Slade and Paragon Formations— New Stratigraphic Nomenclature for Mississippian Rocks along the Cumberland Escarpment in Kentucky

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Chapter B

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GARLAND R. DEVER, JR., and DONALD R. CHESNUT

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A major revision of largely Upper Mississippian nomenclature for northeastern and north-central Kentucky which includes detailed descriptions of two new formations and nine new members

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Slade and Paragon Formations—New Stratigraphic Nomenclature for Mississippian Rocks along the Cumberland Escarpment in Kentucky

By Frank R. Ettensohn[1], Charles L. Rice[2], Garland R. Dever, Jr.[3], *and* Donald R. Chesnut[3]

Abstract

The names Slade Formation and Paragon Formation are given herein to Mississippian rocks of east-central and northeastern Kentucky that were formerly named Newman Limestone and Pennington Formation. The names Newman and Pennington are excluded from the Cumberland Escarpment outcrop belt in Kentucky and are retained only for the Pine Mountain and Cumberland Mountain outcrop belts of southeasternmost Kentucky, eastern Tennessee, and southwestern Virginia. The Slade Formation, mostly carbonate rocks, is divided into 12 members and 1 bed. The Renfro Member of the Borden Formation, and the St. Louis Limestone Member, the Ste. Genevieve Limestone Member, and the Cave Branch Bed of the Newman Limestone are reassigned to the Slade Formation. Additional members of the Slade designated herein are the Warix Run (calcarenite), Mill Knob (calcilutite, calcarenite, and dolostone), Rosslyn (calcarenite), Armstrong Hill (calcilutite), Holly Fork (dolostone), Tygarts Creek (calcarenite), Ramey Creek (limestone and shale), Maddox Branch (shale), and Poppin Rock (calcarenite). The Paragron Formation, mostly shale, is divided into four informal members, a lower dark shale member, a clastic or dolostone member, a limestone member, and an upper shale member.

INTRODUCTION

Many individual Mississippian stratigraphic units of the midcontinent region of the United States are somewhat unique because of their widespread distribution and lithologic homogeneity. For many years, correlations of lithostratigraphic units between the Eastern Interior and Appalachian basins have been influenced by these aspects (Butts, 1922; McFarlan and others, 1955; and McFarlan and Walker, 1956). However, many more recent roadcut and quarry exposures of Mississippian rocks along the Cumberland Escarpment in east-central and northeastern Kentucky reveal previously unknown stratigraphic relations that cast doubt on unit terminology based on older correlations. During the last 20 years, the names used for the major Mississippian stratigraphic units in this area included the Borden Formation, the Newman Limestone, and the Pennington Formation. The Borden Formation and its members as defined by Weir and others (1966) have been depicted in relatively recent geologic maps of east-central and northeastern Kentucky. The overlying rocks, represented by the Newman and Pennington, are distinctive, but in our opinion the names are misapplied. These terms, Newman and Pennington, were introduced to the Cumberland Escarpment in east-central Kentucky from areas in the Pine and Cumberland Mountains outcrop belt in southeastern Kentucky, Tennessee, and southwestern Virginia (Campbell, 1898a, b) (fig. 1). The supposedly equivalent rocks in those two areas differ markedly in general lithologies, thicknesses, and features; these differences reflect their depositional environments. We here propose that the names Newman and Pennington be excluded from the outcrop belt along the Cumberland Escarpment in Kentucky and that the rocks previously assigned to those formations be reassigned to two newly defined lithostratigraphic units, the Slade and Paragon Formations.

Stratigraphic subdivisions of the Newman Limestone of east-central and northeastern Kentucky by Butts (1922) and McFarlan and Walker (1956) (fig. 2) are largely names derived from those of the Eastern Interior basin. The correlation of such units across the Cincinnati arch has, in our opinion, resulted in an inappropriate nomenclature that has been shown to be incorrect. Earlier workers generally did not take into consideration intervening facies changes, and they relied heavily on guide fossils, some of which have since been shown to be facies dependent. The confusion in the identify of those named formational subdivisions is indicated further by some of these subdivisions being known by more than one name. For these reasons, we propose several new well-defined members of the Slade Formation with formally designated type and reference sections.

During this study, done cooperatively with the Kentucky Geological Survey, more than 100 stratigraphic sections containing strata previously assigned to the Newman Limestone and Pennington Formation were described, measured, and photographed. Descriptions and locations of selected sections have been published in Dever (1980a [1973]), Ettensohn (1975, 1980), and Chesnut (1980).

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Figure 1. The distribution of the Slade and Paragon Formations (light area) in northeastern and east-central Kentucky and the Paragon Formation (dark area) in south-central Kentucky. Section numbers refer to measured sections described in the Type and Reference Sections of this report.

HISTORICAL REVIEW

The names Newman Limestone and Pennington Shale were introduced into east-central Kentucky by Campbell (1898a, b), who first formalized them (1893, p. 37, 38) in a study of the Big Stone Gap coal field in southwestern Virginia. He described the formations from exposures in Big Stone Gap (fig. 1); he took the name Newman for the largely carbonate sequence underlying Newman Ridge, Tenn., and the name Pennington for the overlying dominantly shale sequence from nearby Pennington Gap, Va. In the area of Big Stone Gap, Campbell

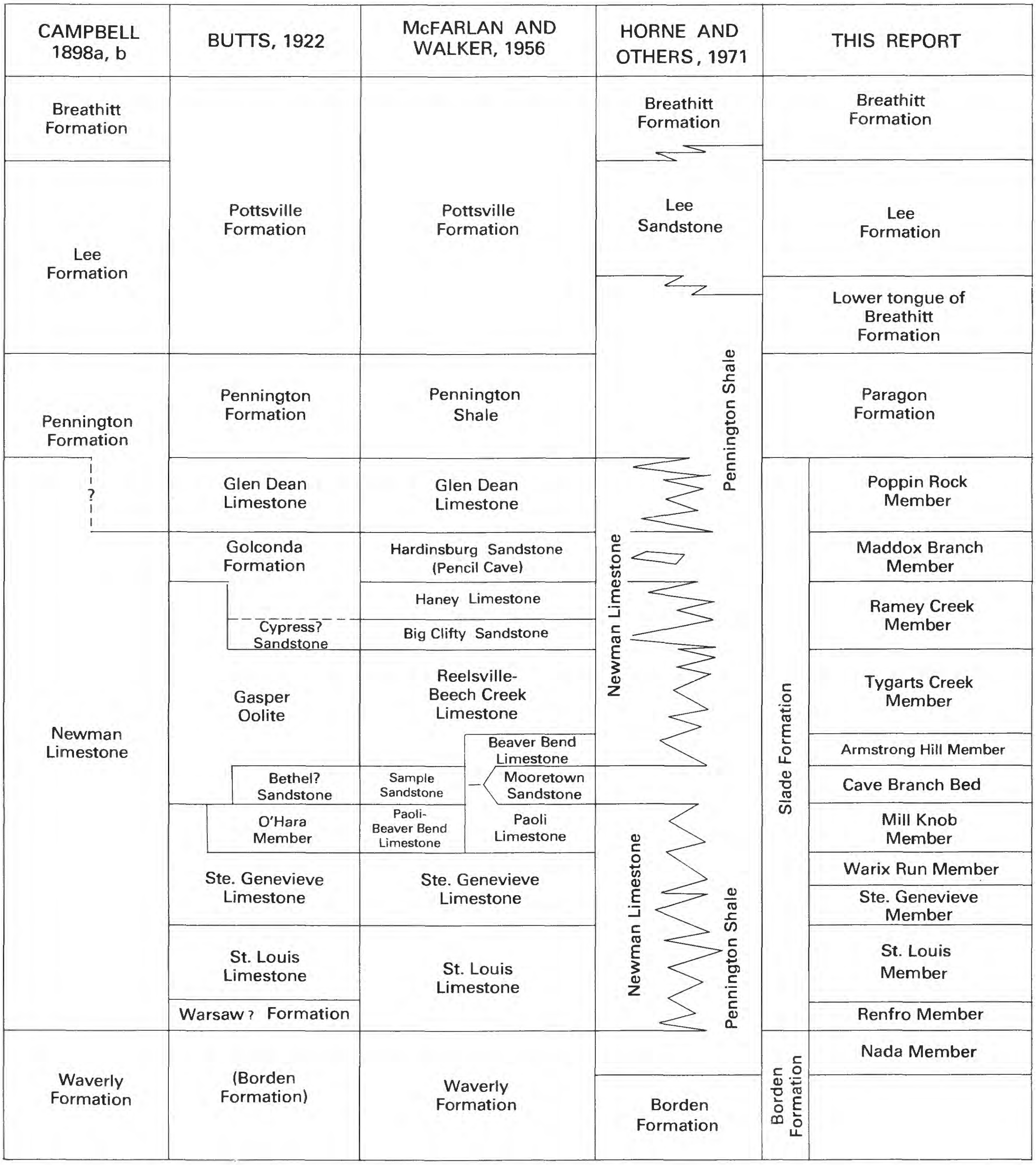

Figure 2. Comparison of major stratigraphic nomenclature applied in east-central Kentucky to subdivisions of the Slade and Paragon Formations. Interval shown for the Armstrong Hill Member of the Slade Formation for this report also locally includes the Holly Fork and Rosslyn Members of the Slade Formation.

(1893) placed a thick sandstone sequence later identified as the Stony Gap Sandstone (Reger, 1926) at the base of the Pennington. He described the underlying Newman Limestone as comprising an upper sandstone and shale unit (about 35 m thick), a middle limestone and shale unit (about 85 m thick), and a basal limestone unit (about 130 m thick). Campbell (1898a, b) did not clearly define the Newman Limestone and Pennington Formation in east-central Kentucky, except to describe the Newman as a limestone and the overlying Pennington as a shale unit containing thin beds of limestone. A. M. Miller (1917), following what became the general usage, restricted the Pennington to the marine shales and carbonates above the highest massive limestone bed of the Newman.

Butts (1922) reported on the Mississippian stratigraphy in eastern Kentucky after completing an examination of Mississippian strata in western Kentucky (Butts, 1917). He described east-central Kentucky units and correlated them mostly with western Kentucky and southern Illinois units whose names he extended into eastern Kentucky. However, Butts (1922, p. 179) used the name Pennington Formation (Campbell, 1898a, b) to designate the predominantly shale uppermost Mississippian unit above the "Glen Dean Limestone" in east-central Kentucky. The work of Stokley (1949), Stokley and McFarlan (1952), Stokley and Walker (1953), McFarlan and Walker (1956), and Patterson and Hosterman (1961) was largely a refinement in the division and correlation of Butts' original units. In addition, in the late 1920's, county reports published by the Kentucky Geological Survey used many different names for the Mississippian carbonate units. These included Gasper (Martin, 1925; Perry, 1925), Chester (McFarlan and Goodwin, 1929), "Big Lime" and "Little Lime" (R. L. Miller and Briggs, 1929; Robinson 1927), Maxville (Perry, 1926), Mammoth Cave (Robinson and others, 1927), and Greenbrier (Williams, 1925; Robinson and others, 1928; Robinson and Hudnall, 1925).

The name Newman was reintroduced into east-central Kentucky during the cooperative geologic mapping program of the U.S. Geological Survey (USGS) and the Kentucky Geological Survey (1960–78). Most geologic quadrangle maps produced for the mapping program use the top of the uppermost massive limestone unit as the top of the Newman Limestone (fig. 3); however, that limestone was included locally in the lower part of the Pennington Formation (Hatch, 1963, 1964). As Englund (1968, p. 12; see also Englund and Teaford, 1981) noted, the division of those rocks into a predominantly limestone unit below (Newman) and a largely shale unit above (Pennington) did not take into consideration that the uppermost part of the type Newman does contain thick beds of shale and sandstone. Thus, some workers (Delaney and Englund, 1973; Englund and Windolph, 1975; Englund, 1976) included in the upper part of the Newman Limestone in northeastern Kentucky shale beds that many previous workers had assigned to the Pennington (fig. 3). The reintroducton of the name Newman into east-central Kentucky also resulted in a change in its original lower boundary. A distinctive yellow- to orange-weathering dolostone that was included within the basal Newman in its type area and in some northeastern and east-central Kentucky quadrangles was given the name Renfro in south-central Kentucky by Weir and others (1966) as the uppermost member of the Borden Formation.

Subsequently, Horne and others (1971, 1974) described the Mississippian rock section in northeastern Kentucky in terms of a depositional model called the Lee-Newman barrier-shoreline model (fig. 2). In their classification, the Newman Limestone was attributed to a carbonate barrier or island deposit that occurred within and intertongued with what they interpreted to be Pennington-type, open-marine shale. This highly controversial Lee-Newman barrier-shoreline model was contested on both litho- and biostratigraphic grounds by Dever (1980a [1973]), Ettensohn and Dever (1975), Ettensohn (1977, 1979, 1980, 1981b), Ettensohn and Peppers (1979), Rice and others (1979), and Englund and Henry (1981).

SLADE FORMATION

The Slade Formation is named for the section of limestone, dolostone, and minor shale exposed in the southwestern highwall of the Natural Bridge Stone Co. quarry (fig. 4) near the Mountain Parkway about 6.5 km west-northwest of Slade, Ky. (see fig. 1 and the Type and Reference Sections, section 1, p. 23). A reference section (incomplete) for the Slade Formation in northeastern parts of its outcrop belt also was measured in the Ken-Mor Stone Co. quarry at Olive Hill, Ky. (see fig. 8 and the Type and Reference Sections, section 6, p. 27). The Slade Formation extends northward to the northern boundary of Kentucky. In Ohio, the Maxville Limestone is mostly equivalent to the middle and upper parts of the Slade. To the southwest along the Cumberland Escarpment, the Slade reaches a maximum thickness of about 100 m in northeastern Pulaski County at the arbitrary southwestern limit of the formation (fig. 1). Southwest of that area (generally south of lat 37°7′30″ N. and west of long 84°37′30″ W.) equivalent units of the Slade are the Muldraugh Member of the Borden Formation, the Salem and Warsaw Formations, the St. Louis and Monteagle Limestones, the Hartselle Formation, and the Bangor Limestone (fig. 3, first column).

The Slade Formation as here defined comprises twelve members and one bed. From oldest to youngest, these are the Renfro, St. Louis, Ste. Genevieve, Warix Run, and Mill Knob Members, the Cave Branch Bed, and the Armstrong Hill, Holly Fork, Rosslyn, Tygarts Creek, Ramey Creek, Maddox Branch, and Poppin Rock Members. For purposes of general description, the Slade Formation is informally divided into two parts (fig. 3, far right column), a lower part that consists primarily of thin- to thick-bedded carbonate members, commonly bounded by disconformities and subaerial-exposure surfaces, and an upper part that mostly consists of persistent

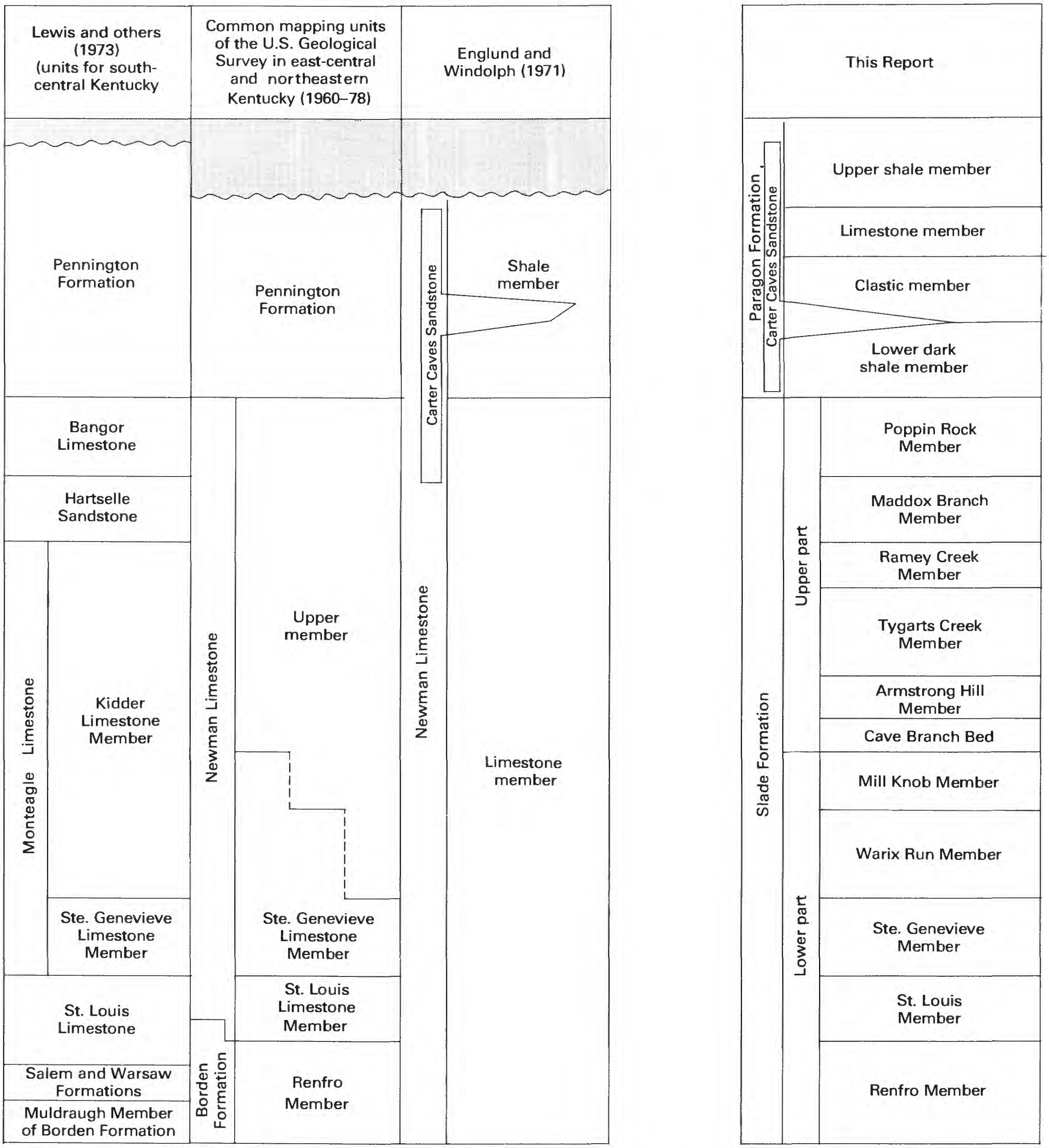

Figure 3. Recent variations in the nomenclature of the Slade and Paragon Formations used in northeastern, east-central, and south-central Kentucky. Interval shown for the Armstrong Hill Member of the Slade Formation for this report also locally includes the Holly Fork and Rosslyn Members of the Slade Formation.

