a minor unconformity between supratidal and subtidal deposits, in which narrow depressions in the surface represent littoral surge channels (Dever, 1973). Irregularity of the surface, however, is now believed to have been caused by irregular dolomitization of basal Burnside limestones, because relict chert, fossils, sedimentary structures, and pockets of limestone characteristic of the Burnside are found in the uppermost dolomite of the Renfro (Moody, 1982).

Because the irregular dolomitization of the Burnside has resulted in substantial variations in thickness of the two members, key beds within them are important in establishing primary depositional thickness of the rock units (Figs. 36–37). In the Burnside, the most important key beds are two zones of acrocyathid corals, containing *Acrocyathus proliferus* and *A. floriformis*. The principal key bed in the Renfro is the Ringgold bed (0.6 to 1.5 m thick) in the lower part of the member. It consists of thin- to medium-bedded, bioclastic calcarenite, with interbedded shale. Another key bed is a resistant dolomite (0.3 to 0.5 m thick) that occurs 0.3 to 0.6 m above the Ringgold (Figs. 36–37).

Prior to the fault movement, Mississippian uplift along the Waverly Arch had interrupted Burnside deposition, resulting in widespread exposure of the sediments across northeastern and east-central Kentucky (Dever, 1973, 1977). A caliche soil developed on the surface of the sediments (Ettensohn and others, 1984a, 1988a).

Mississippian movement on the Glencairn Fault occurred after Burnside deposits were exposed to erosion and before Ste. Genevieve deposition. The pattern of erosion indicates upward displacement on the north side of the fault, and suggests that the movement was accompanied by slight northward tilting (Fig. 38).

Only 0.1 to 1.5 m of Burnside limestone remains above the lower acrocyathid coral zone of the Burnside in sections along the border of the upthrown side of the fault (section 109—High Rock, section 114—Natural Bridge Park, section 115—Mill Creek Mine) (Figs. 36–37). Northward on

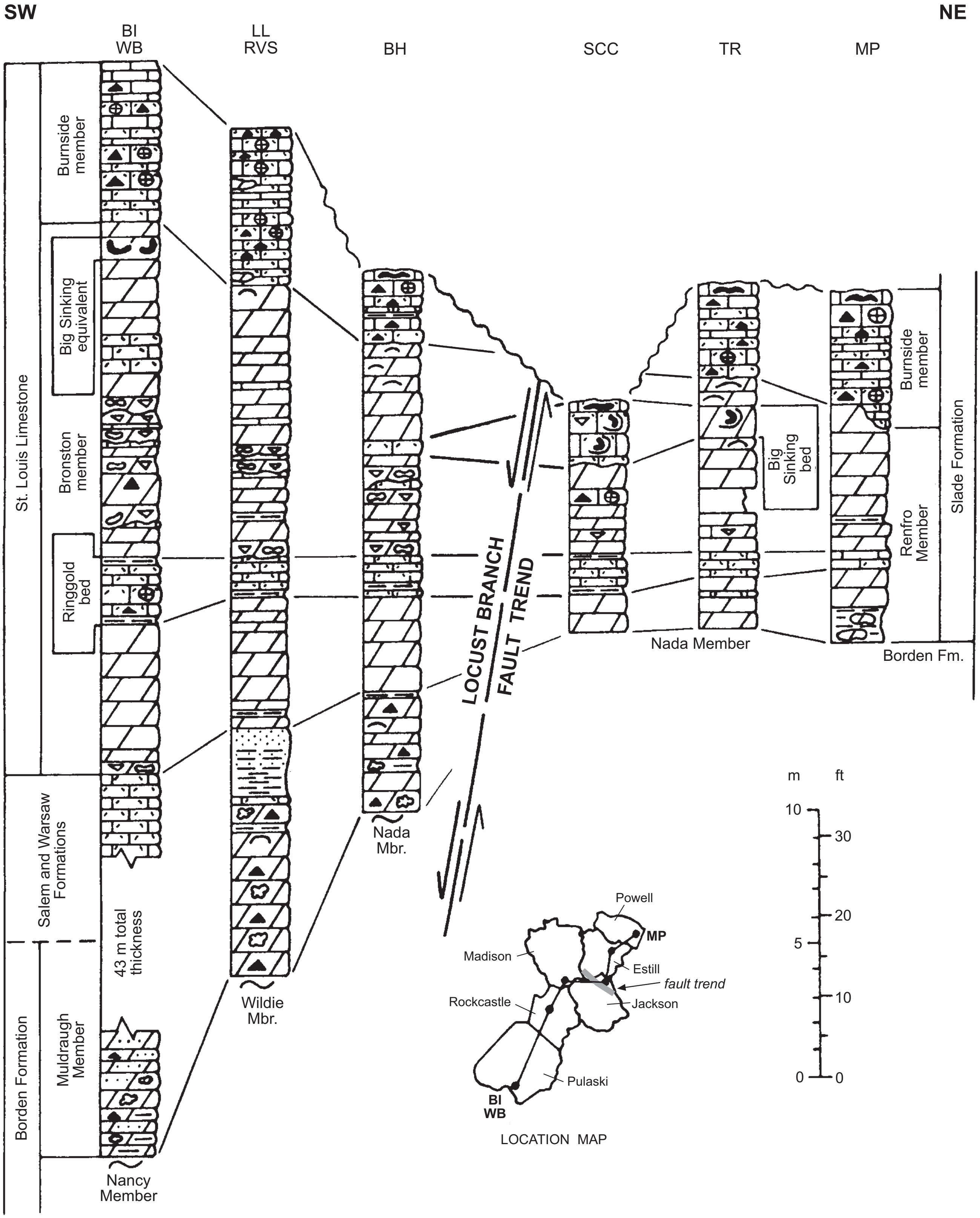


Figure 34. Southwest–northeast cross section showing thinning in lower part of Mississippian carbonate sequence across projected trend of Locust Branch Fault (modified from Figure 10). See Figure 9 for symbol explanation and section identification.

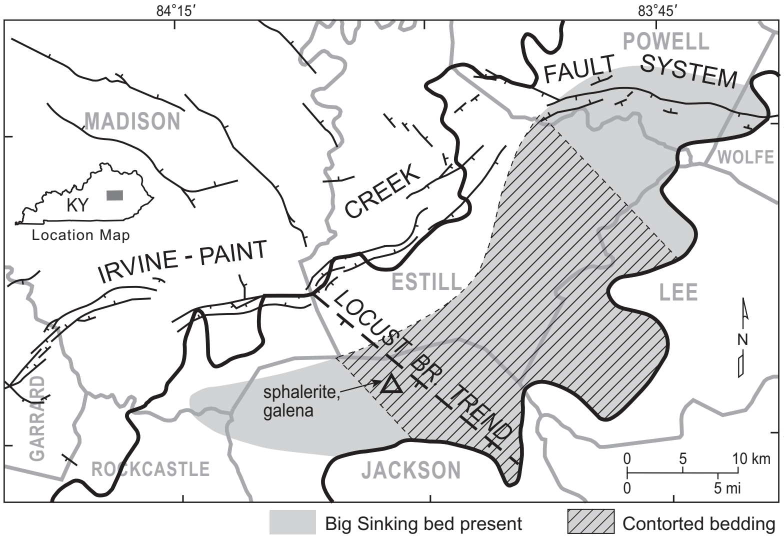


Figure 35. Areal relationship between projected trend of Locust Branch Fault and (1) contorted bedding in Big Sinking bed and (2) site of sphalerite and galena mineralization in Renfro Member.

the upthrown block, away from the fault, 2.1 to 4.0 m of limestone are present above the lower coral zone (section 110—Bowen Quarry, section 113—Mountain Parkway). Comparable thicknesses of limestone, 2.4 to 3.5 m, are preserved on the downthrown side of the fault (section 107—Stump Cave Branch, section 116—Middle Fork).

The upper zone of acrocyathid corals in the member apparently was continuous across the area at the time of Burnside deposition, but, after fault movement it was removed by erosion along the border of the upthrown side. The upper coral zone is preserved only on the downthrown side of the fault and in sections on the upthrown block that are some distance away from the fault (Figs. 36–38).

The caliche soil that developed on the Burnside during subaerial exposure was partly eroded across the entire area, but deepest erosion was along the Glencairn Fault. The upper 0.3 to 0.9 m of the Burnside on the downthrown side of the fault and in sections some distance away from it on the upthrown block contains pedogenic features such as melanized limestone, calcrete, and brecciated limestone. Only 2 to 20 cm of similarly altered limestone (melanized and locally slightly brecciated) remains in the sections along the border of the upthrown side.

The occurrence of uplift and erosion contrasts with the dominance of extensional growth faulting and depositional thickening of units along the Irvine-Paint Creek Fault System through most of Paleozoic time. Dever (1986) suggested that the uplift indicated a change from tensile to compressive stress on the fault system.

A simpler explanation for the uplift is the concept of a tilt block/half graben commonly produced during extensional tectonism, which is accompanied by footwall uplift (Leeder and Gawthorpe, 1987) (Fig. 39). Maximum footwall displacement, associated with normal faulting and tilting along the Glencairn Fault, would have been along the border of the north block, where maximum erosion of the Burnside subsequently occurred.

