



KENTUCKY GEOLOGICAL SURVEY
UNIVERSITY OF KENTUCKY, LEXINGTON SERIES XI, 1980
Donald C. Haney, Director and State Geologist

**STRATIGRAPHIC RELATIONSHIPS
IN THE LOWER AND MIDDLE
NEWMAN LIMESTONE (MISSISSIPPIAN),
EAST-CENTRAL AND
NORTHEASTERN KENTUCKY**

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COVER

Photographic enlargement showing diagenetic texture developed in upper St. Louis Limestone during period of subaerial exposure and vadose diagenesis. Polished slab courtesy of Harry P. Hoge.

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FOREWORD

This thesis was accepted by the Department of Geology and the Graduate School of the University of Kentucky in partial fulfillment of requirements for the degree of Master of Science which was awarded May 1973. The Kentucky Geological Survey is grateful to the author and to the Graduate School for permission to publish this report which deals with Mississippian stratigraphy, depositional environments, and structural relationships in northeastern Kentucky.

ACKNOWLEDGMENTS

The writer gratefully acknowledges the assistance that was provided by many persons during the course of this study. Dr. William C. MacQuown served as thesis director and provided encouragement and help throughout the study. He suggested several lines of inquiry which proved particularly fruitful. Dr. MacQuown and Drs. William R. Brown, Irving S. Fisher, and Bruce R. Moore reviewed the manuscript and contributed suggestions which significantly improved the presentation. Donald W. Hutcheson reviewed parts of the manuscript and offered many helpful suggestions. John E. Kleber, Larry Meadows, and Edward Henson assisted in the field work. Discussions with John C. Horne and John C. Philley were very helpful. Philley also brought several sections in the Morehead area to the writer's attention. The Kentucky Geological Survey furnished support during final preparation of the manuscript. The figures were drafted by Roger B Potts and Terry Hounshell. Karen C. Dever assisted in the field work and typed the manuscript. The writer also wishes to acknowledge the courtesies and assistance extended by quarry operators and numerous landowners in the study area.

This thesis, completed in 1973, was submitted in partial fulfillment of the requirements for the degree of Master of Science at the University of Kentucky.

STRATIGRAPHIC RELATIONSHIPS IN THE LOWER AND MIDDLE NEWMAN LIMESTONE (MISSISSIPPIAN), EAST-CENTRAL AND NORTHEASTERN KENTUCKY

Garland R. Dever, Jr.

ABSTRACT

A complex series of depositional, tectonic, diagenetic, and erosional events are recorded in six lithologic units in the lower and middle Newman Limestone of east-central and northeastern Kentucky. The Newman was deposited during renewed transgression across the area in Late Mississippian time, following regressive deposition of detrital sediments during the Early Mississippian. The Late Mississippian marine advance was interrupted by two periods of renewed uplift along the early Paleozoic Waverly arch, which exposed carbonate sediments to subaerial diagenesis and erosion. Recurrent movement along a Precambrian basement fault system, in association with the second period of movement along the arch, caused differential uplift of the northern part of the area. The tectonic activity was followed by erosional thinning, or, in parts of the area, complete removal of rock units. The effects of uplift and erosion limited or modified the areal extent of deposition during subsequent transgression.

The Newman consists of subtidal, tidal-flat, and supratidal limestones, with lesser amounts of dolomite and detrital clay, silt, and sand. Features developed during exposure to subaerial diagenesis, and the varied areal distribution and thickness of lithologic units furnish the principal evidence of tectonic, diagenetic, and erosional events.

INTRODUCTION

The Newman Limestone (Upper Mississippian) crops out in eastern Kentucky along the western border of the Appalachian basin, in a belt extending along the western border of the eastern Kentucky coal field from the Tennessee state line northeastward to the Ohio River. The Newman consists of calcarenitic, micritic, and fossiliferous limestones, with lesser amounts of shale and dolomite. The underlying Borden Formation and the overlying Pennington Formation (Fig. 1) are composed predominantly of detrital shales and siltstones.

The first use of Newman Limestone as a formational name for the Upper Mississippian carbonate section in the outcrop belt along the western border of the eastern coal field was by Campbell (1898). The name received very limited usage in this outcrop belt until it was reintroduced by Hatch (1963) during the cooper-

ative Kentucky Geological Survey-U.S. Geological Survey areal geologic mapping project. The U.S. Geological Survey divided the Newman into three mappable members for the geologic mapping of 7.5-minute quadrangles in this outcrop belt (Cohee and West, 1965, p. A13; Hatch, 1964; see Simmons, 1967 in Fig. 2). Butts (1922), Stokley and McFarlan (1952), and McFarlan and Walker (1956) correlated the rocks presently designated as Newman Limestone with part of the Upper Mississippian section of western Kentucky (Illinois basin) (Fig. 2).

Many workers have noted lateral variations in the areal distribution of recognizable units within the lower and middle part of the Newman in east-central and northeastern Kentucky, particularly in the occurrence of the units correlated with the St. Louis and Ste. Genevieve Limestones. The patterns of varied areal distribu-

SYSTEM	SERIES	FORMATION OR MEMBER	
PENNSYLVANIAN	LOWER AND MIDDLE	BREATHITT FORMATION	
	LOWER	SANDSTONE MEMBER	
		LEE FORMATION	SHALE MEMBER
MISSISSIPPIAN	UPPER	PENNINGTON FORMATION	
		NEWMAN LIMESTONE	
	LOWER	RENFRO MBR.	
		NADA MBR.	
		BORDEN FORMATION	COWBELL MEMBER
			NANCY MEMBER
			FARMERS MEMBER
		SUNBURY SHALE	
		BEDFORD SHALE	
		DEVONIAN	MIDDLE AND UPPER

Figure 1. Generalized stratigraphic section showing position of Newman Limestone.

tion and thickness have been attributed to the thinning or removal of units by intra-Mississippian erosion and to the depositional thinning of units (McFarlan and Walker, 1956; Patterson and Hosterman, 1962; Shepard, 1964a) or to facies relationships (Ferm and others, 1971; Philley and Dever, 1970; Swinchatt, 1970). In contrast with the variations in lower units of the Newman,

the present distribution of the Reelsville-Beech Creek Limestones and the Haney Limestone of McFarlan and Walker (1956) indicates that they were deposited across the entire area prior to being partly removed by post-Mississippian erosion.

PURPOSE AND SCOPE

The purpose of this study is to determine the origin of the stratigraphic relationships between lithologic units within the lower and middle Newman Limestone. The four upper units in the Newman, designated as the Big Clifty Sandstone equivalent, Haney Limestone, Har-dinsburg Sandstone equivalent, and Glen Dean Limestone by McFarlan and Walker (1956), were not included in the study (Fig. 2). The primary study area is in east-central and northeastern Kentucky and includes parts of Bath, Menifee, Morgan, Powell, Rowan, and Wolfe Counties (Fig. 3). The study indicates that the stratigraphic relationships and the varied areal distribution and thickness of the members in the lower and middle Newman reflect not only the depositional environments of individual members, but also Late Mississippian tectonic activity and subaerial erosion. Renewed uplift along the early Paleozoic Waverly arch and recurrent movement along a Precambrian basement fault system in Late Mississippian time were followed by the erosional thinning or complete removal of units in parts of the area (Fig. 4). The effects of tectonic activity and erosion limited or modified the areal extent of deposition during subsequent transgression.

The structural features and the previously reported record of tectonic activity in northeastern Kentucky are described below. This framework provides for an understanding of the series of events that occurred during deposition of the Newman in the Late Mississippian. The history of deposition, uplift, and erosion described in this paper is supported by a presentation of pertinent information on the lithology, fauna, areal extent, and interpreted depositional environment of each member in the lower and middle Newman, in their order of deposition. A detailed description of the members and a summary of the evidence used by previous workers for interbasinal correlations is provided in Appendix B.

The St. Louis Limestone Member is a formal member of the Newman Limestone (Cohee and West, 1965; Hatch, 1964). The Ste. Genevieve Limestone Member is a formal member of the Newman Limestone (Cohee and West, 1965; Hatch, 1964); however, rocks assigned to the Ste. Genevieve were found to consist of two distinct lithologic units which are separate members of the Newman. The two lithologic units are designated as the southern unit and northern unit of the Ste. Genevieve Limestone Member in this paper. Units designated as the Paoli-Beaver Bend Limestone and Reelsville-Beech Creek Limestone by McFarlan and Walker (1956) are treated as informal members of the Newman in this study (see Appendix B). The Cave Branch Bed (new

BUTTS (1922)	STOKLEY AND McFARLAN (1952)	McFARLAN AND WALKER (1956)	SIMMONS (1967)	NOMENCLATURE OF THIS PAPER		
GLEN DEAN LIMESTONE	GLEN DEAN LIMESTONE	GLEN DEAN LIMESTONE	NEWMAN LIMESTONE	UPPER MEMBER		
GOLCONDA FORMATION	PENCIL CAVE = HARDINSBURG SS.	"PENCIL CAVE" = HARDINSBURG SS.				
GOLCONDA?	GOLCONDA FORMATION	HANEY LIMESTONE				
CYPRESS SS.?	CYPRESS SS.	BIG CLIFTY SS.				
GASPER OOLITE	PAINT CREEK LIMESTONE	REELSVILLE-BEECH CREEK LIMESTONES			NEWMAN LIMESTONE	REELSVILLE-BEECH CREEK LIMESTONE MEMBER
	BETHEL SS.	SAMPLE SS.				CAVE BRANCH BED
BETHEL SS.?	RENAULT LIMESTONE	BEAVER BEND LIMESTONE MOORETOWN SS.				PAOLI-BEAVER BEND LIMESTONE MEMBER
OHARA LIMESTONE MBR.		PAOLI LIMESTONE				
STE. GENEVIEVE LIMESTONE	STE. GENEVIEVE LIMESTONE	STE. GENEVIEVE LIMESTONE				STE. GENEVIEVE LIMESTONE MEMBER
ST. LOUIS LIMESTONE	ST. LOUIS LIMESTONE	ST. LOUIS LIMESTONE				ST. LOUIS LIMESTONE MEMBER
			RENFRO MBR. OF BORDEN FM.			

Figure 2. Correlations of the Newman Limestone with Mississippian units of western Kentucky, and nomenclature of this paper. Members mapped by the U.S. Geological Survey indicated by Simmons (1967).

name) is here designated a formal bed of the Newman Limestone. Formal stratigraphic nomenclature for the two informal members and the northern unit of the Ste. Genevieve will be proposed in a report in preparation. The name Ste. Genevieve Limestone Member should be restricted to the lithologic unit designated as the southern unit of the Ste. Genevieve in this paper.

PALEOZOIC STRUCTURAL FRAMEWORK

The area of study is on the western border of the Appalachian basin and about 40 to 50 miles to the east of the axis of the Cincinnati arch. The principal structural features in the immediate region are: (1) a broad gravity anomaly, (2) a basement fault system, (3) the Waverly arch, (4) the Paint Creek uplift, and (5) surface faults, including the Irvine-Paint Creek fault system and the Little Sandy and Blaine Creek faults (Fig. 4).

A Precambrian platform in northeastern Kentucky, indicated by the gravity anomaly (Fig. 4), was the dominant positive area in the state from Precambrian through Early Ordovician time (McGuire and Howell,

1963). The basement fault system, which formed a steep scarp, separated the northern basement block from the Rome trough to the south. The fault system and scarp have been referred to as a Lower Cambrian coastal declivity (Woodward, 1961), a Cambrian hinge line (McGuire and Howell, 1963), and the Woodward fault zone (Silberman, 1972). The Waverly arch was an axis of low or persistent relief (or an axis of resistance to subsidence) from late Middle Cambrian time through the Early Ordovician; a period of renewed uplift occurred after Black River time (Middle Ordovician) (Woodward, 1961).

The previously reported record of tectonic activity in northeastern Kentucky is summarized in this section. Precambrian to Middle Ordovician activity of elements in the basement fault-Precambrian platform-Waverly arch complex is evidenced by patterns of sedimentation during Cambrian and Early Ordovician time, such as depositional thinning of units across the platform and arch, and by erosional thinning of Lower and Middle Ordovician units (McGuire and Howell, 1963; Silberman, 1972; Woodward, 1961).

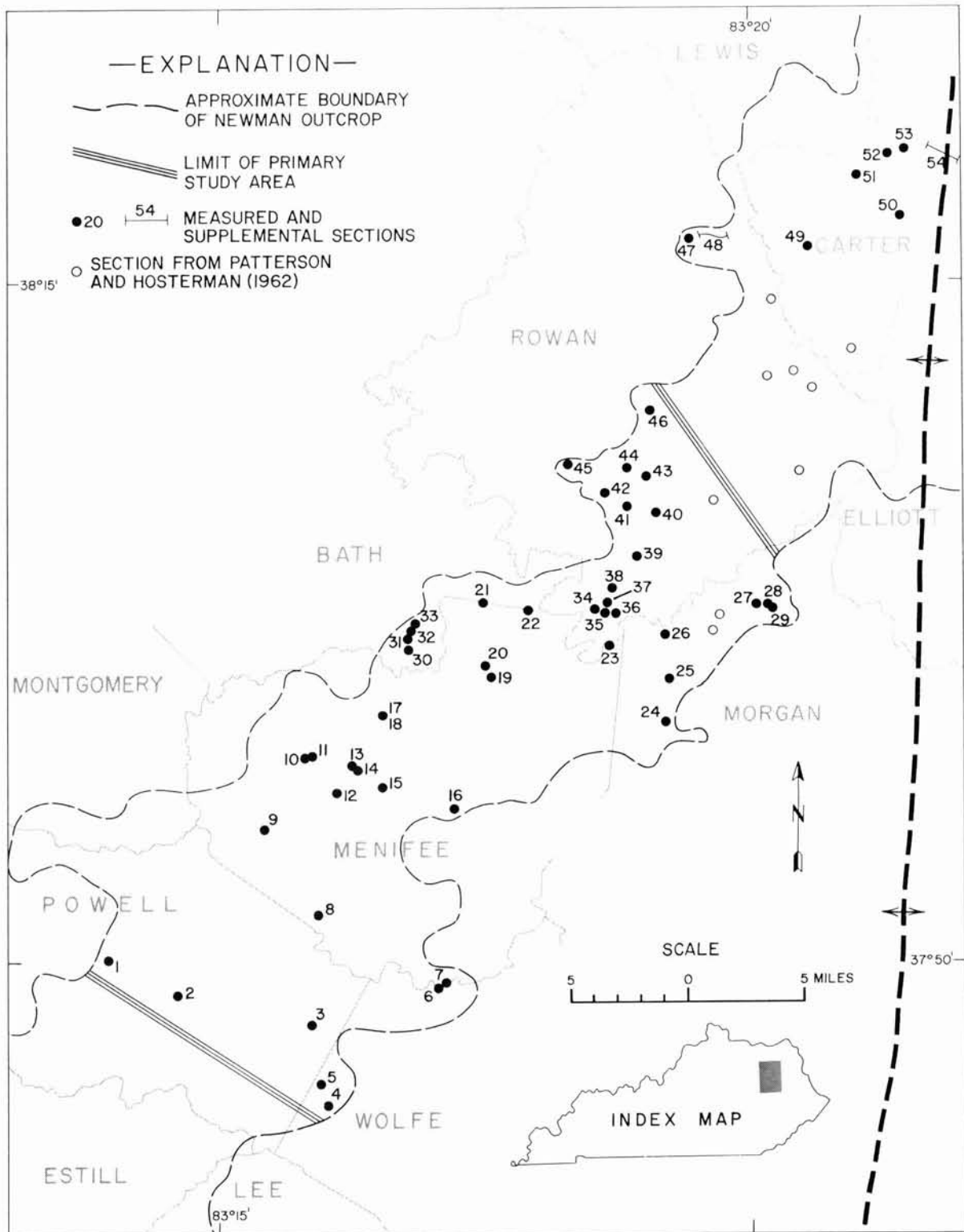
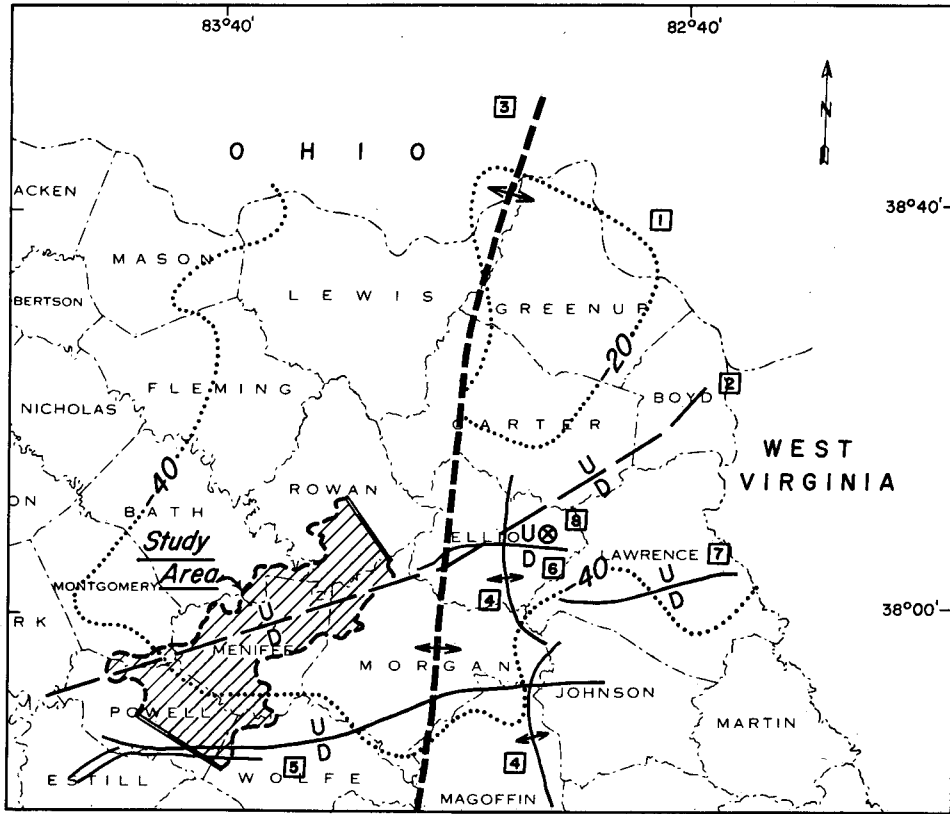


Figure 3. Map showing study area and location of sections (see Appendix A).



EXPLANATION

1-40.....
 BOUGUER GRAVITY ANOMALY
 CONTOUR; CONTOUR INTERVAL
 20 MILLIGALS
 (McGuire and Howell, 1963)

2 ———— U
 D ————
 BASEMENT FAULT
 (Woodward, 1961; Silberman, 1972)

3 ———— +
 -
 AXIS OF WAVERLY ARCH
 LOWER-MIDDLE ORDOVICIAN
 (Woodward, 1961)

4 ———— +
 -
 AXES OF PAINT CREEK UPLIFT
 (Dohm, 1963)

————— U
 D —————
 SURFACE FAULTS
 5 ———— +
 -
 IRVINE-PAINT CREEK SYSTEM
 6 ———— +
 -
 LITTLE SANDY FAULT
 7 ———— +
 -
 BLAINE CREEK FAULT
 (McGuire and Howell, 1963;
 Englund and Delaney, 1966a)

8 ⊗
 PERIDOTITE BODY
 (Koenig, 1956)

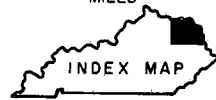
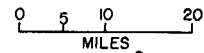


Figure 4. Structural features of northeastern Kentucky.

The Lower Mississippian section in the interval from the top of the Berea Sandstone to the base of the Greenbrier Limestone shows a pronounced thinning across the axis of the northern Paint Creek uplift (Fig. 4), with a maximum loss of section of about 400 feet (Dohm, 1963). Dohm attributed the thinning to vertical movement along the axis during Early Mississippian time, either before or during deposition. Control of the Paint Creek uplift, which trends north-south, was considered to be independent of major features such as the northeast-southwest trending Appalachian structures and east-west faults in the region. The axes of the uplift and the Waverly arch are essentially coincident, and recurrent movement along the arch was suggested as the dominant force in the Early Mississippian and, possibly, the post-Pennsylvanian development of the northern Paint Creek uplift (Dohm, 1963, p. 45, 58-59).

Kearby (1971, p. 54-59) concluded that the Cowbell Member of the Borden Formation (Lower Mississippian) is a lower delta front deposit, with the detrital sediment being derived from a northeast source. Upper delta front and lower delta plain deposits, however, are absent in the interval above the Cowbell; the member is succeeded in turn by the Nada and Renfro Members, which were deposited in shallow marine to supratidal environments. Kearby suggested that after deposition of the Cowbell, uplift of a broad structural feature in the active delta area could have (1) caused cessation of sediment influx by diversion of the distributary system, (2) exposed the Cowbell to erosion in the area of the northern Paint Creek uplift, and (3) formed a shallow marine platform upon which the Nada, Renfro, and the succeeding Newman Limestone were deposited. Uplift was attributed to movement along the Waverly arch in northeastern Kentucky.

Patterson and Hosterman (1962, p. F47) reported that the Pennsylvanian strata dip between 30 and 50 feet per mile to the east and southeast throughout the area of the Haldeman and Wrigley quadrangles, which cover parts of Carter, Elliott, Morgan, and Rowan Counties. Regional dips of the underlying Mississippian units generally conform to the dips of the Pennsylvanian strata, but at a few localities they were found to dip as much as 100 to 150 feet per mile, indicating minor structural warping prior to deposition of the basal Pennsylvanian. Englund (1972) reported that the extent and thickness trends of Mississippian formations beneath the basal Pennsylvanian unconformity in eastern Kentucky and adjacent states show that the Waverly arch was positive in late Paleozoic time.

The east-west trending surface faults (Fig. 4), the Irvine-Paint Creek system, Blaine Creek, and Little Sandy, show post-Pennsylvanian activity. McGuire and Howell (1963, p. 4-2) suggested that the east-west fault systems crossing Kentucky probably are related to the Cambrian hinge line (the basement fault system). Silberman (1972, p. 35) considered the Little Sandy fault to be part of the basement fault complex. An intrusive

peridotite body, described by Koenig (1956) and Hunt and others (1971), is exposed in northeastern Elliott County, in the area between the trace of the Little Sandy fault and the basement fault trace (Fig. 4). The body was dated as Early Permian by Zartman and others (1966). The Permian intrusive activity may have been controlled by the zone of weakness associated with the basement fault system (see Silberman, 1972).

Renewed activity along the early Paleozoic Waverly arch and Precambrian basement fault system in Late Mississippian time, as indicated by this study, should not be unexpected. Elements in the basement fault-Precambrian platform-Waverly arch complex and associated features were active from Precambrian to late Paleozoic time. The present evidence indicates two episodes of tectonic activity, from Precambrian to Middle Ordovician time and from Early Mississippian to Early Permian time.

NEWMAN LIMESTONE

Six lithologic units in the lower and middle Newman Limestone are discussed in this study. Their lithology, fauna, and areal distribution are described. Interpretations of the depositional environments and the effects of tectonic uplift and subsequent erosion upon deposition are presented. The lithologic units, in their order of deposition, are: (1) St. Louis Limestone Member, (2) southern unit of the Ste. Genevieve Limestone Member, (3) northern unit of the Ste. Genevieve Limestone Member, (4) Paoli-Beaver Bend Limestone member, (5) Cave Branch Bed, and (6) Reelsville-Beech Creek Limestone member. The four upper units in the Newman were not included in this study (Fig. 2)

St. Louis Limestone Member

The depositional sequence of deep-water shale, deltaic siltstone, shallow-water shale, and intertidal-supratidal carbonate in the Borden Formation (Kearby, 1971) shows progressive marine regression from the area of this study during Early to early Late Mississippian time. The Newman was deposited during a period of renewed transgression in Late Mississippian time and the St. Louis Limestone Member was deposited during the initial marine advance across the area. The member's areal distribution is shown in Figure 5. Interpretations presented below indicate that the St. Louis mainly consists of subtidal carbonates; the upper part of the unit was altered by subaerial diagenesis following regional tectonic uplift.