thin- to thick-bedded carbonate units with interbedded shale. Most of the members are distributed widely throughout the outcrop belt. Local absence of units is due to erosion or nondeposition, particularly in the northern part of the area where deposition was influenced by contemporaneous minor tectonism (Dever,

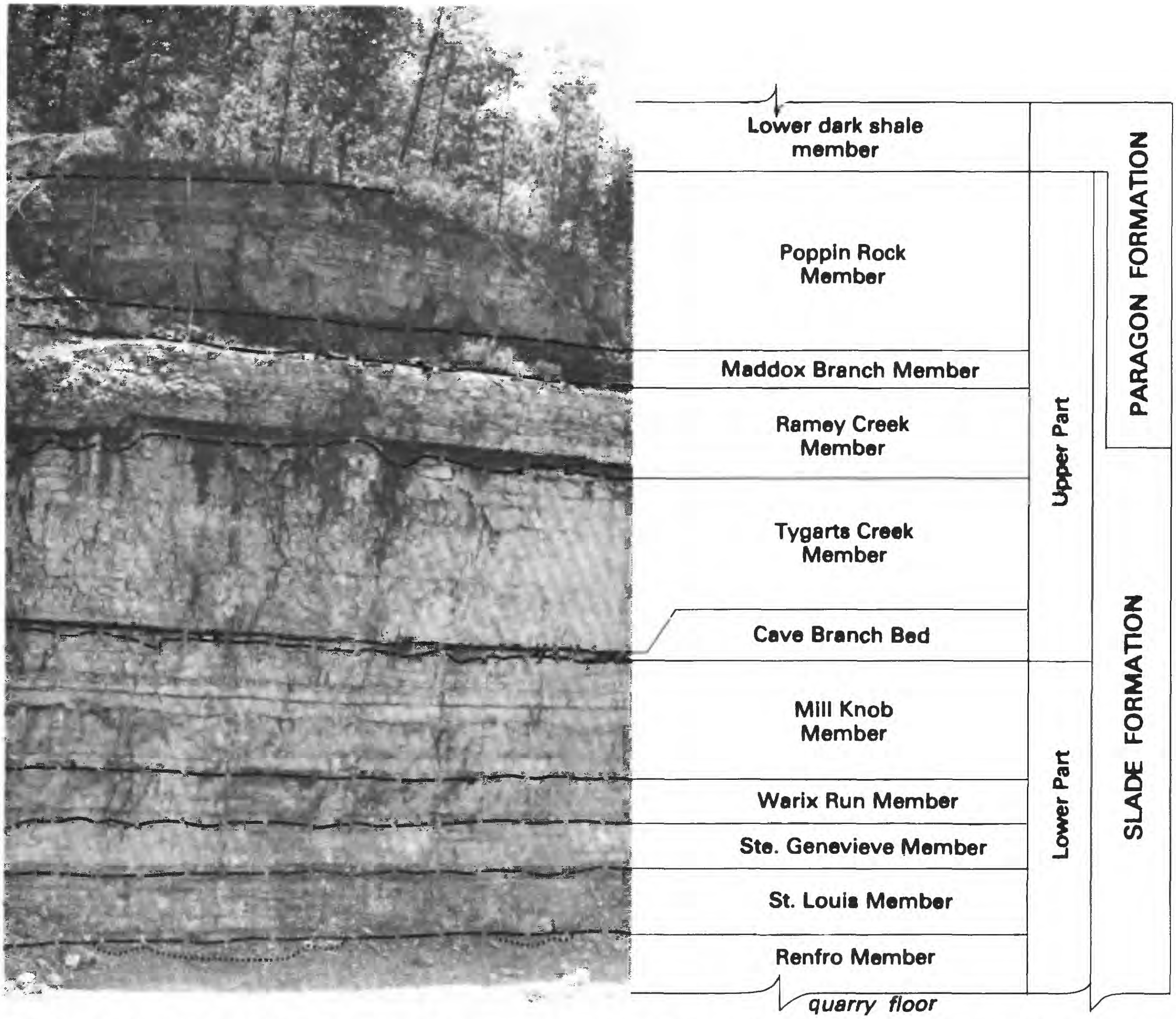

Figure 4. Type section of the Slade Formation showing major members on the southeastern highwall of the Natural Bridge Stone Co. quarry near Bowen, Ky. (see the Type and Reference Sections, section 1, p. 23). The lower members of the Slade are separated by disconformities marked by breccias and exposure-crust horizons that are not readily apparent at the scale of the photograph. The Tygarts Creek Member is 9.3 m thick. (Photograph taken in 1982.)

1977, 1980a [1973], 1980b; Dever and MacQuown, 1974; Ettensohn, 1975, 1977, 1979, 1980, 1981b; Ettensohn and Dever, 1975, 1979a, b, c).

Lower part of Slade Formation

The lower part of the Slade Formation is a Meramecian-early Chesterian onlap sequence of near-shore, shallow-water carbonate rocks that tend to thin toward the northeast. It is divided into five members: the Renfro, St. Louis, Ste. Genevieve, Warix Run, and Mill Knob. The Renfro Member is reassigned from the underlying Borden Formation, and the St. Louis Limestone and Ste. Genevieve Limestone Members are reassigned from the Newman Limestone to the Slade Formation as the St. Louis and Ste. Genevieve Members. The names, St. Louis and Ste. Genevieve, have longstanding use in the limestone and petroleum industries of the State because they represent lithologic units that have distinctive physical and chemical properties. The Warix Run Member was originally designated as the northern unit of the Ste. Genevieve Limestone Member of the Newman by Dever (1980a [1973]). The Mill Knob Member is a newly designated member. The thickness of the lower part of the Slade Formation ranges from 0 to about 75 m. The lower part of the Slade Formation is capped by a widespread exposure zone that forms a prominent disconformity and separates the lower and upper parts of the formation. The complicated stratigraphy and depositional history of this sequence has been largely resolved by Klekamp (1971), Philley (1971), and Dever (1977, 1980a [1973], 1980b). Members in the lower part of the Slade are described in the following sections.

Renfro Member

The Renfro Member, originally defined by Weir and others (1966) as a subdivision of the Borden Formation, is here reassigned to the Slade Formation. The Renfro, mainly dolostone and limestone, was the uppermost member of the Borden in east-central and northeastern Kentucky and the only carbonate-rock unit in a formation predominantly composed of terrigenous clastics. With reassignment to the Slade Formation, the Renfro becomes the basal member of a carbonate-dominated succession of beds.

The Renfro Member has been mapped as generally coextensive with the Newman Limestone except in the Crab Orchard quadrangle at the southwestern end of the outcrop belt (fig. 1). There, the Renfro caps the higher hills. For convenience and consistency, we propose that the Renfro Member of the Borden Formation in the Crab Orchard quadrangle, be designated the Renfro Member of the Slade Formation.

The type section of the Renfro Member of the Slade Formation, described by Weir and others (1966, p. F32–F34), was measured along U.S. Highway 25 beginning about 0.3 km southwest of the village of Roundstone, about 4.8 km north of Renfro Valley, Rockcastle County, Ky., in the Wildie quadrangle (fig. 1). The Renfro at that locality is 25.1 m thick. The thickness of the Renfro Member ranges from about 40 m in the southwest to less than 1 m in northeastern Kentucky where it has been mapped with the Newman Limestone (for example, Denny, 1964; Englund and Windolph, 1975). As a result of intra-Mississippian erosion, the Renfro is absent in parts of northeastern and northern east-central Kentucky; there, the Warix Run Member is at the base of the Slade (see fig. 6).

The Renfro Member is primarily dolostone with interbeds of limestone and lesser amounts of dolomitic siltstone, shale, and sandstone. Dolostone and dolomitic limestone are very finely crystalline, very thick to thin bedded, locally laminated or burrowed. Fresh rock colors are light gray to light olive gray, yellowish gray, and greenish gray; weathered rock colors are pale yellowish orange to dark yellowish orange and grayish orange. Dolostone in the lower part of the Renfro locally grades to dolomitic siltstone. Limestone in the Renfro is light-olive-gray to olive-gray and greenish-gray, very thin to medium-bedded, bioclastic calcarenite and calcilutite. Greenish-gray to dark-greenish-gray shale occurs mainly as partings but locally in beds as much as 1 m thick in the lower part of the member. Conglomeratic sandstone containing quartz granules occurs as a bed about 0.4 m thick in the lower part of the Renfro Member in the vicinity of the type section; this bed pinches out to the northeast. It represents the northern distal part of the Science Hill Sandstone Member of the Warsaw Formation. The percentage of calcarenite, fossiliferous limestone, and sandstone in the Renfro increases southwestward from the type section as those parts correlative with the Salem and Warsaw Formations and Muldraugh Member of the Borden thicken.

Exotic constituents such as geodes as much as 0.6 m across (Gualtieri, 1967) and chert are common in the lower part of the Renfro of southern east-central Kentucky, particularly in the interval correlative with the Muldraugh Member of the Borden. Layers of brecciated dolostone associated with nodular quartz are present in the upper part of the Renfro as far north as Madison County (fig. 1). These layers are at least partly correlative to similar breccia and quartz-nodule zones in the St. Louis Limestone of south-central Kentucky and are considered to have formed during the dissolution and replacement of evaporites (Dever and others, 1978, 1979b).

Fossils are sparse in the dolostone beds of the Renfro Member and include brachiopods, bryozoans, pelmatozoan fragments, and pelecypods. Limestone beds in the Renfro are locally highly fossiliferous and contain brachiopods, bryozoans, echinoids, gastropods, crinoids, blastoids, pelecypods, and colonial corals (*Syringopora* and cf. *Dorlodotia*); foraminifers are also reported by Weir and others (1971). Minor shale beds in the dolostone locally contain small algal masses.

The Renfro Member conformably overlies the Borden Formation. The contact between the basal dolostone of the Renfro and the shale and siltstone of the Borden Formation is generally sharp. In northeastern and most of east-central Kentucky, the Renfro rests on interbedded shale and siltstone of the Nada Member of the Borden. In parts of east-central Kentucky, where a zone of interbedded dolostone and shale occurs in the basal Renfro, the contact is placed at the base of the lowest dolostone bed. In southern east-central Kentucky, the Renfro rests on shale and siltstone of the Wildie Member and locally on siltstone of the Halls Gap Member, both subdivisions of the Borden Formation.

The Renfro Member is conformably overlain by the St. Louis Member of the Slade Formation throughout most of east-central and northeastern Kentucky. Locally, the St. Louis is absent, and the Renfro is disconformably overlain by calcarenites of the Ste. Genevieve or Warix Run Members. The contact between the yellow- to orange-weathering dolostone of the Renfro and light-gray limestone of the St. Louis is generally obvious. The contact is wavy, and the two lithologies commonly are separated by a very thin, greenish-gray shale of the Renfro. In the central part of the outcrop belt, the upper surface of the Renfro is marked by flow-roll or ball-and-pillow structures in which limestone of the St. Louis projects downward as much as 1 m into Renfro dolostone (Rice, 1972; Haney, 1976). In parts of Menifee, Powell, and Wolfe Counties, the upper surface of the Renfro has narrow trough-like depressions, as much as 1.1 m deep, filled with limestone of the St. Louis Member (Dever, 1980a [1973]). Dolomitization of basal limestone beds of the St. Louis has resulted also in a gradational contact between the St. Louis and Renfro at sites in Menifee and Rockcastle Counties (Dever and others, 1977, p. 63; Dever and others, 1979b).

An intertonguing relation between dolostone of the Renfro Member and limestone of the St. Louis Member in parts of Rockcastle County reported by Weir and others (1966) may be inaccurate. An examination of roadcuts and outcrops in the area by Dever and others (1979b) suggests that discrete bodies of dolostone occur locally within the basal St. Louis and that interbeds of limestone in the Renfro can be traced southward from Rockcastle County beyond the arbitrary geographic limits of the Renfro Member of the Slade Formation into the lower and middle St. Louis Limestone of south-central Kentucky. These examples contribute to an appearance of intertonguing between the Renfro and overlying St. Louis.

At its type section, the upper 16.7 m of Renfro correlates with the lower and middle parts of the St. Louis Limestone of south-central Kentucky (Dever and Moody, 1979). Those strata (units 31 through 47, Weir and others, 1966, p. F32–F33) were in fact mainly mapped on the Brodhead and Woodstock quadrangles (Gualtieri, 1967; Weir and Schlanger, 1969) (fig. 1) as part of the St. Louis Limestone Member of the Newman Limestone. The lower 8 m of Renfro, below the 0.4 m of sandstone equivalent to the Science Hill Sandstone Member of the Warsaw Formation (Lewis and Taylor, 1979), consists of dolostone, cherty and geode-bearing dolomitic siltstone, and shale, and it correlates with the Muldraugh Member of the Borden Formation (fig. 3) to the southwest.

Dolostone of the Renfro represents intertidal and supratidal deposition (Kerby, 1971; Dever and others, 1978). Faunal and lithologic characteristics of the limestone beds of the Renfro indicate deposition mainly in a subtidal environment.

St. Louis Member

The St. Louis Limestone Member of the Newman Limestone (Hatch, 1964; Cohee and West, 1965) is reassigned here as the St. Louis Member of the Slade Formation. The St. Louis Limestone retains its formational rank in south-central and western Kentucky. For the reasons given in the description of the Renfro Member, the St. Louis Member of the Slade Formation is lithologically equivalent to the upper part of the St. Louis Limestone in south-central Kentucky (as mapped by the USGS) and to the St. Louis Limestone as described by Butts (1922) and McFarlan and Walker (1956). The St. Louis Member consists mainly of limestone and dolostone, and it ranges in thickness from 0 to 9 m; average thickness along the outcrop is about 5 m. It is absent locally as a result of intra-Mississippian erosion in many parts of the outcrop belt in east-central and northeastern Kentucky (Rice, 1972; Dever, 1980a [1973]; Haney and Rice, 1978).

The St. Louis Member is characterized by light-olive-gray to light-gray calcirudite and calcarenite composed of bioclastic grains and whole fossils, commonly in a micritic matrix. This lithic type is interbedded with light-olive-gray to light-gray bioclastic calcarenite, light-olive-gray to greenish-gray calcilutite, and very thin beds of greenish-gray shale. Locally, discrete bodies of grayish-orange to moderate-yellowish-brown, very finely crystalline dolostone also occur in the St. Louis.

Chert of various colors occurs abundantly as irregularly shaped masses, as spheroidal and discoidal nodules, and as thin to very thin discontinuous beds. Silicification of fossils is common. Micritic crusts and stringers in an exposure zone at the top of the member commonly are silicified selectively and form wavy bands of light-colored chert in the dark-gray altered limestone.