## Tectonic Implications of Structural Activity

The evidence for structural activity across south-central and east-central Kentucky during Mississippian time suggests the influence of regional tectonism. Reactivation of faults in the study area along the western border of the Appalachian Basin, however, occurred during a period of apparent tectonic quiescence, between major phases of Acadian and Alleghenian orogeny along the eastern continental margin.

Recent interpretations of the Mississippian sequence in the Appalachian Basin, based on lithospheric flexural models of Quinlan and Beaumont (1984) and Beaumont and others (1988), show that tectonic activity would have continued across the region after the major phase of Acadian orogeny subsided (Ettensohn and Chesnut, 1989; Ettensohn, 1990, 1993; Ettensohn and Pashin, 1993). The flexural models were outlined previously in the structural setting chapter.

The following elements of the lithospheric flexural models, summarized from Ettensohn and Chesnut (1989) and Ettensohn (1990, 1993), are particularly pertinent to this study. Deformational loading during the last phase of the Acadian Orogeny along the eastern margin of North America produced a downwarped flexural foreland basin immediately cratonward of the orogen and a peripheral bulge on the cratonward margin of the foreland basin. As orogeny proceeded and the thrust load migrated cratonward, the foreland basin and peripheral bulge migrated away from the load. The deformational loading was accompanied by deposition of terrigenous-detrital sediments of the Borden and Grainger Formations in the foreland basin.

When orogeny and thrusting ceased, lithospheric relaxation caused the peripheral bulge to be uplifted and the basin narrowed and deepened. Eastward bulge migration toward the Acadian orogen produced shallow-water environments suitable for carbonate deposition, including sediments of the St. Louis, Monteagle, and Slade.

The study area also would have been affected by a peripheral bulge migrating northward from the Ouachita orogen (Ettensohn, 1993). Along the southern margin of North America, an arc-continent collision at the Alabama Promontory is indicated by the sandstone composition of a southwest-derived Mississippian and Pennsylvanian clastic wedge in Alabama (Mack and others, 1983; Thomas, 1985). Based

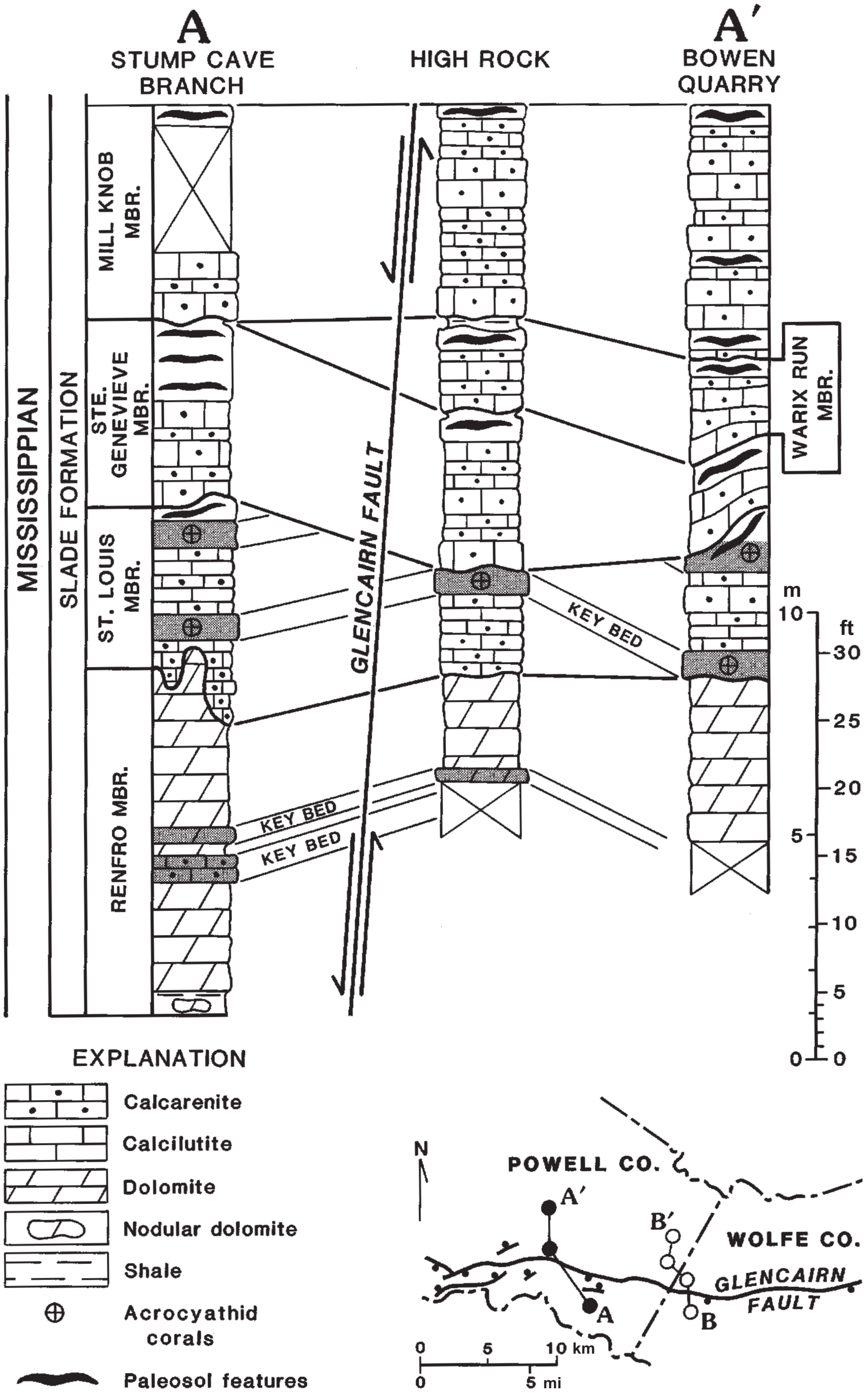


Figure 36. Northwest–southeast cross section showing absence of upper acrocyathid coral zone along border of upthrown side of Glencairn Fault (from Dever, 1986). Datum is top of Mill Knob Member. St. Louis Member includes Burnside member and Big Sinking bed of this study.

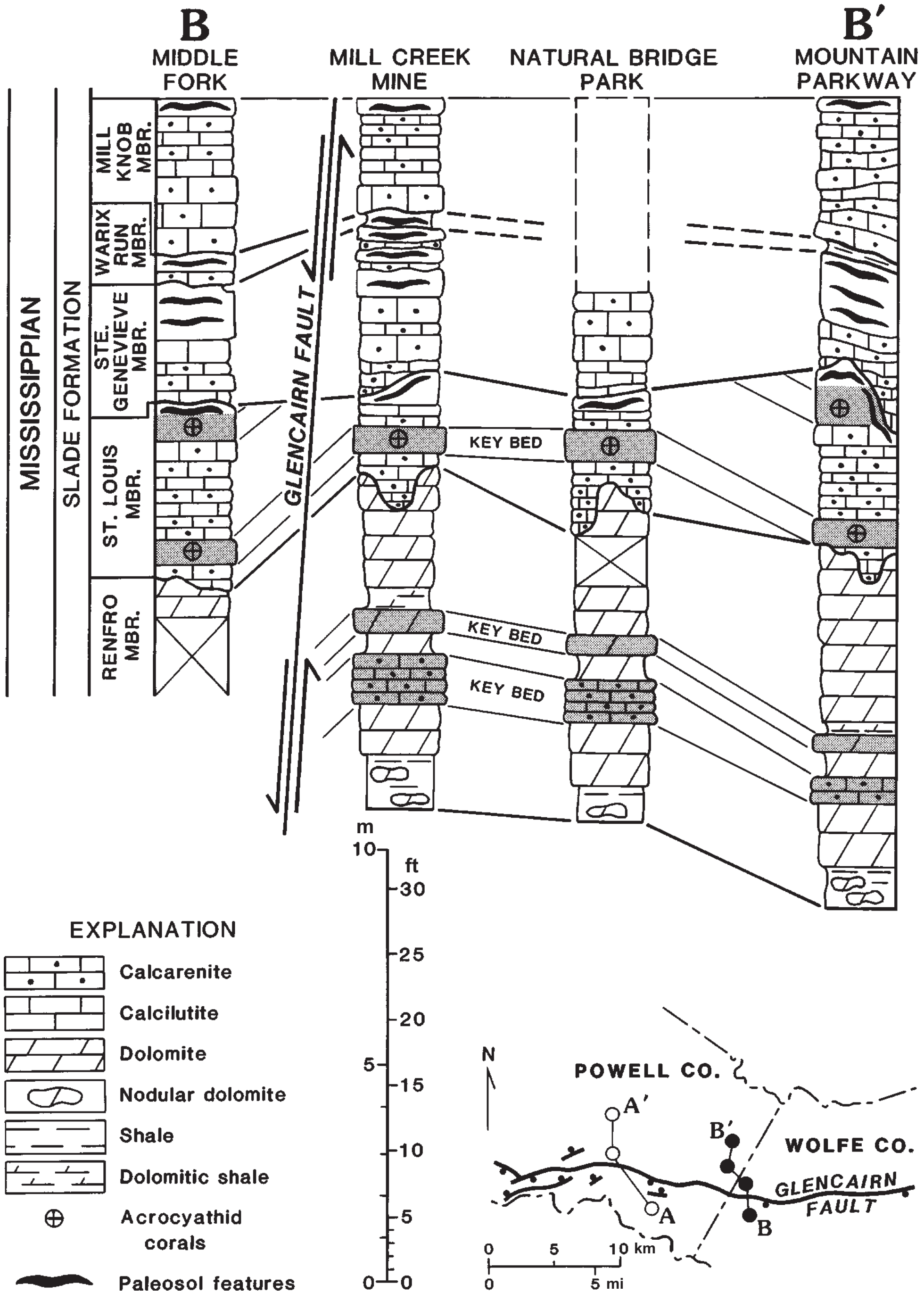


Figure 37. North–south cross section showing absence of upper acrocyathid coral zone along border of upthrown side of Glencairn Fault (from Dever, 1986). Datum is top of Mill Knob Member. St. Louis Member includes Burnside member and Big Sinking bed of this study.