Relationship with the Underlying Borden Formation

Throughout its area of occurrence, the St. Louis is underlain by the Renfro Member of the Borden. Relict laminations and birdseye structures in the Renfro dolomite have been considered indicative of deposition in a supratidal (Philly, 1971) or intertidal to

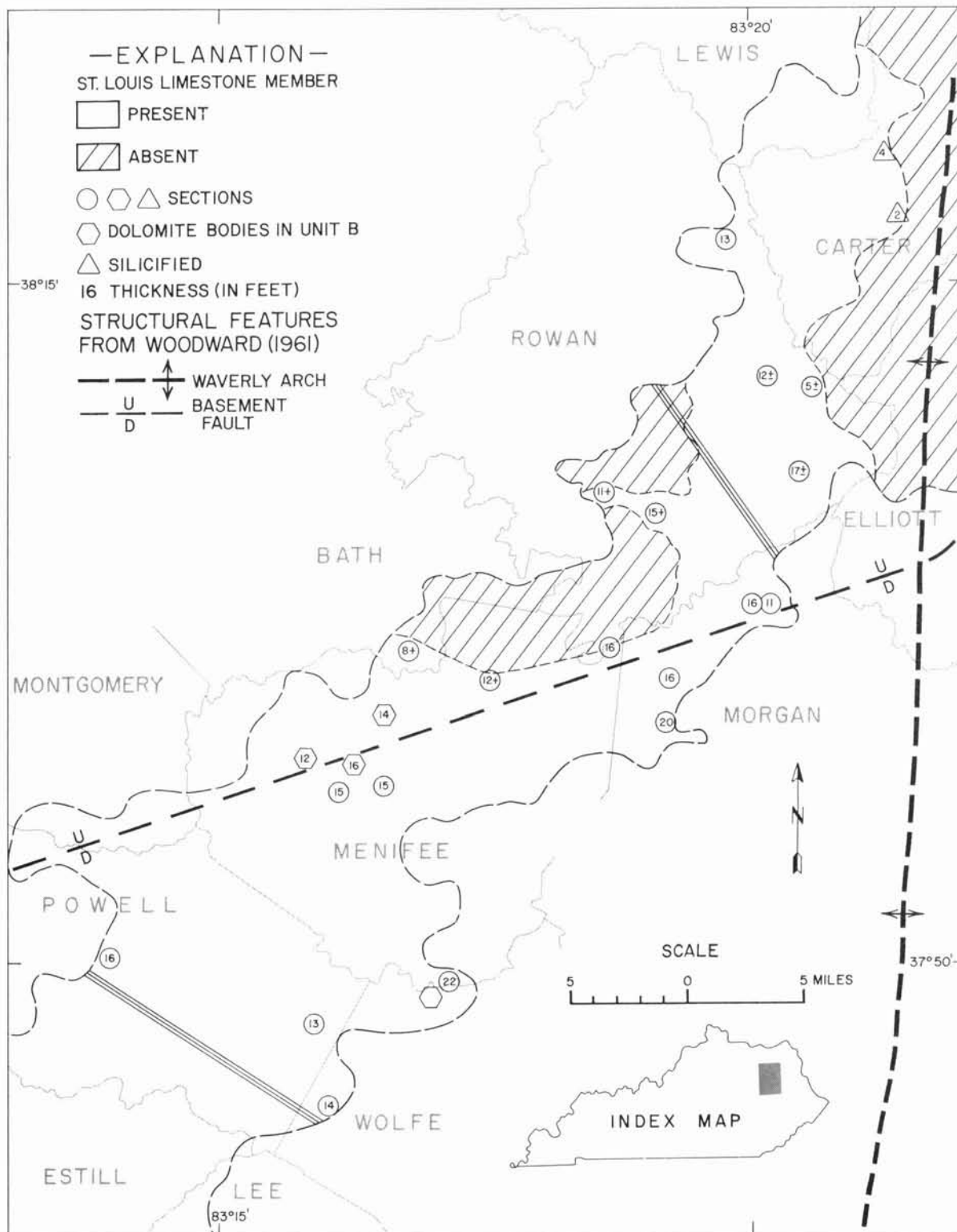


Figure 5. Areal distribution of St. Louis Limestone Member, thickness in representative sections, and occurrence of dolomite bodies in Unit B. Distribution data in part from sources cited in Appendix B. Thickness data in part from Patterson and Hosterman (1962).

supratidal environment (Kearby, 1971). Horizontal laminations and mat-like structures in the unit commonly are broken by vertical features which resemble desiccation cracks. The characteristics of the basal St. Louis overlying the Renfro are indicative of subtidal deposition, as described below. The wavy to very irregular surface between the two units evidently represents a diastem or minor unconformity, formed during the period between cessation of supratidal deposition and subsequent subtidal deposition.

The upper surface of the Renfro in Menifee, Powell, and Wolfe Counties is cut by narrow channel-like depressions, up to 45 inches deep, which are filled with St. Louis limestone (Fig. 6). Though exposures of their third dimension are very limited, they appear to resemble the littoral surge channels developed in semi-consolidated marsh sediments on Cabretta Island, Georgia (Hoyt, 1970) and in Precambrian phyllite and graywacke on wave-cut platforms along the coast of South West Africa (Wright, 1964; Smith, 1964). The maximum depth (45 inches) of the depressions is between the depth range of the shallow 2- to 12-inch Cabretta Island channels and the South West African channels which are as much as 21 feet deep. Surge channels are eroded during transgression (Smith, 1964) and the channel-like depressions may have been developed in a similar manner during marine transgression across the Renfro prior to St. Louis deposition.



Figure 6. Channel-like depression in upper surface of Renfro Member of the Borden Formation, along Ky. Highway 715, southern Menifee County. Depression was filled with limestone during deposition of the overlying St. Louis Limestone Member. RFO, Renfro; STL, St. Louis.

Lithology and Environmental Interpretation

The St. Louis in the study area consists of three distinct lithologies, which, following Philley (1971), are designated A, B, and C (Fig. 7). The position of these lithologies within the member is shown in Figure 8.

Unit A is composed predominantly of micritic lime-

stone containing abundant fossils, both whole and fragmented. The faunal remains (fenestrate bryozoans, pelmatozoans, productoids and other brachiopods, and colonial rugose corals) indicate that the lime mud was deposited in a subtidal environment suitable for supporting a community of sessile, benthonic suspension feeders. In general, the organisms would have required well-oxygenated, clear, circulating water, a firm substrate, and slow deposition of sediment (Heckel, 1972; Schopf, 1969; Wells, 1957). Productoids, however, evidently were adapted for resting on or floating in a soft substratum (Rudwick, 1965). Though the brachiopods probably were more tolerant of turbid conditions than the other suspension feeders, they could not tolerate rapid sedimentation. The structural similarity of modern cidaroids and Paleozoic forms, which include the echinoid *Archaeocidaris* occurring in Unit A, are sufficient to imply similar ecological relationships (Fell, 1966). Cidaroids are predators and predation by the *Archaeocidaris* population may have contributed to the abundance of skeletal debris in the unit. Most modern forms prefer a hard substrate (Fell, 1966) and echinoids generally prefer clear water (Heckel, 1972, p. 281). The fossils and lithology suggest an environment below effective wave base where fine sediment could have settled out slowly, but where currents were sufficient to supply oxygen and nutrients to the benthonic fauna.

Unit B, which overlies and intertongues with Unit A (Fig. 8), consists of thin-bedded limestone (micrite with intercalated bioclastic calcarenite) with intercalated shale. The faunal remains (fenestrate bryozoans, brachiopods, and pelmatozoans) are all forms indicative of a subtidal environment. Fossils are relatively sparse in much of the micritic limestone; they are commonly concentrated in thin zones within beds and on the upper surfaces of beds, occurring beneath and within the intercalated shales. The vertical sequence of barren micrite and thin zones containing the abundant remains of suspension feeders may reflect alternating periods of rapid and slow carbonate deposition. The state of preservation of bryozoan fronds and brachiopods on the upper bedding surfaces suggest these suspension feeders were killed in-place by the rapid influx of detrital clay.

A general model of clear water sedimentation described by Irwin (1965), and discussed by Heckel (1972), shows that, in the subtidal environment, lime mud would settle out in the deeper water below effective wave base, and that shoreward, skeletal sand would be formed and accumulate in the shallower, agitated water where effective wave base intersects the bottom surface. Intercalation of micrite and bioclastic calcarenite in Unit B may record fluctuations, landward and seaward, in the position where effective wave base intersected the sea floor. The carbonate mud settling in the deeper water zone is derived from the wave-agitated zone. Unit A was deposited at a sufficient distance seaward from the agitated zone to per-

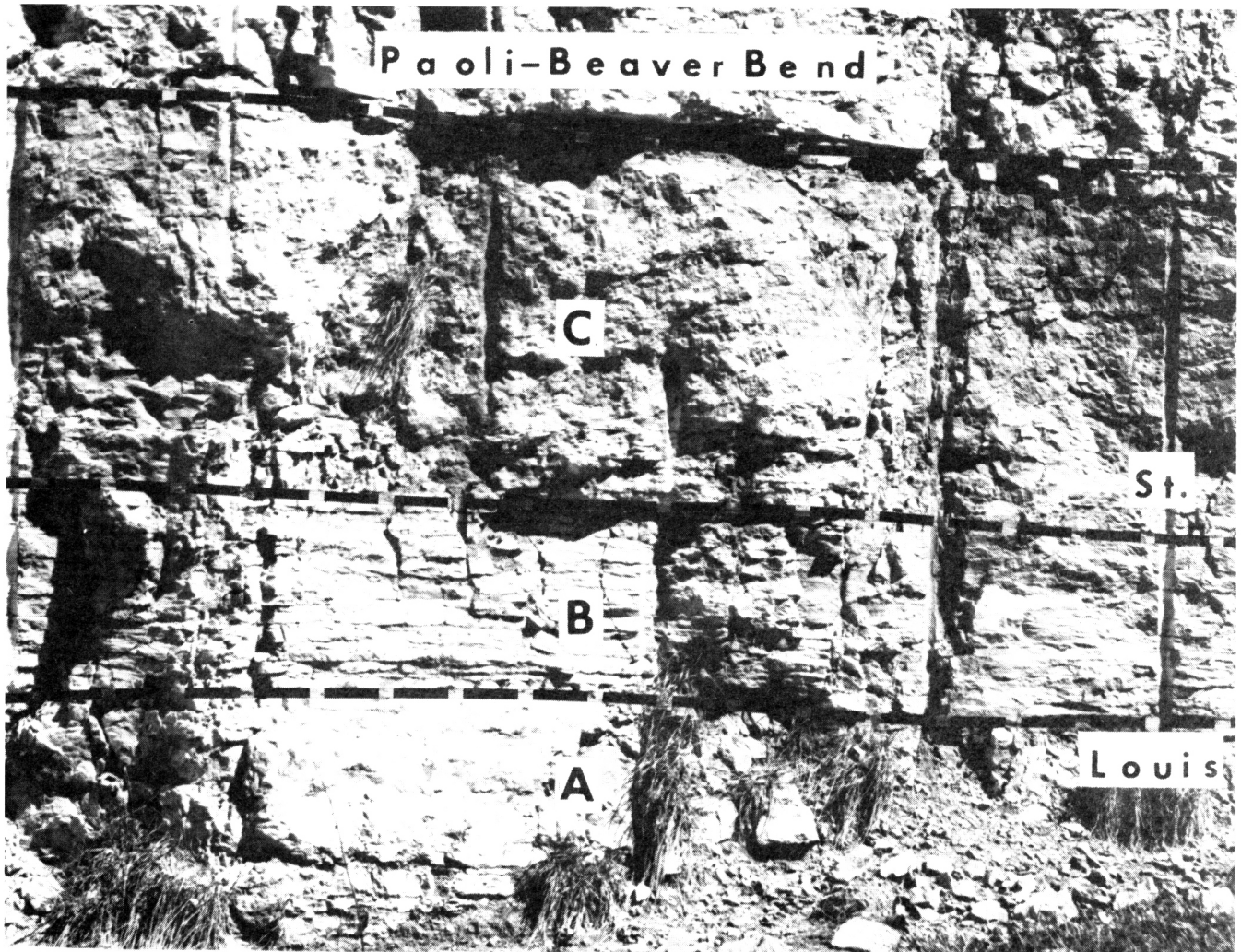


Figure 7. Lithologies A, B, and C in St. Louis Limestone Member, Meniffee County (Section 23S).

mit slow settling of the mud. The intercalation of micrite and calcarenite suggests that Unit B was deposited shoreward near and, at times, within the zone of wave-agitated water. Intertonguing of Units A and B in the southern and central area records lateral migration of these zones resulting from minor transgression and regression.

Unit C forms the upper part of the St. Louis throughout the area (Fig. 8) and, in contrast with the underlying subtidal units, is characterized by the presence of features considered to be indicative of subaerial exposure and diagenesis. Brecciated limestone is a prominent constituent. The breccia consists of lithologies essentially the same as those occurring in Unit B and is complexly interlayered with zones of laminated micritic structures, coated grains and particles, and limestone with a chalky appearance (Fig. 9).

The laminated structures at the top of the St. Louis in Rowan County (Section 48) were interpreted by Ferm

and others (1971, p. 25-26) and Horne and others (1971, p. 7) to be a subaerial crust, similar to those developed on limestone bedrock surfaces in the Florida Keys (Multer and Hoffmeister, 1968). The laminated structures occur at multiple levels within Unit C in St. Louis sections throughout the area, but they do not appear to be underlain by a series of subaerial surfaces. Philley (1971, p. 58-65) considered the structures to be algal stromatolites. Multer and Hoffmeister (1968) noted that subaerial crusts superficially closely resemble algal stromatolites.

The individual features and the association of features in the unit closely resemble those described by James (1972) in Holocene and Pleistocene calcareous crust (caliche) profiles developed during subaerial vadose diagenesis of marine limestone on northern Barbados, West Indies. In the Holocene and Pleistocene profiles, the original limestone is highly fractured and brecciated, and, in most profiles, altered to what

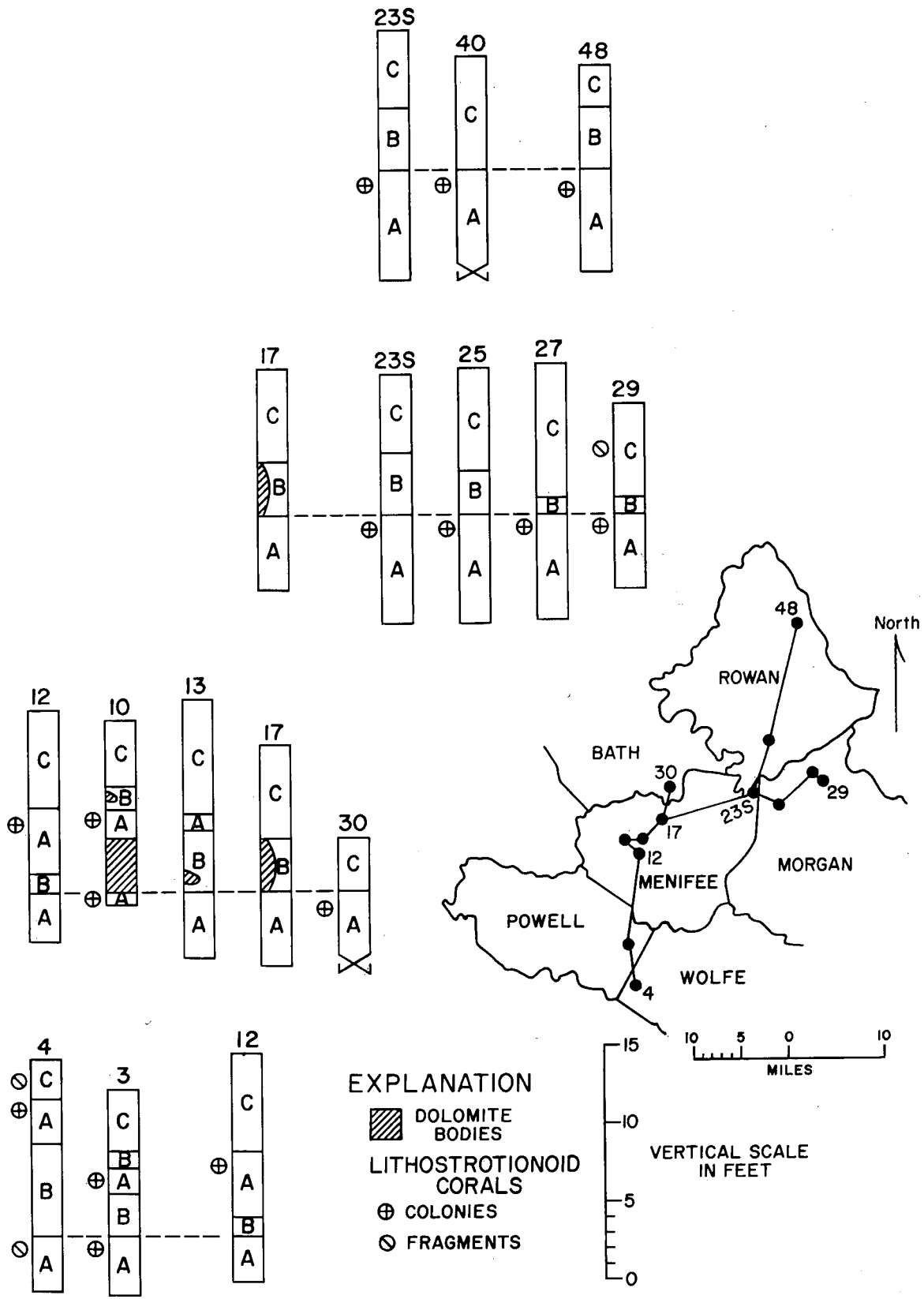


Figure 8. Positions of lithologies A, B, and C within St. Louis Limestone Member in representative sections. Dolomite bodies in Unit B are described in Appendix B.



Figure 9. Brecciated limestone in Unit C of St. Louis Limestone Member, Menifee County (Section 13). Breccia and associated laminated micritic structures and coated grains were developed during a Late Mississippian period of subaerial diagenesis.

James termed chalky carbonate. The limestone surface is veneered by a surficial crust which is underlain by a zone, extending to a depth of several meters, containing additional secondary crusts. The crusts generally consist of interlaminated micrite and needle fibers of calcite. The nuclei (allochems or fragments) of the coated particles in the profiles are enclosed by concentric laminae of micrite and tangential needle fibers of calcite, forming particles identical in appearance to marine oololiths (James, 1972). The most prominent features in Unit C of the St. Louis are zones of laminated micritic structures (interlaminated micrite and crystalline calcite), coated grains and particles (in part with concentrically laminated coatings), and limestone with a chalky appearance, all complexly interlayered with brecciated limestone.

The close similarity of individual features and of the association of features in Unit C to those developed in the diagenetic profiles discussed above indicates that the features in the St. Louis were developed during a period of subaerial diagenesis, prior to deposition of the overlying members of the Newman. The diagenetic features appear to be more extensively developed in the St. Louis in the northern and central part of the area than in the southern part. Post-St. Louis erosion was relatively minor and generally affected only the upper part of the member. Diagenetic alteration has masked the origin of the limestone in Unit C. This limestone may have been deposited in a subtidal environment or in intertidal and supratidal environments during regression following marine subtidal deposition (Units A and B).

Tectonic Activity

Interruption of marine deposition and exposure of the St. Louis carbonates to subaerial diagenesis resulted from regional tectonic uplift along the Waverly arch. Uplift of regional extent is indicated by the presence of an erosional unconformity between the St. Louis and the overlying Ste. Genevieve in the Newman outcrop belt as far to the southwest as southern Pulaski County in south-central Kentucky (Butts, 1922, p. 135), approximately 70 miles to the southwest of the study area. The axis of the north-south trending Waverly arch extends through the area immediately to the east of the study area (Fig. 5). Englund (1972) cited evidence indicating that the arch extends southwestward across eastern Kentucky into northern Tennessee, approximately paralleling the Cincinnati arch. As noted in the section on the structural framework, tectonic activity of elements in the basement fault-Precambrian platform-Waverly arch complex and associated features occurred from Precambrian to Early Permian time. Renewed uplift along the early Paleozoic Waverly arch in the Early Mississippian was suggested by Dohm (1963) and Kearby (1971); Englund (1972) reported the arch was positive in the late Paleozoic.

Summary

The St. Louis was deposited during the first transgression across the area following deposition of the Borden Formation. The member mainly consists of subtidal carbonates (Units A and B). Uplift along the Waverly arch interrupted marine deposition and resulted in subaerial exposure of the carbonates. During exposure, the upper part of the St. Louis was altered by subaerial vadose diagenesis (Unit C). The general occurrence of a regressive sequence of subtidal lithologies in the member may reflect the initiation of tectonic uplift. Seaward Unit A commonly is overlain by shoreward Unit B (Fig. 8).

Ste. Genevieve Limestone Member

Rocks previously assigned to the Ste. Genevieve Limestone by Butts (1922) and McFarlan and Walker (1956) and to the Ste. Genevieve Limestone Member of the Newman Limestone by the U. S. Geological Survey were found to consist of two distinct lithologic units. They are designated as the southern unit and northern unit of the Ste. Genevieve Limestone Member in this study. However, these lithologic units are two separate members of the Newman. The southern unit may correlate with the Ste. Genevieve Limestone of western Kentucky. The northern unit is younger than the southern unit and is separated from it by an erosional unconformity. For the most part, the units are mutually exclusive in their areal distribution on the north side of the basement fault system; south of the fault system, both units form relatively widespread deposits (Fig. 10). The relationship between the southern and northern units, their relationships with underlying units, and their environments of deposition are related to tectonic ac-

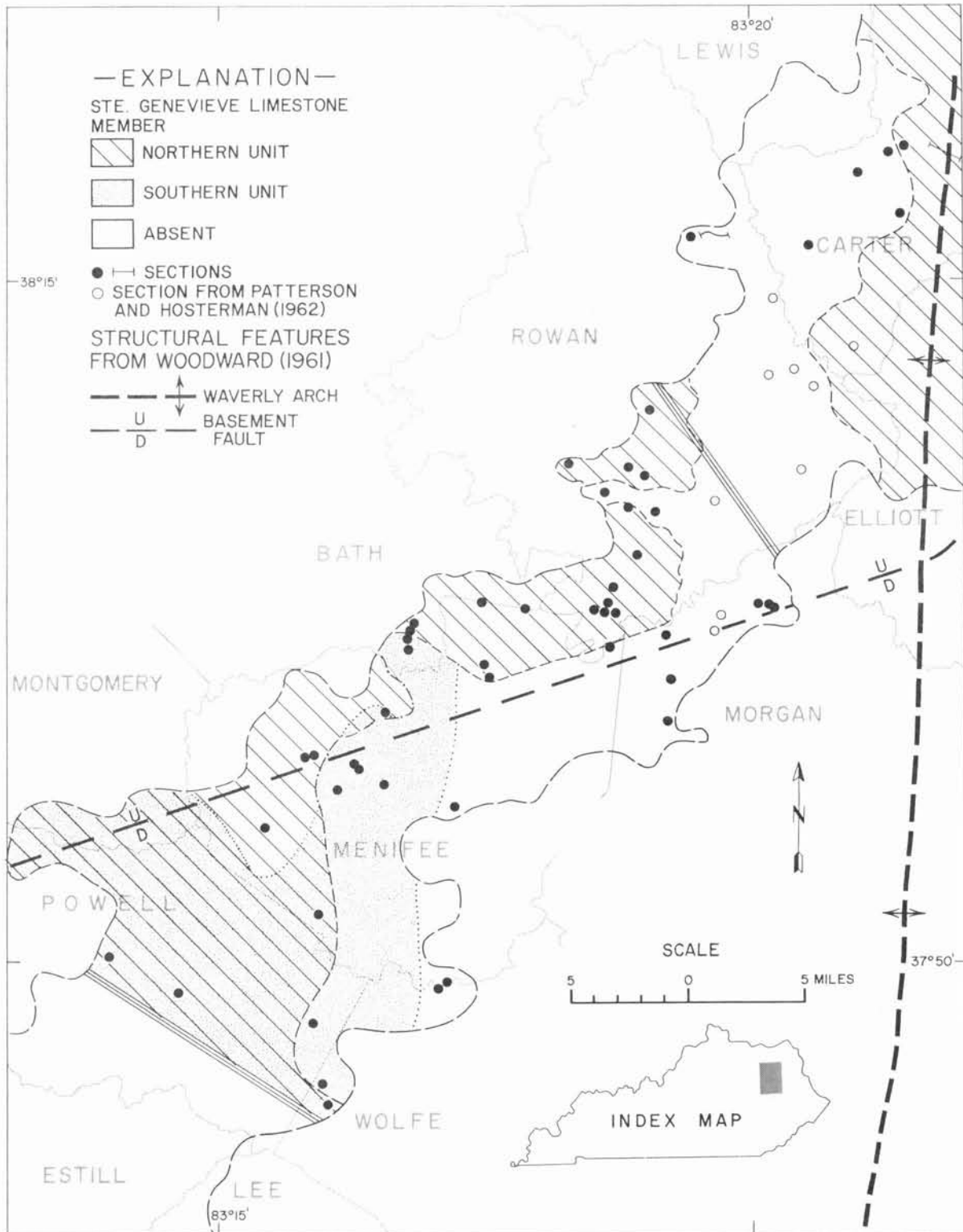


Figure 10. Areal distribution of southern and northern units of Ste. Genevieve Limestone Member. Distribution data in part from sources cited in Appendix B.

tivity. The two units will be considered in their order of deposition.

Southern Unit of the Ste. Genevieve Limestone Member

The southern unit of the Ste. Genevieve Limestone Member (southern Ste. Genevieve) was deposited during the first marine advance into the area following the period of regional uplift and subaerial exposure of the St. Louis. Throughout its area of occurrence, the southern Ste. Genevieve rests unconformably upon the St. Louis.

Lithology and Environmental Interpretation

The southern unit consists of crossbedded calcarenite which grades laterally into micrite. The areal variation of calcarenite and micrite is shown in Figure 11. The calcarenite is composed predominantly of micrite-enveloped grains (Bathurst, 1966) and oololiths, with sparry calcite cement. Composite grains, or lumps (Illing, 1954), and peloids (Bathurst, 1967a; McKee and Gutschick, 1969) are common. Fossils generally are sparse in the unit and mainly consist of skeletal grains in the calcarenite.

The shallow-water depositional environments of modern carbonate sands are thought to be similar to those in which the Mississippian calcarenites were deposited. No evidence was observed in the southern Ste. Genevieve to suggest reworking and redeposition of the sediment at greater depths. Modern oololiths and composite grains are forming and accumulating in water depths of a few meters or less, in areas such as the Bahamas (Bathurst, 1976b). Grains with micrite envelopes are being formed in modern sediments by the repeated process of grain boring by endolithic algae, bore vacation, and subsequent bore filling with micritic carbonate (Bathurst, 1966; 1971). The abundant micrite-enveloped grains in the southern Ste. Genevieve apparently were formed in a similar manner. The peloids probably are grains which were completely replaced by micrite after repeated algal boring, bore vacation, and filling (Bathurst, 1967a; 1971). The depth of formation of algal-bored grains is controlled by light penetration and the amount of solar energy necessary to sustain algal photosynthesis (Swinchatt, 1969). After a study of the distribution of algal-bored sediment in the Great Barrier Reef, Australia, Swinchatt (1969) concluded that an abundance of algal-bored grains indicates deposition at depths less than 120 feet and probably less than 50 to 60 feet. He noted the reported abundance of bored grains in sediments on the Florida shelf and Bahama Banks, areas with maximum water depths of 40 feet and average depths between 12 and 18 feet.

Shallow, protected lagoons behind carbonate sand bodies would have been suitable sites for the deposition of the lime mud which formed southern Ste. Gene-

vieve micrites. Tongues of calcarenite in the micrite may represent washover sands from the seaward carbonate sand bodies. The scarcity of fossil remains in the micrite could indicate possible deposition in the supratidal zone; however, other features characteristic of supratidal deposits generally are absent. Birdseye structures are rare and micrite breccia, where present, generally is restricted to the upper part of the southern unit. If the micrite had been deposited in lagoonal areas, restricted circulation and evaporation of the shallow water could have resulted in hypersaline conditions or salinity and temperature variations unsuitable for the growth of most marine organisms (see Heckel, 1972).