Faunal remains include brachiopods, bryozoans, gastropods, pelmatozoans, echinoids, and corals. Colonial lithostrotionoid corals, commonly identified as "*Lithostrotion*" *proliferum* Hall in Hall and Whitney (1858) and *Lithostrotionella castelnaui* Hayasaka, are common in the member and are useful guides for its field identification. Sando placed Hall's species in the genus *Acrocyathus* d'Orbigny and Hayasaka's species in the synonymy of *A. floriformis floriformis* (d'Orbigny) (1983, p. 20 and p. 17, respectively). *Acrocyathus proliferum* occurs throughout the outcrop belt; the other taxon, common in east-central Kentucky, has not been found northeast of Menifee County. Conodonts (Chaplin and Mason, 1979) and foraminifers (Pohl and Philley, 1971) in the St. Louis Member of northeastern Kentucky indicate correlation with the St. Louis Limestone of the type area in eastern Missouri.

Features indicative of intra-Mississippian subaerial exposure and vadose diagenesis occur at the top of the St. Louis Member throughout northeastern Kentucky and across east-central Kentucky as far south as northern Rockcastle County (fig. 5). Farther southward, in central Rockcastle County, there is no evidence of exposure. There, the top of the member is marked commonly by a bed of limestone containing abundant chert nodules, which upon weathering yield a blocky chert residuum.

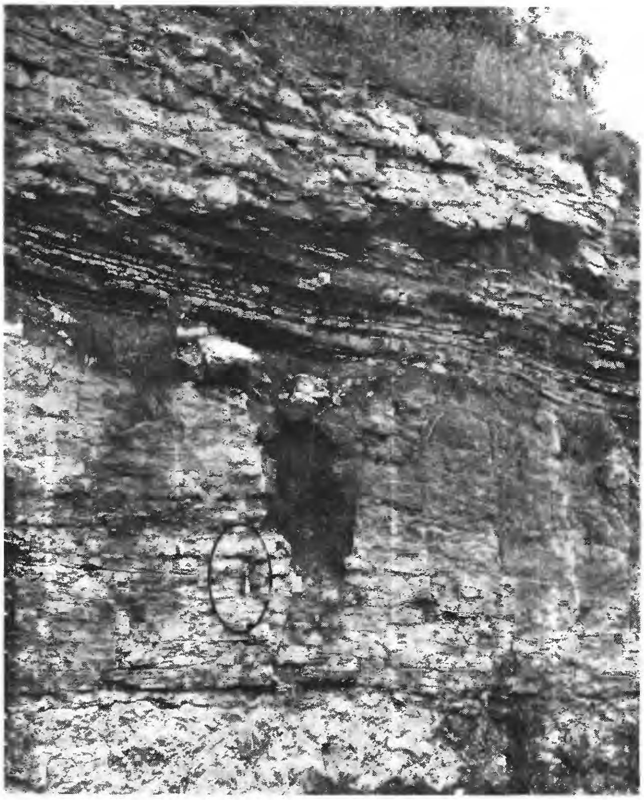

Figure 5. Sink hole in upper part of the St. Louis Member filled with shale of the Cave Branch Bed on Interstate Highway 64 (see the Type and Reference Sections, section 7, p. 29). The irregular, brecciated upper surface at top of St. Louis marks a regional unconformity. Thin-bedded limestone and interbedded shale of the Cave Branch Bed are truncated by a channel containing thicker bedded calcilutites of the Armstrong Hill Member. All of the above units are members or beds of the Slade Formation. The hammer circled on the photograph, is 0.3 m long.

The St. Louis Member rests conformably on the Renfro Member. As noted previously (see p. 8), the contact is locally gradational between orange-weathering dolostone of the Renfro and light-gray limestone of the St. Louis, but in most places the contact is sharp.

In much of east-central Kentucky, the St. Louis Member is overlain disconformably by the Ste. Genevieve Member (fig. 4). The contact between the light-gray calcarenite and local calcilutite of the Ste. Genevieve and the dark-gray altered limestone of the upper part of the St. Louis is sharp. In southern east-central Kentucky, the Ste. Genevieve conformably overlies the St. Louis. Here, a transitional zone of interlayered calcarenite and calcilutite less than 1 m thick occurs between the cherty calcilutite of the upper part of the St. Louis and the lowest thick (about 2 m) beds of Ste. Genevieve calcarenite. In many parts of northeastern Kentucky, the dark-gray altered limestone of the upper part of the St. Louis is disconformably overlain by quartzose calcarenite of the Warix Run Member, calcilutite of the Mill Knob Member, shale of the Cave Branch Bed (see figs. 5 and 9), dolostone of the Holly Fork Member (see fig. 7), or calcarenite of the Tygarts Creek Member.

The St. Louis Member represents deposition in a subtidal environment. Its deposition in northeastern and most of east-central Kentucky was interrupted by tectonic uplift that resulted in episodes of subaerial exposure and vadose diagenesis of the sediments (Dever, 1980a [1973]).

Ste. Genevieve Member

The Ste. Genevieve Limestone Member of the Newman Limestone as defined by Hatch (1964) is principally a calcarenite. Dever (1980a [1973], 1980b) has shown that the Ste. Genevieve Limestone consists of two distinct lithic units separated by an erosional unconformity. The older lithic unit generally occurs in the southern and central parts of the outcrop belt and is reassigned here to the Ste. Genevieve Member of the Slade Formation. It consists mainly of bioclastic and oolitic calcarenite with lesser amounts of calcilutite. The younger unit is the Warix Run Member of the Slade Formation that consists mainly of quartzose, peloidal calcarenite deposited on the post-Ste. Genevieve (as restricted) erosional surface and occurs mainly in the northeastern and central parts of the outcrop belt. Southwest of the geographic limits of the Slade Formation, the Ste. Genevieve Member corresponds to the Ste. Genevieve Limestone Member of the Monteagle Limestone (Lewis and Thaden, 1965). In western Kentucky, the Ste. Genevieve Limestone retains its formational rank.

The Ste. Genevieve Member ranges in thickness from 0 to about 30 m. It is absent in northeastern and northern east-central Kentucky where the member thins and pinches out along the axis of the Waverly arch. The Waverly arch was a positive feature present during Ste. Genevieve deposition and flanked the Cincinnati arch in northeastern Kentucky. The northern limits of the Ste. Genevieve Member in Bath and Menifee Counties represent intra-Mississippian erosional truncation (Dever, 1980a [1973]).

The Ste. Genevieve Member is mostly very light olive gray to olive-gray calcarenite, with lesser amounts of very light olive gray to medium-light-olive-gray calcilutite. The calcarenite is composed of bioclastic grains (commonly micrite-enveloped grains) and ooids. Peloids and lumps are common. The calcarenite is thin-to very thick bedded and is crossbedded; the calcilutite occurs as very thin to thick, planar to wavy and nodular beds that grade laterally into calcarenite. Beds of crinoidal calcirudite are present in southern east-central Kentucky. Shale is sparse, occurring mainly as very thin beds intercalated with calcilutite. Detrital quartz also is sparse, but a thin detrital zone, commonly present at the base of the member, locally contains abundant quartz silt and sand. Chert is a minor constituent mainly associated with selective silicification of fossils and of micritic crusts and stringers in vadose- and subaerial-exposure zones.

The Ste. Genevieve Member contains multiple exposure zones in southern east-central Kentucky that are marked by diagenetic micritic crusts and stringers, zones of secondary coated grains and particles and, locally, brecciated calcilutite. In the northern part of the area, only the exposure zone at the top of the Ste. Genevieve is present, and it is correlated with the Bryantsville Breccia Bed (Malott, 1952; Shaver and others, 1970) at the top of the Ste. Genevieve Limestone of western Kentucky (McFarlan and others, 1955).

Fossils are relatively sparse in the Ste. Genevieve, but beds of fossiliferous limestone occur in the lower part of the member in southern east-central Kentucky. Faunal remains include brachiopods, pelmatozoans, gastropods, echinoids, bryozoans, solitary corals, and ostracodes. The Meramecian crinoid species *Platycrinites penicillus* Meek and Worthen, common in the Ste. Genevieve Limestone member of the Monteagle Limestone in south-central Kentucky, is rare in the member in east-central Kentucky.

The contact between the Ste. Genevieve and St. Louis Members is generally sharp. In much of east-central Kentucky, the Ste. Genevieve rests disconformably on the St. Louis Member, and the basal Ste. Genevieve contains clasts of St. Louis chert and limestone. In southern east-central Kentucky where the Ste. Genevieve conformably overlies the St. Louis, transitional beds, less than 1 m thick, occur between the cherty calcilutite of the St. Louis and the lowest thick calcarenite bed of the Ste. Genevieve. In parts of Estill and Jackson Counties, the St. Louis is absent, and the Ste. Genevieve rests disconformably on the Renfro Member.

The Ste. Genevieve Member is disconformably overlain by quartzose calcarenite of the Warix Run Member in much of east-central Kentucky. Where the Warix Run is absent, the Ste. Genevieve is disconformably overlain by calcilutite or calcarenite of the Mill Knob Member.

Calcarenites of the Ste. Genevieve Member were deposited mainly in very shallow water subtidal environments, whereas the calcilutites represent shallow-water lagoonal deposits. The exposure zone (equivalent to the Bryantsville Breccia Bed) at the top of the Ste. Genevieve is widespread. The prominence of the zone in east-central Kentucky is related to the degree of exposure of the Ste. Genevieve Member during recurrent activity of structural features.

Warix Run Member

The Warix Run Member of the Slade Formation, principally quartzose calcarenite, is named for Warix Run, which is a tributary of the Licking River (Cave Run Lake) in southern Rowan County, Ky. The Warix Run Member was previously designated "the northern unit" of the Ste. Genevieve Limestone Member of the Newman Formation by Dever (1980a [1973]); the name, Warix Run, was introduced by Dever (1977). The type section, described in the Type and Reference Sections, section 2, p. 25, is near the head of Warix Run in the roadcut along Kentucky Highway 801 and is immediately north of the intersection of Kentucky Highways 801 and 1274 in the Bangor quadrangle (fig. 1). Warix Run strata were assigned previously to the Ste. Genevieve Limestone by Butts (1922) and McFarlan and Walker (1956). During the USGS and Kentucky Geological Survey cooperative mapping program, Warix Run strata were included in the Ste. Genevieve Limestone Member of the Newman Limestone (for example, Sheppard, 1964; Hylbert and Philley, 1971).

Thickness of the Warix Run Member ranges from 0 to 31 m. In northeastern and northern east-central Kentucky, it accumulated in low areas on the post-Ste. Genevieve erosional surface, partly filling them. The Warix Run commonly has a maximum thickness near the middle of the erosional lows; it thins and pinches out along the margins and thus forms a series of isolated bodies in the present outcrop. The Warix Run is more widespread to the south; it is commonly less than 3 m thick and forms a blanket-like deposit that has been traced as far south as Rockcastle County.

The Warix Run consists of light-olive-gray quartzose calcarenite and contains a lesser amount of light-olive-gray to olive-gray calcilutite. The calcarenite is composed mainly of peloids, sparse to abundant bioclastic grains (commonly micritic-enveloped grains), and ooids. Bedding in the calcarenite is very thin to very thick and dominantly crossbedded (fig. 6). In some sections, crossbedded calcarenite grades upward into planar-bedded calcarenite. The calcilutite mainly occurs in very thin to thin beds.

The member contains abundant quartz silt and sand, and it locally grades into calcareous sandstone (McFarlan and Walker, 1956; Klekamp, 1971). Shale is sparse but present locally as partings and very thin beds. Locally in Rowan County, the Warix Run contains a lens of shale as much as 2 m thick that is probably reworked from shale of the underlying Nada Member of the Borden Formation (Dever, 1980a, [1973]). Clasts derived from members of the Borden and Slade Formations occur in the basal part of the unit, particularly in the northern part of the outcrop belt; grains and granules of St. Louis chert and limestone are common constituents. Fossils are sparse, but they include pelmatozoan plates, echinoid spines, and brachiopods. Diagenetic features, such as micritic crusts and stringers, are indicative of subaerial exposure and vadose diagenesis and occur at

Figure 6. Crossbedded calcarenite of the Warix Run Member of the Slade Formation overlying disconformably the Cowbell Member of the Borden Formation. The St. Louis and Renfro Members of the Slade Formation and upper parts of the Borden Formation are absent due to erosion. The upper half of the limestone ledge contains the Mill Knob Member and the Cave Branch Bed of the Slade Formation. Tygarts Creek Member of the Slade Formation is the ledge in the upper right-hand corner. Roadcut is on Kentucky Highway 2 just north of its junction with Interstate Highway 64 north of Armstrong Hill.

the top of the Warix Run in parts of the area, but their rather meager development suggests relatively brief periods of exposure.

The basal contact of the Warix Run Member is sharp; the light-gray quartzose calcarenite of the member is distinct from and disconformably rests on strata of the Borden Formation or older members of the Slade Formation (fig. 6). The Warix Run is overlain by the Mill Knob Member of the Slade. In the northern part of the outcrop belt, where the Mill Knob is dominantly calcilutite, its contact with the Warix Run is sharp. Locally, the two lithologies of the members intertongue, and the top of the Warix Run is placed at the top of the highest calcarenite bed. To the south in east-central Kentucky, the contact between quartzose calcarenite of the Warix Run and bioclastic oolitic calcarenite of the basal Mill Knob is generally distinctive.

Results of microfaunal studies suggest that the Warix Run Member may be either Meramecian or Chesterian in age (Pohl and Philley, 1971; Horowitz and Rexroad, 1972). Lithostratigraphic relations suggest a possible Chesterian age because the member disconformably overlies an exposure zone correlated with the Bryantsville Breccia Bed, which is the youngest Meramecian unit in west-central Kentucky (Rice and others, 1979, p. F11). In northeastern Kentucky, the Warix Run Member intertongues with limestone of the Mill Knob Member, which is correlated with *Talarocrinus*-bearing limestone of early Chesterian age in south-central Kentucky (McFarlan and Walker, 1956).

Calcarenites of the Warix Run Member in northeastern Kentucky are probably tidal-channel deposits (Klekamp, 1971) and carbonate-barrier-island and tidal-bar-belt deposits (Horne and others, 1974).

Mill Knob Member

The Mill Knob Member of the Slade Formation, which consists largely of sequences of calcilutite and calcarenite, is named herein for Mill Knob, a hill 3.8 km east of Stanton, Powell County, Ky. The type section, described in the Type and Reference Sections, section 1, p. 23, is in the Natural Bridge Stone Co. quarry (fig. 4), 4 km southeast of Mill Knob and 3 km south of the community of Bowen, Stanton quadrangle (fig. 1).

Strata of the Mill Knob Member previously were assigned to the Ohara Limestone Member of the Ste. Genevieve and, locally, to the Bethel(?) Sandstone and lower part of the Gasper Oolite by Butts (1922); to the Renault Formation by Stokley and McFarlan (1952); and to both the Paoli-Beaver Bend and Paoli Formations by McFarlan and Walker (1956) (fig. 2). During the USGS and Kentucky Geological Survey cooperative mapping program, these strata generally were included in the upper member of the Newman Limestone (fig. 3). Several workers in northeastern Kentucky included both Mill Knob and Warix Run rocks in the Ste. Genevieve Limestone Member of the Newman (Sheppard, 1964; Philley, 1970, 1971; Klekamp, 1971).

Thickness of the Mill Knob Member ranges from 0 to 13 m. In northeastern and northern east-central Kentucky, the member thins and pinches out along the axis of the Waverly arch, which was a positive feature during Mill Knob deposition (Dever, 1980a [1973]).

The Mill Knob Member consists of very light olive gray to medium-light-olive-gray calcarenite and very light olive gray to olive-gray and greenish-gray calcilutite, with lesser amounts of very light gray to grayish-orange and greenish-gray dolostone and greenish-gray silty shale. The calcarenite is composed mainly of bioclastic grains (commonly micritic-enveloped grains) and ooids. It occurs in thin to very thick beds and commonly is crossbedded. The calcilutite occurs in very thin to medium, wavy to nodular, and planar beds, commonly with intercalated shale occurring both as laminae and very thin beds. In east-central Kentucky, the calcarenite and calcilutite form multiple fining-upward sequences commonly capped by exposure zones. In northeastern and northern east-central Kentucky, the member is dominantly calcilutite with varying amounts of interbedded shale.

Very finely crystalline dolostone, in thin to very thick beds, is an important constituent of the Mill Knob of northeastern and northern east-central Kentucky. In Menifee County, the basal dolostone is in discrete bodies as much as 2 m thick, which have an irregular domal shape with a flat base. These beds are enclosed by thin-bedded calcilutite. Chert is relatively common in the Mill Knob Member and is associated generally with the secondary silicification of exposure features such as micritic crusts and stringers and teepee structures. A prominent exposure zone at the top of the Mill Knob can be traced throughout the outcrop belt. It consists of a zone of brecciated and altered calcilutite with micritic crusts and stringers. The breccia texture is masked locally by secondary dolomitization and silicification.