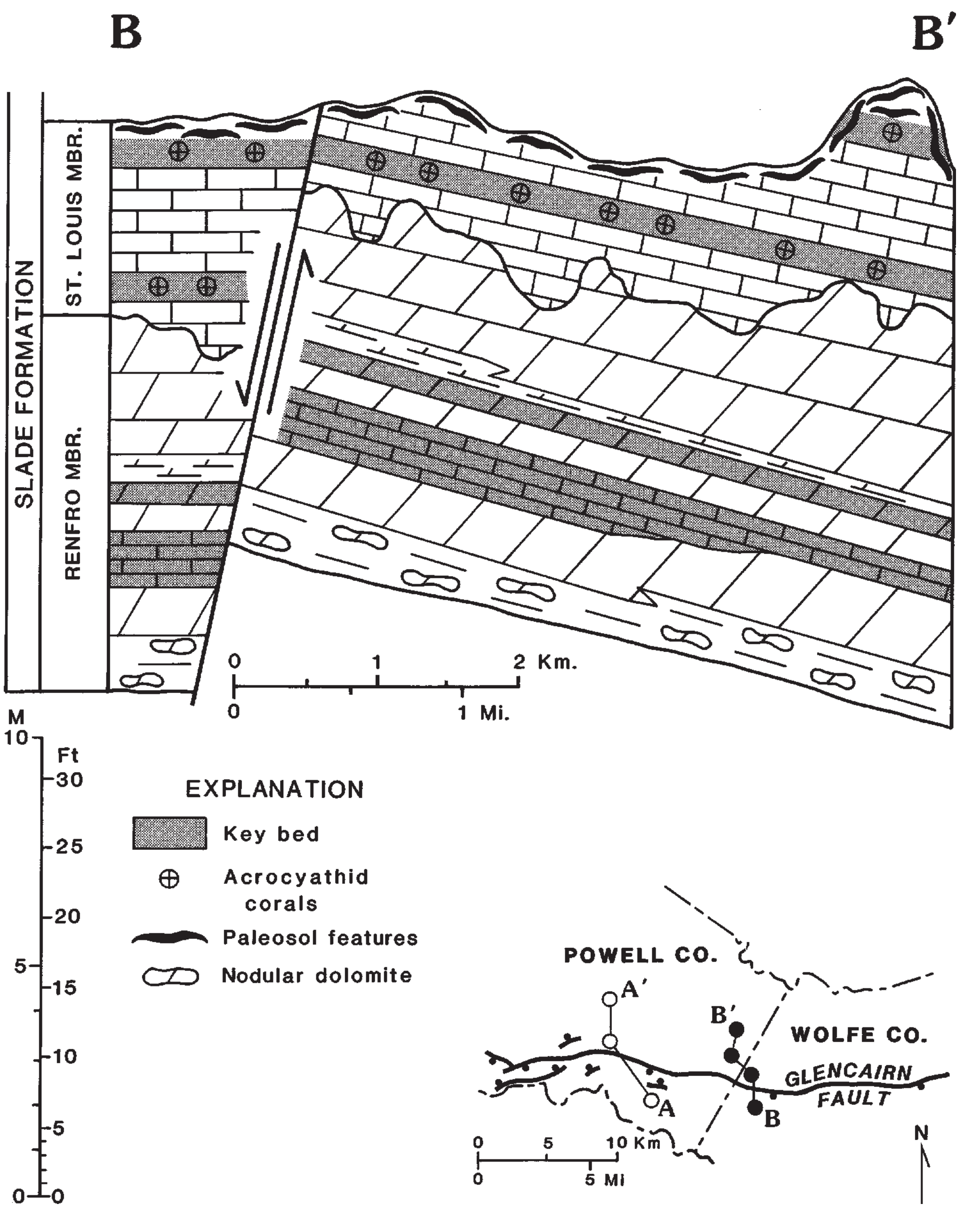


Figure 38. Interpretive north–south cross section showing erosional surface developed on St. Louis Member after Mississippian reactivation along Glencairn Fault (from Dever, 1986). Constructed using columnar sections shown in Figure 37. St. Louis Member includes Burnside member and Big Sinking bed of this study.

on the age of the oldest sediments, the source area and orogenesis were initiated by late Meramecian time (Mack and others, 1983).

Bulge migration through the study area during Mississippian time apparently reactivated faults, which apparently resulted in the erosional and depositional features found in the St. Louis, Monteagle, and Slade. Local unconformities in Kentucky, Ohio, and West Virginia have been attributed to reactivation of basement structures by the migrating Acadian bulge (Ettensohn and Chesnut, 1989). The time of passage by the east-migrating, relaxation-phase, Acadian bulge and north-migrating Ouachita bulge through the study area, as determined by Ettensohn and Chesnut (1989) and Ettensohn (1993), respectively, would have been penecontemporaneous with Meramecian and early Chesterian fault reactivation in south-central and east-central Kentucky.

# SUMMARY

## Stratigraphic Units and Relationships

***Ringgold Bed.*** Composed of limestone interbedded with shale, the Ringgold is a useful stratigraphic marker within the dolomite-dominated Bronston member of the St. Louis and Renfro Member of the Slade. It apparently was deposited across the entire study area.

***Big Sinking Bed.*** Previous workers generally assigned Big Sinking rocks, principally limestone that is commonly cherty, to the St. Louis Limestone, St. Louis Limestone Member of the Newman, or St. Louis Member of the Slade (=Burnside member of this study). The well-sorted, finely laminated, very fine-grained, bioclastic, pelletal calcarenite of the Big Sinking is lithologically distinct from the relatively poorly sorted, coarser grained, bioclastic calcarenite in the lower part of the overlying Burnside.

***False Lost River Bed.*** A limestone containing abundant nodules and irregular bodies of chert at the top of the Burnside member of the St. Louis and Slade yields a bedded chert upon weathering, as much as 0.3 m thick, in parts of Pulaski and Rockcastle Counties. The bed of Burnside chert closely resembles and is easily mistaken for the Lost River Chert Bed in the lower part of the overlying Ste. Genevieve. The presence of basal Ste. Genevieve lithologies (in ascending order,

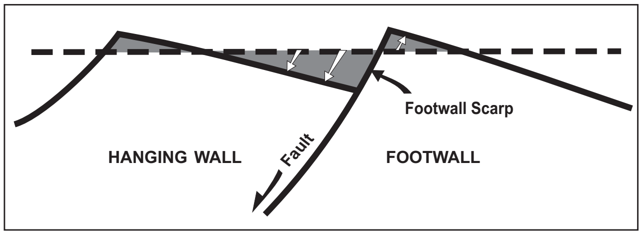


Figure 39. Footwall uplift that accompanies the tilt block/half graben produced during extensional tectonism (modified from Leeder and Gawthorpe, 1987). Reprinted with permission of the Geological Society Publishing House.

cross-laminated calcarenite, calcilutite, and fossiliferous bioclastic calcarenite) below the Lost River bed distinguishes it from the Burnside bed.

***Intra-Ste. Genevieve Erosional Unconformity.*** A Ste. Genevieve conglomerate, 2.5 cm to 3.4 m thick, composed of chert and limestone clasts in a calcarenitic matrix, rests on an erosional surface cut into the lower Ste. Genevieve and upper Burnside of Pulaski, Rockcastle, Casey, and Lincoln Counties, and northeastern Wayne County. The conglomerate rests on the Burnside in many exposures, and earlier workers such as Butts (1922) and McFarlan and Walker (1956) considered it to indicate the presence of a pre-Ste. Genevieve, or inter-Ste. Genevieve–St. Louis, unconformity. However, the unconformity took place during Ste. Genevieve time because the conglomerate also rests on lower Ste. Genevieve rocks as young as the Lost River Chert Bed.

***Upper Ste. Genevieve Paleosols.*** Two widespread paleosols are present in the uppermost Ste. Genevieve of Pulaski and Rockcastle Counties. The upper paleosol caps the Ste. Genevieve member. In Pulaski County, *Platycrinites penicillus,* a Meramecian crinoid, occurs between the two paleosols, supporting their assignment to the Ste. Genevieve. These paleosols may be correlative with two paleosols in the uppermost Ste. Genevieve of west-central Kentucky on the west side of the Cincinnati Arch.