Features considered to be indicative of subaerial exposure and diagenesis are present in the upper part of the southern Ste. Genevieve in the southern part of the area. These consist of laminated micritic structures (interlaminated micrite and crystalline calcite), coated grains and particles (in part with concentrically laminated coatings), limestone with a chalky appearance, and brecciated, leached, and altered rock (Figs. 12 and 13). The laminated structures, coated grains and particles, and chalk-like limestone are similar or identical to those in Unit C of the St. Louis. The close resemblance of individual features and of the association of features in the southern unit to those in the calcareous crust (caliche) profiles described by James (1972) indicate that the features in the southern Ste. Genevieve were developed during a period of subaerial diagenesis. The diagenetic features described by James (1972) were discussed previously in the section on the St. Louis.

The brownish, microcrystalline zone, the Bryantsville Breccia of McFarlan and Walker (1956), at the top of the unit in the southern area may represent a surficial crust, with the micritic zone commonly occurring beneath the crust (James, 1972, p. 820), or both (Fig. 14). A zone comparable to the Bryantsville of McFarlan and Walker (1956) was not observed at the top of the unit in the central area, north of Powell and Wolfe Counties. Erosional thinning of the southern unit may be partly responsible for the general absence of the zone in that area. The southern Ste. Genevieve was subjected to erosion and, locally, was removed in central Menifee County (Fig. 15). An upper breccia zone at Section 13 (Menifee County), reported by Hurd (1960, p. 17, Fig. 11), appears to be an erosional remnant. Laminated micritic structures and associated coated grains occur throughout the unit in parts of Menifee County.

Tectonic Activity

Pre-Ste. Genevieve uplift limited the areal extent of deposition of the southern Ste. Genevieve. Subsequent tectonic activity exposed the southern unit to subaerial diagenesis. The southern Ste. Genevieve was deposited during the first transgression into the area following the period of regional uplift, centered along the Waverly arch, which resulted in subaerial exposure of the St. Louis. The southern unit occurs in a belt along

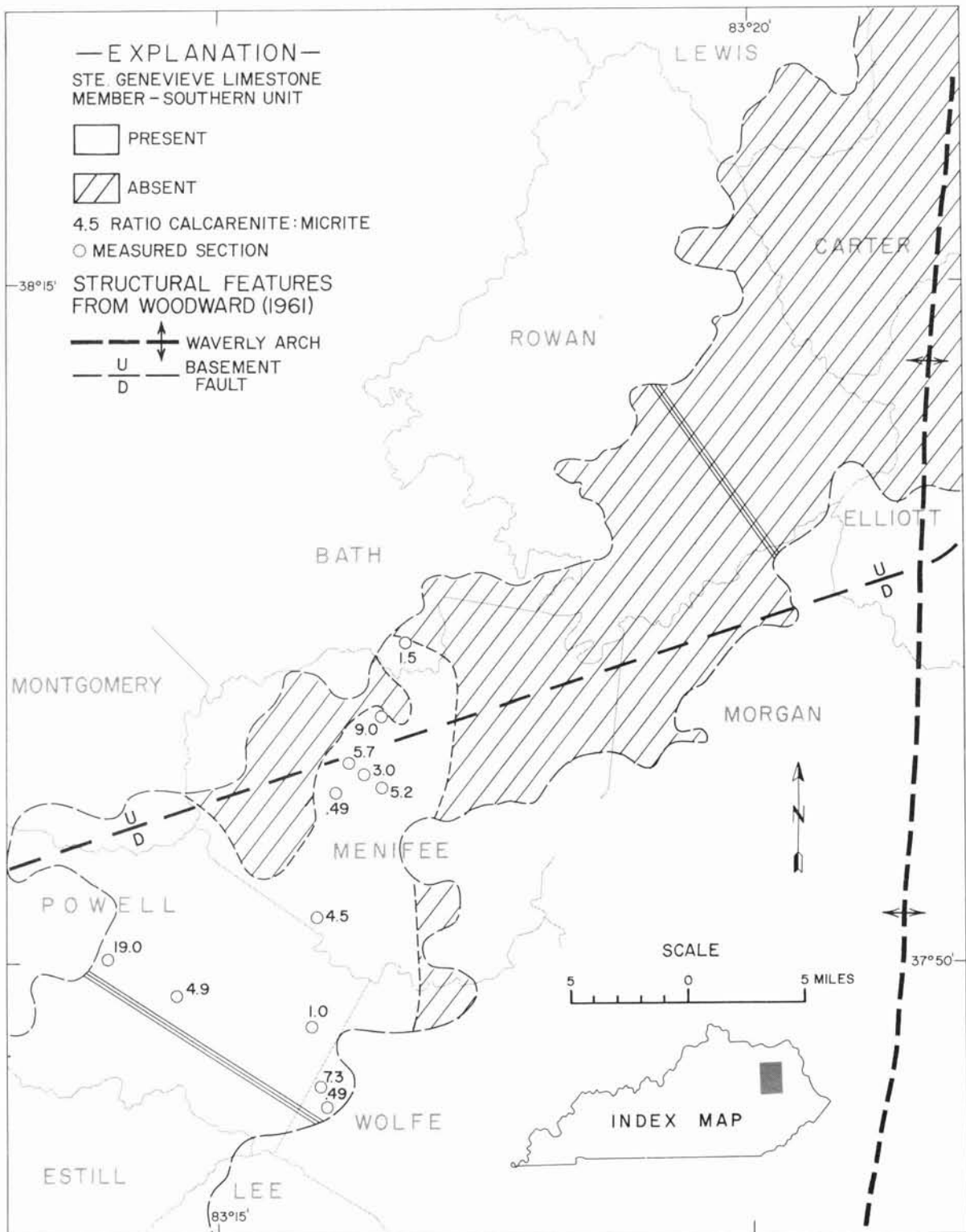


Figure 11. Ratio of calcarenite to micrite in southern unit of Ste. Genevieve Limestone Member.



Figure 12. Zone of altered rock and laminated micritic structures overlying crossbedded calcarenite in southern unit of the Ste. Genevieve Limestone Member, Powell County (Section 1). Altered rock and associated features were developed during a Late Mississippian period of subaerial diagenesis.



Figure 13. Close-up of altered rock and laminated micritic structures in upper part of southern unit of Ste. Genevieve Limestone Member, Powell County (Section 1).

the western flank of the arch (Fig. 10), suggesting that the Waverly arch was a positive feature following the period of uplift and that it restricted the marine advance to the area along its western flank. The southern unit of the Ste. Genevieve has not been found in the Newman outcrop belt northeast of the study area, where the outcrop belt extends across the axis of the arch and northward along its eastern flank. Subaerial diagenetic features in the upper part of the southern Ste. Genevieve indicate that deposition of the unit was followed by a second period of renewed uplift in Late Mississippian time along the early Paleozoic Waverly arch. The progressive eastward overlapping and thinning of post-St. Louis members toward the axis of the Waverly arch indicate that the arch was positive follow-

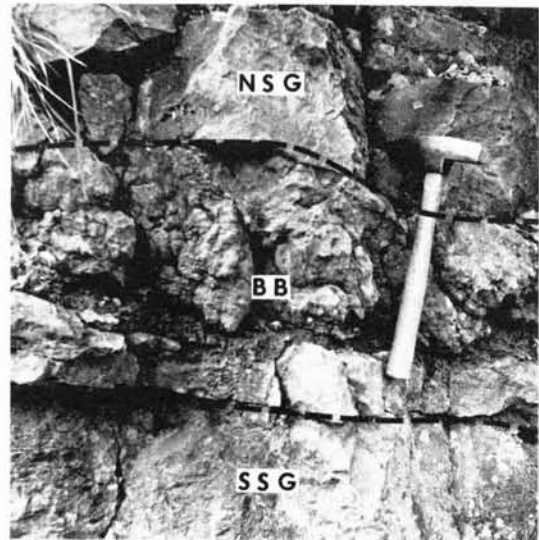


Figure 14. Bryantsville Breccia of McFarlan and Walker (1956) at top of the southern unit of the Ste. Genevieve Limestone Member, Wolfe County (Section 4). SSG, Southern Ste. Genevieve; BB, Bryantsville Breccia; NSG, Northern Ste. Genevieve.

ing both periods of uplift in the Late Mississippian (Fig. 16).

Other tectonic activity during the second period of renewed uplift is suggested by the erosional removal of units on the north, or upthrown, side of the basement fault system. In the northern part of the study area and in the outcrop belt farther to the northeast, erosion cut through the St. Louis, Renfro, Nada, and down into the Cowbell Member of the Borden Formation. Areas where the St. Louis and upper part of the Borden were removed by erosion are restricted to the north, or upthrown, side of the basement fault (Figs. 5 and 17), indicating differential uplift of the northern area as a result of recurrent movement along the Precambrian fault in Late Mississippian time. The southern Ste. Genevieve is abruptly terminated in the area along and north of the fault trace in Bath and Menifee Counties (Fig. 10). Erosional thinning of the southern unit in central Menifee County and its abrupt truncation in the area immediately to the north and northwest indicate that its absence in this area is the result of erosion.

Summary

The southern unit of the Ste. Genevieve was deposited during the first marine advance into the area following the period of uplift and subaerial exposure of the St. Louis. Transgression was restricted to the area along the western flank of the Waverly arch. The unit consists of very shallow subtidal calcarenite (algal-bored grains and oolites) and lagoonal micrite. Re-

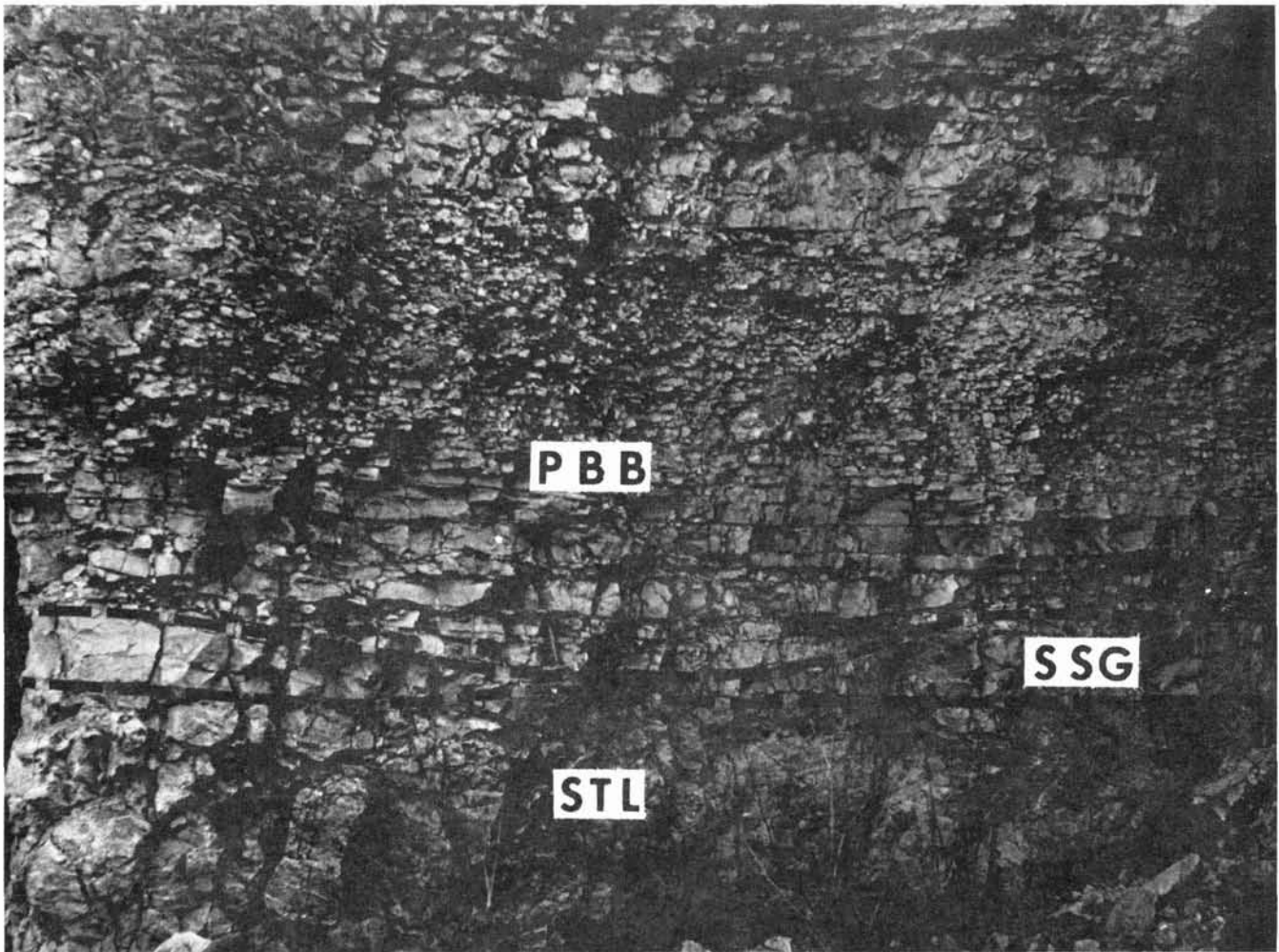


Figure 15. Erosional channel in upper surface of the southern unit of the Ste. Genevieve Limestone Member, Menifee County (Section 13). Geologic hammer at Ste. Genevieve-Paoli-Beaver Bend contract. STL, St. Louis; SSG, Southern Ste. Genevieve; PBB, Paoli-Beaver Bend.

newed uplift along the Waverly arch exposed the southern unit to subaerial diagenesis. Recurrent movement along the basement fault system occurred in association with the uplift along the arch and caused differential uplift of the northern area. Subsequent erosion removed the southern Ste. Genevieve, St. Louis, and upper Borden in parts of the area on the north, or upthrown, side of the fault.

Northern Unit of the Ste. Genevieve Limestone Member

The northern unit of the Ste. Genevieve Limestone Member (northern Ste. Genevieve) was deposited during renewed transgression into the area following the second period of uplift in Late Mississippian time. The carbonates were deposited in low areas on the erosional surface that was developed after the uplift. The unit is represented by a series of isolated limestone bodies in the present outcrop belt (Fig. 10).

Lithology

The northern Ste. Genevieve mainly consists of cross-bedded quartzose calcarenite. Micrite is a relatively minor constituent. It occurs principally in discontinuous beds and laminae, and, locally, contains birdseye structures. Fossils generally are sparse, but include the remains of pelmatozoans, foraminifera, brachiopods, and echinoids(?). Detrital quartz silt and sand (dominantly silt to fine sand) are commonly abundant throughout the unit. Detrital shale generally is sparse, but a lense of shale, up to 6.5 feet thick, occurs locally in Rowan County. Erosional clasts of limestone and chert derived from the St. Louis are present throughout the unit.

The principal constituents in the calcarenite are very fine- to very coarse-grained, rounded to subrounded, spherical to irregularly shaped, light-colored peloids. Several origins for the peloids have been suggested. Philley (1971, p. 77-78) concluded that they were erosional intraclasts. Klekamp (1971, p. 20-21) used the term micritic intraclasts for the peloids, but he indicated

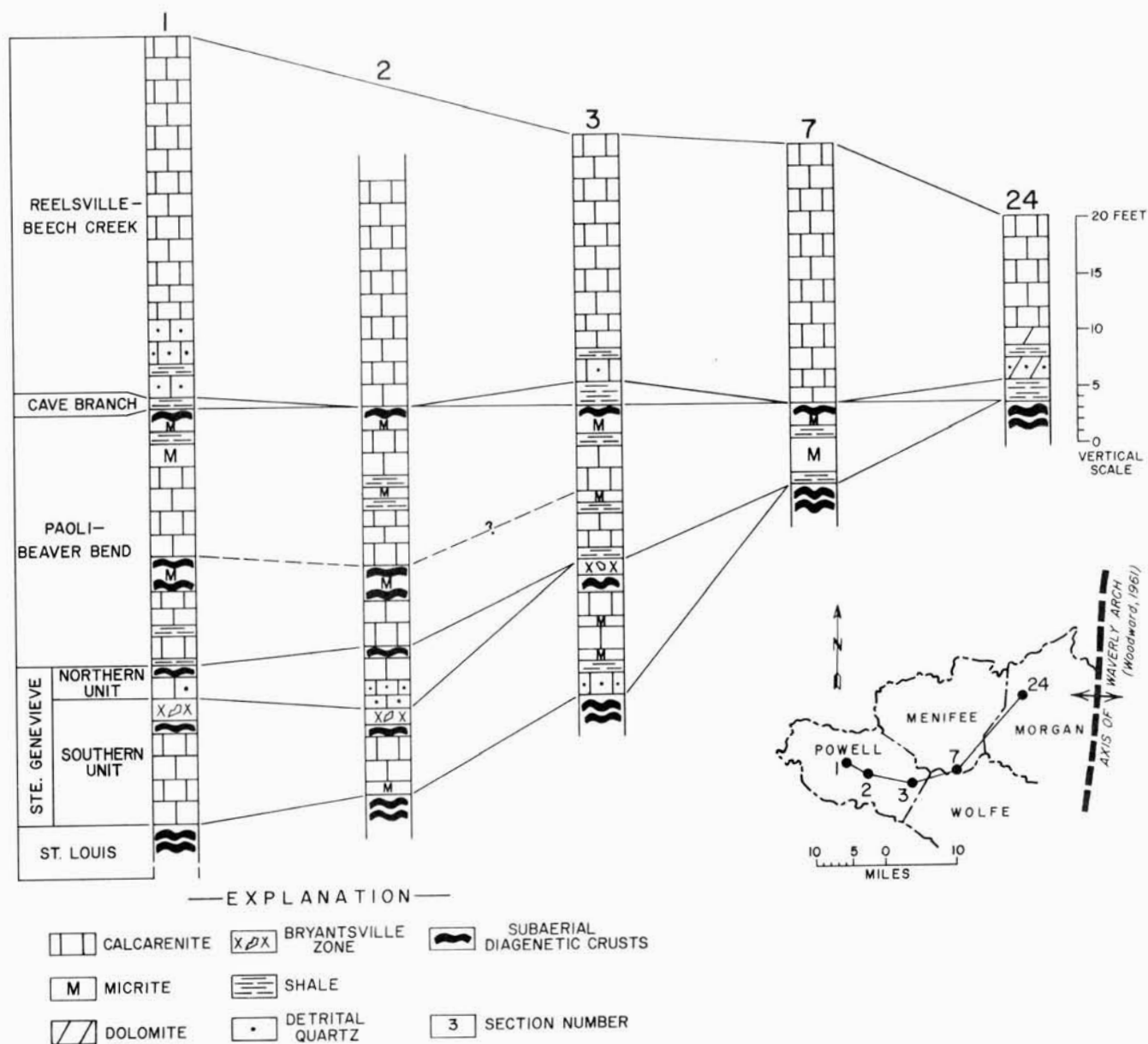


Figure 16. East-west cross section in southern part of study area. Note progressive easterly overlapping and thinning of post-St. Louis members. Datum is base of Cave Branch.

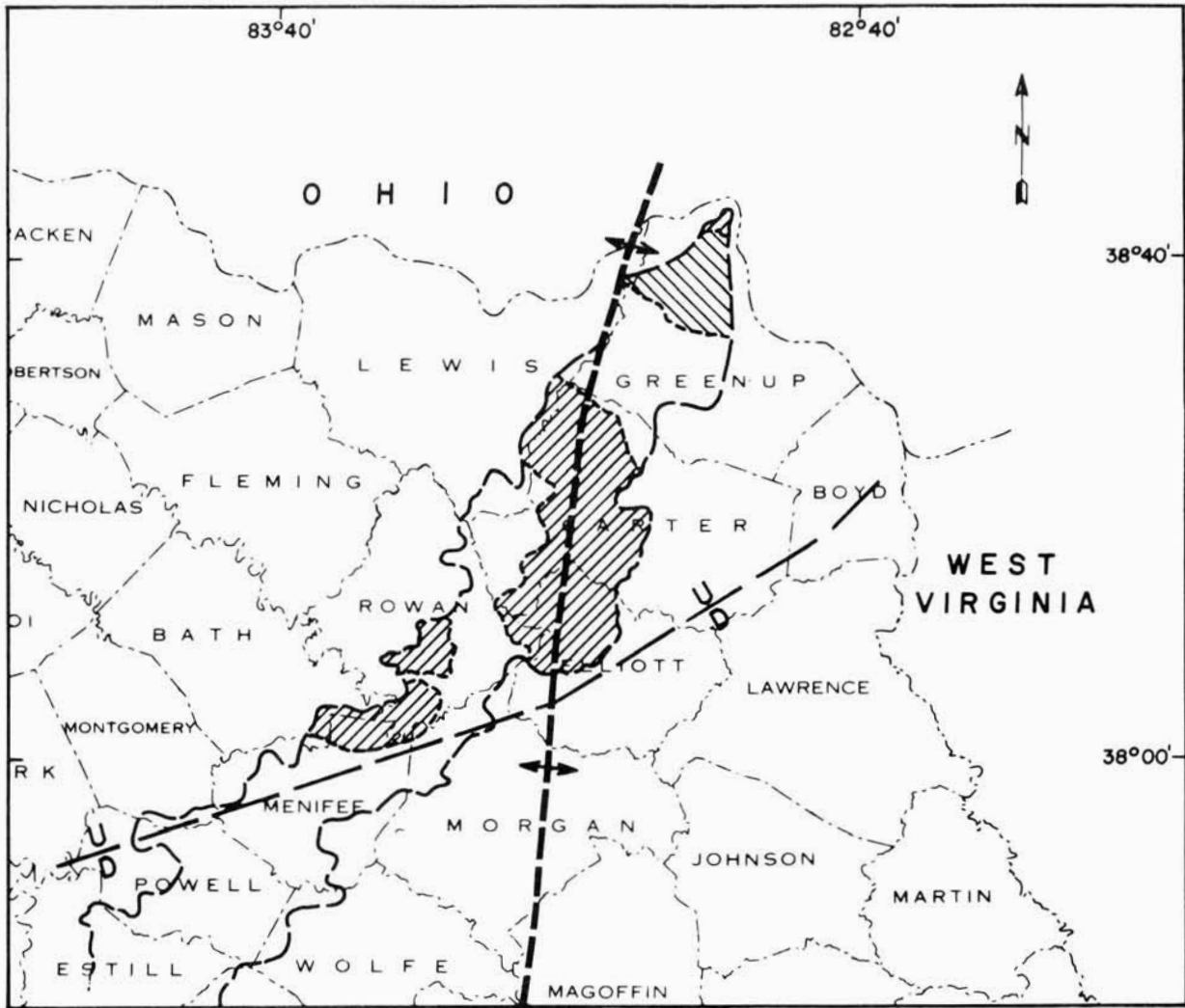
that the presence, in the calcarenite, of a continuum from skeletal grains with micrite envelopes to micritic intraclasts suggested a possible algal origin. Both authors noted evidence that suggested a nonfecal origin.

The northern Ste. Genevieve peloids are not considered to be erosional clasts or intraclasts. In hand specimens of the calcarenite, light-colored peloids are distinguished readily from the sand-sized micrite clasts derived from the St. Louis, which are darker and commonly contain textures characteristic of St. Louis lithologies. The writer favors a micritized grain origin, as suggested by Klekamp (1971). Micritized grains are carbonate grains which have been replaced by micrite after a repeated process of algal boring, bore vacation, and sub-

sequent bore filling with micritic carbonate (Bathurst, 1967a; 1971). Micrite-enveloped grains, oolites, and skeletal grains are sparse to locally abundant in the northern Ste. Genevieve calcarenite, and sand-sized clasts of limestone, derived from the St. Louis, occur throughout the unit. The original grains may have been skeletal grains, oolites, erosional clasts, or a combination of these. Bathurst (1971, p. 381) noted that, in modern sediments, boring endolithic algae cause widespread and wholesale destruction of all types of grains—skeletal, oolitic, and peloidal.

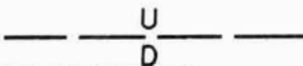
Environmental Interpretation

The lithology, geometry, and areal extent of the northern Ste. Genevieve in the study area indicate that




EXPLANATION

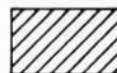



 BASEMENT FAULT
 (Woodward, 1961; Silberman, 1972)




 AXIS OF WAVERLY ARCH
 LOWER-MIDDLE ORDOVICIAN
 (Woodward, 1961)

ST. LOUIS LIMESTONE MEMBER

-  PRESENT
-  ABSENT

NEWMAN LIMESTONE

-  ABSENT

Figure 17. Relationships between major structural features and areas where St. Louis Limestone Member was removed by intra-Mississippian erosion in northeastern Kentucky. Distribution data in part from sources cited in Appendix B.



Figure 18. Northern unit of Ste. Genevieve unconformably overlying the Renfro and Nada Members of the Borden Formation, Menifee County (Section 23N). At Section 23S, about 1,000 feet to the south, the St. Louis Limestone Members rests on the Renfro.

deposition was limited by the erosional topography developed after the second period of uplift in Late Mississippian time, which was previously discussed. Erosion in the area north of the basement fault cut through the southern Ste. Genevieve (where present), St. Louis, and down into the Borden Formation. The southern Ste. Genevieve also was removed in part of the area south of the fault. The northern Ste. Genevieve was deposited during renewed transgression into the area following the period of erosion, and the marine advance invaded the low areas on the erosional surface. In the northern part of the area, the northern Ste. Genevieve rests unconformably upon the Cowbell, Nada, and Renfro Members of the Borden (Fig. 18). In the southern area, it rests unconformably upon the St. Louis and southern Ste. Genevieve (Fig. 19).

Thick deposits of crossbedded calcarenite accumulated in the low areas during the period of transgression and partly filled them (Fig. 20). The local zones of micrite which occur at various levels in the unit show that quiet-water conditions were established temporarily in parts of the areas. The micrite locally contains birdseye structures, which are considered to be indicative of deposition in the supratidal or intertidal zone (Shinn, 1968). The configuration of the two isolated

areas where the northern Ste. Genevieve was deposited in the northern part of the study area suggests that they may have been the upper part of valleys, developed during the period of erosion, which became embayments during subsequent transgression (Fig. 10). The northern Ste. Genevieve generally reaches its maximum thickness in the central part of these areas; it thins and pinches out along the margins of each area.