Fossils are sparse to locally abundant, and they include pelmatozoan plates brachiopods, blastoid thecae, echinoid spines, and gastropods. The Chesterian crinoid *Talarocrinus* was reported from only two localities in the Mill Knob Member in east-central Kentucky. One of these is in Rockcastle County (Butts, 1922) and the other in Powell County (McFarlan and Walker, 1956). The Chesterian crinoid *Agassizocrinus* also was reported from the Mill Knob of Rockcastle County (McFarlan and Walker, 1956).

In most places the Mill Knob intertongues with or rests conformably on the Warix Run Member; it also rests disconformably on the Ste. Genevieve and St. Louis Members. Its basal contact generally is distinct. The contact at the top of the Mill Knob is sharp; diagenetically altered limestone of the upper part of the Mill Knob generally is overlain disconformably by shale of the Cave Branch Bed and locally by calcilutite of the Armstrong Hill Member or calcarenite of the Tygarts Creek Member.

The Mill Knob Member represents deposition in subtidal, intertidal, and supratidal environments (Dever, 1980a [1973], 1980b). Fining-upward sequences indicate transgressive-regressive cycles with progradation of tidal-flat and supratidal deposits across carbonate-sand belts. Progradation of the shoreline resulted in exposure of supratidal deposits and vadose diagenesis.

Upper part of Slade Formation

The upper part of the Slade Formation consists of a basal bed and seven members of which four to six are present in any given outcrop (figs. 3 and 4). From oldest to youngest, these are the Cave Branch Bed, the Armstrong Hill, Holly Fork, Rosslyn, Tygarts Creek, Ramey Creek, Maddox Branch, and Poppin Rock Members. These strata previously were grouped as Upper Mississippian rocks undivided (Patterson and Hosterman, 1961; Hosterman and others, 1961) or as the upper member of the Newman Limestone (Sheppard, 1964; Denney, 1964; Simmons, 1967; Whittington and Ferm, 1965; Sharps, 1966; Pipiringos and others, 1968; Philley, 1970; Englund, 1976). This usage of the "upper member" terminology was inconsistent both within and between rocks of the outcrop belts in Kentucky, and different workers included in the upper member different members of the Newman, as well as parts of the Pennington Formation.

The upper Slade stratigraphic succession consists predominately of thin- to thick-bedded limestone and lesser amounts of shale and dolostone. It varies in thickness from 0 to 27 m, generally thins to the west and north, and probably is absent in much of the area north of the Ohio River because of pre-Pennsylvanian and Early Pennsylvanian erosion. It is thickest in the southern parts of the east-central outcrop belt where sections are almost entirely carbonate and attain thicknesses of 19 to 27 m (Stokley and McFarlan, 1952; Stokley and Walker, 1953; McGrain and Dever, 1967a; Dever and others, 1979a). In south-central Kentucky, beyond the geographic limits of the Slade Formation, the upper part of the Slade corresponds to most of the Kidder Limestone Member of the Monteagle Limestone, the Hartselle Formation, and the Bangor Limestone (fig. 3), all of which are reported to have a combined thickness of as much as 107 m (Lewis and Thaden, 1966; Lewis, 1971). Data from deep drilling and from exposures on Pine Mountain suggest that the upper part of the Slade Formation thickens eastward and interfingers with the upper parts of the Newman Limestone of its type area. The upper Slade disconformably overlies the St. Louis (see figs. 7 and 9) or Mill Knob Members (see figs. 4 and 8). It generally conformably underlies the Paragon Formation except where the latter was removed by erosion; there, it is overlain disconformably by Pennsylvanian rocks of the Lee or Breathitt Formations. Lithostratigraphic units in the upper part of the Slade are described in the following sections.

Cave Branch Bed

The name Cave Branch was introduced by Dever (1980a [1973]) for a thin extensive shale unit in the middle part of the Newman Limestone (fig. 4). The type section is in a roadcut along Kentucky Highway 1274 just south of Cave Branch, 0.2 km south of the Licking River (Cave Run Lake), in northeastern Menifee County, Ky. (Dever, 1980a). The unit has been correlated with various Chesterian units in the Eastern Interior basin (fig. 2). Butts (1922, p. 147) placed the shale unit at the base of the Gasper Formation; he called it the Gasper clay, and he suggested that it was equivalent to the Bethel Sandstone of western Kentucky. Stokley and McFarlan (1952) continued that usage, whereas McFarlan and Walker (1956) correlated the unit with both the Sample Sandstone (above the Bethel) and the Mooretown Sandstone (equivalent to the Bethel). Hosterman and others (1961) included the unit in the St. Louis Limestone, whereas Patterson and Hosterman (1961) and Philley (1970) included it in the Beaver Bend Limestone. Because of its red and green colors, Horne and others (1971; 1974) construed the Cave Branch to be a tongue of a back-barrier, Pennington-type facies (fig. 2). The name, Cave Branch, was formalized as the Cave Branch Bed of the Newman Limestone by Dever (1980a, p. 48–49). The Cave Branch Bed is reassigned herein to the Slade Formation.

The Cave Branch Bed extends throughout the outcrop belt of the upper part of the Slade Formation, except where removed by postdepositional erosion and disconformably overlies the St. Louis (fig. 5) or Mill Knob Members (see figs. 4 and 8). Its thickness varies from 0 to 5 m, and the bed thins southeastward. Where it is most complete, the bed consists of basal red and green shale or arenaceous claystone that grades upward to red and green silty shale interbedded with thin calcilutite lenses. These lenses consist mainly of pellet and detrital-quartz wackestone and packstone, as well as calcareous mudstone.

Fossils in the Cave Branch are rare. However, agglutinated foraminifera, smooth-shelled ostracodes, and girvanellid algae are common; gastropods occur sparsely. Sedimentary structures are not abundant, but mud cracks, small vertical burrows, horizontal burrows and trails, and planed ripples, as well as scour-and-fill structures, are present locally. The bed represents terrigenous and carbonate deposition on intertidal mudflats (Ettensohn, 1974, 1975, 1977, 1980, 1981b; Ettensohn and Dever, 1979a, c).

Armstrong Hill Member

The name Armstrong Hill was given by Ettensohn (1977) to a sequence of calcilutite underlain by the Cave Branch Bed and overlain by either the Holly Fork or Tygarts Creek Members (fig. 7); the name is here formalized. The type section, described in the Type and Reference Sections, section 3, p. 26, is a roadcut on Kentucky Highway 2 north of Armstrong Hill, just north of the highway's intersection with Interstate Highway 64, Carter County, Ky. Butts (1922) placed the unit in the Gasper Oolite, but subsequent workers suggested correlations with the Renault Formation (Stokley, 1949; Stokley and McFarlan, 1952), Beaver Bend formation (McFarlan and Walker, 1956, p. 31; Patterson and Hosterman, 1961), Mooretown Sandstone (McFarlan and Walker, 1956, p. 35), and the Paoli Limestone (Philley, 1970, p. 63; Hylbert and Philley, 1971; Hoge and Chaplin, 1972). More recently, Dever (1980a [1973], 1980b) included it in the "lower unit" of the Reelsville-Beech Creek Member of the Newman Limestone.

The Armstrong Hill Member occurs both north of the Kentucky River fault system and south of the Irvine-Paint Creek fault system; it is absent in the intervening area. The member conformably overlies the Cave Branch and attains a maximum thickness of 5 m, generally thinning to the north and west. The Armstrong Hill consists largely of thin- to thick-bedded, gray calcilutite with thin shale partings, although layers of skeletal and oolitic calcarenite may occur locally; uppermost parts of the member are generally dolomitic. The member consists dominantly of wackestone, packstone, and fossiliferous, pelletal mudstone containing detrital quartz. Oncolite packstone, algal boundstone, and intraclastic packstone are common locally. It is dominated by a molluscan

Figure 7. Type section of the Holly Fork Member (see the Type and Reference Sections, section 4, p. 26) on Interstate Highway 64. The white limestone at the bench is the Tygarts Creek Member. Below this at the left-hand (west) end of the outcrop, the Holly Fork truncates the Armstrong Hill Member and the Cave Branch Bed in a large channel that was eroded to the level of the St. Louis Member. The St. Louis is the thick limestone that forms the lower half of the outcrop. All of the above units are members or beds of the Slade Formation.

fauna represented largely by gastropods. Scaphopods and pelecypods are common locally. Agglutinated foraminifera, brachiopods, and crinoids also are present. A more restricted fauna containing only gastropods, agglutinated foraminifera, ostracodes, and several kinds of algae occur in the member in areas west of the Waverly arch (Ettensohn, 1975, 1977, 1980, 1981b; Ettensohn and Dever, 1979c).

The basal contact of the Armstrong Hill with the Cave Branch Bed is sharp and conformable. The upper contact with dolostone of the Holly Fork Member and calcarenite of the Tygarts Creek Member also is distinct.

The Armstrong Hill Member contains trails and burrows throughout; ripple marks and channeling occur locally. The member represents an open, channel-lagoon deposit with locally restricted areas (Ettensohn, 1974, 1975, 1977, 1980, 1981b; Ettensohn and Dever, 1979c).

Holly Fork Member

The name Holly Fork was given by Ettensohn (1977) to a dolomitic unit, restricted to northeastern Rowan County, that overlies the Armstrong Hill Member and underlies the Tygarts Creek Member; the name is here formalized. The type section, described in the Type and Reference Sections, section 4, p. 26, is a roadcut south of Holly Fork along the westbound lane of Interstate Highway 64, 16 km west of the intersection with Kentucky Highway 2, Rowan County, Ky. (fig. 7). The member has a maximum thickness of 4.6 m in the western part of its outcrop area and thins and pinches out to the north, south, and east. The member was included in the Gasper by Butts (1922); later it was included in the Beaver Bend Limestone by Philley (1970, p. 63) and in the lower part of the Reelsville-Beech Creek unit by McFarlan and Walker (1956) and Dever (1980a [1973], 1980b).

The Holly Fork is an upward-fining dolomitic channel-sequence. The basal part of the member is largely dolomitic intraclast packstone and includes dolorudites containing mudchips and intraclasts, as well as fragments of stromatolites and other fossils. The middle part is a thin- to thick-bedded sequence of ferroan dololutite or dolosiltite with abundant birdseyes; this part of the member is characterized by intraclast grainstone, packstone, and mudstone, as well as bioclastic wackestone containing dolomitic pellets. The uppermost part is light-gray laminated calcilutite, in contract to the dark-yellowish-orange-weathering dolostone of the lower and middle parts. It consists of calcareous mudstone and pelletal packstone. Birdseyes occur throughout the member; burrows are restricted to the uppermost calcilutites; channeling, scour-and-fill structures, cross-bedding, and rare mud cracks are in lower parts of the member. Rare stromatolites, agglutinated foraminifera, and ostracodes are the only preserved organisms.

The Holly Fork Member is unconformable with both the overlying Tygarts Creek and the underlying Armstrong Hill Members, although intertonguing may occur locally with these units. Because of deep channeling prior to deposition of the member, the Holly Fork also locally overlies disconformably the St. Louis Member or the Cave Branch Bed (fig. 7). The member represents deposition on carbonate tidal flats (Ettensohn, 1975, 1977, 1980, 1981b; Ettensohn and Dever, 1979c).

Rosslyn Member

The name Rosslyn is given to a thin, largely calcarenite sequence generally overlying the Cave Branch Bed and underlying the Tygarts Creek Member and is restricted to central Powell and southern Montgomery Counties, Ky. The member is named for the community of Rosslyn, 2 km east of the type section described in the Type and Reference Sections, section 5, p. 27 . The member was included in the Renault Formation by Stokley and McFarlan (1952); Dever (1980a [1973], 1980b) placed it in the "lower unit" of the Reelsville-Beech Creek Limestone Member of the Newman Limestone.

The Rosslyn Member is as much as 2 m thick in central Powell County and thins and apparently pinches out away from that area. The basal 8 to 20 cm of the member is a conglomerate composed of dolomitic mudchips, shale fragments, rounded calcilutite clasts, and fossil fragments reworked from the underlying Mill Knob Member and the Cave Branch Bed. The conglomerate grades upward to thin-bedded, brownish-gray, rippled calcarenite lenses interbedded with very thin flaser-bedded greenish-gray shale, argillaceous dololutite, or argillaceous calcilutite. To the west, the member is more massive in appearance, although internally laminated. The calcarenite is primarily a pelletal packstone with detrital quartz or pelletal oolitic grainstone; thin muddy interbeds are predominately argillaceous dolomitic mudstone.

The contact at the base of the member is a disconformity, and the member grades upward into calcarenite of the Tygarts Creek Member. Lateral relations between the Rosslyn and adjacent members are uncertain.

Ripple marks are abundant locally, as are *Cruziana*-like and *Phycodes*-like trails and burrows. Although agglutinated foraminifera are abundant, megafossils are extremely rare. This member represents deposition on back-sand-belt intertidal flats (Ettensohn, 1975).

Tygarts Creek Member

The name Tygarts Creek is given to a very light gray calcarenitic unit formerly called the Reelsville-Beech Creek [Limestone] by McFarlan and Walker (1956). The type section, described in the Type and Reference Sections, section 6, p. 28, is the southeastern highwall of the Ken-Mor Stone Company's Olive Hill quarry, Carter County, Ky. (fig. 8). The member is named for the creek that flows adjacent to the quarry. The Tygarts Creek corresponds approximately to the Gasper Oolite of Butts (1922) and also was assigned to the Paint Creek Formation (Stokley, 1949; Stokley and McFarlan, 1952; Stokley and Walker, 1953). Most workers (McGrain and Dever, 1967a, b; Philley, 1970; Hylbert and Philley, 1971; Hoge and Chaplin, 1972; Dever, 1980a [1973]) used the combined terminology, Reelsville-Beech Creek, whereas Patterson and Hosterman (1961, 1962) and Hosterman and others (1961) split the member into the two constituent units, the Reelsville and Beech Creek Limestones.

The Tygarts Creek is the most widespread member of the upper part of the Slade and occurs generally throughout the outcrop belt of the Slade Formation in eastern Kentucky. The member varies in thickness from 0 to 10 m; it thins to the north and northwest and thickens to the south and east.

The Tygarts Creek Member is a white, medium to coarsely crystalline calcarenite. Basal parts of the unit locally contain grayish-orange dolomitic layers or as many as 20 thin stringers of argillaceous dolarenite or dololutite alternating with white calcarenite stringers. Alternating stringers occur only where the Tygarts Creek is underlain by the Armstrong Hill and may represent intertonguing of the two members. Except for areas where the dolomitic stringers are present, the basal Tygarts Creek is dominantly oolitic and probably corresponds to the "Bowling Green Oolite" of Butts (1922, p. 141). Beds throughout the member are generally medium- to very thick bedded and are commonly bounded by stylolites. The lower boundary of the member generally is disconformable, whereas the upper boundary is conformable. Intertonguing also may occur locally with the underlying Armstrong Hill and Holly Fork Members.

Basal portions of the member are typically finer grained than the upper parts and are characterized by generally well-sorted oolitic grainstone or calcareous mudstone and wackestone with ooids, pellets, intraclasts, or rare detrital quartz; dolomitic stringers are typically bioclastic packstone or wackestone. Upper parts of the member are composed principally of moderately to poorly sorted ooid grainstone containing pelmatozoan fragments, pellets, pseudoolites, and grapestones.