***Warix Run Member.*** The Warix Run Member of the Slade, mainly crossbedded quartzose calcarenite, is a widespread unit in the Slade outcrop belt, extending from northeastern Kentucky southwestward into northeastern Pulaski County. Its distinctive lithology as yet has not been recognized in the Monteagle of central and western Pulaski County.

Speculative correlation of the paleosol capping the Warix Run in northeastern Pulaski County with a paleosol in the lower Mill Knob member of the Monteagle in central Pulaski County suggests that the nonquartzose calcarenite, dolomite, and calcilutite in the lowermost Mill Knob of central Pulaski County might be correlative with Warix Run quartzose calcarenite to the northeast. This possible correlation remains to be resolved.

### Structural Activity

Evidence for structural activity during Meramecian and early Chesterian time is associated with several features in the study area.

***Greenwood Anomaly and Grenville Front.*** Previous investigations have considered the Greenwood Anomaly to be part of a Proterozoic rift, and the Grenville Front has been identified as the western margin of the Grenville allochthon. Mississippian structural activity indicates reactivation of rift-related faults associated with the Greenwood Anomaly, both interior and bounding faults, and faults associated with the Grenville Front, which parallels the western border of the Greenwood Anomaly in south-central Kentucky.

Subaerial exposure of Burnside sediments and depositional thinning of lower Ste. Genevieve sediments apparently resulted from local uplifts produced by reactivation of rift-related faults. Broader uplift later interrupted Ste. Genevieve deposition across the Greenwood Anomaly and was followed by development of an extensive erosional surface cut into lower Ste. Genevieve and upper Burnside deposits. Faulting also is indicated by thickness variations in Mississippian units across the Greenwood Anomaly and Grenville Front, including growth faulting off the western flank of the anomaly and front. Local thickening of subsurface Mississippian rocks near the crest of the Greenwood Anomaly may reflect deposition in a rift-related downfaulted block or downward movement on the subsurface Rockcastle River-Warfield Fault.

***Locust Branch Fault of Irvine-Paint Creek Fault System.*** Meramecian reactivation along the projected southeastward trend of the Locust Branch Fault in east-central Kentucky affected three successive members of the Slade. Uplift caused abrupt northeastward thinning in the lower part of the Renfro. Next, fault activity probably triggered movement and deformation of carbonate sediments in the Big Sinking bed. Renewed uplift was followed by extensive erosion of the Burnside on the upthrown side. The occurrence of epigenetic sphalerite and galena in the Renfro of northern Jackson County supports the projection of a zone of faulting and fracturing southeastward from the Locust Branch Fault.

***Glencairn Fault of Irvine-Paint Creek Fault System.*** Meramecian movement along the Glencairn Fault in east-central Kentucky was followed by differential erosion of the Burnside. Erosional thinning is most pronounced adjacent to the fault, along the border of the upthrown (north) side. Tilting of the northern block during normal faulting caused uplift along the border of the block.

***Tectonic Implications of Structural Activity.*** Recent investigations of the Mississippian sequence in the Appalachian Basin, based on lithospheric flexural models, conclude that the sedimentary sequence reflects the formation and migration of foreland basins and peripheral bulges. Bulge migration apparently reactivated faults in the study area. Based on the recent studies, passage of an east-migrating, relaxation-phase, Acadian bulge and a north-migrating Ouachita bulge through the area seems to have been contemporaneous with the Meramecian and early Chesterian fault movements in the area and is the likely cause of these movements.

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# APPENDIX A: LIST OF SECTIONS

FORMAT:
County
Section number and name.
Geographic location (English units).
Type of section—measured or reconnaissance.
7.5-minute quadrangle. Carter coordinate location.
Formation (member, bed).

WAYNE COUNTY

1. Eastview. Roadcuts along Ky. Highway 90, 1.7 mi northeast of junction with Ky. Highway 90 Business and Ky. Highway 1275 in Monticello. Measured section. Mill Springs quadrangle. 3,000′FNL x 1,500′FEL, 15-E-57. St. Louis (Burnside), Monteagle (Ste. Genevieve, Lost River).

2. Gap of the Ridge. Roadcuts along Ky. Highway 90, northeast and southwest of road junction in gap, 4.2 mi northeast of junction with Ky. Highway 90 Business and Ky. Highway 1275 in Monticello. Reconnaissance section. Mill Springs quadrangle. 100′FSL x 1,250′FEL, 3-E-57. Monteagle (Ste. Genevieve, Mill Knob, Cave Branch).

3. Touristville. Roadcuts along north side of Ky. Highway 90, 0.2 mi west of Touristville (Mill Springs Christian Church). Reconnaissance section. Mill Springs quadrangle. 2,400′FNL x 2,250′FWL, 21-F-57. Monteagle (Ste. Genevieve, Lost River).

4. Meadow Creek. Outcrops in pasture and at edge of woods along Ky. Highway 1619, 1.1 mi (airline) south of junction with Ky. Highway 90. Reconnaissance section. Frazer quadrangle. 850′FNL x 150′FEL, 24-F-58. St. Louis (Burnside), Monteagle (Ste. Genevieve).

5. Tuttle Church South. Outcrops along Ky. Highway 1619, 0.3 mi (airline) southeast of junction with Ky. Highway 90. Reconnaissance section. Frazer quadrangle. 2,450′FNL x 900′FWL, 18-F-58. St. Louis (Burnside), Monteagle (Ste. Genevieve, Lost River).

6. Tuttle Church. Outcrops along Ky. Highway 1619, 200 ft southeast of junction with Ky. Highway 90. Reconnaissance section. Frazer quadrangle. 1,200′FNL x 50′FWL, 18-F-58. Monteagle (Ste. Genevieve, Lost River).

7. Rankin Knob. Outcrops on knob, 0.4 mi (airline) southeast of Ky. Highway 761. Reconnaissance section. Mill Springs quadrangle. 200′FSL x 2,400′FWL, 7-F-57. St. Louis (Burnside), Monteagle (Ste. Genevieve).

8. Cub Creek Hill. Outcrops along farm road and slope on east side of hill, 0.3 mi (airline) west of Dry Branch embayment of Lake Cumberland. Reconnaissance section. Mill Springs quadrangle. 1,000′FNL x 1,550′FEL, 9-F-56. St. Louis (Burnside), Monteagle (Ste. Genevieve).

PULASKI COUNTY

9. Hill Knob. Outcrops along trail on west slope of knob, 1.1 mi (airline) east of Vinnie. Reconnaissance section. Faubush quadrangle. 2,900′FSL x 200′FEL, 22-G-56. Monteagle (Ste. Genevieve, Lost River).

10. Barker Knob. Outcrops in draw between Barker Knob and Old Brown Knob, and in pasture on south side of Barker Knob, 0.7 mi (airline) southwest of Faubush. Reconnaissance section. Faubush quadrangle. 2,250′FNL x 1,400′FEL, 10-G-56. St. Louis (Burnside), Monteagle (Ste. Genevieve, Lost River).

11. Rainwater Knob. Outcrops above Faubush Road on west slope of knob, 1.3 mi (airline) north of Faubush. Reconnaissance section. Faubush quadrangle. 100′FSL x 900′FEL, 25-H-57. St. Louis (Burnside), Monteagle (Ste. Genevieve).

12. Berkett Hollow. Roadcuts along south side of Cumberland Parkway at milepost 77.3, 1.1 mi west of Ky. Highway 80 overpass. Reconnaissance section. Faubush quadrangle. 2,600′FNL x 900′FEL, 25-H-57. St. Louis (Bronston, Ringgold).

13. Siever Knob. Abandoned Ed Kramer and Son Quarry. Northeast side of Ky. Highway 80, 5.2 mi northwest of Nancy post office. Measured section. Faubush quadrangle. 150′FNL x 1,400′FWL, 17-H-57. St. Louis (Bronston, Burnside), Monteagle (Ste. Genevieve).

14. Green River Knob. Abandoned American Concrete Stone Co. quarry. West side of Ky. Highway 837, 1.2 mi north of junction with Ky. Highway 80. Measured section. Mintonville quadrangle. 600′FNL x 500′FWL, 10-H-56. St. Louis (Bronston, Ringgold, Burnside), Monteagle (Ste. Genevieve, Mill Knob, Cave Branch).

15. Garland Road. Cuts and outcrops at boat ramp on Cox Bend, at west end of Garland Road. Reconnaissance section. Burnside quadrangle. 500′FNL

x 1,800′FWL, 22-F-59. St. Louis (Bronston, Big Sinking equivalent, Burnside), Monteagle (Ste. Genevieve).

16. Mayfield Branch. Outcrops in bed and along banks of stream, 2 mi south of Quinton via Echo Point Road. Reconnaissance section. Burnside quadrangle. 350′FSL x 1,450′FEL, 18-F-59. St. Louis (Burnside), Monteagle (Ste. Genevieve).