The lense of shale in the northern Ste. Genevieve occurs near the southern margin of the northernmost area (Fig. 20). The shale resembles that in the Nada Member of the Borden and may represent reworked Nada which was derived from the south shore of the area. The larger clasts of St. Louis limestone and chert mainly occur in the basal part of the unit and along the outer margins, which would have been near shoreline outcrops of the St. Louis at the time of deposition. The provenance of the detrital quartz has not been determined. Klekamp (1971, p. 36) cited previous studies of Mississippian carbonates in the Appalachian basin, possibly correlative with the Ste. Genevieve, which indicate a north or northwest source area for the detrital constituents.

Features considered to be indicative of subaerial exposure and diagenesis are present in the northern Ste.

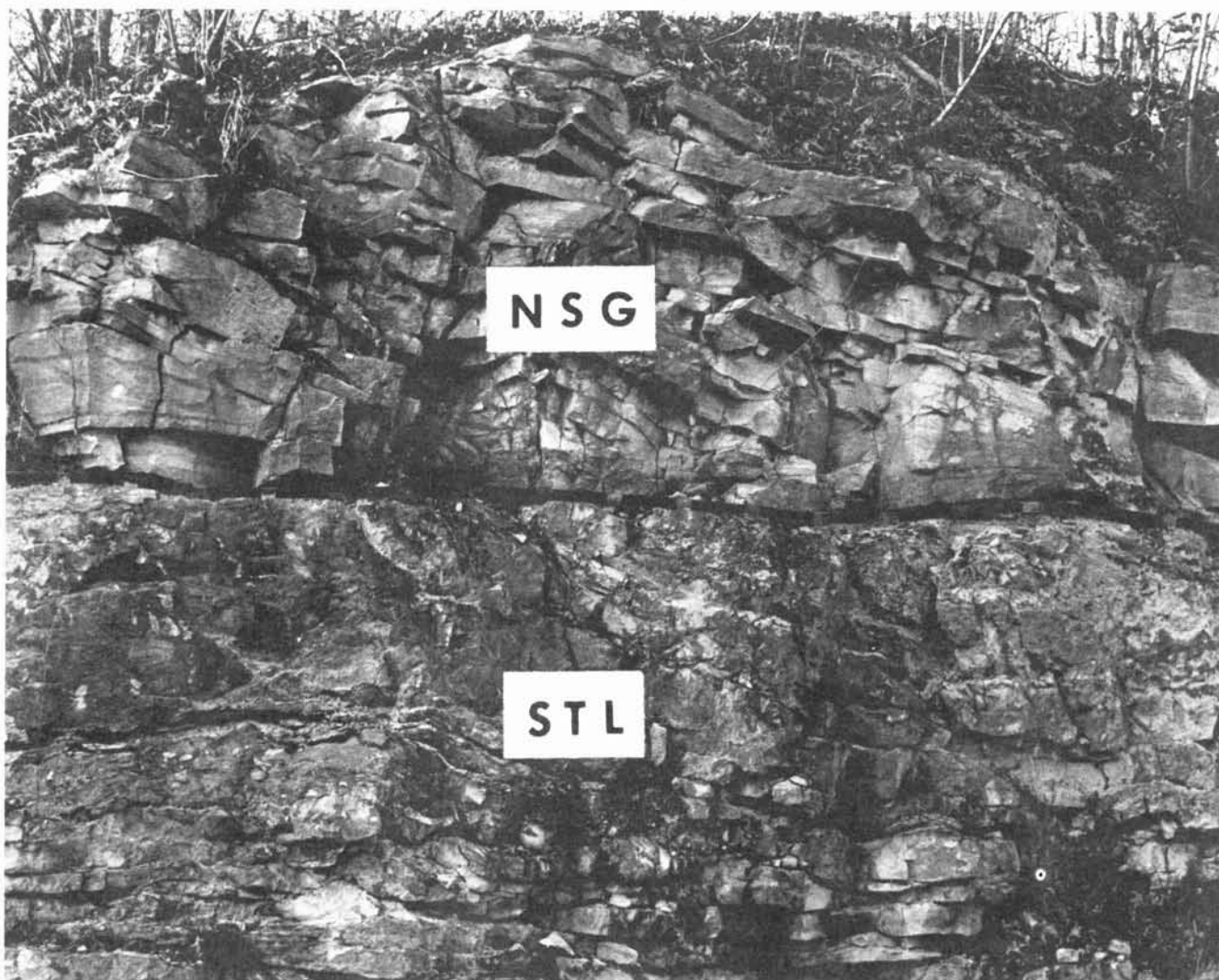


Figure 19. Crossbedded calcarenite of the northern unit of the Ste. Genevieve Limestone Member overlying the St. Louis Limestone Member, Menifee County (Section 10). The two units are separated by an erosional unconformity. STL, St. Louis; NSG, Northern Ste. Genevieve.

Genevieve. Very thin laminated micritic structures, similar or identical to those developed in the St. Louis and southern Ste. Genevieve during subaerial diagenesis, occur locally in the upper few feet of calcarenite. The meager development of the diagenetic features in the unit suggests a relatively brief period of subaerial exposure, which evidently represents a diastem. The contact between the northern Ste. Genevieve calcarenite and the overlying Paoli-Beaver Bend micrite and shale appears to be conformable and to represent only a distinct change in sedimentary regime, from sand deposition to mud deposition.

Interpretations of the depositional environment of the northern Ste. Genevieve in western Carter County, northeast of the study area, were reported by Ferm and others (1971, p. 21-23), Horne and others (1971, p. 7), and Klekamp (1971). Relationships between the Ste. Genevieve, St. Louis, and Renfro in northeastern Ken-

tucky were discussed by Philley (1971). The conclusions of these authors are presented and discussed in a following section on alternative interpretations.

Age of the Northern Ste. Genevieve

The possible Meramecian or Chesterian age of the northern unit of the Ste. Genevieve has not been resolved. The southern unit of the Ste. Genevieve is the youngest unit that was observed underlying the northern Ste. Genevieve in the study area. The southern Ste. Genevieve may be correlative with the Ste. Genevieve Limestone of western Kentucky (see Butts, 1922; McFarlan and Walker, 1956). The findings of this study indicate that the northern Ste. Genevieve and southern Ste. Genevieve are separated by an erosional unconformity. In addition, in sections where the northern unit overlies the southern unit, features formed during subaerial diagenesis are extensively developed in the

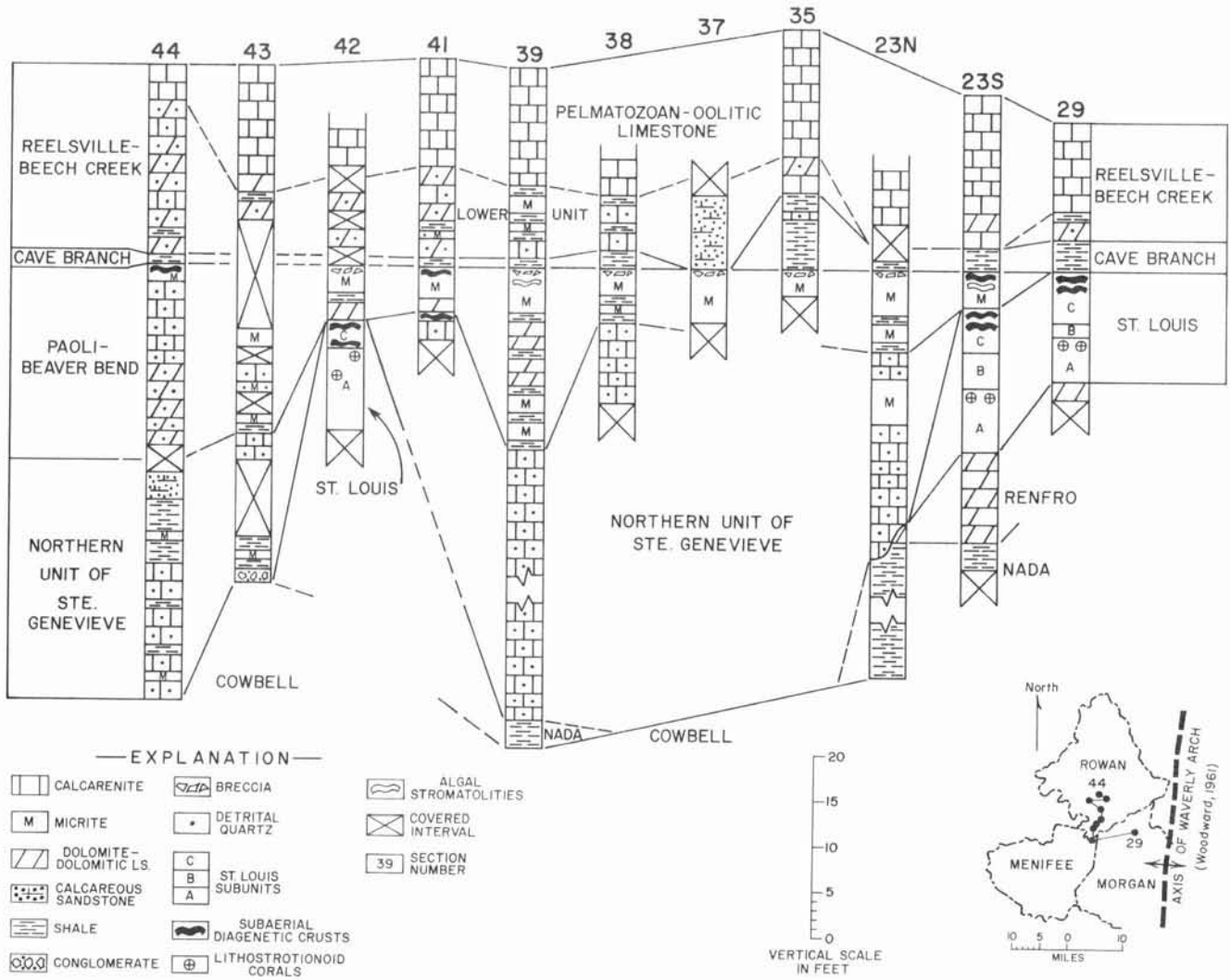


Figure 20. North-south cross section in northern part of study area. St. Louis, Renfro, and Nada removed by intra-Mississippian erosion in parts of the area. Subsequent deposition of northern unit of Ste. Genevieve limited to low areas on the erosional surface. Datum is base of Cave Branch.

southern unit. The features are absent in the lower and middle part of the overlying northern Ste. Genevieve calcarenite.

Microfaunal elements from the northern Ste. Genevieve in western Carter County (Section 53) were studied by Pohl and Philley (1971) and Horowitz and Rexroad (1972). The unit designated as Ste. Genevieve in both studies included the quartzose calcarenite (northern Ste. Genevieve of this study) and the overlying micritic limestones (Paoli-Beaver Bend of this study), following the designation of Philley (1970, p. 25). Microfaunal evidence for the age of the quartzose calcarenite was inconclusive. The presence of the foraminifer *Endothyranella* indicated a late Genevievian or later age for the micritic limestone overlying the calcarenite (Pohl and Philley, 1971; J. C. Philley, 1971, personal comm.). Conodonts recovered from the micritic limestone apparently consisted of forms which

are typically found in the Ste. Genevieve Limestone and Chesterian strata (see Horowitz and Rexroad, 1972, Table 2).

Summary

The northern Ste. Genevieve was deposited during renewed transgression into the area following the second period of uplift in Late Mississippian time. Deposition on the north side of the basement fault system was limited to low areas on the erosional surface which had been developed after the period of uplift. The unit mainly consists of quartzose calcarenite. Carbonate sand deposition, in parts of the area, was followed by a brief period of subaerial exposure, which evidently represents a diastem.

Paoli-Beaver Bend Limestone Member

The Paoli-Beaver Bend Limestone Member was de-

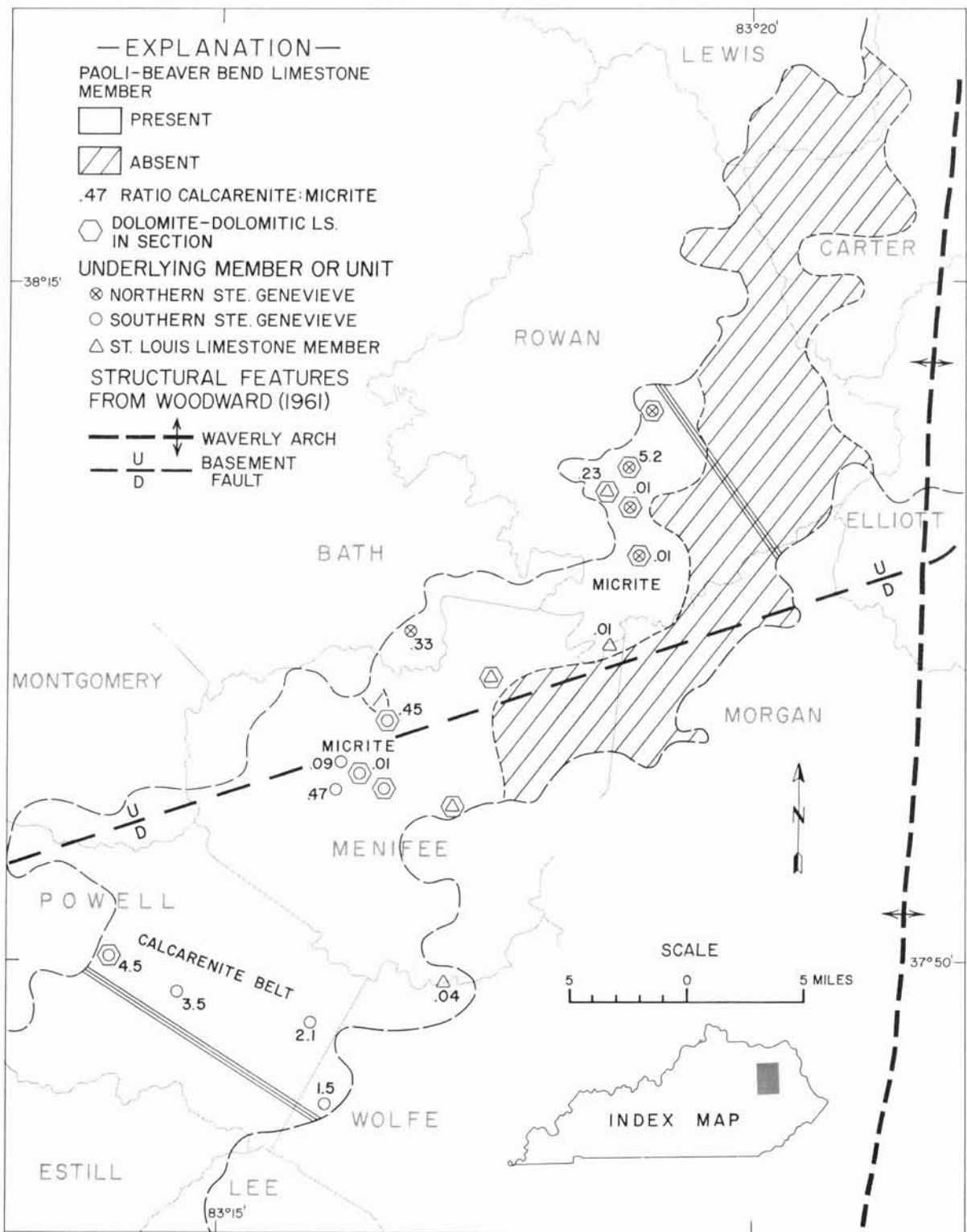


Figure 21. Areal distribution of Paoli-Beaver Bend Limestone member, ratio of calcarenite to micrite, and occurrences of dolomite. Distribution data in part from sources cited in Appendix B.

posited during a renewed marine advance into the area following deposition and minor subaerial exposure of the northern Ste. Genevieve. Upon continuation of transgression, the sea spread across the subaerial surface developed upon the northern Ste. Genevieve (locally), southern Ste. Genevieve, and St. Louis. Transgression was followed by regressive deposition and subaerial exposure. The areal distribution of the member is shown in Figure 21.

Lithology and Environmental Interpretation

The Paoli-Beaver Bend in the southern part of the study area mainly consists of calcarenite. The calcarenite is composed of micrite-enveloped grains, with sparse to abundant oolites and skeletal grains, and generally has sparry calcite cement. Calcarenite in the middle part of the member fines upward through calcisiltite and interlaminated micrite and calcisiltite into micrite at the top of the unit. In the central and northern part of the area, the member is predominantly micrite, with tongues of calcarenite. The areal variation of calcarenite and micrite is shown in Figure 21. Fossils are sparse to locally abundant and include the remains of pelmatozoans, brachiopods, foraminifera, echinoids(?), and gastropods. Intercalated shale is present in the member throughout the area and represents the first major influx of detrital clay following deposition of the interbedded limestone and shale of Unit B in the St. Louis.

A carbonate sand belt developed across the southern part of the area, and lime mud and detrital clay accumulated in the area to the north and northeast of the sand belt (Fig. 21). Constituent grains in the calcarenite deposited in the sand belt are essentially the same as those in the southern Ste. Genevieve calcarenite, indicating probable formation and accumulation under comparable shallow subtidal conditions. A tidal-flat to shallow subtidal environment is indicated for the area of lime mud and detrital clay accumulation north of the sand belt. The interval of thin-bedded micrite with intercalated shale deposited in the area is overlain by supratidal deposits. Lucia (1972) noted that rocks deposited in the intertidal and tidal-flat environment are best recognized by their position immediately below the more distinctive supratidal rocks, assuming the presence of tides during deposition. The upper part of the micritic interval (and the micrite occurring at the top of the member throughout the area) is characterized by the presence of birdseye structures, interlaminated calcisiltite, wavy algal stromatolites, flat-pebble breccia, and a scarcity of fossils, all features considered to be indicative of rocks deposited in the supratidal to high intertidal zone (Logan and others, 1964; Lucia, 1972; Roehl, 1967; Shinn, 1968).

Tongues of calcarenite in the interval of micritic limestone may represent washover sands and shallow tidal channels. Fossils generally are sparse. Small concen-

trations of pelmatozoan plates occur locally in the lower part of the member in Meniffee County and may have been transported from a deeper subtidal environment.

The vertical sequence of lithologies in the member in the southern area suggests that the tidal-flat and supratidal sediments in the area north of the carbonate sand belt prograded southward toward this belt. The calcarenite in the middle part of the member grades upward into micrite and supratidal rocks at the top of the unit. A tidal-flat environment will tend to prograde seaward (regression) if the rate of tidal-flat sedimentation is greater than the rate of transgression or sea-level rise (Lucia, 1972, p. 160). Short-term supratidal to high intertidal conditions and subaerial exposure occurred earlier in the area as indicated by a zone consisting of birdseye micrite or intercalated birdseye micrite, calcarenite, and laminated micritic structures (similar to those in the upper part of the St. Louis and southern Ste. Genevieve) in the middle of the member in the southern and central area (Fig. 16).

In the northern part of the area, tidal flat to shallow subtidal deposition of lime mud and detrital clay completed the filling of the erosional lows during continued transgression following northern Ste. Genevieve calcarenite deposition. The tidal-flat deposits grade upward into supratidal rocks at the top of the member. After the low areas were filled, the tidal-flat and supratidal sediments prograded across former topographic highs, underlain by the St. Louis, in adjoining areas (Figs. 20 and 21).

Very thin laminated micritic structures and brecciated and altered rock are present at the top of the Paoli-Beaver Bend throughout much of the area. The laminated micritic structures are similar to those in the upper parts of the St. Louis and southern Ste. Genevieve which were developed during subaerial diagenesis. The St. Louis and southern Ste. Genevieve carbonates were exposed to subaerial diagenesis following tectonic uplift. In contrast, the carbonates in the upper Paoli-Beaver Bend were originally deposited above high-tide level in the supratidal zone, and they remained subaerially exposed after the shoreline migrated laterally during progradation of the supratidal and tidal-flat environments.

Extremely finely crystalline dolomite occurs in the basal Paoli-Beaver Bend in parts of Meniffee and Rowan Counties and in the upper part of the member at sections in Meniffee and Powell Counties (Fig. 21). The basal dolomites in Rowan County and the upper dolomites in Meniffee and Powell Counties grade into micritic and calcarenitic limestones and probably were formed by the secondary replacement of limestone. A gradation from dolomite to limestone was not observed in the basal dolomites in Meniffee County. Relict pelmatozoan plates were found in the dolomite at two sections. Small concentrations of plates occur locally in the lower Paoli-Beaver Bend in that area. Dolomite bodies at Section 14, in central Meniffee County, have

an irregular domal shape and a flat base (Figs. 22 and 23). No relict texture was found in the extremely finely crystalline dolomite. The bodies may have been bioherms. However, the tidal-flat to shallow subtidal environment suggested for the enclosing micritic limestone would then be too shallow. Moreover, if the bodies were bioherms, the enclosing limestone also should contain abundant skeletal debris, derived in part from the bioherms. Except for the small concentrations of pelmatozoan plates noted above, fossils are sparse in the limestone. On the other hand, the dolomite bodies could have been algal mounds. Certain noncalcareous algae and blue-green algae commonly are poorly preserved and therefore difficult to identify after diagenesis. The dolomite bodies occur near the location of the basement fault (Fig. 21), which, after a period of recurrent movement, could have been the site of hinge-line development during the Late Mississippian. This hinge line could have given rise to a change in the sea-floor slope, with the zone of shallower water being north of the slope change. The shal-

low-water zone adjacent to the slope change could have provided optimum conditions for the growth of algal mounds, with their basinward growth being limited by the change in slope.

Summary

Deposition of the Paoli-Beaver Bend was initiated during renewed transgression after deposition of the northern Ste. Genevieve. Subsequent regressive deposition was followed by subaerial exposure of the carbonates. In the southern part of the area, shallow subtidal calcarenite is dominant. In the central and northern area, the principal lithology is tidal-flat to shallow subtidal micrite with intercalated shale. Supratidal rocks occur at the top of the unit throughout the study area. Laminated micritic structures and brecciated limestone were developed in the upper Paoli-Beaver Bend during exposure to subaerial diagenesis.

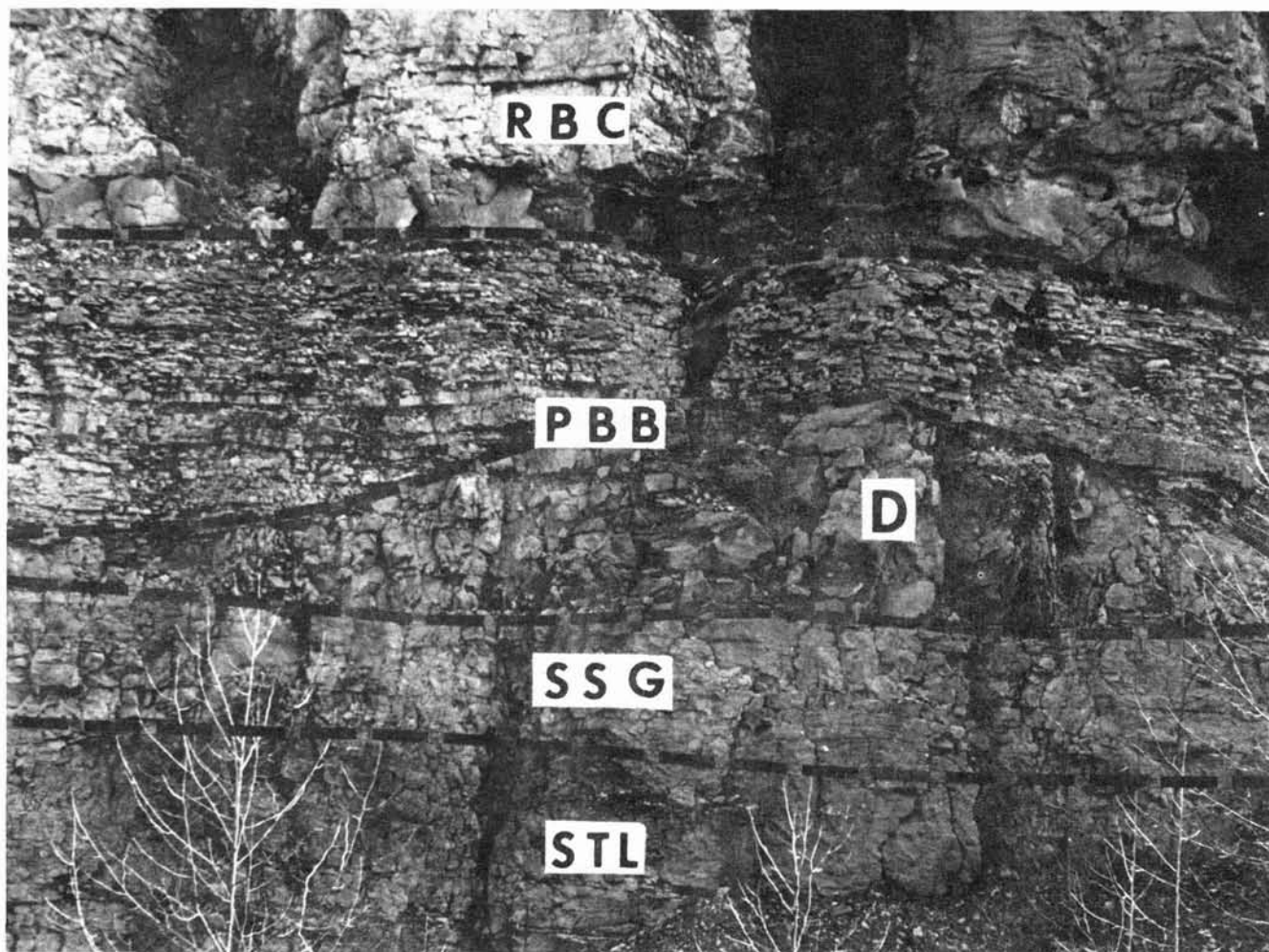


Figure 22. Dolomite body in lower part of Paoli-Beaver Bend Limestone member, Menifee County (Section 14). The Paoli-Beaver Bend (dolomite and thin-bedded limestone) is about 12 feet thick. D, dolomite; STL, St. Louis; SSG, Southern Ste. Genevieve; PBB, Paoli-Beaver Bend; RBC, Reelsville-Beech Creek.