Basal conglomerates occur locally; they include reworked fragments from underlying members. The upper part of the member locally has subaerial-exposure crusts, caliche, microkarst, or flat-pebble conglomerate. High- to low-angle tabular and lenticular crossbedding, usually with a herringbone pattern, is common throughout the member. Channeling and large intraclasts are prominent also. Ripple marks and sand volcanoes are known from a few localities. Indigenous fauna in the member is restricted to large, heavily constructed

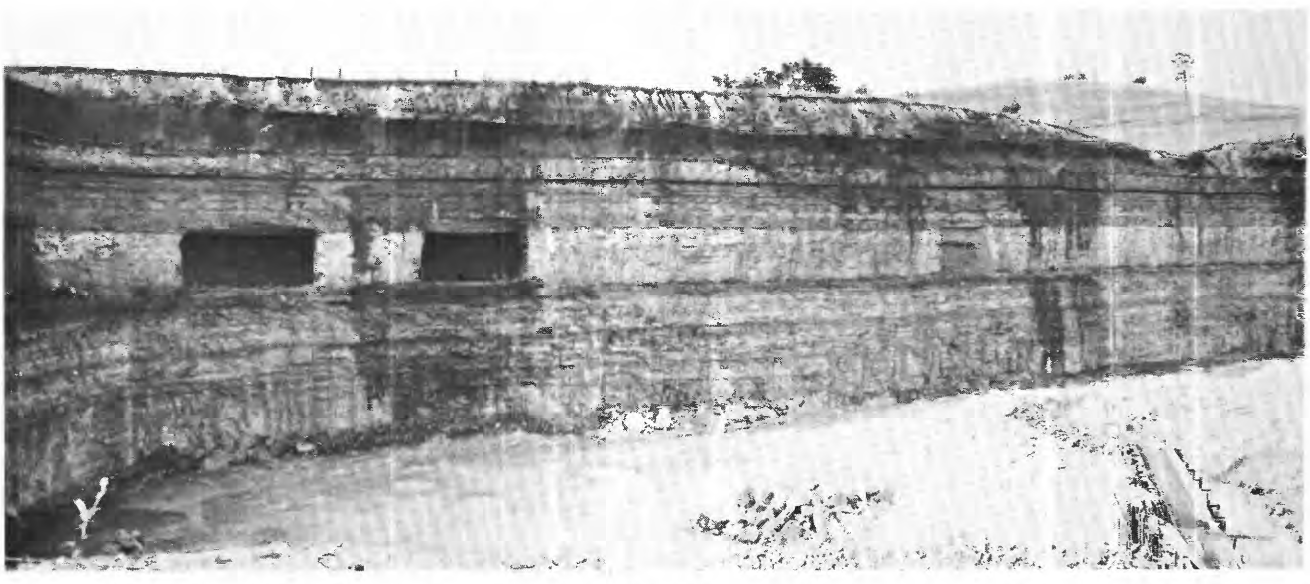

Figure 8. South highwall of the Ken-Mor Stone Company's Olive Hill quarry, the type section of the Tygarts Creek Member of the Slade Formation and reference section for the Slade and Paragon Formations (see the Type and Reference Sections, section 6, p. 27). The adits of the drift mines are approximately 5 m high and are at the level of the Armstrong Hill and Tygarts Creek Members of the Slade Formation. The dark band at the base of the adits is the Cave Branch Bed of the Slade Formation. The Warix Run and Mill Knob Members of the Slade Formation form the highwall below the Cave Branch. The uppermost limestone bed is the Poppin Rock Member of the Slade Formation. The bed of dark shale in the upper part of the highwall is the lower dark shale member of the Paragon Formation. Lenses of Carter Caves Sandstone at the top intertongue with shale of the lower dark shale member. (Photograph taken in 1980.)

straparollid and bellerophontid gastropods, the stemless crinoid *Agassizocrinus*, as well as a large unidentified crinoid pluricolumnal, blastoid thecae, and endothyrid foraminifera. The dominant floral component is fragmental phylloid algae. This member represents deposition in an agitated, carbonate sand-belt environment (Ettensohn 1974, 1975, 1977, 1980, 1981b; Ettensohn and Dever, 1979a).

Ramey Creek Member

The name Ramey Creek is given to interbedded limestone and shale formerly assigned to the Cypress Sandstone and overlying Golconda Formation of Butts (1922) and to the Big Clifty Sandstone and overlying Haney Limestone by McFarlan and Walker (1956). It is named for a creek west of the type section. The type section, described in the Type and Reference Sections, section 2, p. 25, is a roadcut at the intersection of Kentucky Highways 1274 and 801, Rowan County, Ky. The Ramey Creek Member generally is present in the area south of Greenup County. It ranges in thickness from 0 to 10 m and thickens to the southwest.

The dominant lithology of the Ramey Creek Member is thin-bedded, grayish-green calcarenite and interbedded shale (see fig. 11). It is distinguished from the underlying limestone of the Tygarts Creek by its thin-bedded nature, its shale, and by its limestone beds that contain an argillaceous and calcareous-mud matrix. It is distinguished from the overlying shale of the Maddox Branch Member by its associated limestone beds. The Ramey Creek also is characterized by abundant chert and includes widespread replacement of megafossils by red chert, a diverse fauna, and abundant horizontal burrows.

The lower part of the Ramey Creek Member is typically fine grained, and it contains 0.3 to 1.5 m of shale intercalated with thin lenses of calcarenite or, less commonly, intercalated with thin-bedded calcisiltite or calcilutite layers. The middle part includes as much as 0.6 m of thin-bedded calcarenite with interbedded shale; commonly, fossils are abundant at bedding surfaces. Interbedded with and commonly occurring above the calcarenite beds are abundantly fossiliferous nodular calcilutites and shale beds. In areas north of Menifee and Morgan Counties, the nodular calcilutite beds locally grade laterally to argillaceous, dololutitic channel fills that are as much as 0.6 m thick. A single massive, cross-bedded, skeletal or oolitic calcarenite, 0.3 to 2.1 m thick, that has a scoured planar upper surface commonly defines the top of the Ramey Creek Member.

The limestone of the Ramey Creek Member is dominantly a wackestone or packstone; the wackestone commonly contains fossil fragments or pellets, ooids, and spicules. The shaly nodular calcilutite of the Ramey Creek is typically a bioturbated spicule wackestone. Many of the fine-grained limestone beds of the Ramey Creek are calcareous mudstones.

Because the coarser calcarenite of the Ramey Creek Member is a packstone, it is readily distinguished from the better sorted calcarenite (generally grainstone) of the Tygarts Creek Member. In the Ramey Creek, packstone containing ooids, fossil fragments, and intraclasts is the most abundant lithic type. Oolitic and pelmatozoan grainstone is locally a major constituent in the member.

The Ramey Creek conformably overlies the Tygarts Creek and is overlain conformably by the Maddox Branch Member. Both contacts generally are gradational; the member may intertongue with the Maddox Branch.

The Ramey Creek Member contains abundant burrows and trails. This member is the most highly fossiliferous and contains the most diverse fauna of any member in the upper part of the Slade Formation. Brachiopods, rugose corals, and various types of echinoderms are the dominant fossils. Foraminifera, conularids, sponges, pelecypods, gastropods, bryozoans, and several forms of algae also are known. The Ramey Creek Member represents deposition in a shallow open-marine environment (Ettensohn, 1974, 1975, 1977, 1980, 1981b; Ettensohn and Dever, 1979a).

Maddox Branch Member

The name Maddox Branch is given herein to the prominent shale sequence formerly assigned to the Hardinsburg Sandstone by McFarlan and Walker (1956). The member is named for a creek just northeast of the type section, which is a roadcut along the westbound lane of Interstate Highway 64, Rowan County, Ky. (fig. 9). The type section, described in the Type and Reference Sections, section 7, p. 29, is 15.7 km west of the Intersection of Interstate Highway 64 and Kentucky Highway 2.

The Maddox Branch Member, predominantly shale, was assigned to the Golconda by Butts (1922) and Stokley (1949). Subsequently, the drillers' term "Pencil Cave" was used for the member (Stokley and McFarlan, 1952; Stokley and Walker, 1953). However, McFarlan and Walker (1956) equated the "Pencil Cave" with the type Hardinsburg of west-central Kentucky. Thus, the term Hardinsburg commonly has been used east of the Cincinnati arch by all workers except Patterson and Hosterman (1961, 1962) and Hosterman and others (1961), who included it in the upper part of the Haney Limestone. Because the unit occurs in the upper part of what was called formerly the Newman Limestone and contains red and green shale, it commonly was mistaken for either the Pennington Formation itself (Hatch, 1963) or intertongues of the Pennington occurring within the Newman (Horne and others, 1971, 1974) (fig. 2).

The Maddox Branch Member ranges in thickness from 0 to 14 m and extends throughout the outcrop belt

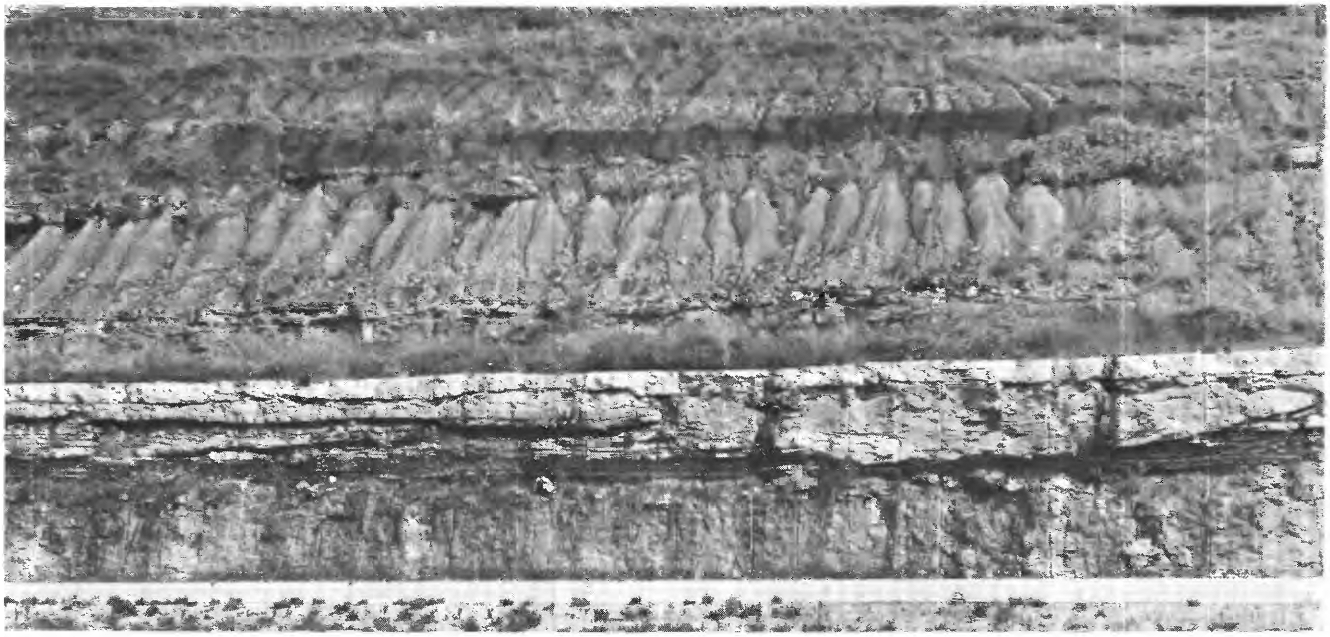

Figure 9. Type section of the Maddox Branch Member (see the Type and Reference Sections, section 7, p. 29) along Interstate Highway 64. The gullied slope is the Maddox Branch Member. The thin white limestone at the bench is about 0.8 m thick and is the Tygarts Creek Member. Below this, the Holly Fork and Armstrong Hill Members and Cave Branch Bed complexly intertongue in what was a lagoon-tidal-flat environmental mosaic. The thick limestone forming the lower one-third of the exposure near road level is the St. Louis Member. All of the above units are members or beds of the Slade Formation.

south of Greenup County, Ky. To the north, it is absent locally because of postdepositional erosion. The member thickens southward.

The Maddox Branch Member is mostly a green calcareous shale with very thin, irregularly bedded lenses of calcilutite. Locally, it is primarily red and green shale. Most of the limestone lenses are calcareous mudstone. Calcilutite lenses are abundant in the lowermost 0.6 m of the member and commonly are brecciated; others are nodular with load features on the lower and upper surfaces.

The uppermost part of the Maddox Branch Member, in contrast to the underlying shale, is a thin-bedded, argillaceous calcilutite or calcisiltite as much as 0.8 m thick. Limestone forming this part of the member commonly is laminated and intensely bioturbated and may be dolomitic; it is largely argillaceous, calcareous mudstone containing detrital quartz.

The Maddox Branch Member conformably overlies the Ramey Creek Member and is either conformably or disconformably overlain by the Poppin Rock Member of the Slade Formation. To the southwest, beyond the limits of the Slade Formation, strata equivalent to this member are the shale and sandstone of the Hartselle Formation (Lewis, 1971) (fig. 3).

The faunas of the Maddox Branch Member are limited in diversity and characterized by rhabdomesoid and fenestrate bryozoans, pelecypods, and the productid brachiopod *Diaphragmus*. Fossils are restricted largely to limestone lenses. The Maddox Branch was deposited in a relatively deep, outer-platform, open-marine environment (Ettensohn, 1974, 1975, 1977, 1980, 1981b; Ettensohn and Dever, 1979a).

Poppin Rock Member

The name Poppin Rock is given to a limestone previously called the Glen Dean Limestone in eastern Kentucky (Butts, 1922; McFarlan and Walker, 1956); these strata also were referred to as the "Little Lime," a drillers' term (R. L. Miller and Briggs, 1929; Robinson, 1927; Robinson and others, 1927, 1928). The Glen Dean type section is in western Kentucky, and, because that unit is eroded and does not extend across the Cincinnati arch, use of its name in eastern Kentucky is here abandoned. Also, palynology (Ettensohn and Peppers, 1979) and conodont biostratigraphy (Ettensohn and Bliefnick, 1982) indicate that the unit is only partially equivalent to the type Glen Dean. The Poppin Rock Member is in the same stratigraphic position and lithologically similar to the Bangor Limestone (of formational rank) in south-central Kentucky. However, the Bangor type section is in Alabama, and application of that name to rocks of eastern Kentucky is questionable. As a result, use of the newly designated member, the Poppin Rock, as the uppermost member of the Slade Formation is restricted here to the geographic limits of the formation. The member is named for the Poppin Rock tunnel near

Paragon, Ky., about 5.5 km east of the type section in Rowan County. The type section, described in the type and Reference Sections, section 8, p. 30, is a roadcut along the western side of Kentucky Highway 1274, 1.1 km north of the Licking River (Cave Run Lake) (fig. 10).

The Poppin Rock Member occurs throughout the outcrop belt of the Slade Formation south of Greenup County, but in northern parts of the belt, it has a very patchy distribution due to erosion following deposition. Its thicknesses range from 0 to 12 m; the member thickens eastward where it probably correlates with portions of the upper part of the type Newman Limestone (Wilpolt and Marden, 1959). The Poppin Rock Member also thickens to the south where it is mapped as the Bangor Limestone, as used in south-central Kentucky (Lewis and Thaden, 1965).

The Poppin Rock is mostly composed of thin- to thick-bedded, medium- to coarsely crystalline calcarenite, which is hard, dense, and typically brownish or bluish gray. Dolostones occur locally in the southern parts of the outcrop belt (Ettensohn and Chesnut, 1979a). Thin shale partings separate carbonate beds in lower parts of the member, and they increase in thickness and abundance in the upper parts of the member. The Poppin Rock generally overlies the Maddox Branch member disconformably. It generally is conformable with the overlying Paragon Formation (formerly the Pennington Formation). Locally, the Poppin Rock Member intertongues with the Paragon Formation. However, in northern parts of the study area, the Paragon, Lee, or Breathitt Formations may disconformably overlie the Poppin Rock (fig. 11).

Pelmatozoan and foraminiferal-pelmatozoan packstone is the most common petrographic type of limestone in the Poppin Rock Member, although grainstone, wackestone, and mudstone are present locally; ooids are rare. Detrital quartz, absent in the Tygarts Creek, Ramey Creek, and lower part of the Maddox Branch Members, occurs throughout the Poppin Rock Member. Large intraclasts, crossbedding, and channeling are common in lower parts of the member.

Like the Tygarts Creek Member, indigenous faunas from the lower part of the Poppin Rock consist of heavily constructed straparollid and bellerophontid

Figure 10. Type section of the Poppin Rock Member of the Slade Formation and type section of the Paragon Formation (see the Type and Reference Sections, section 8, p. 30). The thin-bedded limestone at the bottom of the picture is the upper part of the Poppin Rock Member. The lower dark shale member of the Paragon Formation and the basal parts of the clastic member of the Paragon Formation are covered by vegetation. The limestone member of the Paragon Formation is the fourth and highest of the resistant beds in the upper part of the outcrop. A thin ledge of the Corbin Sandstone Member of the Lee Formation unconformably overlies the Paragon at the top of the exposure. The interval between the top of the Poppin Rock Member and the base of the limestone member of the Paragon Formation (shown by a bracket on the photograph) is about 10 m thick.