17. Cedar Sinking Creek. Outcrops in bed and along banks of stream, 1.3 mi south of Quinton via Echo Point Road. Reconnaissance section. Frazer and Burnside quadrangles. 900′FSL x 2,200′FWL, 18-F-59. St. Louis (Bronston, Big Sinking equivalent, Burnside), Monteagle (Ste. Genevieve).

18. Quinton Substation. Outcrops on west side of Ky. Highway 790, 1.7 mi south of Bronston post office. Reconnaissance section. Burnside quadrangle. 450′FNL x 1,200′FWL, 12-F-59. Monteagle (Ste. Genevieve).

19. Burnside South. Roadcut along east side of U.S. Highway 27 and outcrops on hillside above roadcut, 0.9 mi south of Burnside post office. Measured section. Burnside quadrangle. 1,750′FNL x 1,700′FWL, 10-F-59. St. Louis (Bronston, Big Sinking equivalent, Burnside), Monteagle (Ste. Genevieve, Mill Knob).

20. Burnside Island. Roadcut along west side of entrance road and outcrops on hillside below road, east side of General Burnside Island State Park. Measured section. Burnside quadrangle. 2,350′FNL x 450′FWL, 10-F-59. Salem and Warsaw, St. Louis (Bronston, Ringgold, Big Sinking equivalent, Burnside), Monteagle (Ste. Genevieve).

21. Bronston South. Roadcut along east side of Ky. Highway 790, 0.7 mi south of Bronston post office. Reconnaissance section. Burnside quadrangle. 2,200′FNL x 100′FEL, 8-F-59. Monteagle (Ste. Genevieve).

22. Burnside North. Roadcuts along Ky. Highway 90, 0.1 mi southwest of junction with U.S. Highway 27. Reconnaissance section. Burnside quadrangle. 450′FNL x 1,600′FWL, 2-F-59. Monteagle (Ste. Genevieve, Mill Knob).

23. Buck Creek Boat Dock. Roadcuts and outcrops on west side of boat dock road, 2.9 mi southeast of junction of Ky. Highways 769 and 1643, via Ky. Highway 769. Reconnaissance section. Hail quadrangle. 1,650′FNL x 1,050′FWL, 5-F-61. St. Louis (Bronston, Big Sinking equivalent, Burnside), Monteagle (Ste. Genevieve, Lost River, Mill Knob).

24. Hound Hollow. Outcrops and cuts along unimproved road at mouth of hollow, 1.6 mi (airline) southeast of Buck Creek Church. Reconnaissance section. Dykes quadrangle. 2,700′FSL x 1,700′FWL, 24-G-61. St. Louis (Burnside), Monteagle (Ste. Genevieve, Lost River).

25. Waitsboro. Roadcuts along road to Waitsboro Recreation Area, 0.1 mi west of U.S. Highway 27, and outcrops east of pumping station along north shore of Lake Cumberland. Reconnaissance section. Delmer quadrangle. 600′FNL x 600′FWL, 23-G-59. Borden (Muldraugh), Salem and Warsaw, St. Louis (Bronston, Ringgold).

26. Wait Knob. Outcrops along east side of Bourbon Road, 0.5 mi north of junction with Ky. Highway 1642. Reconnaissance section. Delmer quadrangle. 2,050′FSL x 2,500′FEL, 14-G-59. St. Louis (Burnside), Monteagle (Ste. Genevieve, Lost River).

27. Dry Branch. Roadcuts and outcrops along Ky. Highway 1247, 1.9 mi northeast of junction with U.S. Highway 27. Reconnaissance section. Somerset quadrangle. 2,100′FSL x 1,650′FWL, 20-G-59. St. Louis (Burnside), Monteagle (Ste. Genevieve).

28. Sinking Creek. Roadcuts along Ky. Highway 1642, 0.2 mi south of junction with Ky. Highway 1247. Reconnaissance section. Somerset quadrangle. 2,300′FNL x 200′FEL, 12-G-59. St. Louis (Bronston, Big Sinking equivalent, Burnside).

29. Rush Branch Church. Outcrops and roadcuts along Ky. Highway 769, north of church, 3.3 mi south of junction with Ky. Highway 80. Measured section. Somerset quadrangle. 2,850′FNL x 950′FWL, 7-G-60. St. Louis (Burnside), Monteagle (Ste. Genevieve, Lost River).

30. Alcalde. Roadcuts along west side of Ky. Highway 769, 0.5 mi north of Alcalde Post Office. Measured section. Somerset quadrangle. 1,300′FSL x 350′FWL, 8-G-60. St. Louis (Burnside), Monteagle (Ste. Genevieve, Lost River).

31. Clay Hill Church. Outcrops along south side and in bed of Pitman Creek, 0.3 mi south of church. Reconnaissance section. Somerset quadrangle.

650′FNL x 1,950′FEL, 9-G-60. St. Louis (Burnside), Monteagle (Ste. Genevieve).

32. Blaze Valley. Outcrops along secondary road on north side of valley, 1.0 mi (airline) north of Ruth. Reconnaissance section. Somerset quadrangle. 2,300′FSL x 2,200′FWL, 22-H-60. Monteagle (Ste. Genevieve).

33. Fishing Creek. Roadcuts along Cumberland Parkway, mileposts 86 to 85.2, 2.6 mi west of junction with U.S. Highway 27 in Somerset. Measured section. Delmer quadrangle. 300′FNL x 1,400′FEL, 21-H-58. Borden (Nancy, Muldraugh), Salem and Warsaw, St. Louis (Bronston, Ringgold).

34. Denham Knob. Roadcut and outcrops along south side of Cumberland Parkway, milepost 86.8, 1.8 mi west of junction with U.S. Highway 27 in Somerset. Reconnaissance section. Delmer quadrangle. 2,100′FNL x 400′FEL, 25-H-59. St. Louis (Burnside), Monteagle (Ste. Genevieve, Lost River).

35. Hale Knob. Outcrops along Hale Knob Road, 0.2 mi south of Ky. Highway 80. Reconnaissance section. Delmer quadrangle. 1,600′FSL x 550′FWL, 23-H-59. Monteagle (Ste. Genevieve, Lost River).

36. Colyer Quarry. Abandoned Strunk Construction Co. quarry on north side of Ky. Highway 80, 1.3 mi east of junction with U.S. Highway 27 in Somerset. Reconnaissance section. Somerset quadrangle. 700′FSL x 300′FWL, 20-H-59. Monteagle (Ste. Genevieve, Mill Knob, Cave Branch).

37. Somerset Stone Co. Quarry. Active quarry on north side of Ky. Highway 80; Ross Street entrance to quarry, 2.7 mi east of junction of Ky. Highway 80 and U.S. Highway 27 in Somerset. Measured section. Somerset quadrangle. 2,500′FSL x 700′FWL, 16-H-60. St. Louis (Burnside), Monteagle (Ste. Genevieve, Lost River, Mill Knob, Cave Branch).

38. Garner School. Roadcuts along Ky. Highway 80, 2.9 mi east of junction with U.S. Highway 27 in Somerset. Measured section. Somerset quadrangle. 2,000′FSL x 2,100′FEL, 16-H-60. St. Louis (Burnside), Monteagle (Ste. Genevieve, Mill Knob).

39. Sugar Hill. Roadcuts along Ky. Highway 80, 4.6 to 5.3 mi east of junction with U.S. Highway 27 in Somerset. Measured section. Bobtown and Somerset quadrangles. 2,400′FNL x 1,200′FEL, 14-H-60. St. Louis (Burnside), Monteagle (Ste. Genevieve, Mill Knob).

40. Big Knob. Roadcuts along south side of Ky. Highway 80, 0.2 to 0.7 mi west of junction with Ky. Highway 1317 at Barnesburg. Reconnaissance section. Bobtown quadrangle. 2,900′FSL x 1,600′FEL, 8-H-60. Monteagle (Ste. Genevieve, Mill Knob).

41. Nelson Knob. Outcrops on north slope of knob, 1.5 mi (airline) southwest of Norwood. Reconnaissance section. Science Hill quadrangle. 1,950′FNL x 2,150′FEL, 6-H-59. Monteagle (Ste. Genevieve).

42. Norwood. Outcrops on east side of hill, 0.4 mi (airline) west of Norwood. Reconnaissance section. Science Hill quadrangle. 400′FSL x 1,800′FEL, 4-H-59. St. Louis (Burnside), Monteagle (Ste. Genevieve).

43. Holtzclaw Knob. Abandoned quarry on south side of knob; north side of Norwood Road, 0.6 mi east of junction with U.S. Highway 27. Reconnaissance section. Bobtown quadrangle. 2,800′FNL x 1,000′FEL, 3-H-59. Monteagle (Ste. Genevieve, Mill Knob).

44. Mount Zion South. Outcrops on hilltop, 0.6 mi (airline) southeast of Mount Zion. Reconnaissance section. Science Hill quadrangle. 2,400′FNL x 600′FEL, 21-I-58. St. Louis (Burnside), Monteagle (Ste. Genevieve).

45. Dungan Knob. Outcrops in pasture on south side of knob, 1 mi north of Science Hill (intersection of Ky. Highways 635 and 1247). Reconnaissance section. Science Hill quadrangle. 2,350′FSL x 850′FEL, 17-I-59. St. Louis (Burnside), Monteagle (Ste. Genevieve, Lost River).