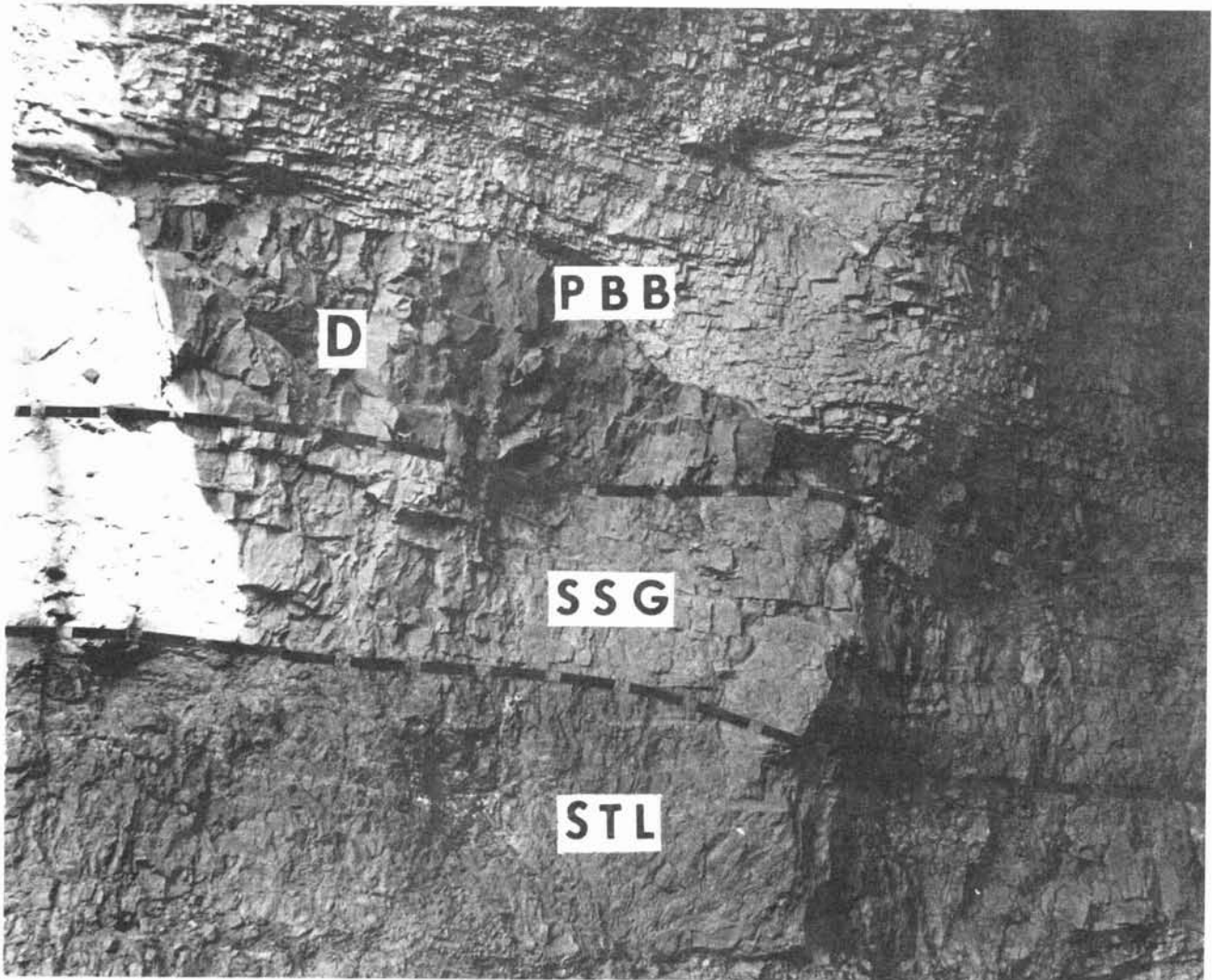


Figure 23. Dolomite body in lower part of Paoli-Beaver Bend Limestone member, Menifee County (Section 14). Contact between dolomite and thin-bedded limestone in member is sharp. The underlying southern unit of the Ste. Genevieve Limestone Member is about 4 feet thick. D, dolomite; STL, St. Louis; SSG, Southern Ste. Genevieve; PBB, Paoli-Beaver Bend.

Cave Branch Bed and Reelsville-Beech Creek Limestone Member

The purpose of this study is to determine the origin of the stratigraphic relationships between the lithologic units in the lower and middle Newman which have a varied areal distribution and thickness (St. Louis, southern Ste. Genevieve, northern Ste. Genevieve, and Paoli-Beaver Bend). The Cave Branch Bed and Reelsville-Beech Creek Limestone member, on the other hand, are significant in that they have a relatively uniform distribution and more limited variation in thickness. These rocks were deposited during the second marine advance in Late Mississippian time (the St. Louis transgression having been the first) to extend across the entire area (Figs. 16 and 24).

Lithology and Environmental Interpretation

The Cave Branch is composed of shale which generally contains abundant quartz silt and sand. The Reelsville-Beech Creek consists of two distinct lithologic units. A limestone consisting partly of calcarenite and partly of calcirudite is the dominant lithology in the member and is present throughout the area. Commonly, the lower part of this limestone is a well-sorted calcarenite composed of oolites and micrite-enveloped skeletal grains; the middle and upper part is somewhat poorly sorted and pelmatozoan remains are a dominant constituent. In parts of the area, the pelmatozoan-oolitic limestone is underlain by a lower lithologic unit consisting of limestone and dolomite which are partly quartzose, with intercalated shale in the lower

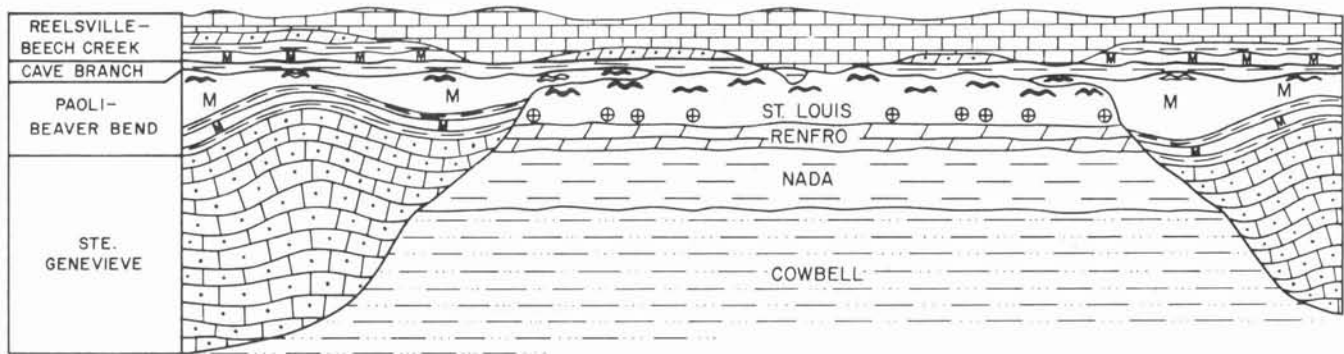


Figure 24. Schematic diagram showing relationships between members of Newman Limestone, and between Newman Limestone and Borden Formation (Cowbell, Nada, and Renfro) in northern part of study area. See Figure 20 for explanation of symbols.

part of the unit. Elsewhere in the area the pelmatozoan-oolitic limestone generally rests on the Cave Branch.

A thin blanket of detrital clay (Cave Branch) was deposited during the transgression across the subaerial surface developed upon the supratidal carbonates of the Paoli-Beaver Bend, and, in the eastern part of the area, on the St. Louis. As the influx of detrital material decreased, carbonate deposition was initiated in parts of the area (lower unit of the Reelsville-Beech Creek). Subtidal carbonate deposition is indicated by faunal remains (pelmatozoans, brachiopods, gastropods, and echinoids) and by the presence, in some sections, of numerous horizontal burrows and trails (Fig. 25). Horizontal feeding burrows and trails are developed in sediments deposited under subtidal conditions (Seilacher, 1967). The occurrence of tidal-flat and supratidal deposits in this interval north of the study area (Section 48) was reported by Ferm and others (1971, p. 26-27). The subtidal carbonates in the study area were succeeded by shallow subtidal oolitic and skeletal sands (minor regression). During renewed transgression, communities of pelmatozoans were established, and the carbonate sand deposits were succeeded by accumulations of skeletal debris (pelmatozoan-oolitic limestone of the Reelsville-Beech Creek).

Summary

The initial transgression extended across the entire area and was accompanied by detrital sedimentation. As the influx of detrital material decreased, carbonate deposition was initiated. Minor regression followed. During renewed transgression, shallow subtidal carbonate sands were succeeded by deeper-water accumulations of skeletal debris.

SUMMARY OF GEOLOGIC HISTORY

The sequence of deep-water shale, deltaic siltstone, shallow-water shale, and intertidal-supratidal carbonate in the Borden Formation described by Kearby (1971) is a record of progressive marine regression from the area of northeastern and east-central Kentucky during Early to early Late Mississippian time. The Newman was

deposited during renewed transgression across the area in the Late Mississippian. The depositional, tectonic, early diagenetic, or erosional events involving each member in the lower and middle Newman are summarized below.

Lower and Middle Newman Limestone, Kentucky

St. Louis

The initial marine advance in Late Mississippian time extended across the entire study area and established subtidal conditions suitable for the growth of abundant sessile, benthonic suspension feeders and the slow accumulation of lime mud in the zone below effective wave base and for the formation of skeletal sand in the zone of wave-agitated water. Carbonate deposition



Figure 25. Zone of irregularly bedded calcisiltite and calcarenite with intercalated shale and argillaceous limestone in lower unit of Reelsville-Beech Creek Limestone member, Powell County (Section 1). Zone contains abundant horizontal burrow structures, as below pick-point of geologic hammer.

was interrupted by a period of renewed uplift along the axis of the early Paleozoic Waverly arch which exposed the St. Louis to subaerial diagenesis and erosion.

Southern Ste. Genevieve

Transgression following the uplift was restricted to the area along the western flank of the Waverly arch. Shallow subtidal carbonate sand, partly oolitic, and lagoonal lime mud were the dominant deposits of this advance. A second period of renewed uplift along the Waverly arch exposed the southern Ste. Genevieve to subaerial diagenesis and erosion. Recurrent movement along the Precambrian basement fault system, in association with the second uplift, caused differential uplift of the north, or upthrown, side of the fault. Subsequent erosion removed the southern Ste. Genevieve, St. Louis, Renfro, and Nada in parts of the northern area.

Northern Ste. Genevieve

The transgression following the second period of uplift invaded low areas on the erosional surface; carbonate and detrital quartz sand were deposited in the erosional lows, partly filling them. A brief halt in deposition was accompanied by subaerial exposure of the northern Ste. Genevieve in parts of the area.

Paoli-Beaver Bend

During renewed transgression, the sea spread across the subaerial surface on the northern Ste. Genevieve and southern Ste. Genevieve and onto the surface underlain by the St. Louis. A carbonate sand belt developed across the southern part of the area. Shallow subtidal, tidal-flat, and supratidal deposition of lime mud and detrital clay (1) completed the filling of the erosional lows in the northern area, (2) concurrently extended across the central area, and (3) prograded southward toward the sand belt. Subaerial exposure followed the sequence of regressive deposition. The upper surface of the St. Louis remained exposed subaerially in the eastern part of the area.

Cave Branch

The period of regressive deposition and exposure was followed by a marine advance across the entire area with deposition of detrital clay, silt, and sand.

Reelsville-Beech Creek

As the influx of detrital material decreased, carbonate deposition was initiated. Subtidal carbonates were succeeded by shallower subtidal oolitic and skeletal sands. During renewed transgression, deeper subtidal conditions suitable for the growth of abundant pelmatozoans were established.

Maxville Group, Ohio

The sequence of events during deposition of the

lower units in the Maxville Group (Upper Mississippian) in east-central Ohio, as described by Scatterday (1963), was similar to those occurring during deposition of the lower units of the Newman in northeastern Kentucky. Both areas of study lie near the axis of the Waverly arch and north of the basement fault system, and were affected by renewed tectonic activity along these structural features. Scatterday reported the following sequence: (1) transgression and deposition of the Dillon Falls Formation on an irregular post-Logan (Borden) surface; (2) uplift and erosional removal of the Dillon Falls in parts of the area; and (3) renewed transgression and deposition, initially in the erosional lows, of the Jonathan Creek Formation. Conodont elements indicated that the Dillon Falls is correlative with the St. Louis Limestone, and that the Lower Jonathan Creek probably is younger than the Ste. Genevieve of northeastern Kentucky (northern Ste. Genevieve), indicating transgression into Ohio from the south.

ALTERNATIVE INTERPRETATIONS OF STRATIGRAPHIC RELATIONSHIPS AND DEPOSITIONAL ENVIRONMENTS

This section presents a summary and discussion of previous interpretations of relationships between St. Louis and Ste. Genevieve carbonates, and between Newman carbonates and Pennington shale. Previous interpretations of the depositional environment of the northern Ste. Genevieve in western Carter County are summarized and briefly discussed.

St. Louis-Ste. Genevieve Relationships

The results of this study indicate that the St. Louis and Ste. Genevieve are separated by an erosional unconformity, as previously reported by Butts (1922), McFarlan and Walker (1956), and Sheppard (1964a). In contrast, Philley (1970, p. 69; 1971) and Philley and Dever (1970) proposed that the carbonates assigned to the St. Louis and Ste. Genevieve in northeastern Kentucky were deposited as penecontemporaneous facies.

Philley and Dever (1970) suggested that the topography of a pre-St. Louis erosional surface may have provided environmental conditions suitable for penecontemporaneous deposition of the distinct lithologies of the two units and controlled their areal distribution. The presence of a correlative zone of algal stromatolites or subaerial crusts at the top of both units was implied. Limestone clasts in the basal Ste. Genevieve were considered to be intraformational clasts.

Philley (1971) studied Ste. Genevieve, St. Louis, and Renfro relationships in northeastern Kentucky and concluded that the Ste. Genevieve was deposited in migrating intertidal channels which incised penecontemporaneous shallow subtidal and intertidal flats (St.

Louis) and supratidal flats (Renfro). The distribution of the various facies was considered to have been controlled by the topography of a "precarbonate" erosional surface. The unit Philley designated as Ste. Genevieve in the northern part of his study area included the quartzose calcarenite (northern Ste. Genevieve of this study) and the overlying micritic limestones (Paoli-Beaver Bend of this study); the unit designated as Ste. Genevieve in the southern part of his study area was the southern Ste. Genevieve of this study.

The principal evidence cited for penecontemporaneous deposition of the St. Louis and Ste. Genevieve was that the algal stromatolites and flat-pebble conglomerates in the upper St. Louis intertongue with and extend across the upper Ste. Genevieve (Philley, 1971, p. 103-105). The laminated structures in the upper St. Louis that Philley interpreted to be algal stromatolites are instead calcareous crusts developed during subaerial vadose diagenesis, and his flat-pebble conglomerates are diagenetic breccias (see section on St. Louis Limestone Member). However, regardless of the origin of these features, the zone in the upper St. Louis containing these features does not intertongue with or extend across the Ste. Genevieve. A zone containing algal stromatolites, flat-pebble conglomerate, diagenetic calcareous crusts, and diagenetic breccia occurs at the top of the Paoli-Beaver Bend. This is the zone Philley described as occurring at the top of the Ste. Genevieve and as being correlative with the upper St. Louis. As noted above, the unit he designated as Ste. Genevieve in the northern area included rocks designated as the Paoli-Beaver Bend in this study. The zone of supratidal rocks and subaerial diagenetic features in the upper Paoli-Beaver Bend is much younger, as indicated by this study, than the zone of subaerial diagenetic features in the upper St. Louis. Moreover, the zone in the upper Paoli-Beaver Bend in the northern area is correlative with the zone of supratidal rocks and subaerial diagenetic features in the upper Paoli-Beaver Bend in the southern part of the area, where the member is underlain by the Ste. Genevieve (northern and southern units or southern unit) which in turn is underlain by the St. Louis. In parts of the northern area, the supratidal and tidal-flat rocks of the Paoli-Beaver Bend overlap the northern Ste. Genevieve and rest on the St. Louis (Fig. 20). The contact between the two units is nongradational and, as indicated by this study, unconformable. At Section 23S (Menifee County), a basal conglomerate of St. Louis clasts occurs in the Paoli-Beaver Bend.

The presence in the Ste. Genevieve of abundant limestone and chert clasts derived from the St. Louis was also cited by Philley as evidence for penecontemporaneous deposition of the two units. Migrating intertidal channels of the Ste. Genevieve eroded intertidal flats of the St. Louis and the disrupted "silica 'gells' and algal sediment" were incorporated into the Ste. Genevieve (Philley, 1971, p. 106). This evidence for penecontemporaneity of the two units would require a pri-

mary or very early diagenetic origin for the St. Louis chert. Philley (1971, p. 73, 106) suggested that support for a primary or very early diagenetic origin of the St. Louis chert was provided by the penecontemporaneity of the St. Louis and Ste. Genevieve.

Characteristics of the chert in the St. Louis indicate a postdepositional replacement origin, and not an origin as a syngenetic gel. Modes of preservation of fossil remains in the St. Louis range from unsilicified, to partly or completely silicified, to faint relict structures in chert nodules; all of the modes are found in proximity. Some chert nodules contain remnants of the host limestone. Pettijohn (1957, p. 439-440) listed evidence that supports an epigenetic, or postdepositional replacement, origin for nodular cherts, as opposed to an origin by the direct precipitation of masses of silica gel on the sea floor. His list includes several characteristics generally found in St. Louis cherts: (1) very irregular shape of some chert nodules, (2) presence of irregular patches of limestone within some nodules, (3) association of silicified fossils and cherts in some limestones, and (4) presence of replaced fossils in some cherts. Clasts of St. Louis chert occurring in the Ste. Genevieve (northern and southern units) would have been derived from the unit during postdepositional erosion, rather than by erosion which was concurrent with deposition.

The age of the units as determined by faunal remains does not indicate that the carbonates assigned to the St. Louis and Ste. Genevieve were deposited penecontemporaneously. Microfaunal elements indicated a St. Louis age for the unit assigned to the St. Louis in eastern Rowan County (Section 48) (Pohl and Philley, 1971). The results of limited sampling of the microfauna in the northern unit of the Ste. Genevieve in western Carter County (Sections 53) were rather inconclusive, but did not indicate a St. Louis age for the unit (Horowitz and Rexroad, 1972, p. 887-889; Pohl and Philley, 1971).

Newman-Pennington Relationships

Various aspects of a model proposing penecontemporaneous deposition of barrier, lagoonal-bay, and deltaic-fluvial sands, clays, and coals (Lee and Breathitt) and offshore carbonates and clays (Newman and Pennington) during the Carboniferous in northeastern Kentucky were described by Ferm and others (1971), Horne and Ferm (1970), Horne and others (1971), and Swinchatt (1970). A detailed evaluation of this depositional model is not within the scope of this paper, but the relationships between the Newman Limestone and Pennington Formation that were proposed in the model are of interest. The offshore carbonates (Newman) were described as being deposited in a series of barriers, bars, and tidal flat-island complexes which graded seaward and landward into red and green marine clays (Pennington). A similar gradation of the Newman Limestone into the Pennington Formation has not been found in the area of this study. The Newman carbonates described in the model are ex-

posed along Interstate Highway 64 in eastern Rowan County and western Carter County (Sections 48, 51, 52, 53, and 54).

As shown by Ferm and others (1971, Fig. 13), a body of Newman limestone in eastern Rowan County (Section 48) grades eastward into a body of marine shale (Pennington) which, in turn, grades eastward into a second body of Newman limestone, in western Carter County in the vicinity of Section 53 (see Fig. 26A). The shale underlying the western Newman body (Section 48) was shown by them as being thicker to the east in the area where the Newman is absent. However, a large body of marine shale, as shown by Ferm and others (1971, Fig. 13) is not present in this area, nor is there evidence indicating that the bodies of Newman limestone grade laterally into a body of shale. The following relationships were observed during examination of the exposures along Interstate Highway 64 in this area (see Fig. 26B). The Newman in the western exposures (Section 48) is underlain in turn by Renfro dolomite and Nada shale. In the area between Sections 48 and 51, sandstones and dark shales (Lee and Breathitt?) rest on Nada shale, which is underlain by Cowbell siltstone (see Kearby, 1971, App. C). The Nada shale is no thicker in the area between Sections 48 and 51 (where the Newman is absent) than it is to the west at Section 48 (where it is overlain by Renfro and Newman), contrary to the increase in thickness shown by Ferm and others (1971, Fig. 13) (see Fig. 26). In the area between Sections 51 and 52, the Nada is overlain in turn by Renfro and Newman. At the west end of Section 53, a channel-fill of Newman limestone rests unconformably upon the Nada; the limestone at this location does not grade laterally into shale as was reported by Ferm and others (1971, p. 23).

The relationships between members within the Newman Limestone and between the Newman Limestone and Borden Formation in this area are similar to those to the southwest, in the area of this study (compare Figs. 24 and 26B). Section 53, the site of northern Ste. Genevieve deposition, is on the margin of a low area on the erosional surface that was developed after differential uplift of the north side of the basement fault system in association with the second period of renewed uplift along the Waverly arch in Late Mississippian time. The area from Section 52 westward to Section 48 was a topographic high on the erosional surface which was underlain by the St. Louis. The absence of the Newman Limestone in the area along Interstate Highway 64 between Sections 48 and 51 resulted from removal during a pre-Pennsylvanian period of subaerial erosion. Erosional remnants of Newman limestone are present in parts of the areas to the north and south of the highway.

It should be noted that the period of pre-Pennsylvanian erosion in northeastern Kentucky may reflect renewed activity of elements in the basement fault-Pre-cambrian platform-Waverly arch complex. The most extensive areas in Kentucky where Upper Mississippian

rocks are absent are in the northeastern part of the state in the area along the axis of the Waverly arch and north of the basement fault system (see Englund, 1972). The Maxville Group (Upper Mississippian) to the north in Ohio also has a very erratic distribution in the area along the Waverly arch. Pennsylvanian rocks rest on Lower Mississippian formations in much of this bi-state area. Extensive erosion of the marine units (Upper Mississippian) prior to deposition of the sequence of barrier, lagoonal-bay, and deltaic-fluvial sediments (Pennsylvanian) indicates that they were not deposited penecontemporaneously within this tectonically active area, as was proposed by Ferm and others (1971) and Horne and Ferm (1970). A continuous depositional sequence of offshore marine (Upper Mississippian) and shoreline and deltaic-fluvial (Pennsylvanian) deposits, however, may occur elsewhere in the more stable areas of the Appalachian basin.

Depositional Environments of the Northern Ste. Genevieve

The depositional environment of the northern Ste. Genevieve in western Carter County (northeast of the area of this study) has been studied in detail by several recent workers. The interpretation reported by Ferm and others (1971, p. 21-23) and Horne and others (1971, p. 7) was based on a study of the Newman carbonates along Interstate Highway 64 (Sections 53 and 54). According to these authors, the northern Ste. Genevieve limestone in the western roadcuts was deposited on and around topographic highs, underlain by Borden siltstone (Cowbell Member), which were the sites of carbonate barrier development. They described the deposits on the highs as a sequence of subaerial crust, storm deposits, and tidal-channel fill; the limestone around the highs was described as consisting of bar and beach deposits. The northern Ste. Genevieve calcarenite in the eastern roadcuts was interpreted to represent a tidal-bar belt, similar to those described by Ball (1967) in the Florida-Bahama area, which was deposited in a large marine bay landward of the carbonate barrier.

Klekamp (1971) studied the Ste. Genevieve in a four-quadrangle area of western Carter County. The unit designated as Ste. Genevieve in his study included the quartzose calcarenite (northern Ste. Genevieve of this study) and the overlying micritic limestones (Paoli-Beaver Bend of this study). In contrast with the barrier and tidal-bar belt environments proposed by Ferm and others (1971) and Horne and others (1971), Klekamp (1971, p. 31-38) concluded that the calcarenite represents tidal-channel sediments, deposited in low areas between topographic highs on a post-Borden or post-St. Louis erosional surface. Transport of the carbonate and detrital sand was in the form of migrating large-scale sand waves.

The northern Ste. Genevieve calcarenite described in these studies was deposited on an erosional surface un-

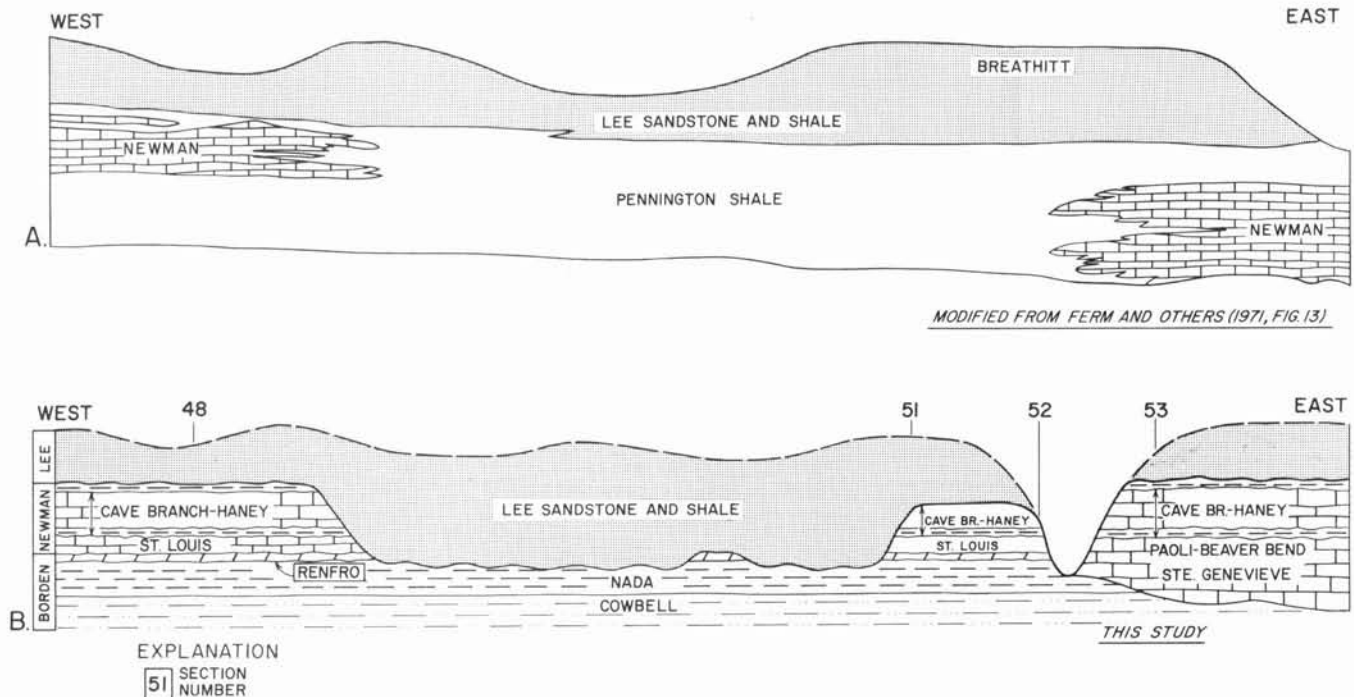


Figure 26. Schematic diagrams of relationships between Borden, Newman, and Pennington (Mississippian) and Lee and Breathitt (Pennsylvanian) along Interstate Highway 64, from about Milepost 144 to 155, in eastern Rowan and western Carter Counties. (A) Relationships indicated by FERM and others (1971). (B) Relationships indicated by this study.

derlain mainly by Cowbell siltstone (Borden). This erosional surface was developed after differential uplift of the north side of the basement fault system in association with the second period of renewed uplift along the Waverly arch in the Late Mississippian. This erosional low covers a broad area where the St. Louis is absent along the axis of the Waverly arch (see Fig. 17). The irregular topography of this surface could have provided environmental conditions suitable for the development of tidal channels as well as barriers and tidal bar belts.