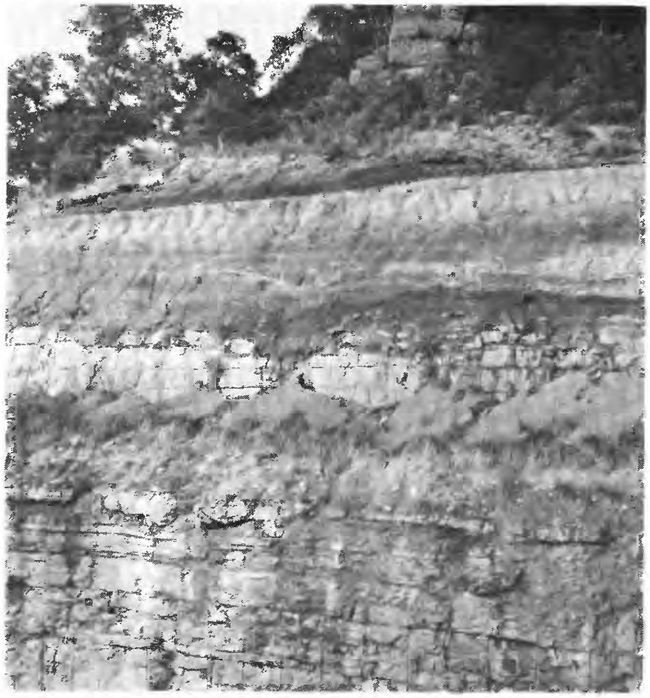

Figure 11. Clastic member of the Paragon Formation disconformably overlying the eroded surface of the Poppin Rock Member of the Slade Formation. Erosion of the Poppin Rock is related to postdepositional uplift. The thin dark unit in the upper part of the Paragon is a coal bed approximately 6 m above the Poppin Rock. A thick ledge of Corbin Sandstone Member of the Lee Formation in the upper right-hand part of the exposure unconformably overlies the Paragon. The Maddox Branch (talus-covered bench), Ramey Creek (thin-bedded limestone), and Tygarts Creek (massive limestone) Members of the Slade Formation are shown below the Poppin Rock. Location is on Kentucky Highway 1274, south of the Licking River (Cave Run Lake).

gastropods, foraminifera, and the stemless crinoid *Agassizocrinus*. However, fossils are more abundant in limestone and interbedded shale in the upper parts of the member, where brachiopods, bryozoans, rugose corals, and crinoids largely constitute the fauna. The upper part of the Poppin Rock Member is progressively more fossiliferous in the southern parts of the outcrop belt. The lower parts of the member represent deposition in a carbonate sand-belt environment; upper parts represent deposition in a shallow-water, back-sand-belt environment (Ettensohn, 1975, 1977, 1980, 1981b; Ettensohn and Chesnut, 1979b).

PARAGON FORMATION

The Paragon Formation is named for a sequence of shale, dolostone, and limestone of Late Mississippian age that overlies the Slade Formation or equivalents in the area of the Cumberland Escarpment in eastern Kentucky. The formation varies in thickness from 0 to 60 m and thickens southward and eastward. The strata assigned to the Paragon Formation are the same as those of the Pennington Formation as defined along the Cumberland Escarpment by A. M. Miller (1917, 1919) and Butts (1922). However, as previously outlined in the section on Historical Review, the name Pennington has been applied inappropriately in this area and therefore is here excluded from the Cumberland Escarpment outcrop belt in Kentucky. Furthermore, the name Newman Limestone was applied locally in the area by Sigleo and Randall (1981) and by Englund and Teaford (1981), who assigned strata previously designated as Pennington to the upper part of the Newman Limestone. Because the name Newman conflicts with the previous usage established by Lewis (1971) (fig. 3) for the sequence mapped in many U.S. Geological Survey Geological Quadrangle Maps in south-central Kentucky, the use of the name Newman for these strata is inapplicable. The name Newman also is here excluded from the Cumberland Escarpment outcrop belt in Kentucky.

The name Paragon is derived from the community of Paragon, about 5.6 km east of the type section, in Rowan County, Ky. The type section, described in the Type and Reference Sections, section 8, p. 29, occurs in a roadcut along the western side of Kentucky Highway 1274, 1.1 km north of the Licking River (Cave Run Lake) (figs. 10 and 12). Because of the great variation in thickness of the Paragon Formation, a reference section is also established in south-central Kentucky where the unit is thickest (see the Type and Reference Sections, section 9, p. 31).

The Paragon Formation occurs throughout the outcrop belt south of Greenup County. In northern parts of the area, however, its distribution is extremely patchy (Ettensohn, 1980, fig. 22D) because of sub-Pennsylvanian erosion. The Paragon in most places conformably overlies the Poppin Rock Member of the Slade Formation or its equivalent to the southwest in south-central Kentucky, the Bangor Limestone. On or near the Waverly arch and Kentucky River fault system in the northern part of the area, the lower contact is commonly disconformable (fig. 11) (Ettensohn, 1975, 1977, 1980, 1981b; Ettensohn and Peppers, 1979; Ettensohn and Dever, 1979b). The upper contact of the Paragon with overlying Pennsylvanian units is typically disconformable in northeastern and east-central Kentucky (Rice and others, 1979; Rice and Haney, 1980; Ettensohn, 1980, 1981a, b), although the amount of relief on the disconformity may decrease southeastward (Chesnut, 1983).

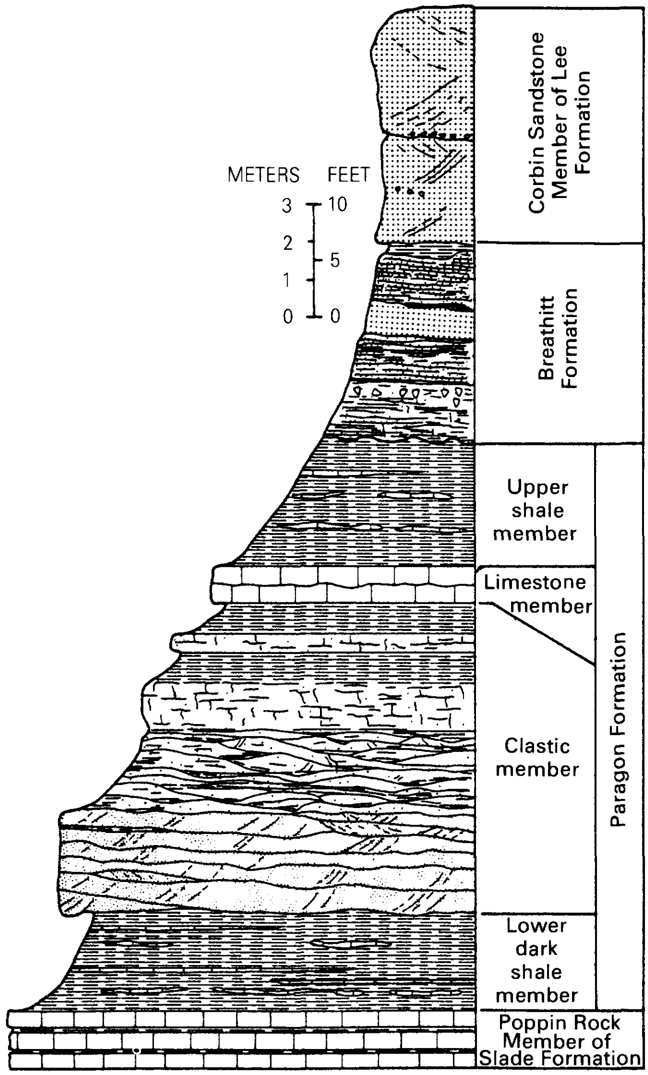

Figure 12. Lithologic diagram of the type section of the Paragon Formation along the northbound lane of Kentucky Highway 1274, in southern Rowan County. The section is continuous with a nearly complete section of the underlying Slade Formation. (Modified from Ettensohn, 1975.)

The Paragon Formation exhibits a vertical succession of lithologies, which are here divided into four informal members: (1) lower dark shale member; (2) clastic or dolostone member; (3) limestone member; and (4) upper shale member. In the northern parts of the outcrop belt, the clastic or dolostone member is dominated by coarse-grained clastics, but this interval in the southern parts of the outcrop belt is predominantly dolostone (Ettensohn and Chesnut, 1979a, 1979b). These informal members appear to be widespread, but lateral continuity cannot be demonstrated because of postdepositional erosion and poor exposures. Additionally, only the lower and middle parts of the formation crop out on and near structural elements in the area (Ettensohn and Peppers, 1979; Ettensohn, 1977, 1981b). The informal members of the Paragon are described in the following paragraphs.

Lower dark shale member

The lower dark shale member of the Paragon was informally called the Rowan member by Ettensohn (1975) and the Sloans Valley member by Chesnut (1980). The member consists of dark-gray, silty-calcareous shale with lenses of limestone. In the northern and central parts of the outcrop belt, this sequence contains a few thin calcilutite limestone lenses, which thicken and increase in number southward. The lenses grade to barlike calcarenite bodies, as much as 3 m thick and 200 m long.

The shale contains abundant organic debris and locally is fossiliferous. In the northern parts of the area, bioturbation is rare and the sparse fauna is characterized by rhabdomesoid and fenestrate bryozoans, the crinoid *Pterotocrinus*, and the productid brachiopod *Diaphragmus cestriensis* (Worthen). To the south, the member is characterized by an abundant, diverse fauna dominated by echinoderms (Ettensohn and Chesnut, 1979b; Chesnut, 1980); this fauna is associated with the limestone lenses in the unit. The member was deposited in a lagoonal environment (Ettensohn, 1975, 1977, 1980, 1981b; Ettensohn and Chesnut, 1979b).

Clastic or dolostone member

A fining-upward sequence of coarse clastics commonly overlies the basal lower dark shale member in northeastern Kentucky. This clastic sequence, as thick as 30 m, is typically a well-bedded to irregularly lenticular quartzose sandstone. Low- to high-angle crossbedding characterizes the sequence. Contorted crossbedding, ball-and-pillow, and slump structures are common locally. Small ripples and reactivation surfaces occur locally; trails and burrows occur on bedding planes. The sequence grades upward to ripple-bedded micaceous sandstone with flaser beds of micaceous, organically rich shale, all of which are highly bioturbated. The laminated organic-rich shale, with a few lenses of brecciated or dolomitic argillaceous siltstone or calcareous claystone, is concentrated in the upper part of the sequence. Fossils and fossil fragments are imbricated locally in the siltstone and claystone beds. The member locally contains one or more fining-upward sequences that in places are capped by thin underclays and thin coals beds (fig. 11) (Ettensohn, 1975; Ettensohn and Peppers, 1979).

The clastic facies of the member is probably related genetically to the Carter Caves Sandstone and its overlying sandy shale. The Carter Caves Sandstone, named by Englund and Windolph (1971), is a channel-shaped lentil within the clastic member (fig. 3; see also the type section of the Paragon in the Type and Reference Sections, section 8, p. 29) and is represented within the member by a basal sandstone. The clastic member represents tidal-flat deposits (Ettensohn, 1975, 1977, 1980, 1981b; Ettensohn and Chesnut, 1979b). Although Englund and Windolph (1971) interpreted the Carter Caves Sandstone to be a beach-barrier-bar or tidal-delta deposit, we interpret it to represent a tidal-channel deposit whose orientation is structurally controlled.

Southward from southern Rockcastle County, the clastic member is represented largely by dolostone. Although both the clastic and dolostone facies occupy generally the same stratigraphic interval within the Paragon Formation and probably represent deposition in adjacent environments, their exact relation is uncertain. The dolostone facies consists mostly of massive, vuggy dolostone and dolomitic limestone beds interbedded with shale. The dolostone beds weather light brown to grayish orange and are cherty.

The lower one-third of the dolostone facies generally contains the most massive dolostone and limestone beds and was called the Spann Limestone Member of the Pennington by Munn (1914). In places the sandy to silty dolostone is sparsely fossiliferous and contains laminae, burrows, mud clasts, contorted bedding, and birdseyes. Vugs as much as 30 cm in diameter are filled with crystalline calcite, dolomite, barite, celestite, or strontianite. Stylolites are common. Limestone is very thick bedded, crossbedded, oolitic calcarenite.

The middle one-third of the dolostone facies is characterized by thin-bedded limestone and rubbly dolostone stringers interbedded with green shale. The limestone is largely calcisiltite and calcilutite, and it locally has brecciated upper surfaces that suggest exposure. Some beds contain a restricted fauna including pelecypods and the braciopod *Orthotetes*.

The upper one-third of the dolostone facies is a very thick bedded dolostone bed similar to but thinner than those of the lower part of the facies. The bed, however, is not fossiliferous.

The dolostone facies thickens to the south and varies from 0 to 15 m in thickness. It represents intertidal deposition on a carbonate tidal flat (Ettensohn and Chesnut, 1979b).

Limestone member

A thin, bluish- or brownish-gray limestone, commonly less than 1 m thick, overlies the clastic or dolostone member (fig. 10). In northern parts of the outcrop belt, the bed is a platy, argillaceous calcisiltite. In the south, however, the bed is a crossbedded, silty, bioclastic calcarenite, which pinches out locally into dark fossiliferous shale. The bed has a very patchy distribution because of postdepositional erosion. Petrographically, the limestone is a bioclastic wackestone or packstone. Most fossils are broken, bored, encrusted, or coated with mud, and show preferential orientation—all indicating postmortem transportation and reworking. The limestone was deposited during a brief, shallow-marine transgression that terminated the tidal-flat deposition characterizing the underlying clastic member (Ettensohn, 1975, 1980, 1981b; Ettensohn and Chesnut, 1979b).

Upper shale member

The upper shale member consists of red and green shale as much as 35 m thick. The basal 3 m of the member is gray to black, organically rich, calcareous shale with thin lenses of fossiliferous limestone. This basal dark shale grades upward into silty red and green shale and contains layers and lenses of brecciated dolomite, crossbedded sandstone, and siltstone, although the shale contains abundant macerated plant debris and is bioturbated, fossils are rare and generally occur in small lenses of calcareous siltstone.

This shale is the youngest Mississippian unit in east-central and northeastern Kentucky. Its thickness is highly variable because of postdepositional erosion along the Mississippian-Pennsylvanian unconformity. In areas north of the Irvine-Paint Creek and Kentucky River fault systems, only a part of the basal 3 m of the member is preserved; south of the fault systems the basal shale is thicker. The member represents clastic tidal-flat deposition.

CORRELATIONS

Figure 13 shows the approximate currently interpreted correlations between the members of the Slade and Paragon Formations and the formations of the Mississippian type section as described by Swann (1963). Many earlier correlations of stratigraphic units of eastern Kentucky with units in the Mississippian type area were based largely on the supposed correspondence of lithologic successions of strata in the two areas (for example, Butts, 1922; Stokley, 1949; Stokley and McFarlan, 1952; McFarlan and Walker, 1956). Although guide fossils are important attributes of the strata, these are not always present. The resulting earlier correlations generally were successful for some of the lower stratigraphic units such as the St. Louis and Ste. Genevieve that could be traced east of the Cincinnati arch via the Cumberland saddle in south-central Kentucky. Detailed maps published by the USGS in cooperation with the Kentucky Geological Survey have confirmed the correspondence of those units. For most of the units in the upper part of the carbonate sequence, however, correlations proved unsatisfactory and resulted in the application of many different names and combination of names to eastern Kentucky Chesterian units.

The stratigraphic occurrence in Kentucky of selected Mississippian fossil fauna on a basis of general abundance and ease of recognition was presented in Rice and others (1979, fig. 6). Those fauna have been successfully used in tracing, mapping, and correlating many Mississippian rock units in Kentucky. However, many species appear to be long ranging and facies related, and therefore, they generally constitute a poor basis for regional and interregional correlation. A more complete knowledge of the fossil fauna and flora of Mississippian rocks will undoubtedly lead to a better understanding of Mississippian stratigraphy in Kentucky. The correlations suggested on figure 13 are biostratigraphic rather than lithologic and are based on microfaunal, palynological, and macrofaunal data; these have been summarized by Ettensohn (1980, 1981b) and Chaplin (1982).

TYPE AND REFERENCE SECTIONS

Although the type sections of the Slade and Paragon Formations and their members are distributed almost 100 km along the Cumberland Escarpment in east-central and northeastern Kentucky, the following nine sections are designed to describe not only the type sections but numerous reference sections that show the continuity and variation of each of the newly named stratigraphic units. For example, section 6, p. 27, which contains the type section of the Tygarts Creek Member of the Slade Formation, also includes reference sections for both the Slade and Paragon Formations for the eastern edge of the outcrop belt. Additionally, because of the great variation in thickness of the Paragon Formation, a reference section (section 9, p. 31) is established in south-central Kentucky where the unit is thickest.