46. The Kentucky Stone Co. Pulaski Quarry. Active quarry on west side of Ky. Highway 1003, 0.7 mi south of junction with Ky. Highway 80. Measured section. Shopville quadrangle. 2,200′FNL x 400′FWL, 8-H-61. Slade (Renfro, Burnside, Ste. Genevieve, Lost River, Warix Run, Mill Knob, Cave Branch).

47. Stab. Outcrops along east side of Buck Creek, beneath Ky. Highway 80 bridge, and roadcuts along Ky. Highway 80 from Buck Creek bridge eastward to junction with Ky. Highway 1675. Measured section. Shopville quadrangle. 800′FSL x 1,200′FEL, 2-H-61 Slade (Burnside, Ste. Genevieve, Warix Run, Mill Knob, Cave Branch).

48. Elmo Greer & Sons Price Valley Quarry. Active quarry on north side of Ky. Highway 80, 1.3 mi east of junction with Ky. Highway 1675. Reconnaissance section. Shopville quadrangle. 2,400′FNL x 200′FWL, 5-H-62. Slade (Warix Run, Mill Knob, Cave Branch).

49. Shopville. Roadcut along north side of Ky. Highway 80, 1.6 mi east of junction with Ky. Highway 461 at Shopville post office. Reconnaissance section. Shopville quadrangle. 2,300′FSL x 1,300′FEL, 4-H-61. Slade (Burnside, Ste. Genevieve).

50. Flat Lick Creek. Roadcuts along Ky. Highway 461, north of bridge across stream, 0.5 mi northeast of junction with Ky. Highway 80 at Shopville post office. Reconnaissance section. Shopville quadrangle. 700′FNL x 1,500′FWL, 5-H-61. Slade (Renfro, Ringgold).

51. Flat Lick Knob. Roadcuts along Ky. Highway 461, 2.1 mi northeast of junction with Ky. Highway 80 at Shopville post office. Reconnaissance section. Shopville quadrangle. 50′FNL x 2,300′FEL, 24-I-61. Slade (Renfro, Burnside, Ste. Genevieve).

52. Valley Oak. Roadcuts along east side of Ky. Highway 461, 2.8 mi northeast of junction with Ky. Highway 80 at Shopville post office. Reconnaissance section. Shopville quadrangle. 2,000′FNL x 400′FEL, 17-I-61. Slade (Renfro, Big Sinking equivalent, Burnside).

53. Leroys School. Roadcuts along Ky. Highway 461, 0.7 mi northeast of Buck Creek bridge. Reconnaissance section. Shopville quadrangle. 500′FSL x 600′FEL, 8-I-61. Slade (Burnside, Ste. Genevieve).

54. Sunnyside Church South. Roadcuts along Ky. Highway 461, northeast of south junction with Sunnyside Church Road. Reconnaissance section. Shopville quadrangle. 3,050′FNL x 1,850′FWL, 9-I-61. Slade (Warix Run, Mill Knob).

55. Fanny Knob. Roadcuts along Ky. Highway 461, 0.4 mi northeast of south junction with Sunnyside Church Road. Reconnaissance section. Shopville quadrangle. 1,000′FNL x 1,150′FEL, 9-I-61. Slade (Mill Knob, Cave Branch).

56. Plato-Vanhook. Roadcuts along Ky. Highway 461, north of junction with Plato-Vanhook Road. Reconnaissance section. Shopville quadrangle. 1,600′FNL x 650′FWL, 1-I-61. Slade (Mill Knob, Cave Branch).

57. Mount Pleasant Church. Roadcuts along Ky. Highway 461, 0.4 mi south of Pulaski-Rockcastle county line. Measured section. Maretburg quadrangle. 2,400′FSL x 1,350′FWL, 21-J-61. Slade (Renfro, Big Sinking equivalent, Burnside, Ste. Genevieve, Warix Run, Mill Knob).

58. Warren Knob. Outcrops on east side of knob, 0.5 mi west of Clarence. Reconnaissance section. Woodstock quadrangle. 2,500′FNL x 200′FWL, 14-J-60. Slade (Burnside, Ste. Genevieve).

CASEY COUNTY

59. Elliott Knob. Outcrops on east slope of knob, 1.3 mi (airline) south of Lawhorn Hill. Reconnaissance section. Yosemite quadrangle. 900′FNL x 2,100′FWL, 19-J-56. Monteagle (Ste. Genevieve, Lost River).

60. Casey Stone Co. Bethelridge Mine. Portal of active mine and outcrops on Rocky Knob above portal; northeast side of Ky. Highway 70, 1.0 mi northeast of Bethelridge post office. Measured section. Mintonville quadrangle. 1,050′FNL x 650′FEL, 2-I-57. St. Louis (Bronston, Burnside), Monteagle (Ste. Genevieve).

61. Brown Ridge. Outcrops in fields on upper part of ridge, 0.3 mi (airline) west of Brown Cemetery. Reconnaissance section. Eubank quadrangle. 2,400′FNL x 300′FWL, 25-J-58. St. Louis (Burnside), Monteagle (Ste. Genevieve, Lost River).

62. McClure Knob. Outcrops in pasture along southeast side of Ky. Highway 837, northwest of McClure Knob, 0.3 mi (airline) southwest of Mount Olive. Reconnaissance section. Yosemite quadrangle. 2,300′FNL x 550′FEL, 19-J-57. St. Louis (Burnside), Monteagle (Ste. Genevieve, Lost River).

LINCOLN COUNTY

63. Powell Church. Float on hill, 0.5 mi southwest of Powell Church. Reconnaissance section. Eubank quadrangle. 1,100′FNL x 1,700′FEL, 14-J-59. Monteagle (Ste. Genevieve, Lost River).

ROCKCASTLE COUNTY

64. Friendship South. Roadcuts along Ky. Highway 461, 0.4 mi north of Pulaski-Rockcastle county line. Reconnaissance section. Maretburg quadrangle. 1,500′FSL x 2,500′FWL, 20-J-61. Slade (Renfro, Big Sinking equivalent, Burnside, Ste. Genevieve).

65. Level Green School. Roadcut along southeast side of Ky. Highway 461, 1.4 mi north of Pulaski-Rockcastle county line. Reconnaissance section. Maretburg quadrangle. 700′FSL x 1,400′FEL, 11-J-61. Slade (Renfro, Big Sinking equivalent, Burnside, Ste. Genevieve).

66. Pinnacle Knob. Roadcuts along Ky. Highway 461, 1.9 mi north of Pulaski-Rockcastle county line. Reconnaissance section. Maretburg quadrangle. 2,000′FSL x 300′FWL, 15-J-62. Slade (Renfro, Ringgold, Big Sinking equivalent, Burnside, Ste. Genevieve, Warix Run).

67. Browne Fork. Roadcuts along Ky. Highway 461, 2.5 mi northeast of Pulaski-Rockcastle county line. Reconnaissance section. Maretburg quadrangle. 2,000′FNL x 1,600′FEL, 15-J-62. Slade (Renfro, Big Sinking equivalent, Burnside, Ste. Genevieve).

68. Skegg Creek. Roadcut along northwest side of Ky. Highway 461, 3.1 mi northeast of Pulaski-Rockcastle county line. Reconnaissance section. Maretburg quadrangle. 200′FNL x 1,000′FWL, 14-J-62. Slade (Renfro, Big Sinking equivalent, Burnside, Ste. Genevieve).

69. Jones Creek. Roadcut along west side of Ky. Highway 461, 3.9 mi northeast of Pulaski-Rockcastle county line. Reconnaissance section. Maretburg quadrangle. 2,700′FSL x 1,400′FEL, 7-J-62. Slade (Renfro, Big Sinking equivalent, Burnside, Ste. Genevieve).

70. Wabd North. Roadcuts along Ky. Highway 461, 1.6 mi south of intersection with U.S. Highway 150. Measured section. Maretburg quadrangle. 1,400′FNL x 350′FWL, 3-J-62 Slade. (Renfro, Burnside, Ste. Genevieve, Lost River, Warix Run).

71. Mount Vernon West. Outcrops on north side of U.S. Highway 150 and railroad, and roadcut along south side of U.S. Highway 150, 0.3 mi west of junction with Ky. Highway 2549. Measured section. Mount Vernon quadrangle. 50′FSL x 400′FWL, 19-K-62. Slade (Burnside, Ste. Genevieve).

72. The Kentucky Stone Co. Mount Vernon Quarry. Inactive quarry on north side of U.S. Highway 150, 0.4 mi west of junction with U.S. Highway 25 in Mount Vernon. Measured section. Mount Vernon quadrangle. 800′FSL x 500′FEL, 19-K-62. Slade (Ste. Genevieve, Warix Run, Mill Knob, Cave Branch).

73. Town Branch. Roadcuts along Interstate Highway 75, mileposts 60.6 to 61.1, and outcrops on hillside northwest of roadcuts along northbound lanes, 0.7 mi southeast of interchange with U.S. Highway 25 (Renfro Valley). Measured section. Mount Vernon quadrangle. 100′FSL x 1,100′FWL, 14-K-63. Slade (Burnside, Ste. Genevieve, Warix Run, Mill Knob, Cave Branch).