SUMMARY OF CONCLUSIONS

The stratigraphic relationships and the varied areal distribution and thickness of the members in the lower and middle Newman Limestone reflect both the depositional environments of individual members and the effects of Late Mississippian tectonic activity and sub-aerial erosion. Two periods of renewed uplift took place along the early Paleozoic Waverly arch. The first period of recurrent uplift began either during or after deposition of the St. Louis; the second uplift occurred after deposition of the southern Ste. Genevieve. Recurrent movement also occurred along a Precambrian basement fault system following deposition of the southern Ste. Genevieve. Erosional thinning or complete removal of rock units in parts of the area followed the period of uplift along the arch and fault system. The effects of tectonic activity and erosion limited or modified the areal extent of deposition of the southern Ste.

Genevieve, northern Ste. Genevieve, and Paoli-Beaver Bend.

The following stratigraphic relationships in the lower and middle Newman are the direct or indirect result of Late Mississippian tectonic activity and subsequent sub-aerial erosion.

1. The St. Louis is separated from younger members of the Newman by an erosional unconformity.
2. Rocks assigned to the Ste. Genevieve Limestone or to the Ste. Genevieve Limestone Member of the Newman Limestone were found to consist of two distinct lithologic units, designated as the southern and northern units of the Ste. Genevieve Limestone Member in this study. The southern unit may be correlative with the Ste. Genevieve Limestone of western Kentucky. The northern unit is younger than the southern unit and is separated from it by an erosional unconformity.
3. The contact between the southern Ste. Genevieve and the Paoli-Beaver Bend is unconformable. The contact between the northern Ste. Genevieve and the Paoli-Beaver Bend commonly appears to be conformable; in parts of the area it is a diastem.
4. In the southern and central parts of the area the progressive easterly overlapping and thinning of post-St. Louis members toward the axis of the Waverly arch indicates that it was a pos-

itive feature. The onlapping of members in the northern area largely reflects local topographic control.

Correlations indicated by McFarlan and Walker (1956) between certain units in the northern part of the area and units in the central and southern area were found to be in error (see Paoli-Beaver Bend Limestone member in Appendix B). The northern unit they designated as Paoli is correlative with the Paoli-Beaver Bend in the area to the south. The shale regarded as a possible Mooretown Sandstone equivalent is correlative with the southern shale that was regarded as the equivalent of the Sample Sandstone (Cave Branch Bed of this study). The northern unit designated as Beaver Bend is in the lower part of the interval they assigned to the Reelsville-Beech Creek.

The two lithologic units (Paoli-Beaver Bend and Reelsville-Beech Creek) treated as informal members and the unit designated as the northern unit of the Ste. Genevieve in this study warrant designation as formal members of the Newman Limestone and should be renamed. Formal stratigraphic nomenclature will be proposed in a report now in preparation.

Laminated micritic structures in the upper St. Louis, described by previous workers as subaerial crusts developed on bedrock surfaces or algal stromatolites, are considered to be calcareous crusts developed during subaerial vadose diagenesis of marine limestone, as described by James (1972). Similar structures occur in the upper parts of the southern Ste. Genevieve, northern Ste. Genevieve (locally), and Paoli-Beaver Bend, and these also are considered to be subaerial diagenetic features.

The sequence of carbonate deposition, uplift, subaerial diagenesis, and erosion in Late Mississippian time and the field relationships between the St. Louis and Ste. Genevieve do not indicate penecontemporaneous deposition of the St. Louis and Ste. Genevieve carbonates as described by Philley (1971). Field relationships of lithologic units along Interstate Highway 64 do not indicate that the Newman is absent in part of the area because it grades laterally into a large body of marine shale, as suggested by Ferm and others (1971). The Newman was removed from this area by pre-Pennsylvanian erosion.

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APPENDIX A LIST OF SECTIONS

FORMAT:

Section number. Description and location.

County 7.5-minute quadrangle Carter Coordinate (CC) section

Lithologic units

Borden Formation: Cowbell (CBL), Nada (NDA), Renfro (RFO).

Newman Limestone: St. Louis (STL), southern Ste. Genevieve (SSG), northern Ste. Genevieve (NSG), Paoli-Beaver Bend (PBB), Cave

Branch (CB), Reelsville-Beech Creek (RBC)

1. Abandoned quarry, on ridge 1 mile (airline) southeast of Stanton city limits; and outcrops in adjacent area.

Powell County Stanton quadrangle CC section: 21-Q-68

RFO, STL, SSG, NSG, PBB, CB, RBC

2. Natural Bridge Stone Co. quarry, on ridge between Hall Branch and Cow Creek, 1.9 miles (airline) south-southwest of Bowen.

Powell County Stanton quadrangle CC section: 9-P-69

STL, SSG, NSG, PBB, RBC

3. Roadcuts along Ky. Highway 15, 1.45 to 1.70 miles (airline) east of junction with Ky. Highway 11 at Slade.

Powell County Slade quadrangle CC section: 11-P-70

RFO, STL, SSG, PBB, CB, RBC

4. Roadcuts along Ky. Highway 11, south of confluence of Sinking Fork with Middle Fork of Red River, 4.9 to 5.0 miles south of interchange with Mountain Parkway; and outcrops along Middle Fork.

Wolfe County Zachariah quadrangle CC section: 5-O-71

RFO, STL, SSG, NSG, PBB, RBC

5. Porter Construction Co. mine, east side of Ky. Highway 11, 0.25 mile south of Glencairn.

Wolfe County Slade quadrangle CC section: 21-P-70

STL, SSG, PBB, CB, RBC

6. Roadcut along Ky. Highway 715, west side of Swift Camp Creek.

Wolfe County Pomeroyton quadrangle CC sec-

tion: 5-P-72

RFO, STL

7. Outcrops along north bank of Red River, east of Moonshiners Arch, 1100 to 1600 feet east of the Ky. Highway 715 bridge.

Menifee County Pomeroyton quadrangle CC section: 5-P-72

RFO, STL, PBB, RBC

8. Outcrops along ridge on west side of East Fork of Indian Creek, approximately 1800 feet northeast of confluence of the East Fork with Indian Creek.

Menifee County Slade quadrangle CC section: 20-Q-70

STL, SSG, NSG, PBB, RBC

9. Outcrop along road, 1200 feet southeast of Fagan.

Menifee County Frenchburg quadrangle CC section: 3-Q-70

NSG

10. Roadcut along U.S. Highway 460, 3.5 miles west of Menifee County Courthouse, or 0.7 mile east of Rothwell.

Menifee County Frenchburg quadrangle CC section: 11-R-70

RFO, STL, NSG

11. Roadcuts along U.S. Highway 460, 3.0 miles west of Menifee County Courthouse, or 1.2 miles east of Rothwell.

Menifee County Frenchburg quadrangle CC section: 11-R-70

STL, NSG

12. A.W. Walker and Son, Indian Creek quarry, head of Indian Creek, 3.1 miles (by road) southwest of Menifee County Courthouse.

Menifee County Frenchburg quadrangle CC section: 16-R-71

RFO, STL, SSG, PBB, CB, RBC

13. A.W. Walker and Son quarry and mine (abandoned; Lyons property), north side of U.S. Highway 460, 1 mile west of Menifee County Courthouse.

Menifee County Frenchburg quadrangle CC section: 14-R-71

RFO, STL, SSG, PBB, CB, RBC

14. A.W. Walker and Son quarry and mine (abandoned; Montgomery-Kash property), north side of

- U.S. Highway 460, 0.9 west of Menifee County Courthouse.
Menifee County Frenchburg quadrangle CC section: 14-R-71
STL, SSG, PBB, CB, RBC
15. Roadcuts along U.S. Highway 460, 0.8 mile south of Menifee County Courthouse.
Menifee County Scranton quadrangle CC section: 18-R-71
RFO, STL, SSG, PBB
16. Abandoned quarry, west side of Meyers Fork, 1 mile (airline) north of U.S. Highway 460.
Menifee County Scranton quadrangle CC section: 24-R-72
PBB, CB, RBC
17. Roadcuts along Ky. Highway 36, to the southwest and northwest of Hill Top Church, which is 3.2 miles north of Menifee County Courthouse.
Menifee County Scranton quadrangle CC section: 3-R-71
RFO, STL, SSG, NSG, RBC
18. Abandoned quarry, 350 feet south of Hill Top Church.
Menifee County Scranton quadrangle CC section: 3-R-71
RFO, STL, SSG, NSG?, PBB, CB, RBC
19. Outcrops at head of Skidmore Creek.
Menifee County Salt Lick quadrangle CC section: 23-S-72
STL, NSG?, PBB?, RBC
20. Outcrops along right-hand fork at head of Cape Branch.
Menifee County Salt Lick quadrangle CC section: 23-S-72
NSG
21. Outcrops south of Tater Knob Lookout Tower. Supplemental section.
Menifee County Salt Lick quadrangle CC section: 8-S-72
NSG, PBB
22. Outcrops at east end of ridge, north of Buck Creek.
Menifee County Salt Lick quadrangle CC section: 11-S-72
NSG, PBB, RBC
23. Roadcuts along relocated Ky. Highway 1274, north and south of Cave Branch. North cut is at south end of Licking River bridge. South cut is 0.3 mile south of the bridge.
Menifee County Bangor quadrangle CC section: 19-S-73
23N: NDA, RFO, NSG, PBB, CB, RBC
23S: RFO, STL, PBB, CB, RBC
24. Licking River Limestone Co. quarry, along east bank of Licking River.
Morgan County Ezel quadrangle CC section: 7-R-74
RFO, STL, CB, RBC
25. Ken-Mor Stone Inc. (M) quarry, along east bank of Licking River. Sections in abandoned pit south of Laurel Branch and in abandoned trench north of Laurel Branch.
Morgan County Bangor quadrangle CC section: 24-S-74
RFO, STL, CB, RBC
26. Abandoned quarry, 1 mile south of Poppin Rock Tunnel. Supplemental section.
Morgan County Bangor quadrangle CC section: 14-S-74
STL, CB, RBC
27. Kentucky Road Oiling Co., Wrigley quarry, along south bank of North Fork of Licking River, east of Rockhouse Branch.
Morgan County Wrigley quadrangle CC section: 6-S-75
RFO, STL, CB, RBC
28. Abandoned quarry, along north bank of North Fork of Licking River, west of Bucket Branch.
Morgan County Wrigley quadrangle CC section: 6-S-75
RFO, STL, CB, RBC
29. Dragonfly quarry (abandoned), along north bank of North Fork of Licking River, 0.9 mile west of Leisure.
Morgan County Wrigley quadrangle CC section: 14-S-75
RFO, STL, CB, RBC
30. Outcrops on slope southwest of natural bridge, head of Gladly Hollow.
Bath County Salt Lick quadrangle CC section: 19-S-71
STL, SSG, PBB
31. Outcrops at second saddle in ridge south of "The Sinks."

- Bath County Salt Lick quadrangle CC section:
19-S-71
STL, SSG, PBB
32. Outcrops adjacent to Forest Service Trail 115, southwest of "The Sinks."
Bath County Salt Lick quadrangle CC section:
11-S-71
NSG, PBB
33. Outcrops along Forest Service Trail 115, 0.6 mile (airline) southwest of Clear Creek Recreation Area.
Bath County Salt Lick quadrangle CC section:
11-S-71
NSG, PBB, RBC
34. Outcrops at head of Charity Branch. Supplemental section.
Rowan County Bangor quadrangle CC section:
13-S-73
NSG, PBB
35. Roadcut along relocated Ky. Highway 1274, 1.2 miles north of Licking River.
Rowan County Bangor quadrangle CC section:
12-S-73
PBB, CB, RBC
36. Outcrops along road to Bangor. Supplemental section.
Rowan County Bangor quadrangle CC section:
12-S-73
NSG, PBB
37. Roadcut along relocated Ky. Highway 1274, 1.6 miles north of Licking River.
Rowan County Bangor quadrangle CC section:
9-S-73
PBB, RBC
38. Roadcut along relocated Ky. Highway 1274, 2.2 miles north of Licking River.
Rowan County Bangor quadrangle CC section:
9-S-73
NSG, PBB, CB, RBC
39. Roadcuts along relocated Ky. Highway 801, and outcrops along abandoned road leading westward from Ky. Highway 1274 into valley of Sugar Camp Branch.
Rowan County Bangor quadrangle CC section:
1-S-73
NDA, NSG, PBB, CB, RBC
40. Outcrops along ridge, east side of Lick Fork.
- Rowan County Bangor quadrangle CC section:
16-T-74
STL, RBC
41. Ken-Mor Stone Inc. (K) quarry, west side of Ky. Highway 1274.
Rowan County Bangor quadrangle CC section:
20-T-73
NSG, PBB, CB, RBC
42. Outcrops on south side of Lockege Rock.
Rowan County Bangor quadrangle CC section:
12-T-73
STL, PBB, RBC
43. Roadcuts and outcrops along Ky. Highway 519, north side of Clack Mountain.
Rowan County Morehead quadrangle CC section:
15-T-74
CBL, NSG, PBB, RBC
44. Ken-Mor Stone Inc. (C) quarry, on ridge extending north from Clack Mountain, west of Ky. Highway 519.
Rowan County Morehead quadrangle CC section:
10-T-73
CBL, NSG, PBB, CB, RBC
45. Outcrops on east and southwest sides of Limestone Knob.
Rowan County Morehead quadrangle CC section:
7-T-73
CBL, NSG, PBB, RBC
46. Outcrops along Triangle Tower road.
Rowan County Morehead quadrangle CC section:
25-U-74
CBL, NSG, PBB
47. Abandoned quarry, east side of Ky. Highway 799, north of Interstate Highway 64. Supplemental section.
Rowan County Cranston quadrangle CC section:
18-V-74
STL, CB, RBC
48. Roadcuts along Interstate Highway 64, Milepost 143.8 to 145.1. Supplemental section.
Rowan County Soldier quadrangle CC sections:
18, 19, 20-V-74
RFO, STL, CB, RBC
49. Outcrops east side of Ky. Highway 1626, 1.1 miles north of intersection with Ky. Highway 174 at Soldier. Supplemental section.

Carter County Soldier quadrangle CC section: 18-V-75
STL, PBB?

50. Roadcut along north side of U.S. Highway 60, west of Olive Hill. Supplemental section.

Carter County Olive Hill quadrangle CC section: 13-V-76
RFO, STL, CB, RBC

51. Roadcut along Interstate Highway 64, at Milepost 151.2. Supplemental section.

Carter County Olive Hill quadrangle CC section: 6-V-76
RFO, STL, CB, RBC

52. Roadcut along Interstate Highway 64, at Milepost 152.9. Supplemental section.

Carter County Olive Hill quadrangle CC section: 4-V-76
RFO, STL, PBB, CB, RBC

53. Roadcuts at interchange of Interstate Highway 64 and Ky. Highway 2, and along Ky. Highway 2 north of the interchange. Supplemental section.

Carter County Olive Hill quadrangle CC section: 3-V-76
CBL, NDA, NSG, PBB, CB, RBC

54. Roadcuts along Interstate Highway 64, Milepost 154.3 to 157. Supplemental section.

Carter County Olive Hill quadrangle CC sections: 1, 2-V-76
CBL, NSG, PBB, CB, RBC

APPENDIX B DESCRIPTION OF THE LOWER AND MIDDLE NEWMAN LIMESTONE

St. Louis Limestone Member

The St. Louis Limestone Member of the Newman Limestone (Cohee and West, 1965; Hatch, 1964), formerly designated as the St. Louis Limestone, has been described by Butts (1922), McFarlan (1943), and McFarlan and Walker (1956). Colonial rugose corals commonly identified as "*Lithostrotion*" *proliferum* Hall and *Lithostrotionella castelnaui* Hayasaka (*Lithostrotion basaltiforme* or *L. canadensis* of earlier reports) have been considered useful guide fossils because of their common occurrence in the St. Louis. The stratigraphic range of "*L.*" *proliferum* in Kentucky is reported to extend from the Salem Limestone (Fox and Seeland, 1964), through the St. Louis, and into the lower Ste. Genevieve Limestone (Weller, 1931, p. 257). *L. castelnaui* has been reported as being restricted to the

St. Louis in Kentucky (McFarlan, 1943, p. 78; Weller, 1931, p. 257), but, evidently, it also occurs in the Salem (see Fox, 1965; Fox and Seeland, 1964; Sample, 1967).

Colonies of "*L.*" *proliferum* are present in the St. Louis throughout the study area. *L. castelnaui* was observed only at Sections 1 and 12 (Powell and Menifee Counties); it is associated with "*L.*" *proliferum* at both localities. *L. castelnaui* also has been found in the member in the upper reaches of the East Fork of Indian Creek, about 3.5 miles to the southeast of Section 12 (G.W. Weir, 1971, personal comm.). Fragmented corallites of "*L.*" *proliferum*, associated with limestone and chert clasts derived from the St. Louis, occur locally in the basal Ste. Genevieve. Pohl and Philley (1971) reported the presence of the foraminifera *Archaediscus* gr. *gigas* and *Eoendothyranopsis* gr. *ermakiensis* in the St. Louis in Rowan County (Section 48). Therefore, the unit corresponds in age to the upper part of the mid-St. Louis at the Mississippian type area.

The areal distribution of the St. Louis in the study area and in the Newman outcrop belt to the northeast is shown in Figures 5 and 17. The distribution is based in part on maps and reports by Denny (1964), Englund and DeLaney (1966b), Erickson (1966), Hoge and Chaplin (1972), Hylbert and Philley (1971), Klekamp (1971), Morris (1966), Patterson and Hosterman (1962), Pipingos and others (1968), Sharps (1966), Sheppard (1964a; 1964b), and Whittington and Ferm (1965). In areas where the St. Louis is absent, a quartzose calcarenite correlated with the Ste. Genevieve Limestone (Butts, 1922; McFarlan and Walker, 1956) rests on the Borden Formation.

Underlying Renfro Member of the Borden Formation

Beds of dolomite and dolomitic limestone that were included in the lower St. Louis by Butts (1922) have been assigned to the Renfro Member of the Borden Formation (Weir and others, 1966, p. F19). Philley (1971) proposed that the Renfro be assigned to the Newman. The contact between the gray micritic limestone of the St. Louis and the yellow- to orange-weathering dolomitic rock of the Renfro is generally distinct; the two lithologies are commonly separated by a very thin, greenish-gray shale. The upper surface of the Renfro is slightly wavy to very irregular and, in Menifee, Powell, and Wolfe Counties, the surface is cut by narrow, channel-like depressions, up to 45 inches deep, which are filled with St. Louis limestone (Fig. 6).

Lithology

The St. Louis in the study area typically consists of three distinct lithologies, designated as A, B, and C (Fig. 7). They essentially correspond to the St. Louis subfacies A, B, and C described by Philley (1971). The position of the lithologies within the member is shown in Figure 8.

Unit A is composed predominantly of very light-gray to light-olive-gray micritic limestone containing abundant fossils, both whole and fragmented. A bioclastic calcarenite, generally less than 1 foot thick, occurs at the top of the unit. Common fossils include whole productoid brachiopods, valves of other brachiopod genera, pelmatozoan stem plates, fenestrate bryozoan fronds, and spines and plates of the echinoid *Archaeocidaris*. Colonies and fragmented corallites of "*Lithostrotion*" *proliferum* and *Lithostrotionella castelnaui* occur in the upper part of the unit. The lower part commonly is thin to very thin bedded; the upper part generally is thick bedded and stylonitic. Locally, the unit is relatively thin and consists of one bed, about 1 to 2 feet thick. Laminae and very thin beds of shale occur in the lower thin-bedded interval. Chert is present in irregularly-shaped masses and spheroidal and discoidal nodules, and preferentially has replaced individual fossils.

Unit B consists of thin- to very thin-bedded limestone with intercalated shale. The limestone is composed of two types. Light-greenish-gray and light-olive-gray to dark-greenish-gray micritic limestone containing sparse to abundant fossils commonly is dominant. Very light-olive-gray to light-gray bioclastic calcarenite is intercalated with the micrite. Philley (1971, p. 52) noted that within beds the contact between micrite and an overlying calcarenite commonly is marked by minor scour and fill structures. Brachiopods, bryozoans (predominantly fenestrate forms), and pelmatozoan stem plates occur within the limestone beds (commonly concentrated in thin zones) and are abundant on the upper surfaces of beds. Within beds, planar fossils such as bryozoan fronds generally have a horizontal orientation. Locally, fragmented corallites of "*Lithostrotion*" *proliferum* are present in the unit. The intercalated shale, in very thin beds and laminae, is greenish gray. Chert predominantly occurs in thin and very thin discontinuous beds, partly replacing the limestone beds. It also is present in irregularly-shaped masses and, rarely, in spheroidal nodules. As in Unit A, individual fossils have been replaced preferentially. Unit B was not recognized in some of the sections in the northern part of the area (Fig. 8).

Discrete bodies of dolomite occur within Unit B at sections in central Menifee County and at Section 6 in Wolfe County (Figs. 5 and 8). The dolomite is moderate yellowish brown and pale yellowish brown to grayish orange and microcrystalline to extremely finely crystalline. The bodies are commonly lenticular, and at their maximum thickness some bodies occupy the entire interval of Unit B. They generally are surrounded by a clay film. Thin layers of chert occur in the dolomite in Sections 6 and 10. Remains of brachiopods and pelmatozoan stem plates have been found in the chert, and fenestrate bryozoan fronds occur in both the chert and dolomite.

Philley (1971, p. 94) reported an intertonguing relationship between the Renfro and the St. Louis in the

Frenchburg and Slade quadrangles. The dolomite bodies resemble the Renfro lithologically, but an intertonguing relationship between the two units was not observed in the vicinity of either Frenchburg or Slade. Its occurrence in discrete bodies and presence of relict fauna and chert common to Unit B suggest that the dolomite was formed by selective replacement of limestone within the unit and that it is not a tongue of Renfro dolomite.

Unit C is present at the top of the St. Louis throughout the area. It characteristically consists of dark-colored brecciated limestone which is complexly interlayered with zones of light-colored, laminated micritic structures (interlaminated micrite and crystalline calcite), coated grains and particles, and limestone with a chalky appearance (Fig. 9). Limestone occurs in part as beds which are partly fractured, and in part as breccia fragments. The degree of brecciation generally increases upward through the unit. The limestone consists of lithologies essentially the same as those occurring in Unit B. The dominant type is dark-olive-gray and olive-black to light-olive-gray micritic limestone containing sparse to locally abundant fossil fragments. Some bioclastic calcarenite is present, predominantly in the lower part of the unit. Fossil fragments are relatively sparse in the unit and include pelmatozoan stem plates, fenestrate bryozoan fronds, and fragmented corallites of "*Lithostrotion*" *proliferum*. The latter were found in Sections 4, 14, and 29 (Wolfe, Menifee, and Morgan Counties). Thin shales are present locally in the basal part and rarely in the upper part. Chert occurs in spheroidal nodules and irregularly-shaped masses, and preferentially has replaced laminated micritic structures.

The contact between Units B and C generally is gradational. Commonly, the limestone in the uppermost part of Unit B is fractured to slightly brecciated and grades directly into the more highly brecciated limestone of Unit C. In some of the sections where Unit B was not recognized in the interval below Unit C, a zone of thin-bedded limestone is present locally in the basal part of Unit C and may represent an unbrecciated remnant of Unit B. In other sections, a 1- to 2-foot zone of intercalated micrite and calcarenite, which are identical to limestone in Unit B, is present above the interbedded limestone and shale of Unit B. The limestone is unbrecciated to slightly brecciated and grades upward into the zone of interlayered laminated micritic structure and brecciated limestone in the upper part of Unit C.

Sandstone bodies occurring in Unit C at a quarry in Menifee County (Section 13) have been described by Hurd (1960) and McFarlan and Walker (1956, p. 28-29). Hurd also found three bodies in the interval of the Paoli-Beaver Bend at this locality. He concluded that the sandstone bodies resulted from the filling of solutional openings that were developed during the period of pre-Pennsylvanian erosion. However, this origin does not explain their restriction to the upper brecciated

ciated part of the St. Louis or their absence in the Ste. Genevieve (Hurd, 1960, p. 42). As shown in Hurd's detailed figures, all of the bodies appear to have been formed as post-depositional features and those that extend upward to the top of the St. Louis appear to be truncated along the upper contact of the member. They were not examined in detail during this study, but an alternate explanation which might be suggested is that the bodies in the two units were formed at different times. The formation of sandstone bodies in Unit C may have resulted from a period of post-St. Louis, and pre-Ste. Genevieve subaerial exposure, while the Paoli-Beaver Bend bodies were formed in solutional openings developed during the period of pre-Pennsylvanian exposure.