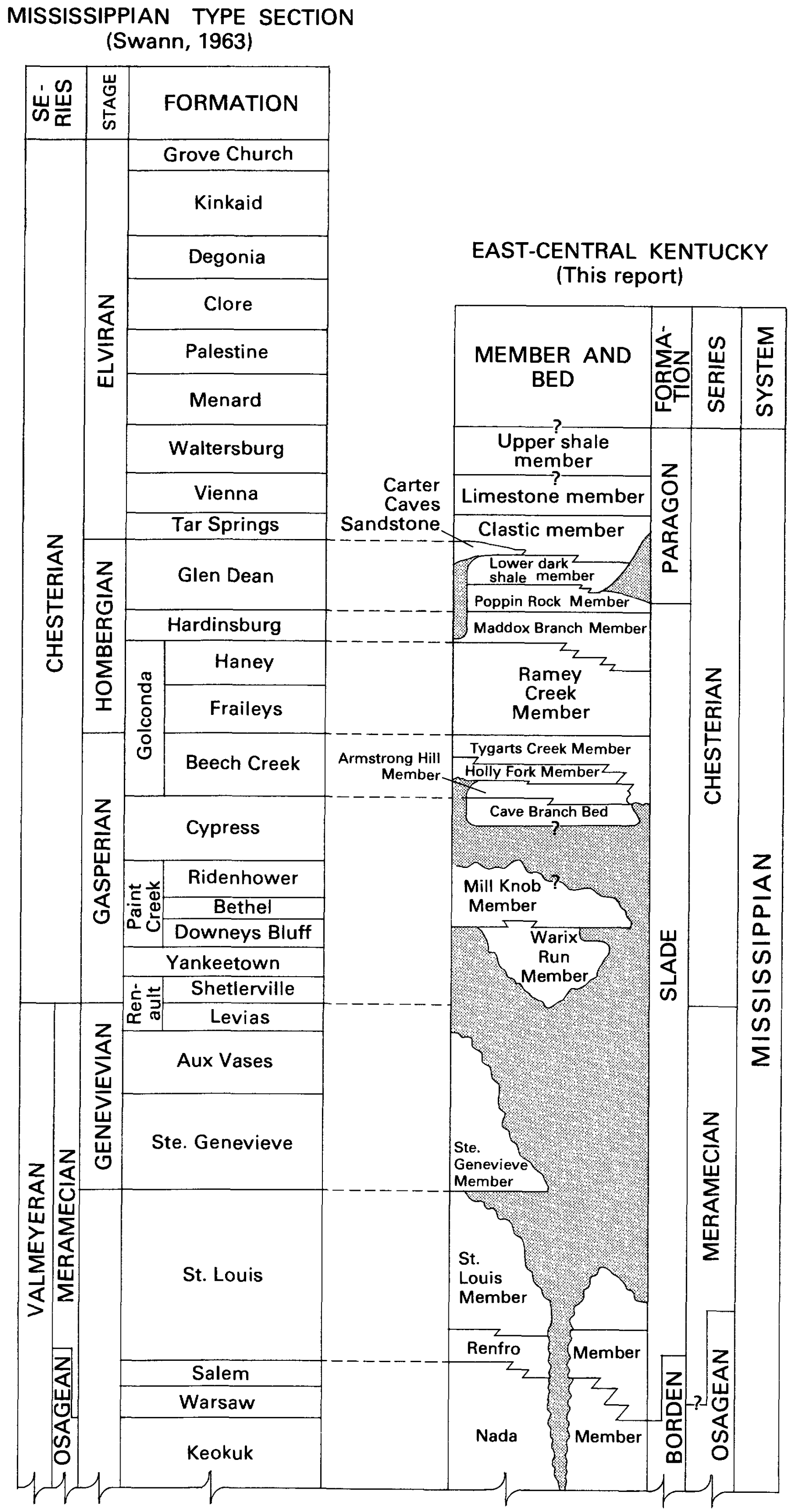

Figure 13. Tentative correlations between members of the Slade and Paragon Formations and formations of the Mississippian type section. No attempt is made to show the disconformities in the Mississippian type section. The Meramecian-Chesterian Boundary in Kentucky is shown as defined by McDowell (1981); however, Gordon and Henry (1981, p. 165) placed the base of the Chesterian at the base of the Aux Vases in the Mississippian type section.

Section 1

Type sections of the Slade Formation and the Mill Knob Member of the Slade Formation at the southwestern highwall of the Natural Bridge Stone Co. quarry, 2.1 km (1.3 mi) southwest up the right fork of Cow Creek on a gravel road, which intersects Kentucky Highways 11 and 15, 1.6 km (1 mi) south of Bowen, Stanton (7½-minute) quadrangle, Powell County, Ky., lat 37°48′49″ N., long 83°46′50″W.

	Thickness (equivalents) Meters	(Feet)
Breathitt Formation (Pennsylvanian):		
Basal shale member (not measured):		
29. Shale, dark-gray, silty.		
Unconformity.		
Paragon Formation (Mississippian):		
Lower dark shale member:		
28. Shale, black to olive-gray, silty; contains scattered marine fossils and fossil plant debris	2.3	(7.5)
Slade Formation (Mississippian) type section:		
Poppin Rock Member:		
27. Shale, grayish-brown to olive-gray, silty, fossiliferous; contains thin-bedded, bioclastic, argillaceous calcarenite	1.5	(4.9)
26. Calcarenite, medium-dark-gray, medium- to thin-bedded, coarse-grained, bioclastic, fossiliferous; contains very thin beds of shale, rare black chert nodules, and large horizontal burrows on bedding planes	5.2	(17.1)
Total thickness of Poppin Rock Member	6.7	(22.0)
Maddox Branch Member:		
25. Shale, grayish-red and greenish-gray; contains scattered thin lenses of calcilutite	2.1	(6.9)
Ramey Creek Member:		
24. Calcarenite, medium-gray, thin- to medium-bedded, irregularly bedded, fine-grained, bioclastic, argillaceous, interbedded with very thin beds of greenish-gray shale; fossils common on bedding planes and generally replaced by red chert	3.3	(10.8)
23. Shale, greenish-gray, contains nodular lenses of calcilutite	0.7	(2.3)
Total thickness of Ramey Creek Member	4.0	(13.1)
Tygarts Creek Member:		
22. Dolostone, brownish-gray, weathers yellowish brown; irregularly bedded; brecciated; contains brecciated fossils, vugs, calcite-filled veins, solutions cavities filled with shale from the overlying Ramey Creek Member, and rare exposure crusts	0.6	(2.0)
21. Calcarenite, white, medium- to thick-bedded, even bedded, bioclastic; contains oolitic intraclasts and large gastropods	6.6	(21.7)
20. Calcarenite, white, thin- to medium-bedded, oolitic; contains large cavities and other recent solution features	1.6	(5.2)
19. Calcarenite, white, thin-bedded (2 to 8 cm, 0.8 to 3.1 in.), oolitic; contains discontinuous lenses of calcilutite; many beds contain a conglomerate of shell fragments, shale clasts from Cave Branch Bed, and calcilutite fragments from Mill Knob Member; brachiopods concentrated in upper parts of beds; load casts common on basal bedding surfaces	0.6	(2.0)
Total thickness of Tygarts Creek Member	9.4	(30.8)
Cave Branch Bed:		
18. Shale and claystone, interbedded; maroon and greenish gray; rubbly; contains scattered clasts of calcilutite from underlying Mill Knob Member	0.5	(1.8)
Disconformity.		
Mill Knob Member type section:		
17. Calcilutite, light-olive-gray, thin-bedded; contains brownish-gray laminated exposure crusts and a few thin beds of reddish-brown chert; birdseye structures prevalent; uppermost surface solution-pitted and brecciated	0.6	(2.0)
16. Calcarenite, white to very light gray, thin- to medium-bedded, coarse- to fine-grained, bioclastic, oolitic; unit fines upward; contains in places thin discontinuous exposure crusts and thin lenses of chert in upper 0.2 m (0.7 ft); basal contact irregular on erosional surface	1.5	(4.9)
15. Calcilutite, medium-light-gray, in irregular thin beds interbedded with silty greenish-gray shale; beds lensoidal and bioturbated; contains thin lenses of fine-grained calcarenite	0.6	(2.0)
14. Calcarenite, very light gray, thick-bedded, bioclastic, oolitic; indistinct low-angle planar crossbeds; contains stylolites near base; locally contains greenish-gray shale	0.8	(2.6)
13. Shale, medium bluish-gray, silty	0.1	(0.3)

	Thickness (equivalents) Meters	(Feet)
12. Calcarenite, light-brownish-gray, bioclastic; indistinct small-scale planar crossbeds; contains root tubes and discontinuous exposure crusts in upper 0.6 m (2 ft); upper surface brecciated and irregular with solution pitting	2.3	(7.5)
11. Calcarenite, grades upward to calcilutite; very light gray to white; irregularly thin bedded; conglomeratic; basal part contains reworked clasts from underlying Warix Run Member; unit very variable in thickness	0.6	(2.0)
Total thickness of Mill Knob Member	6.5	(21.3)
Disconformity.		
Warix Run Member:		
10. Calcarenite, light-gray at base to light-brownish-gray at top; coarse- to fine-grained, fining upward; thin to thick-bedded with some large, high-angle festoon crossbeds; peloidal; contains sand grains of milky quartz and reddish-brown chert; thin discontinuous exposure crusts in upper 0.3 m (1 ft); thin conglomerate at base	2.1	(6.9)
9. Shale, light-greenish-gray; sandy, containing reworked clasts from the underlying Ste. Genevieve Member; unit highly variable in thickness	0.2	(0.7)
Total thickness of Warix Run Member	2.3	(7.5)
Disconformity.		
Ste. Genevieve Member:		
8. Calcarenite, white to light-gray, fine- to coarse-grained, thick-bedded; small-scale bimodal crossbeds throughout; oolitic to skeletal; contains rare discontinuous stringers of red chert in upper part; upper surface solution pitted and upper part intensely brecciated; exposure crusts occur at irregular intervals, in places as fillings of voids and tubes or concentrated along bedding planes; intraclasts and chert clasts throughout; large gastropods common; thin basal conglomerate of limestone and chert clasts reworked from the underlying St. Louis Member	2.3	(7.5)
Disconformity.		
St. Louis Member:		
7. Calcilutite and calcarenite, interbedded; medium gray; in thin irregular beds; thin light-greenish-gray shale partings in lower part; upper surface very irregular and brecciated; exposure crusts rare at top	0.7	(2.3)
6. Calcarenite, very light gray, thin-bedded; contains lenses of light-greenish-gray calcilutite at base	0.7	(2.3)
5. Calcisiltite and calcarenite, interbedded; pale-blue-green; thin-bedded; contains blue-green shale partings and thin reddish-brown beds of chert; contains glauconite(?) especially near burrows; abundant fenestrate bryozoans and brachiopods on bedding planes; rare dololutite lenses near base	0.7	(2.3)
4. Calcarenite, white to very light gray, thin- to medium-bedded; contains thin bluish-green shale partings and reddish-brown to pinkish-gray spherical to irregular chert nodules; brachiopods, bryozoans, echinoderm debris, and lithostrationid corals	0.9	(3.0)
Total thickness of St. Louis Member	3.0	(9.8)
Renfro Member (measured at north end of quarry):		
3. Dolosiltite, very light gray, weathers dark yellowish orange; thin- to medium-bedded; indistinct laminae; contains thin partings of bluish-green shale in upper 0.8 m (2.6 ft); orthotetid brachiopods, fenestrate bryozoans, and pelmatozoan debris common in upper 1.4 m (4.6 ft); voids and veins filled with sparry calcite common	3.8	(12.5)
2. Dolosiltite, same as unit 3 above except beds are silty to sandy and are interbedded with silty grayish-green shale	3.5	(11.5)
Total thickness of Renfro Member	7.3	(24.0)
Total thickness of Slade Formation	44.1	(144.7)
Borden Formation (Mississippian):		
Nada Member (not measured):		
1. Shale, dark-grayish-green, poorly bedded, silty.		

Section 2

Type sections of the Warix Run and Ramey Creek Members of the Slade Formation on Kentucky Highway 801 at the junction of Kentucky Highway 1274, Bangor (7½-minute) quadrangle, Rowan County, Ky., lat 38°04′54″ N., long 83°25′20″ W.

	Thickness (equivalents) Meters	(Feet)
Lee Formation (Pennsylvanian):		
Corbin Sandstone Member (not measured):		
17. Sandstone, coarse- to fine-grained, quartzose, pebbly, crossbedded; massive weathering.		
Unconformity.		
Slade Formation (Mississippian):		
Maddox Branch Member:		
16. Dolostone and clay residuum, yellowish-orange, laminated, argillaceous; highly weathered, shows iron stains and liesegang structures	0.8	(2.6)
15. Shale, greenish-gray, calcareous, fossiliferous; contains thin, nodular, brecciated lenses of calcilutite; a prominent lense of calcarenite occurs about 1 m (3.3 ft) above base	3.4	(11.2)
Total thickness of Maddox Branch Member	4.2	(13.8)
Ramey Creek Member type section:		
14. Calcarenite, brownish-gray, oolitic, bioclastic; planar crossbeds; scoured upper surface	0.7	(2.3)
13. Calcilutite, medium-gray, in irregular thin to medium beds; argillaceous; contains thin shale beds, dominantly shale with nodular lenses of calcilutite in uppermost 0.5 m (1.6 ft), fossiliferous, bioturbated; contains chert nodules	1.7	(5.6)
12. Shale, olive, green, calcareous, fossiliferous; contains irregular thin beds of calcarenite	0.5	(1.6)
Total thickness of Ramey Creek Member	2.9	(9.5)
Tygarts Creek Member:		
11. Calcarenite, white, thick-bedded, bioclastic; contains intraclasts, large crinoid stems, blastoids, and stylolites	4.0	(13.1)
Armstrong Hill Member:		
10. Calcilutite, medium-gray, in irregular thin to medium beds with shale partings; uppermost 0.3 m (1 ft) is dolomitic; basal part is brecciated; contains burrows and fossils	2.5	(8.2)
Cave Branch Bed:		
9. Shale, greenish-gray, silty to sandy, weathers to rubble; contains clasts of calcilutite from underlying Mill Knob Member	0.2	(0.7)
Disconformity.		
Mill Knob Member:		
8. Calcilutite, light-gray, locally laminated, in irregular thin beds; contains birdseyes, vertical burrows, and local chert beds; upper 0.5 to 0.9 m (1.6 to 3 ft) of unit is brecciated and dolomitized and is overlain by a solution-pitted, dolomitized zone of caliche	1.7	(5.6)
7. Dolosiltite, light-gray, weathers yellowish brown; medium-bedded; laminated	2.4	(7.9)
6. Shale, greenish-gray; contains lenses of laminated shaly sandstone	0.2	(0.7)
5. Calcarenite and calcilutite, interbedded; light-gray; fine-grained; thin-bedded, containing thin interbeds of shale; upper part is brecciated and contains exposure crusts	2.0	(6.6)
4. Shale, greenish-gray, sandy	0.2	(0.7)
Total thickness of Mill Knob Member	6.5	(21.5)
Warix Run Member type section:		
3. Calcarenite, light-gray, pale-red in basal 5.8 m (19 ft); thick-bedded; sandy with prominent red grains in upper 6.1 m (20 ft); conspicuous channels and crossbeds throughout; exposure crusts in uppermost 0.5 m (1.6 ft)	11.9	(39.0)
Total thickness of Slade Formation	32.1	(105.3)
Disconformity		
Borden Formation (Mississippian):		
Nada Member:		
2. Shale, maroon to light-green; silty; rubbly	1.2	(3.9)
Cowbell Member (not measured):		
1. Siltstone, olive-gray to olive-brown, thin- to thick bedded, interbedded with shale.		

Section 3

Type section of the Armstrong Hill Member of the Slade Formation at roadcuts on Kentucky Highway 2 north of Armstrong Hill just north of its junction with Interstate Highway 64, Olive Hill (7½-minute) quadrangle, Carter County, Ky., lat 38°20′05″ N., long 83°12′21″ W.