74. Renfro Valley South. Roadcuts along Interstate Highway 75 and exit ramp at southeast side of interchange with U.S. Highway 25 (Renfro Valley). Measured section. Wildie and Mount Vernon quadrangles. 2,700′FNL x 2,000′FWL, 15-K-63. Borden (Wildie), Slade (Renfro, Science Hill, Ringgold, Burnside, Ste. Genevieve, Lost River).

75. Lake Linville. Roadcuts along west side of Interstate Highway 75 and outcrops on hillside above northern roadcut, 0.3 mi north of Lake Linville. Measured section. Wildie quadrangle. 1,900′FNL x 1,300′FEL, 10-K-62. Slade (Renfro, Science Hill, Ringgold, Burnside, Ste. Genevieve, Warix Run, Mill Knob).

76. Renfro Valley North. Roadcuts along west side of U.S. Highway 25, 0.9 mi north of Renfro Valley. Reconnaissance section. Wildie quadrangle. 1,900′FSL x 700′FEL, 1-K-62. Slade (Renfro, Ringgold, Burnside, Ste. Genevieve).

77. Sigmon Cemetery. Roadcuts along U.S. Highway 25, 2.8 mi north of Renfro Valley. Measured section. Wildie quadrangle. 1,400′FNL x 500′FWL, 25-L-63. Borden (Wildie), Slade (Renfro, Ringgold, Burnside, Ste. Genevieve).

78. Mullins. Abandoned quarry at Mullins, 2.5 mi northeast of U.S. Highway 25 via Mullins Station Road. Reconnaissance section. Livingston quadrangle. 1,300′FNL x 1,850′FWL, 24-K-64. Slade (Renfro, Burnside, Ste. Genevieve, Warix Run, Mill Knob).

79. Orlando. Roadcuts and outcrops along Ky. Highway 1004, 1.1 mi east of bridge across Roundstone Creek at Orlando. Reconnaissance section. Mount Vernon quadrangle. 2,600′FSL x 1,750′FEL, 11-K-63. Slade (Renfro, Big Sinking equivalent, Burnside, Ste. Genevieve).

80. Corinth Church. Roadcuts and outcrops along Halcomb Road, 0.3 mi south of Corinth Church (north Corinth Church). Reconnaissance section. Johnetta quadrangle. 800′FSL x 2,600′FWL, 2-K-64. Slade (Burnside, Ste. Genevieve).

81. Dry Fork. Roadcuts and outcrops along Ky. Highway 1797, 1.4 mi northwest of Owen Allen School. Reconnaissance section. Johnetta quadrangle. 2,800′FSL x 1,100′FWL, 23-L-64. Slade (Burnside, Ste. Genevieve).

82. Morrill. Roadcuts and outcrops along Hammonds Fork Road, 0.5 mi south of junction with U.S. Highway 421. Measured section. Bighill quadrangle. 100′FSL x 1,800′FEL, 19-M-64. Slade (Renfro, Burnside, Ste. Genevieve, Warix Run, Mill Knob).

MADISON COUNTY

83. Bighill. Roadcuts along west side of U.S. Highway 421, 2.3 mi south of Bighill. Measured section. Bighill quadrangle. 1,800′FNL x 1,650′FWL, 19-M-64. Slade (Renfro, Ringgold, Big Sinking, Burnside, Ste. Genevieve, Warix Run, Mill Knob).

84. Tilday Mountain. Outcrops along trail leading up west slope of mountain, 2.3 mi (airline) northeast of Bighill. Measured section. Bighill quadrangle. 500′FSL x 700′FEL, 1-M-64. Slade (Renfro, Ringgold, Burnside, Ste. Genevieve, Warix Run, Mill Knob).

85. Wolf Gap Mountain. Outcrops on north and west slopes of mountain, 0.1 mi east of Wolf Gap. Measured section. Bighill quadrangle. 400′FNL x 600′FWL, 16-N-65. Slade (Renfro, Burnside, Ste. Genevieve, Warix Run, Mill Knob).

JACKSON COUNTY

86. Little Clover Creek. Outcrops on hillside along east side of stream, east of Ky. Highway 1955 bridge. Measured section. Johnetta quadrangle. 700′FNL x 2,150′FEL, 24-L-65. Slade (Burnside, Ste. Genevieve, Warix Run, Mill Knob).

87. Owsley Fork. Outcrops and cuts along unimproved roads and stream banks in upper reaches of Owsley Fork, 1.1 mi (airline) west of Kerby Knob. Measured section. Bighill quadrangle. 2,450′FSL x 50′FEL, 17-M-65. Borden (Nada), Slade (Renfro, Burnside, Ste. Genevieve, Warix Run, Mill Knob).

88. Cane Branch. Outcrops along bulldozed road descending from upland into unnamed hollow, and at mouth of hollow on east side of Cane Branch, 1.0 mi (airline) south of Alcorn. Measured section. Alcorn quadrangle. 1,100′FNL x 700′FEL, 14-M-66. Slade (Renfro, Big Sinking, Ste. Genevieve, Warix Run, Mill Knob).

89. Rock Lick Creek. Bulldozed prospect (“Platinum Mine”) and outcrops on north side of creek, 0.3 mi (airline) west of Big Hollow. Measured section. Alcorn quadrangle. 2,800′FNL x 600′FEL, 13-M-66. Borden (Nada), Slade (Renfro, Big Sinking, Ste. Genevieve).

90. Cavanaugh Creek. Outcrops along unimproved road on east side of stream, 0.6 mi (airline) northwest of Wind Cave post office. Reconnaissance section. Leighton quadrangle. 3,050′FSL x 1,400′FWL, 18-M-67. Borden (Nada), Slade (Renfro, Big Sinking, Ste. Genevieve, covered interval, Mill Knob).

91. South Fork. Outcrops in upper part of unnamed hollow on north side of South Fork of Station Camp Creek, 1.1 mi (airline) northwest of Ky. Highway 89 bridge. Reconnaissance section. Leighton quadrangle. 300′FNL x 700′FEL, 6-M-67. Slade (Big Sinking, Burnside, Ste. Genevieve).

92. Pond School. Roadcuts, outcrops, and abandoned M.A. Walker and Co. quarry along north side of Ky. Highway 89, 2.7 mi south of Estill-Jackson county line. Measured section. Leighton quadrangle. 2,500′FSL x 1,100′FWL, 8-M-67. Slade (Renfro, Big Sinking, Burnside, Ste. Genevieve, Warix Run, Mill Knob).

93. Station Camp Creek. Roadcuts along east side of Ky. Highway 1209, 10 mi south of junction with Ky. Highway 89. Measured section. Leighton quadrangle. 2,800′FSL x 450′FWL, 15-M-68. Borden (Nada), Slade (Renfro, Ringgold, Big Sinking, Ste. Genevieve, Warix Run, Mill Knob).

94. War Fork. Outcrops along banks and in bed of stream, north of mouth of Big Buck Lick. Measured section. McKee quadrangle. 1,900′FSL x 1,400′FWL, 5-L-68. Slade (Renfro, Big Sinking, Ste. Genevieve, Warix Run, Mill Knob).

ESTILL COUNTY

95. Drip Rock. Roadcuts along southeast side of Ky. Highway 89, 2.0 mi south of bridge across Station Camp Creek. Measured section. Leighton quadrangle. 900′FNL x 700′FWL, 23-N-67. Borden (Nada), Slade (Renfro, Ringgold, Big Sinking, Ste. Genevieve, Warix Run, Mill Knob, Cave Branch).

96. Zion Mountain. Outcrops along trails on northeast side of mountain, 1.4 mi (airline) south of Noland. Measured section. Panola quadrangle.

2,050′FNL x 1,700′FEL, 14-N-66. Slade (Renfro, Burnside, Ste. Genevieve, Warix Run, Mill Knob).

97. Big Round Mountain. Outcrops on west and north slopes of mountain, 0.7 mi (airline) west of Noland. Measured section. Panola quadrangle. 300′FNL x 50′FEL, 6-N-66. Slade (Renfro, Burnside, Ste. Genevieve, Warix Run, Mill Knob).

98. Grindstone Hollow. Outcrops on west slope at head of hollow, 1.4 mi (airline) northeast of North Irvine. Measured section. Irvine quadrangle. 3,000′FSL x 2,250′FWL, 8-O-67. Slade (Burnside, Ste. Genevieve, Warix Run, Mill Knob).

99. Sweet Lick Branch. Outcrops along south side of unimproved road on ridge at head of hollow, 0.9 mi northeast of Rawlins Cemetery. Measured section. Irvine quadrangle. 2,200′FNL x 600′FWL, 9-O-67. Slade (Burnside, Ste. Genevieve, Warix Run, Mill Knob).

100. Tipton Ridge. Roadcuts along south side of Ky. Highway 52, 4.1 mi northeast of junction with Ky. Highway 1571 in Ravenna. Measured section. Irvine quadrangle. 2,800′FSL x 2,150′FEL, 14-O-68. Slade (Renfro, Ringgold, Big Sinking, Burnside, Ste. Genevieve, Warix Run, Mill Knob, Cave Branch).