Thickness

The thickness of the St. Louis in the study area ranges from about 11 feet to 23 feet, the latter figure reported by Pipiringos and others (1968); the average thickness is approximately 15 feet. Only a silicified remnant of the member, 2.5 to 4.5 feet thick, is present at Sections 50 and 52 in western Carter County (Fig. 5).

Ste. Genevieve Limestone Member

The Ste. Genevieve Limestone Member of the Newman Limestone (Cohee and West, 1965; Hatch, 1964), formerly designated as the Ste. Genevieve Limestone, has been described by Butts (1922) and McFarlan and Walker (1956). The crinoid *Platycrinites penicillus* Meek and Worthen has been considered a useful guide fossil because of the common occurrence of its distinctive plates in the Ste. Genevieve. The stratigraphic range of the species in Kentucky is reported to extend from the upper St. Louis to the top of the Ste. Genevieve (Weller, 1931, p. 258; Pohl, 1970, p. 6, 8).

In the Newman outcrop belt along the western border of the eastern Kentucky coal field, *P. penicillus* plates have been found in the Ste. Genevieve from the Tennessee state line northeastward to the vicinity of Berea (Butts, 1922, p. 152; McFarlan and Walker, 1956, p. 10), approximately 30 miles southwest of the study area. During this study, the writer found a stem plate of *P. penicillus* in a detritus-rich zone in the basal Ste. Genevieve in eastern Powell County (Section 3). A second stem plate was found in the same section by E.G. Sable (U.S. Geological Survey), but the second plate is in a micritic limestone in the upper St. Louis. The detrital zone in the basal Ste. Genevieve contains many clasts of limestone, chert, and bryozoan fronds derived from the underlying St. Louis, suggesting that the stem plate found in this zone also was derived from the St. Louis.

The rocks previously assigned to the Ste. Genevieve Limestone by Butts (1922) and McFarlan and Walker (1956) and to the Ste. Genevieve Limestone Member of the Newman Limestone by the U.S. Geological Survey were found to consist of two distinct lithologic units.

They are designated as the southern unit and northern unit of the Ste. Genevieve Limestone Member in this study, but the lithologic units form two distinct members in the Newman. The southern unit may be correlative with the Ste. Genevieve Limestone of western Kentucky. The northern unit is younger than the southern unit and is separated from it by an erosional unconformity. For the most part, the units are mutually exclusive in their areal distribution on the north side of the basement fault system; south of the fault system, both units form relatively widespread deposits (Fig. 10). The distribution shown in Figure 10 is based in part on maps and reports by Hoge and Chaplin (1972), Hylbert and Philley (1971), Klekamp (1971), Morris (1966), Patterson and Hosterman (1962), and Pipiringos and others (1968).

Southern Unit of the Ste. Genevieve Limestone Member

Lithology

The southern unit of the Ste. Genevieve consists of crossbedded calcarenite which grades laterally into micrite. The areal variation of calcarenite and micrite is shown in Figure 11. Southern unit limestones generally are very light olive gray to light olive gray. The calcarenite is composed predominantly of fine- to medium-grained, micrite-enveloped grains (Bathurst, 1966) and oolites, with sparry calcite cement. Composite grains, or lumps (Illing, 1954), and peloids (Bathurst, 1967a; McKee and Gutschick, 1969) are common. In intervals of intercalated micrite and calcarenite, the calcarenite contains angular to subrounded micrite intraclasts. Carbonate silt and sand are sparse to locally abundant in the micrite. Birdseye structures are rare. Macrofossils generally are sparse in the southern unit, but are common in some of the sections in central Menifee County and in Bath County. Fossils include pelmatozoan plates, small brachiopods, foraminifera, ostracods, and discoidal, planispiral gastropods. Skeletal grains form the nuclei of many micrite-enveloped grains and of some oolites.

Fine to coarse quartz sand is sparse throughout the southern unit. A detrital zone, containing abundant quartz silt and sand, occurs at the base. The zone is as much as 6 inches thick and, locally, is very argillaceous. Shale generally is rare, but in Sections 3 and 5 (Powell and Wolfe Counties), a zone (1.5 to 4 feet thick) of wavy to nodular-bedded micritic limestone with interbedded shale occurs in the lower part of the unit. Angular to subrounded clasts of limestone, chert, laminated micritic structures, and fossil fragments, derived from the underlying St. Louis, are present in the basal part of the unit throughout the area. Very thin to thin, discontinuous beds of chert occur locally in the calcarenitic limestone.

A conspicuous dark-colored zone, generally 1 to 2 feet thick, at the top of the southern unit in Powell and

Wolfe Counties was correlated with the Bryantsville Breccia of western Kentucky by McFarlan and Walker (1956, p. 10, Figs. 16 and 17). The rock is dark yellowish brown to dusky yellowish brown and, in hand specimens, has a microcrystalline texture. In thin section, a dominant feature is neomorphic microspar (Folk, 1965). The rock contains clast-like particles of both micritic limestone and laminated micritic structures, and individual coated grains and particles and oololiths. The appearance of the zone in fresh exposures ranges from dense and microcrystalline to slightly leached and weathered (Fig. 14). Slickensides are common. The underlying interval generally contains abundant laminated micritic structures (interlaminated micrite and crystalline calcite), associated with zones of coated grains and particles and limestones with a chalky appearance. These features have been found as low as 8 feet below the top of the southern unit. Calcareenite and, locally, brecciated micrite are interlayered with the laminated structures and zones of coated grains and particles (Fig. 12). The general orientation of the laminated structures ranges from essentially horizontal to inclined, where it follows the surface of cross-beds in calcarenite bodies. Some of the structures have been silicified preferentially.

A zone comparable to the Bryantsville Breccia of McFarlan and Walker (1956) was not observed at the top of the southern Ste. Genevieve in the area north of Powell and Wolfe Counties. In southern Menifee County (Section 8), the upper 1 foot of the unit consists of yellowish-brown micrite interlayered with laminated micritic structures. The laminated structures occur throughout the southern unit in some sections in central and northern Menifee County; micritic limestone at the top of the unit in this area is slightly brecciated. Hurd (1960, p. 17, Fig. 11) reported that a breccia, 3 to 4 inches thick, was found locally at the top of the Ste. Genevieve at one location (Section 13). As figured by Hurd, the breccia zone appears to be truncated along the upper contact of the unit.

Thickness

The thickness of the southern Ste. Genevieve in Powell and Wolfe Counties ranges from about 7 feet to 18 feet. The thickest sections are formed by calcarenite bodies. To the north in Menifee and Bath Counties, the unit generally is about 4 to 5 feet thick. Hurd (1960) reported the absence of the Ste. Genevieve at two quarries in central Menifee County. One of the quarries is 400 feet south of Section 14, where the southern unit is more than 4 feet thick. At the other site (Section 13), the unit is absent only locally. The southern Ste. Genevieve is as much as 4 feet thick at Section 13, but extensive exposures in the quarry show that channels were cut into and through the Ste. Genevieve, indicating erosional thinning prior to the deposition of the overlying Paoli-Beaver Bend (Fig. 15; see Hurd, 1960, Fig. 10). The southern unit is absent in the northern and

eastern part of the study area (Figs. 10 and 16). Throughout its area of occurrence, the southern unit of the Ste. Genevieve rests unconformably upon the St. Louis.

Northern Unit of the Ste. Genevieve Limestone Member Lithology

The northern unit of the Ste. Genevieve principally consists of crossbedded quartzose calcarenite. The calcarenite is light olive gray to very light olive gray, very fine to very coarse grained (dominantly fine to medium grained), with sparry calcite cement. Rounded to subrounded, light-colored peloids are the principal constituent. The term *peloid* has been suggested for grains composed of microcrystalline or cryptocrystalline carbonate, irrespective of their origin (McKee and Gutschick, 1969), and has been applied to grains considered to be micrite intraclasts (McKee and Gutschick, 1969), micritized skeletal grains, and faecal pellets (Bathurst, 1967a; 1971). Micrite-enveloped grains, oololiths, bioclastic grains, and lumps are sparse to locally abundant. Calcareenite at the top of the unit locally is dolomitized. Discontinuous beds of chert occur in the calcarenite at Section 46 and in the vicinity of Section 45 (Rowan County).

Micrite is a relatively minor constituent in the northern unit. It generally is light olive gray to olive gray, mainly occurs in discontinuous beds and laminae which are locally brecciated, and, in part, contains birdseye structures. A 5-foot zone of micrite occurs in the upper half of the unit at Section 23N in northeastern Menifee County. At Section 33 (Bath County), the quartzose calcarenite of the northern Ste. Genevieve is underlain by a 7.5-foot zone that consists predominantly of light-olive-gray to dark-olive-gray micrite, which is slightly brecciated at the top. The stratigraphic position of this micrite section within the lower Newman has not been determined because the underlying interval is covered.

Fossils generally are sparse in the northern unit, but include pelmatozoan plates, echinoid(?) spines, foraminifera, and brachiopods. Very thin laminated micritic structures occur locally in the upper part of the unit.

Quartz silt and very fine to coarse sand are abundant to locally sparse, with the silt to fine sand fraction generally predominant. In some sections, quartzose calcarenite grades into calcareous quartzose sandstone. The sandstone is largely very fine to fine grained. Angular to subrounded clasts of limestone, chert, laminated micritic structures, and abraded fossil fragments (including bryozoan fronds, pelmatozoan plates, and brachiopod valves), all derived from the St. Louis, occur in the basal part of the northern Ste. Genevieve throughout the area. The basal conglomerate at Section 32 (Bath County) also contains dolomite clasts, evidently derived from the Renfro Member of the Bor-

den. In west-central Menifee County (Sections 10 and 11), clasts of quartzose calcarenite, light-colored micrite, and calcarenite composed of micrite-enveloped grains occur in the basal part and may represent clasts derived from the southern unit of the Ste. Genevieve and intraclasts.

Rounded grains and granules of St. Louis limestone and chert occur throughout the northern unit, but are more abundant in the lower part. Chert grains are abundant in the middle and upper part at Section 32 (Bath County). The St. Louis detritus and quartz sand are commonly concentrated in the coarser laminae of cross-laminated intervals.

Shale generally is sparse in the northern unit, but in Rowan County a relatively thick zone of shale occurs at Sections 43 and 44, and laminae and very thin beds of shale are intercalated with calcarenite at Sections 41 and 44. The shale zone at Section 44 is 6.5 feet thick and is about 15 feet above the base of the northern Ste. Genevieve, which rests on the Cowbell Member of the Borden. The shale is dark greenish gray to dusky yellow green and grayish red purple. It is very silty in the upper part of the zone. Very thin- to thin-bedded and nodular micrite and quartzose calcarenite occur in the middle and lower part. The micrite contains scattered birdseye structures.

The northern unit thins to the southeast and, at Section 43, the shale zone forms the lower part of the unit (Fig. 20). The middle part is covered in the section; the lower 3.5 feet of the unit consist of greenish-gray and grayish-red silty shale, with thin- to very thin-bedded and nodular limestone. The limestone consists of micrite, in part with birdseye structures, and argillaceous and quartzose calcarenite containing clasts of limestone, chert, laminated micritic structures, and fossil fragments derived from the St. Louis. The basal 2 inches consist of conglomeratic limestone containing abundant St. Louis clasts.

The northern Ste. Genevieve rests on the Cowbell at Section 43. In an exposure 2,000 feet south of the section, it rests on the Nada Member of the Borden. The basal shale in the northern Ste. Genevieve is distinguished from the underlying red and green shale of the Nada by the presence of the conglomeratic limestone. The shale zone at Section 43 previously had been assigned to the Rothwell Shale Member of the Muldraugh Formation (Nada Member of the Borden) by Thomas and others (1955, Fig. 9), and to the Waverly (Borden) by McFarlan and Walker (1956, p. 11, Pl. 2).

Thickness and Relationship with Underlying Units

The northern unit in the present outcrop belt occurs in a series of isolated areas, which, in part, somewhat resemble embayments (Fig. 10). The unit generally reaches its maximum thickness in the central part of these areas, where it is as much as 80 feet thick (Hylbert and Philley, 1971). It thins and pinches out along the margins of each area. In the northern part of

the study area, the northern Ste. Genevieve rests unconformably upon the Borden Formation, mainly upon the Cowbell Member. Along the margins of the areas, it commonly rests on the Nada Member and, locally, upon the Renfro Member (Figs. 18 and 20). The northern areas are bordered by the St. Louis (Fig. 5) but the northern unit was not observed overlying the St. Louis in the northern part of the area. At Section 19 in northern Menifee County, however, the St. Louis is overlain by 5 to 6 inches of quartzose calcarenite which may represent the northern Ste. Genevieve. To the southwest, in western Menifee County, the northern unit rests unconformably on the St. Louis (Fig. 19). The northern unit unconformably overlies the southern unit in parts of western Menifee County and Montgomery, Powell, and Wolfe Counties where it forms a thin, but relatively widespread unit. Its thickness ranges from 1.5 to 6 feet in Sections 1, 2, and 4 (Powell and Wolfe Counties) in the southern part of the study area (see Fig. 16).

Paoli-Beaver Bend Limestone Member

The carbonate unit designated as the Paoli-Beaver Bend by McFarlan and Walker (1956) was recognized as a distinct lithologic unit throughout the study area. The unit is treated as an informal member of the Newman in this study and is redesignated the Paoli-Beaver Bend Limestone member of the Newman Limestone (Fig. 1).

McFarlan and Walker (1956) correlated the carbonate unit with the interval occupied by the Paoli Limestone, Mooretown Sandstone, and Beaver Bend Limestone in the Mississippian section of western Kentucky. The unit in eastern Kentucky occupies the interval between the top of the Ste. Genevieve and a persistent shale at the base of a carbonate unit containing faunal elements characteristic of the Reelsville and Beech Creek Limestones of western Kentucky. The shale was regarded as the eastern equivalent of the Sample Sandstone of western Kentucky.

McFarlan and Walker (1956) treated the unit as a composite formation, the Paoli-Beaver Bend, in most of the area covered by this study. In Carter and Rowan Counties, the Paoli and Beaver Bend were treated as separate units because of the presence of a shale they regarded as a possible Mooretown equivalent (McFarlan and Walker, 1956, p. 9-10, Figs. 21-22). This shale, however, has been found to be correlative with the shale at the top of the unit they assigned to the Paoli-Beaver Bend in the central and southern part of the study area. Consequently, the unit McFarlan and Walker designated as Paoli in Carter and Rowan Counties is correlative with the Paoli-Beaver Bend in the area to the south; the unit designated as Beaver Bend is in the interval of carbonate rock that they assigned to the Reelsville-Beech Creek in the area to the south (Fig. 27).

The Paoli Limestone (and correlative strata in the lower Girkin Formation) is the basal formation of the

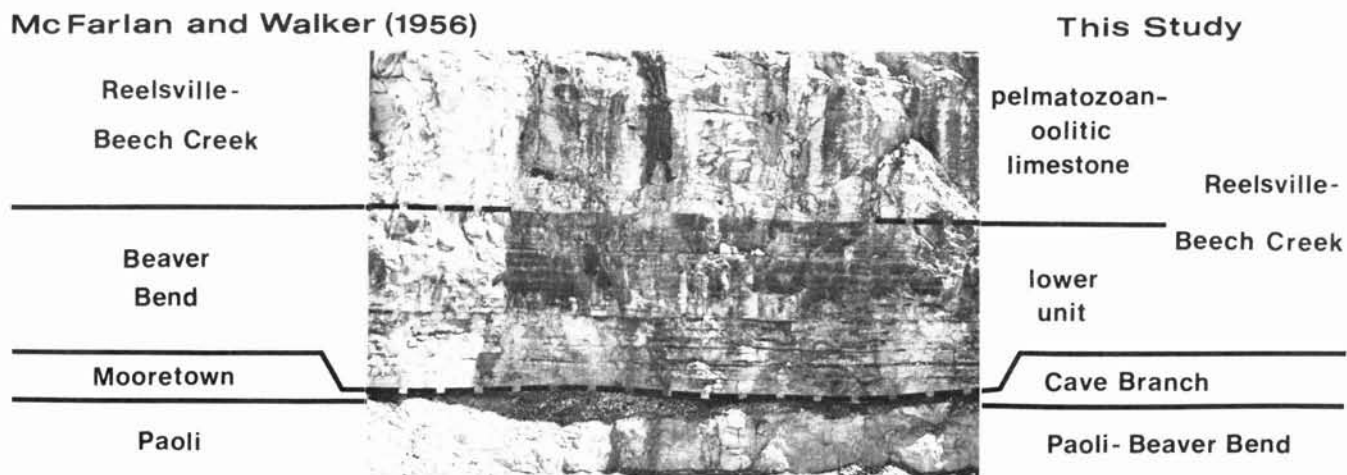


Figure 27. Comparison of previous correlation by McFarlan and Walker (1956, Fig. 21) with those indicated by this study for units in northern part of study area. Cave Branch Bed is the shale McFarlan and Walker (1956) regarded as the Sample Sandstone equivalent in southern part of the area. The Reelsville-Beech Creek Limestone member (this study) is about 22 feet thick. Quarry is Section 41, Rowan County.

Chester Series along the eastern and southeastern border of the western Kentucky coal field (McFarlan and others, 1955). In western Kentucky the boundary between the Meramec and Chester Series and between the Ste. Genevieve and Paoli Limestones is placed above the highest occurrence of *Platycrinites penicillus* and below the lowest occurrence of *Talarocrinus* (other than *T. simplex*) (see Swann, 1963). Along the western border of the eastern Kentucky coal field, *Talarocrinus* has been found in the interval of the Paoli-Beaver Bend in the area from the Tennessee state line northeastward to Rockcastle County and at one quarry in Powell County (Butts, 1922, Pl. 69; McFarlan and Walker, 1956, Pl. 2).

The areal distribution of the Paoli-Beaver Bend member is shown in Figure 21. The distribution is based in part on maps by Hoge and Chaplin (1972), Hylbert and Philley (1971), Morris (1966), and Pipiringos and others (1968), and a report by Patterson and Hosterman (1962).

Limestone

In the southern part of the study area, the lower and middle part of the member is predominantly calcarenite. The calcarenite fines upward through

calcisiltite and interlaminated micrite and calcisiltite into micrite at the top of the unit. The micrite contains birdseye structures and wavy laminated structures which are interpreted to be algal stromatolites. In the central and northern part of the area, the member is predominantly micrite, with tongues of calcarenite. Laminated and birdseye micrite and algal stromatolites occur in the upper part, and the top of the unit generally is brecciated. A zone, as much as 3 feet thick, of birdseye micrite or birdseye micrite interlayered with calcarenite and laminated micritic structures (similar to those in the upper part of the St. Louis and southern Ste. Genevieve) occurs near the middle of the member in some of the sections in the southern and central part of the area. The areal variation of calcarenite and micrite is shown in Figure 21.

Paoli-Beaver Bend limestones generally are very light olive gray to olive gray. The calcarenite, which predominantly is fine to medium grained, is composed of micrite-enveloped grains, with sparse to abundant ooliths and bioclastic grains, and generally has sparry calcite cement. It occurs in thin to very thick beds with intercalated shale. Thicker beds display crossbedding. In contrast with the general predominance of micrite in the northern part of the area, the member at Section 44

(Rowan County) is mainly a very fine- to fine-grained calcarenite containing abundant quartz silt and very fine to fine sand. It grades downward into a quartzose dolomite which forms the lower part of the member at that location. To the southeast and west, at Sections 43 and 45, the quartzose calcarenite intertongues with micrite, which, in part, contains quartz silt and sand.

The micritic limestone in the member predominantly occurs in very thin to thin, wavy to planar, and nodular beds with intercalated shale (Figs. 15, 22, and 23). It contains sparse to locally abundant carbonate silt and very fine sand, and, in parts of the unit, the micrite contains birdseye structures and interlaminated calcisiltite. A very thin, burrowed micrite commonly occurs at the base in Powell and Wolfe Counties. The brecciated micrite in the upper part consists of primary flat-pebble breccia (conglomerate) and breccia that apparently was developed during a period of subaerial diagenesis. Very thin, laminated micritic structures, similar to those in the upper part of the St. Louis and the Ste. Genevieve units, occur in the upper part of the Paoli-Beaver Bend. Fossils, which are sparse to locally abundant in the member, include pelmatozoan plates, brachiopods, foraminifera, echinoid(?) spines, and discoidal, low-spined gastropods.

Dolomite

Dolomite occurs in the basal Paoli-Beaver Bend in Menifee (Sections 14, 15, and 18) and Rowan Counties (Sections 41, 44, and 46) (Fig. 21). It is yellowish brown to grayish orange, and extremely finely crystalline. Calcite is present in very thin veinlets and in porphyrotopic and poikilotopic fabrics as pseudospars replacement. The dolomite generally contains sparse quartz silt and very fine sand. At Section 44, however, the basal dolomite is quartzose and grades upward into a quartzose calcarenite. A few relict pelmatozoan plates were observed in the dolomite at Sections 15 and 18; pelmatozoan plates locally are abundant in micritic limestone in the lower part of the member in Menifee County. In some of the sections in Rowan County, the limestone at the base of the Paoli-Beaver Bend or immediately overlying the basal dolomite is in part yellowish brown, microcrystalline to extremely finely crystalline, and dolomitic; the dolomitic limestone grades upward into micritic limestone.

The thickness of the basal dolomites ranges from less than 1 foot to more than 9 feet. The dolomite exposed in the quarry face and mine walls at Section 14 (Menifee County) occurs in discrete bodies which have an irregular domal shape and a flat base (Fig. 22). The bodies have a maximum thickness of more than 5 feet. They are enclosed by thin-bedded micrite with intercalated shale and rest on a very thin shale that overlies the Ste. Genevieve. The distal part of a basal lense from one body extends into the micrite (Fig. 23). Exposures at the other sections were too limited to determine if

the basal dolomite at those locations occurs in similar bodies.

Irregular areas of dolomite, several feet wide, occur in the micritic limestone in the upper Paoli-Beaver Bend at Section 1 (Powell County). The upper 4 to 5 feet of the member is exposed at Section 16 (Menifee County), and limestone at the top of the unit grades, laterally and downward, into dolomite. Relict limestone textures and thin layers of chert are preserved in the dolomite, which, otherwise, appears to be similar to the basal dolomites. At Section 39 (Rowan County), about 8 feet of thick- to very thick-bedded, very light-gray, extremely finely crystalline dolomitic limestone is present in the middle of the member. An 8.5-foot interval of dolomite, which appears similar to the basal dolomites, occurs at Section 19 in northern Menifee County and may be correlative with the Paoli-Beaver Bend. The dolomite is overlain by the Reelsville-Beech Creek and is underlain in turn by a quartzose calcarenite (northern Ste. Genevieve?) and the St. Louis.

Detrital Constituents and Chert

Quartz silt and very fine to coarse sand are sparse in Paoli-Beaver Bend limestones throughout the area. The occurrence of a quartzose calcarenite and dolomite in central Rowan County (Sections 43, 44, and 45) was noted previously. In contrast with the minor occurrence of shale in the Ste. Genevieve, intercalated shale is present in the Paoli-Beaver Bend throughout the area. It is greenish gray, occurs in very thin beds and laminae, and contains abundant to sparse quartz silt and sand. Shale commonly is absent in the interval of laminated and birdseye micrite at the top of the unit. A zone of silty to sandy shale, as much as 9 inches thick, generally occurs at the base of the member in Powell and Wolfe Counties. In the northern part of the area, the contact between the Paoli-Beaver Bend and the underlying northern Ste. Genevieve is marked by a zone of greenish argillaceous limestone and siltstone, and calcareous shale, which is as much as 2 feet thick (Patterson and Hosterman, 1962, p. F18). Chert is present in thin to very thin beds and in irregularly shaped and spheroidal nodules, and preferentially has replaced some laminated micritic structures. In Bath County and northern Menifee County, the breccia zone at the top of the member has been silicified.

Thickness

The thickness of the Paoli-Beaver Bend, where it rests on the Ste. Genevieve, is about 12 to 23 feet in Powell and Wolfe Counties, and about 8 to 15 feet in Menifee County. The unit overlaps the southern unit of the Ste. Genevieve, thins, and pinches out to the east (Figs. 16 and 21). The Paoli-Beaver Bend was not recognized in Section 17 (Menifee County), but it is present at Section 18, 400 feet to the southeast. In the northern part of the study area, the member is as much as 25 feet thick

where it rests on the Ste. Genevieve. The northern unit of the Ste. Genevieve, as noted previously, occurs in a series of isolated areas. The Paoli-Beaver Bend onlaps the Ste. Genevieve along the margins of these areas, thins, and pinches out (Fig. 20). It pinches out to the east and south from the areas in Rowan County and northern Menifee County, and to the west from the area in western Carter County (Fig. 21).

Cave Branch Bed

A shale which McFarlan and Walker (1956) regarded as the eastern equivalent of the Sample Sandstone is a wide-spread detrital unit in the study area. Their correlation was based on the shale's position between the carbonate units in eastern Kentucky that had been correlated with the Paoli-Beaver Bend and Reelsville-Beech Creek intervals in the Mississippian section of western Kentucky (Fig. 2). The Sample Sandstone in western Kentucky is underlain by the Beaver Bend Limestone and is overlain by the Reelsville Limestone (McFarlan and others, 1955).

The shale is here designated a formal unit of the Newman and named the Cave Branch Bed of the Newman Limestone. The bed is named for Cave Branch, a tributary of the Licking River in northeastern Menifee County and northwestern Morgan County. The type section (Section 23S; Appendix C) is on the south side of the valley of Cave Branch in a roadcut along relocated Ky. Highway 1274 about 0.3 mile south of the Licking River (Fig. 28).

The bed is composed predominantly of dark-greenish- to greenish-gray, platy to bladed, clayey shale which generally contains abundant detrital quartz (dominantly silt to very fine sand). A zone of grayish-red shale, up to 21 inches thick, occurs in the lower to middle part of the unit in the eastern part of the study area and, locally, in Powell County. In some sections, shale in the upper part is calcareous. Limestone clasts are present in the basal Cave Branch in areas where it rests on the St. Louis; the upper part contains rare angular to rounded chert clasts.