101. Furnace Fork. Roadcuts along west side of Ky. Highway 52, 1.0 mi (airline) northwest of junction with Ky. Highway 975. Measured section. Cobhill quadrangle. 400′FSL x 700′FEL, 13-O-68. Slade (Renfro, Ringgold, Burnside, Ste. Genevieve, Warix Run, Mill Knob, Cave Branch).

102. Furnace South. Outcrops along north side of unimproved road leading from Furnace into valley of Furnace Fork, 0.4 mi (airline) southwest of Furnace. Reconnaissance section. Stanton quadrangle. 2,950′FSL x 650′FEL, 21-P-68. Slade (Renfro, Burnside, Ste. Genevieve).

LEE COUNTY

103. The Kentucky Stone Co. Yellow Rock Mine. Face of former open-pit quarry with portals of active mine, 6.9 mi south of Ky. Highway 52, via Ky. Highway 399 and Yellow Rock Road. Measured section. Heidelberg quadrangle. 2,900′FSL x 1,600′FEL, 4-M-69. Slade (Renfro, Big Sinking, Ste. Genevieve, Warix Run, Mill Knob, Cave Branch).

104. Hatton Hollow. Outcrops, roadcuts, and abandoned quarry along northeast side of Ky. Highway 52, 0.1 mi southeast of bridge across Big Sinking Creek. Measured section. Cobhill quadrangle. 1,100′FSL x 1,000′FWL, 9-N-69. Borden (Nada), Slade (Renfro, Ringgold, Big Sinking, Burnside, Ste. Genevieve, Warix Run, Mill Knob).

105. Big Sinking Creek. Outcrops along north side of stream, 1.4 mi (airline) northeast of Ky. Highway 52 bridge across Big Sinking Creek. Measured section. Cobhill quadrangle. 600′FNL x 1,100′FWL, 10-N-69. Slade (Renfro, Ringgold, Big Sinking, Burnside, Ste. Genevieve, Warix Run, Mill Knob, Cave Branch).

106. Billey Fork. Outcrops along banks and in bed of stream, 2.2 mi (airline) west of Standing Rock. Measured section. Zachariah quadrangle. 550′FNL x 450′FWL, 15-O-70. Slade (Renfro, Big Sinking, Burnside, Ste. Genevieve).

POWELL COUNTY

107. Stump Cave Branch. Roadcuts along west side of Ky. Highway 1639 and outcrops along east side of stream, 4.3 mi south of junction with Ky. Highway 1057. Measured section. Zachariah quadrangle. 300′FNL x 1,850′FEL, 5-O-70. Borden (Nada), Slade (Renfro, Ringgold, Big Sinking, Burnside, Ste. Genevieve, Mill Knob).

108. Rogers Chapel. Roadcuts and outcrops along north side of Ky. Highway 1057, 0.4 mi (airline) north of Rogers Chapel. Reconnaissance section. Stanton quadrangle. 2,000′FNL x 700′FWL, 19-P-69. Slade (Renfro, Big Sinking, Burnside, Ste. Genevieve).

109. High Rock. Roadcuts and outcrops along north side of Ky. Highway 1057, 0.2 mi southwest of junction with Ky. Highway 3354 at High Rock. Measured section. Stanton quadrangle. 300′FSL x 1,550′FWL, 12-P-69. Slade (Renfro, Big Sinking, Burnside, Ste. Genevieve, Warix Run, Mill Knob).

110. Natural Bridge Stone Co. Bowen Quarry. On ridge along east side of Hall Branch; entrance to quarry yard, 1.0 mi southeast of Bowen via Ky. Highway 15. Measured section. Stanton quadrangle. 900′FNL x 850′FWL, 9-P-69. Slade (Renfro, Burnside, Ste. Genevieve, Warix Run, Mill Knob, Cave Branch).

111. Stanton South. Abandoned Works Progress Administration quarry and roadcuts on southwest side of Ky. Highway 213, 1.2 mi (airline) southeast of interchange with Mountain Parkway in

Stanton. Reconnaissance section. Stanton quadrangle. 900′FNL x 2,000′FEL, 1-P-68. Borden (Nada), Slade (Renfro, Ringgold, Burnside, Ste. Genevieve, Warix Run, Mill Knob, Cave Branch).

112. Baker Quarry. Abandoned quarry on ridge on south side of Mountain Parkway, 1.3 mi (airline) southeast of interchange with Ky. Highway 213 in Stanton. Measured section. Stanton quadrangle. 900′FSL x 400′FEL, 21-Q-68. Slade (Burnside, Ste. Genevieve, Warix Run, Mill Knob, Cave Branch).

113. Mountain Parkway. Roadcuts and outcrops along north side of Mountain Parkway, mileposts 34.2 to 34.6, 1.4 mi east of interchange with Ky. Highway 11 at Slade. Measured section. Slade quadrangle. 1,300′FNL x 1,800′FWL, 11-P-70. Borden (Nada), Slade (Renfro, Ringgold, Burnside, Ste. Genevieve, Warix Run?, Mill Knob, Cave Branch).

114. Natural Bridge State Park. Roadcut and outcrops along Ky. Highway 11, 2.9 mi southeast of junction with Ky. Highway 15 at Slade. Measured section. Slade quadrangle. 2,950′FSL x 2,300′FWL, 20-P-70. Borden (Nada), Slade (Renfro, Ringgold, Big Sinking, Burnside, Ste. Genevieve).

WOLFE COUNTY

115. Mill Creek Stone Co. Mill Creek Mine. Mine portals and outcrops on east side of Ky. Highway 11, 4.5 mi southeast of junction with Ky. Highway 15 at Slade. Measured section. Slade quadrangle. 2,500′FNL x 700′FEL, 21-P-70. Borden (Nada), Slade (Renfro, Ringgold, Big Sinking, Burnside, Ste. Genevieve, Warix Run, Mill Knob, Cave Branch).

116. Middle Fork. Roadcuts along Ky. Highway 11 and outcrops along stream, 5.4 mi southeast of junction with Ky. Highway 15 at Slade. Measured section. Zachariah quadrangle. 1,200′FNL x 1,400′FWL, 5-O-71. Slade (Renfro, Big Sinking, Burnside, Ste. Genevieve, Warix Run, Mill Knob, Cave Branch).

## Selected Structural Geology Publications Available from the Kentucky Geological Survey

KGS Bulletin 1 (ser. 11): Barite deposits of Kentucky, by W.H. Anderson, R.D., Trace, and P. McGrain, 1982, 56 p. **$6.00**

KGS Bulletin 3 (ser. 11): Stratigraphic and structural framework of the Carboniferous rocks of the central Appalachian Basin in Kentucky, by D.R. Chesnut Jr., 1992, 42 p., 8 plates. **$12.00**

KGS Information Circular 54 (ser. 11): Cambrian hydrocarbon potential indicated in Kentucky's Rome Trough, by D.C. Harris and J.A. Drahovzal, 1996, 11 p. **$3.00**

KGS Map and Chart Series 5 (ser. 11): Structure on top of the Middle Ordovician High Bridge/Black River Groups in the tristate area of northern Kentucky, southwestern Ohio, and southeastern Indiana, by P.E. Potter, 1993, 1 sheet. **$3.00**

KGS Map and Chart Series 8 (ser. 11): Preliminary map of the structure of the Precambrian surface in eastern Kentucky, by J.A. Drahovzal and M.C. Noger, 1995, 9 p. plus 1 sheet **$12.00**

KGS Report of Investigations 14 (ser. 10): Preliminary report of the oil and gas possibilities between Pine and Cumberland Mountains, southeastern Kentucky, by A.J. Froelich, 1973, 12 p. **$2.00**

KGS Report of Investigations 4 (ser. 11): Mineralization and hydrocarbon emplacement in the Cambrian–Ordovician Mascot Dolomite of the Knox Group in south-central Kentucky, by W.H. Anderson, 1991, 31 p. **$6.00**

KGS Special Publication 14 (ser. 11): The great Central Mississippi Valley earthquakes of 1811–1812, by R. Street and O. Nuttli, 1990, 14 p. **$3.00**

KGS Special Publication 18 (ser. 11): The East Continent Rift Basin: A new discovery, by J.A. Drahovzal and others, 1992, 25 p. **$4.00**

KGS Thesis Series 1 (ser. 11): Stratigraphic relationships in the lower and middle Newman Limestone (Mississippian), east-central and northeastern Kentucky, by G.R. Dever Jr., 1980, 49 p. **$5.00**

KGS Map (ser. 10): Structural geology, Bouguer gravity, and aeromagnetic intensity for a portion of central Kentucky, by D.F.B. Black and others, 1977, scale 1:48,000, 4 sheets **$2.50 per sheet**

U.S. Geological Survey Geologic Quadrangle Maps. **Consult KGS "List of Publications" for specific locations and prices.**

Geological Society of Kentucky Guidebook: Selected structural features and associated dolostone occurrence in the vicinity of the Kentucky River Fault System, by D.F.B. Black and D.C. Haney, 1975, 27 p. **$2.50**

Geological Society of Kentucky Guidebook: Stratigraphic evidence for late Paleozoic tectonism in northeastern Kentucky, by G.R. Dever Jr. and others, 1977, 80 p. **$4.00**

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