The Cave Branch generally overlies the Paoli-Beaver Bend throughout the latter member's area of occurrence. It onlaps the Paoli-Beaver Bend and rests on the St. Louis in the area of northeastern Menifee County and northwestern Morgan County, and in northeastern Rowan County and western Carter County. The contact between the Cave Branch and the underlying members of the Newman is distinct. Locally, shale has filled fractures and cavities developed in the brecciated zone at the top of the Paoli-Beaver Bend. The unit is overlain by the Reelsville-Beech Creek Limestone member throughout the area, and the contact between the two units generally is distinct. In parts of the study area, the lower Reelsville-Beech Creek consists of limestone and dolomite with intercalated shale containing abundant quartz silt and sand; the Cave Branch at Sections 23S and 35 (Menifee and Rowan Counties) contains very

thin beds and laminae of limestone containing abundant quartz silt. The upper contact in such cases is transitional and is placed at the base of the interval composed predominantly of carbonate rock.

The bed commonly is about 0.5 to 3.5 feet thick; the maximum thickness in the study area is 8.5 feet. The thickness varies considerably across the area and within individual exposures. The variation results from deposition on the irregular upper surface of the Paoli-Beaver Bend and St. Louis, and from removal by erosion, either prior to or in association with deposition of calcarenitic limestone of the Reelsville-Beech Creek (Fig. 29). At some locations where the Cave Branch is absent and the Reelsville-Beech Creek rests on the Paoli-Beaver Bend or St. Louis, pockets of shale are preserved along the irregular upper surface of the lower member. At Section 25 (Morgan County), the shale is preserved in "potholes," about 1 foot deep and 1 foot wide, in the top of the St. Louis; in exposures about 1200 feet to the south, the Cave Branch is as much as 2 feet thick. The bed is absent across a north-south-trending area that extends from northern Morgan through eastern Rowan into southwestern Carter County (see Patterson and Hosterman, 1961; 1962, p. F19, Pl. 4 and 5). As the Cave Branch is present in the surrounding area, it may have been onlapped locally by the Reelsville-Beech Creek or it may have been removed by erosion.

It should be noted that the Cave Branch was assigned to two stratigraphic positions by McFarlan and Walker (1956). The shale in the southern part of the study area was regarded as the eastern equivalent of the Sample Sandstone of western Kentucky (McFarlan and Walker, 1956, Figs. 16 and 17). In Carter and Rowan Counties, it was regarded as the eastern equivalent of the Mooretown Sandstone of western Kentucky (McFarlan and Walker, 1956, p. 9-10, Figs. 21 and 22). The shale in the Carter-Rowan area has been found to be correlative with the shale in the southern part of the study area, as noted previously in the section on the Paoli-Beaver Bend (see Fig. 27).

Reelsville-Beech Creek Limestone Member

The carbonate unit designated as the Reelsville-Beech Creek by McFarlan and Walker (1956) was recognized as a distinct lithologic unit throughout the study area. The unit is treated as an informal member of the Newman in this study and is redesignated the Reelsville-Beech Creek Limestone member of the Newman Limestone (Fig. 2).

McFarlan and Walker (1956) correlated the eastern Kentucky carbonate unit with the interval occupied by the Reelsville Limestone, Elwren Sandstone, and Beech Creek Limestone in the Mississippian section of western Kentucky. The correlation is based on the presence of a distinctive crinoid stem, 1/2 to 3/4 inch in diameter, and its association with *Agassizocrinus cf. laevis*

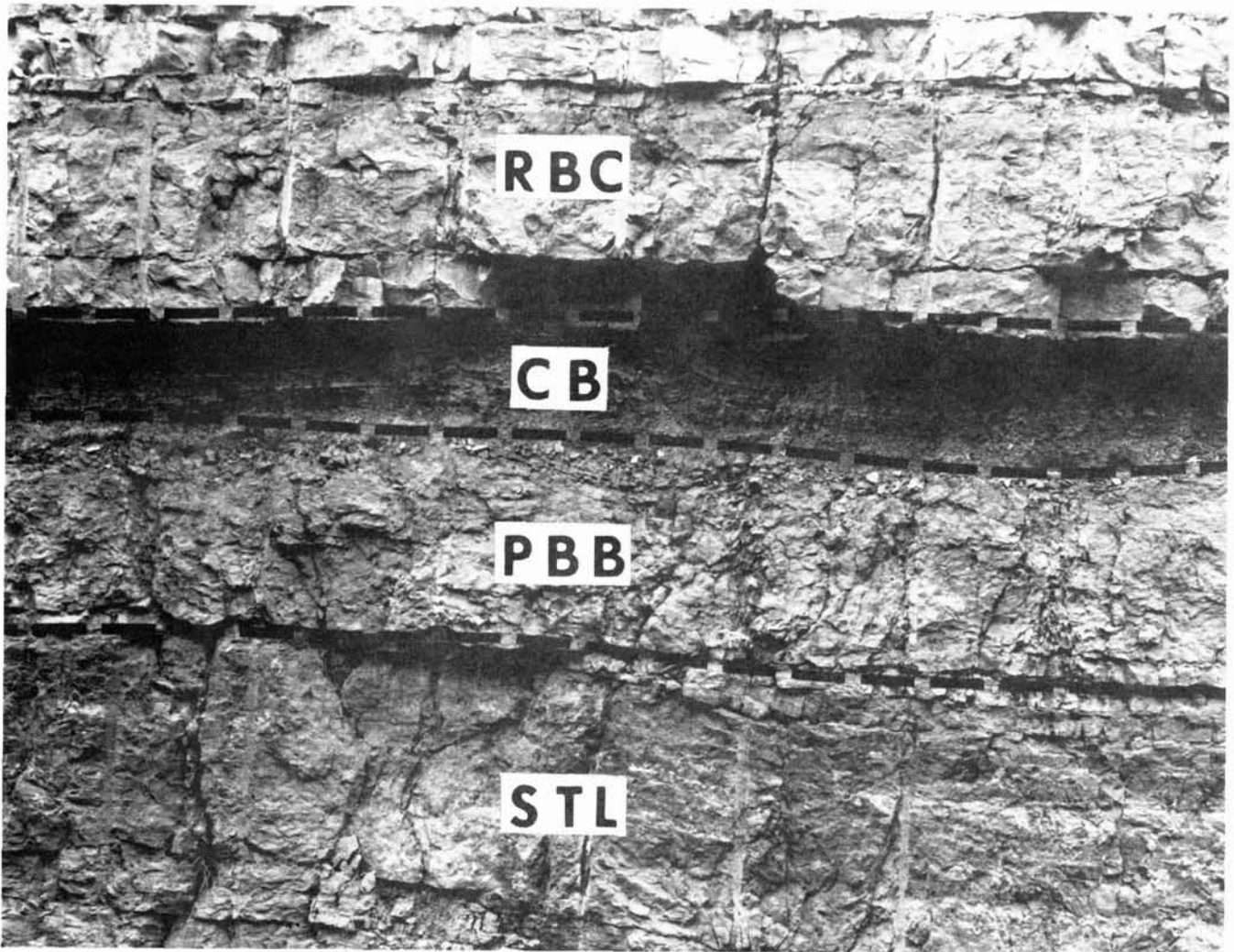


Figure 28. Type section of the Cave Branch Bed, Section 23S, Menifee County (see Appendix C). Very thin beds of quartzose calcisiltite in upper part of unit. Cave Branch is 2.5 feet thick. STL, St. Louis; PBB, Paoli-Beaver Bend; CB, Cave Branch; RBC, Reelsville-Beech Creek.

(Roemer), which was regarded as indicating a post-Sample age for the eastern unit (McFarlan and Walker, 1956, p. 8-9). The distinctive crinoid stem, which occurs in the Paoli, Beaver Bend, and Beech Creek Limestones in western Kentucky (McFarlan and others, 1955), is restricted to this unit in the Mississippian section of eastern Kentucky. The lowest occurrence of *A. cf. laevis* in western Kentucky is in the Reelsville Limestone (McFarlan and others, 1955); its lowest occurrence in eastern Kentucky is in this unit (McFarlan and Walker, 1956). The foraminifera genera *Climacamina* Brady and *Neoarchaediscus* Maclay, which are abundant in the Beech Creek in its type area in the Illinois basin, have been found in the Reelsville-Beech Creek in eastern Powell County (Pohl, 1970, p. 12) and in western Carter County (Pohl and Philley, 1971).

Pelmatozoan-Oolitic Limestone Unit

A pelmatozoan-oolitic limestone is the dominant lithologic unit in the Reelsville-Beech Creek; in parts of the

study area, this limestone is underlain by a lower unit consisting of dolomite and limestone with intercalated shale. The dominant lithology is a light-olive-gray to very light-gray calcarenite-calcirudite composed of fragmented fossils (dominantly pelmatozoans), ooliths, and micrite-enveloped grains, with sparry calcite cement. Intraclasts of oolitic limestone are common. The basal part locally has a micritic matrix. Fossils include crinoids, blastoids of the groups *Pentremites godoni* and *P. pyriformis* (see Galloway and Kaska, 1957), foraminifera, brachiopods, and rare remains of fenestrate bryozoans. Commonly, the lower part of the interval occupied by this limestone is well sorted and is composed predominantly of ooliths and micrite-enveloped grains; the middle and upper parts are somewhat poorly sorted and pelmatozoan fragments are the dominant constituent.

In parts of Menifee, Morgan, and Rowan Counties, the basal 1 to 3 feet of calcarenite is partly replaced by extremely finely crystalline dolomite. In some sections,

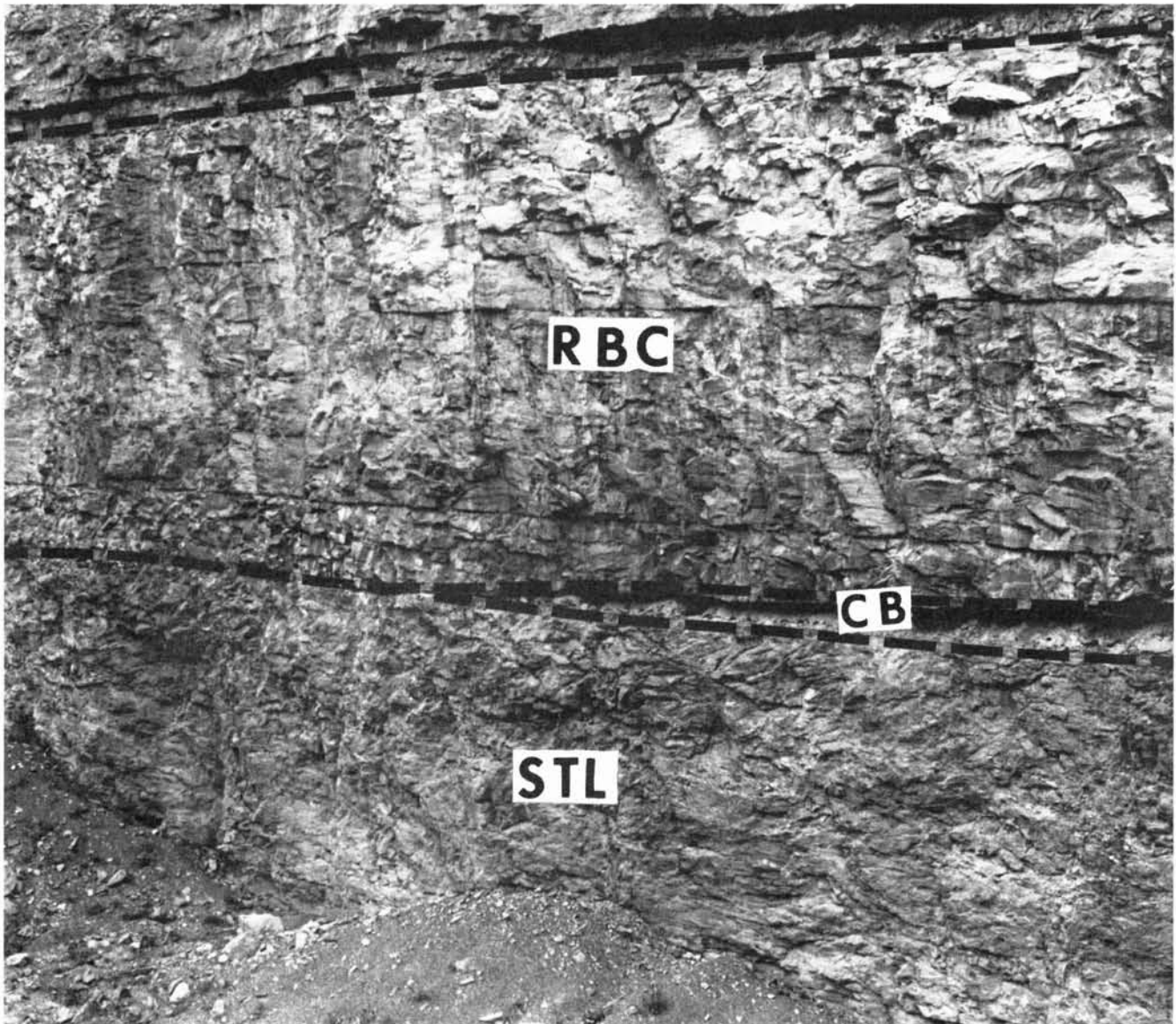


Figure 29. Local pinch-out of Cave Branch Bed, resulting from erosional removal, Morgan County (Section 24). Pockets of shale are preserved along irregular upper surface of the St. Louis Limestone Member along the quarry face to the left of the pinch-out. Cave Branch is up to 1.5 feet thick. STL, St. Louis; CB, Cave Branch; RBC, Reelsville-Beech Creek.

the cement or matrix was replaced before the grains; at other locations, whole grains and the nuclei of coated and enveloped grains are dolomitized, but the sparry cement and some bioclastic grains remain unaltered. The pattern of dolomitization in some samples indicates that replacement was concentrated initially along horizontal zones. The lower part of the limestone unit, in parts of Menifee and Rowan Counties, contains one or two individual beds of dolomite, from about 1 to 4 feet thick. The dolomite is yellowish brown, extremely finely crystalline, and contains rare relict pelmatozoan plates.

Quartz silt and sand, and intercalated shale occur locally in the basal part, but the limestone generally is

very pure, being composed of 95 to 99 percent calcium carbonate (CaCO_3) (Stokley and McFarlan, 1952, p. 72-74, 85-86; Patterson and Hosterman, 1962, Table 1). Clasts of micrite, derived from the Paoli-Beaver Bend, and dolomite clasts, derived from the lower unit of the member, are present in the basal part.

The pelmatozoan-oolitic limestone is present throughout the study area. It generally forms a massive, resistant ledge; the lower part commonly is very thin to thin bedded (Fig. 30). The Reelsville-Beech Creek member has a relatively uniform thickness across the area. The thickness of the limestone unit ranges from about 2 feet to 25 feet, being thinner in sections where the lower unit of the member is present.

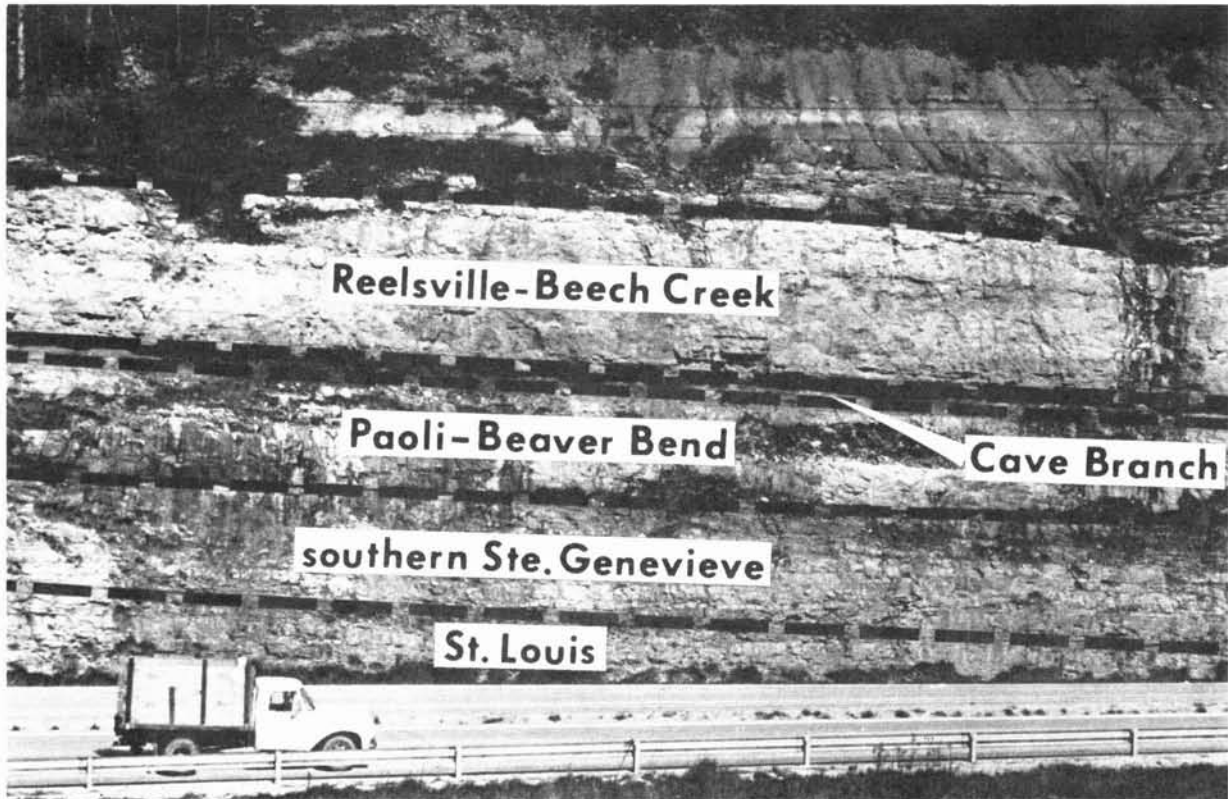


Figure 30. Newman Limestone along Mountain Parkway east of Slade, Powell County. Reelsville-Beech Creek Limestone member consists entirely of the pelmatozoan-oolitic limestone.

Lower Unit

In parts of the study area, the pelmatozoan-oolitic limestone is underlain by a lower unit which predominantly consists of dolomite and limestone with intercalated shale; the lower unit rests on the Cave Branch. The lower unit in Carter and Rowan Counties was designated as Beaver Bend by McFarlan and Walker (1956, p. 9-10, Figs. 21 and 22). They restricted the Reelsville-Beech Creek in that area to the overlying pelmatozoan-oolitic limestone, which contains the diagnostic faunal elements. The shale underlying the lower unit was regarded as the eastern equivalent of the Mooretown Sandstone. The shale, however, has been found to be correlative with the shale overlying the unit they assigned to the Paoli-Beaver Bend in the central and southern part of the study area, as noted previously in the sections on the Paoli-Beaver Bend and Cave Branch. Consequently, the unit that McFarlan and Walker designated as Beaver Bend in Carter and Rowan Counties is in the interval of carbonate rock that they assigned to the Reelsville-Beech Creek in the area to the south (see Fig. 27).

The lower unit in central Rowan County predominantly consists of light-olive- to very light-olive-gray, very fine-grained calcarenite and calcisiltite which grade, laterally and vertically, into yellowish-gray to

yellowish-brown, extremely finely crystalline dolomite. The calcarenite-calcisiltite is composed of peloids, bioclastic grains, and foraminifera, with scattered coarser fossil fragments, in a matrix of micrite and neomorphic microspar. Quartz silt and very fine sand are abundant in the limestone and dolomite. Thin beds and lenses of micrite and coarser calcarenite, composed of micrite-enveloped and bioclastic grains, occur throughout this unit. These beds contain pelmatozoan remains, brachiopods, high- and low-spined gastropods, and echinoid spines. Silty to sandy shale and argillaceous limestone, in laminae and very thin beds, are present in the lower part. At Sections 41 and 44, the contact between the dolomite at the top of the lower unit and the overlying pelmatozoan-oolitic limestone is stylolitic. In central Rowan County, the lower unit is about 10 to 17 feet thick.

To the south, at Sections 38 and 39 (Rowan County), the lower unit consists of about 6 to 8 feet of thin-bedded calcarenite and micrite with intercalated silty to sandy shale and siltstone. The limestone contains abundant to sparse quartz silt and sand. At Section 37, an 8-foot interval of calcareous sandstone is exposed above the top of the Paoli-Beaver Bend; the sandstone is considered to be correlative with the lower Reelsville-Beech Creek (Fig. 20).

In parts of northeastern Menifee, northwestern Morgan, and eastern Rowan County, the lower 1 to 3 feet of the Reelsville-Beech Creek consists of light-olive- to greenish-gray, quartzose (quartz silt) and argillaceous dolomite and dolomitic limestone with intercalated shale. Hosterman and others (1961) and Patterson and Hosterman (1961; 1962) designated this lower unit as the Reelsville Limestone of Malott (1919) and the overlying pelmatozoan-oolitic limestone, the Beech Creek Limestone of Malott (1919). As no faunal evidence for the division was cited, the member is not similarly divided in this study. At Section 25 (Morgan County), the lower 2 to 3 feet of the member consists, in ascending order, of dolomitic siltstone, bioclastic calcarenite, and dolomitic calcarenite, with intercalated shale. Burrow structures occur along the contact between the siltstone and calcarenite. In central Menifee County (Sections 12, 13, and 14), 0.5 to 3 feet of yellowish-brown to grayish-orange, extremely finely crystalline dolomite occurs at the base of the member. The dolomite contains inclusions of greenish-gray, silty to sandy clayey shale; calcite occurs in thin veinlets and as porphyrotopic pseudospar. Locally, the dolomite appears to grade into the partly dolomitized calcarenite in the basal part of the pelmatozoan-oolitic limestone.

In the southern part of the study area, a lower unit was observed in the Reelsville-Beech Creek only at Section 1 in Powell County, where it is 7 feet thick. The lower unit consists of a basal conglomerate and two lithologic zones which intertongue laterally. The basal conglomerate contains clasts of micrite and dolomite derived from the Paoli-Beaver Bend, pelmatozoan stem plates, and bryozoan fragments in a calcarenitic matrix. The lower zone consists of irregularly-bedded calcisiltite and very fine-grained calcarenite, with intercalated shale and argillaceous limestone. The upper zone is composed of very thin- to thin-bedded calcisiltite and very fine- to fine-grained calcarenite, which are partly dolomitized. Quartz silt and very fine sand are abundant in both zones. Horizontal burrow structures occur throughout the unit and are abundant in the lower zone (Fig. 25); vertical burrow structures are sparse. Trails are abundant on the surface of beds in the upper zone.

**APPENDIX C
TYPE SECTION OF CAVE BRANCH
BED OF THE NEWMAN LIMESTONE**

Section measured along relocated Kentucky Highway 1274, south of Cave Branch, 0.3 mile south of Licking River, Menifee County, Ky. (Section 23S)

Newman Limestone (upper part not measured):	Thickness (feet)
Haney Limestone of McFarlan and Walker (1956) (basal part only):	
13. Limestone, light-olive-gray (5Y	

5/2); micrograined to fine-grained; thin-bedded; intercalated shale. Not measured.

Reelsville-Beech Creek Limestone member:

12. Limestone, light-olive-gray (5Y 6/1); very fine- to very coarse-grained, bioclastic; pelmatozoan fragments; massive; thin-bedded in upper 2.5 feet.	11.6
11. Dolomite, grayish-orange (10YR 7/4); extremely finely crystalline; varied thickness; local lense bioclastic limestone.	1.3
10. Limestone, light-olive-gray (5Y 6/1); medium- to coarse-grained, bioclastic, oolitic	2.2
9. Dolomite, grayish-orange (10YR 7/4); extremely finely crystalline; relict bioclastic grains.	0.8
8. Limestone, light-olive-gray (5Y 5/1); fine- to coarse-grained, bioclastic, oolitic; pinches out laterally; abundant horizontal burrow structures on basal surface.	0.5
Total Reelsville-Beech Creek Limestone member	<u>16.4</u>

Cave Branch Bed

7. Shale, dusky-yellow (5Y 6/4) to light-olive-gray (5Y 5/2); clayey, slightly silty, calcareous; platy to bladed; very thin beds and laminae of quartzose calcisiltite to calcareous siltstone, olive-gray (5Y 4/1)	1.3
6. Shale, dark-greenish-gray (5GY 4/1); clayey, very silty and sandy; platy to bladed	1.2
Total Cave Branch Bed	<u>2.5</u>

Paoli-Beaver Bend Limestone member:

5. Limestone, very light-olive-gray (5Y 6/2) to yellowish-gray (5Y 7/2); micrograined; birdseye structures; interlaminated calcisiltite and sparse algal stromatolites in upper 1.0 to 2.0 feet; laminated micritic structures and brecciated limestone in upper 1.5 feet; thick-bedded	3.1
4. Limestone, very light-olive-gray (5Y 6/2) to yellowish-gray (5Y 7/2); micrograined; birdseye structures; basal conglomerate of clasts derived from the St. Louis; thin-bedded; intercalated shale.	0.9
Total Paoli-Beaver Bend Limestone member	<u>4.0</u>

St. Louis Limestone Member:

- 3. Limestone, dark-olive-gray (5Y 3/1); micrograined; partly brecciated; laminated micritic structures and coated grains, more numerous in upper part; micrograined and bioclastic limestone as in unit 2, and spherical nodules and irregularly shaped masses of chert in lower 1.5 feet; contact between lower and upper limestones is gradational.
- 2. Limestone, very light-olive-gray (5Y 7/1) to light-olive-gray (5Y 6/1); very fine- to medium-grained, bioclastic; intercalated and gradational with moderate-greenish-yellow (10Y 7/2) to light-olive-gray (5Y 6/1) micrograined limestone; brachiopods and abundant bryozoans (dominantly fenestrate

5.0

forms); nodules and discontinuous, very thin beds of chert; thin-bedded; intercalated argillaceous limestone and shale

4.0

- 1. Limestone, very light-olive-gray (5Y 7/1) micrograined; abundant fossils, whole and fragmented (fenestrate bryozoans, pelmatozoans, and brachiopods); "*Lithostrotion proliferum*" colonies and fragments in upper 1.5 feet; bioclastic calcarenite in upper 0.3 to 0.7 feet; irregularly-shaped masses of chert in upper 2.5 feet; thick-bedded in upper 2.5 feet; thin-bedded with intercalated shale in lower part

7.0

Total St. Louis Limestone Member . .

16.0

Borden Formation:

Renfro Member: dolomite.