Breathitt Formation (Pennsylvanian):

19. Shale, dark-gray; contains sandstone lenses (not measured).

	Thickness (equivalents) Meters	(Feet)
Unconformity.		
Slade Formation (Mississippian):		
Maddox Branch Member:		
18. Shale, pale-green, clayey; contains thin lenses of fossiliferous calcilutite near base (largely covered) ----	2.3	(7.5)
Ramey Creek Member:		
17. Calcarenite, light-gray, fine-grained, thin-bedded; contains thin shale partings and nodules of dark-gray chert; fossiliferous (principally brachiopods), bioturbated -------	0.4	(1.3)
16. Calcisiltite, light-gray to greenish-gray, thin-bedded to nodular, interbedded with greenish-gray silty shale; contains light-yellowish-brown chert nodules; fossiliferous, bioturbated; basal part locally contains lenses of dark-yellowish-orange dolosiltite ---------------	1.2	(3.9)
15. Shale, greenish-gray, silty, calcareous ------------------------	0.1	(0.3)
Total thickness of Ramey Creek Member ---	1.7	(5.6)
Tygarts Creek Member:		
14. Calcarenite, white, weathers grayish pink; coarse-grained; thin- to thick-bedded; bioclastic; locally channelled; to the north, unit becomes a white calcarenite with lenses of calcarenite that weather grayish pink ------------------	2.7	(8.9)
13. Calcarenite, white, coarse-grained, thin- to thick-bedded; commonly crossbedded; oolitic; bioclastic ---	1.9	(6.2)
12. Calcarenite, dolomitic, moderate-yellowish-brown, fine-grained; argillaceous; contains alternating lenses of oolitic and skeletal calcarenite ----------------------	0.5	(1.6)
Total thickness of Tygarts Creek Member --	5.1	(16.7)
Armstrong Hill Member type section:		
11. Calcilutite, dolomitic, moderate-yellowish-brown, fine-grained, thin-bedded; contains fossil fragments -----------------------	0.8	(2.6)
10. Shale, greenish-gray -------------	0.25	(0.8)
9. Calcilutite, medium-gray, fine-grained, thick-bedded ----------	0.6	(2.0)
8. Shale, greenish-gray -------------	0.1	(0.3)
7. Calcilutite, medium-gray, fine-grained, thin-bedded in irregular nodular beds containing thin (0.5 to 2.5 cm, 0.2 to 1 in.) beds of medium-gray shale; fossiliferous --	1.5	(4.9)
6. Shale, greenish-gray, containing very thin bedded nodular lenses of calcilutite ----------------------	0.1	(0.3)
5. Calcilutite, medium-gray, fine-grained, in thin planar beds interbedded with thin (2.5 to 5 cm, 1 to 2 in.) beds of medium-gray shale; fossiliferous ------------------	0.6	(2.0)
Total thickness of Armstrong Hill Member -	4.0	(13.1)
Cave Branch Bed:		
4. Shale, dark-gray, silty, calcareous; irregularly bedded containing thin, nodular beds of dark-gray sandy calcilutite, mottled-reddish-brown where oxidized ----------------	0.8	(2.6)
3. Shale, light-green, clayey, silty, sandy, slightly calcareous; irregularly bedded, weathers rubbly; contains sand- to pebble-size clasts of limestone from underlying unit ---	0.3	(1.0)
2. Shale, dark-reddish-brown, clayey, silty, sandy, slightly calcareous; irregularly bedded, weathers rubbly; has thin light-green reduced zones along joints; contains sand- to pebble-sized clasts of calcilutite from underlying Mill Knob Member -------------------------	0.6	(2.0)
Total thickness of Cave Branch Bed -------	1.7	(5.6)
Disconformity.		
Mill Knob Member (not measured):		
1. Calcilutite, light-gray; upper part brecciated and upper surface pitted.		
Total measured thickness of Slade Formation -	14.3	(46.9)

Section 4

Type section of Holly Fork Member of the Slade Formation at western end of roadcut along westbound lane of Interstate Highway 64, 16 km (10 mi) west of its junction with Kentucky Highway 2, Soldier (7½-minute) quadrangle, Rowan County, Ky., lat 38°16′39″ N., long 83°22′18″ W.

	Meters	(Feet)
Slade Formation (Mississippian):		
Tygarts Creek Member:		
5. Calcarenite, white, coarse-grained, thick-bedded, locally crossbedded, oolitic, bioclastic, fossiliferous containing large crinoid stems, gastropod molds, and blastoids; locally intertongues with upper part of underlying Holly Fork Member	0.9	(3.0)
Holly Fork Member type section:		
4. Calcilutite, white, fine-grained, laminated and interbedded with very thin beds of green shale; contains birdseyes and gastropods; unit highly variable in thickness -------	0.3	(1.0)

	Thickness (equivalents) Meters	(Feet)
3. Dolostone, yellowish-orange, fine- to coarse-grained; contains birdseyes; unit is largely a channel fill that thins abruptly to 0.3 m (1 ft) in eastern part of roadcut; basal parts of channel deposit contain partially dolomitized interclastic calcirudite from underlying Cave Branch Bed and Armstrong Hill Member [Note: these two units are absent here where the Holly Fork Member is thickest]; beds in channel are dololutite or birdseye dolorudite; channel fill in middle and upper parts of unit consists of thin concave-upward lenses ----------	2.4	(7.9)
Total thickness of Holly Fork Member -----	2.7	(8.9)
Disconformity.		
Cave Branch Bed:		
2. Shale, dark-reddish-brown, clayey, sandy, slightly calcareous, irregularly bedded, weathers rubbly; contains sand- to pebble-size clasts of limestone from underlying St. Louis Member; unit varies in thickness due to overlying disconformity --------------------------	0.3	(1.0)
Disconformity.		
St. Louis Member (not measured):		
1. Calcilutite, black to brown; upper part contains exposure crusts and breccias; upper surface pitted.		
Total measured thickness of Slade Formation -	3.9	(12.8)

Section 5

Type section of Rosslyn Member of Slade Formation at abandoned Baker Quarry on a ridge 1.6 km (1 mi) southeast of Stanton, Ky., north of Kentucky Highway 213, Stanton (7½-minute) quadrangle, Powell County, Ky., lat 37°50′08″ N., long 83°50′03″ W.

	Thickness (equivalents) Meters	(Feet)
Slade Formation (Mississippian):		
Tygarts Creek Member:		
8. Calcarenite, white, coarse-grained, thin- to thick-bedded, crossbedded, oolitic, bioclastic; contains stylolite structures --------------	5.7	(18.7)
7. Calcarenite, white, fine-grained, thin-bedded, oolitic -----------------	0.6	(2.0)
Total thickness of Tygarts Creek Member --	6.3	(20.7)
Rosslyn Member type section:		
6. Calcarenite, brownish-gray, fine-grained; in even, thin beds, interbedded with thin beds of yellowish-orange dolomitic shale; beds thicker in lower part of unit; trails and burrows on bedding planes; rare megafossils ----------------	1.1	(3.6)
5. Calcarenite, brownish-gray, fine-grained, in irregular very thin lenses interbedded with flaser beds of yellowish-orange shale; trails and burrows on basal plane of thicker beds; megafossils rare -----	1.1	(3.6)
4. Shale, greenish-gray, calcareous; contains very thin lenses (6 to 12 mm, 0.2 to 0.5 in.) of pelletoidal calcarenite ----------------------	0.1	(0.3)
3. Calcirudite, medium-gray to yellowish-orange, conglomeratic, in thin beds interbedded with yellowish-orange shale; contains sand- to pebble-size clasts of limestone and fossil fragments; prominent dolomitic mudchips; burrows on bedding planes --------------------	0.2	(0.7)
Total thickness of Rosslyn Member --------	2.5	(8.2)
Cave Branch Bed:		
2. Shale, greenish-gray, silty; poorly exposed ----------------------	0.2	(0.7)
Disconformity.		
Mill Knob Member (not measured):		
1. Calcilutite		
Total measured thickness of Slade Formation -	9.0	(29.5)

Section 6

Type section of the Tygarts Creek Member and reference sections for the Slade and Paragon Formations on eastern edge of outcrop belt. Sections are at southeastern highwall of the Ken-Mor Stone Company, Olive Hill quarry, 0.5 km (0.3 mi) south of the juncton of U.S. Highway 60 and Interstate Highway 64, northeast of Olive Hill, Grahn (7½-minute) quadrangle, Carter County, Ky., lat 38°19′39″ N., long 83°07′25″ W.

	Thickness (equivalents) Meters	(Feet)
Paragon Formation (Mississippian):		
Clastic member (incomplete):		
22. Shale, green to grayish-green, sandy; contains lenses and thin beds of chloritic, micaceous, argillaceous, bioturbated sandstone ----------	1.3	(4.3)
Carter Caves Sandstone (Mississippian):		
21. Sandstone, yellowish-brown, quartzose; very fine to medium-grained; locally crossbedded and ripple bedded; pinches out to the west into unit 20 below -----------------	0.9	(3.0)

	Thickness (equivalents) Meters	(Feet)
Disconformity.		
Paragon Formation:		
Lower dark shale member:		
20. Shale, black to greenish-black, silty, micaceous; contains calcilutite lenses toward bottom of unit and chloritic sandstone lenses toward the top; marine fossils sparse	4.6	(15.1)
Total measured thickness of Paragon Formation	5.9	(19.3)
Slade Formation (Mississippian):		
Poppin Rock Member:		
19. Calcarenite, medium-dark-gray, coarse-grained, dense (very hard); very thick bedded; bioclastic	0.2	(0.7)
18. Shale, brownish-black; contains abundant marine fossils	0.5	(1.6)
17. Calcarenite, white to medium-dark-gray, coarse-grained, dense, thick-bedded, bioclastic	2.0	(6.6)
Total thickness of Poppin Rock Member	2.7	(8.9)
Maddox Branch Member:		
16. Shale, greenish-gray; contains thin lenses of calcilutite	1.5	(4.9)
Ramey Creek Member:		
15. Calcarenite, white, medium-grained, thin-bedded and interbedded with greenish-gray shale; contains chert nodules	0.3	(1.0)
14. Shale, greenish-gray, irregularly bedded, calcareous and highly fossiliferous; contains nodules and lenses of calcisiltite	2.0	(6.6)
13. Calcarenite, white, coarse-grained, thick-bedded, locally crossbedded; crinoidal; locally contains chert nodules	0.6	(2.0)
12. Calcilutite, medium-gray, fine-grained, thin-bedded and interbedded with shale; fossiliferous	1.8	(5.9)
Total thickness of Ramey Creek Member	4.7	(15.4)
Tygarts Creek Member type section:		
11. Calcarenite, white, coarse-grained, oolitic and skeletal; thin to thick bedded	1.8	(5.9)
10. Calcarenite, white, coarse- to fine-grained, thin-bedded, interbedded with stringers of brown dolostone	1.9	(6.2)
Total thickness of Tygarts Creek Member	3.7	(12.1)
Armstrong Hill Member:		
9. Dololutite, light-brown, fine-grained, thick-bedded	0.8	(2.6)
8. Calcilutite, medium-gray, fine-grained, thin-bedded and interbedded with greenish-gray shale; fossiliferous	1.1	(3.6)
Total thickness of Armstrong Hill Member	1.9	(6.2)

	Thickness (equivalents) Meters	(Feet)
Cave Branch Bed:		
7. Shale, medium-gray, finely laminated calcareous mudstone with massive appearance	1.5	(4.9)
6. Shale, greenish-gray, arenaceous, slightly calcareous; contains clasts of calcilutite from underlying Mill Knob Member; weathers rubbly	0.6	(2.0)
Total thickness of Cave Branch Bed	2.1	(6.9)
Disconformity.		
Mill Knob Member:		
5. Calcilutite, dark-brownish-gray, irregular thin beds; brecciated and platy with interstices filled with light-greenish-gray shale; bedding surfaces solution-pitted and brecciated; contains thin discontinuous exposure crusts, birdseyes, and rare fragments of ostracodes and gastropods	1.1	(3.6)
4. Calcilutite, white to light-gray, in irregular thin to medium beds with light-greenish-gray shale partings; locally arenaceous; contains birdseyes and fragmented gastropods	3.3	(10.8)
3. Shale, dark-greenish-gray, silty, sandy; contains reworked limestone clasts from unit 2 below	0.2	(0.7)
2. Calcilutite and calcisiltite, interbedded; light-gray to dark-brownish-gray; in irregular thin beds; platy; brecciated with interstices filled with light-greenish-gray shale; contains thin, discontinuous exposure crusts throughout and birdseyes and "slickensides"	2.0	(6.6)
Total thickness of Mill Knob Member	6.6	(21.7)
Warix Run Member (incomplete):		
1. Calcarenite, white to brownish-gray, arenaceous, thin- to thick-bedded with high-angle festoon crossbeds and scours throughout; locally a thin greenish-gray bed of shale at top of unit; thin beds of white arenaceous calcilutite in upper 0.7 m (2.3 ft); prominent zone of exposure crusts 1.2 m (3.9 ft) below top of unit and thin discontinuous exposure crusts throughout upper 4.6 m (15.1 ft); contains conglomeratic lenses of chert and limestone fragments from St. Louis Limestone Member below (section measured to base of quarry)	10.1	(33.1)
Total measured thickness of Slade Formation	33.3	(109.3)

Section 7

Type section of Maddox Branch Member of Slade Formation at roadcut along west-bound lane of Interstate Highway 64, 15 km (9.3 mi) west of its junction with Kentucky Highway 2, Soldier (7½-minute) quadrangle, Rowan County, Ky., lat 38°16′35″ N., long 83°21′28″ W.

	Thickness (equivalents) Meters	(Feet)
Breathitt Formation (Pennsylvanian) (not measured):		
11. Shale, dark-gray to black, silty, contains thin basal hematitic sandstone		
Unconformity.		
Paragon Formation (Mississippian):		
Clastic member:		
10. Shale, light-green, silty, weathers rubbly; fills solution features in underlying Poppin Rock Member of Slade Formation	0.6	(2.0)
Disconformity.		
Slade Formation (Mississippian):		
Poppin Rock Member:		
9. Calcarenite, white, coarse-grained, bioclastic; uppermost part contains solution features and in places limestone is stained or replaced by iron ore	1.1	(3.6)
Maddox Branch Member type section:		
8. Calcilutite, grayish-brown, weathers yellowish orange; thick-bedded; dolomitic; silty	0.5	(1.6)
7. Shale, green, calcareous, containing thin lenses of brecciated fossiliferous calcilutite	4.3	(14.1)
Total Maddox Branch Member	4.8	(15.7)
Ramey Creek Member:		
6. Calcilutite, medium-gray, laminated, in very thin beds and interbedded with green shale; sparsely fossiliferous	0.2	(0.7)
5. Calcilutite, medium-bluish-gray, nodular and irregularly bedded in thin beds, interbedded with thin beds of green shale; contains fragments of silicified fossils	0.6	(2.0)
4. Calcisiltite, grayish-brown, weathers yellowish brown; fine-grained; silty; dolomitic; contains shale and limestone intraclasts and fossil fragments	0.9	(3.0)
3. Shale, green, calcareous with thin lenses of fossiliferous calcarenite; uppermost 0.3 m (1 ft.) in places contains contorted dolosiltite	1.7	(5.6)
Total thickness of Ramey Creek Member	3.4	(11.2)
Tygarts Creek Member:		
2. Calcarenite, medium-gray to white, oolitic; contains intraclasts, large crinoid columnals, large gastropod molds, and blastoids	0.8	(2.6)
Holly Fork Member (not measured):		
1. Dolostone		
Total measured thickness of Slade Formation	10.1	(33.1)

Section 8

Type sections of the Poppin Rock Member of the Slade Formation and the Paragon Formation at roadcut (western side) on Kentucky Highway 1274, 4.8 km (3.0 mi) south of its junction with Kentucky Highway 801, Bangor (7½-minute) quadrangle, Rowan County, Ky., lat 38°02′26″ N., long 83°26′49″ W.

	Thickness (equivalents) Meters	(Feet)
Lee Formation (Pennsylvanian):		
Corbin Sandstone Member (not measured):		
33. Sandstone, fine- to coarse-grained, pebbly		
Unconformity.		
Paragon Formation (Mississippian) type section:		
Upper shale member:		
32. Shale, black to dark-gray, calcareous, contains thin lenses of dark-gray fossiliferous calcilutite and fossil-plant debris	3.5	(11.5)
Limestone member:		
31. Calcarenite, medium-dark-gray, coarse- to fine-grained, argillaceous, in irregular thin beds; weathers platy; very fossiliferous	0.9	(3.0)
Clastic member:		
30. Shale, black to dark-gray, platy, contains fossil-plant debris	0.7	(2.3)
29. Siltstone, dark-gray, weathers brown; argillaceous, grades upward to calcareous mudstone, intensely burrowed; contains unoriented broken brachiopods	0.4	(1.3)
28. Shale, greenish-gray, platy; contains fossil-plant debris	0.8	(2.6)
27. Claystone, greenish-gray, weathers brown and to columnar masses; silty, calcareous; contains burrows	0.3	(1.0)
26. Sandstone, greenish-gray, weathers brown where cemented; very argillaceous; intensely burrowed	0.8	(2.6)
25. Shale, greenish-gray, silty to sandy, micaceous; contains thin lenses of sandstone and burrows	0.9	(3.0)
24. Sandstone, greenish-gray, lenticular; micaceous; contains flaser beds of silty shale, burrows, and fossil-plant fragments	0.6	(2.0)

	Thickness (equivalents) Meters	(Feet)
23. Sandstone, moderate-brown, quartzose, fine- to very fine grained, laminated to thin-bedded, in high-angle unimodal crossbeds showing rare reactivation surfaces; bedding planes have tracks and burrows; contains mudchips and has basal conglomerate of mudchips and reworked marine fossils	3.0	(9.8)
Total thickness of clastic member	7.5	(24.6)
Lower dark shale member:		
22. Shale, dark-gray, thinly laminated, silty, calcareous, fossiliferous, especially brachiopods and fenestrate bryozoans; contains thin lenses of light-gray calcilutite	2.7	(8.9)
Total thickness of Paragon Formation	14.6	(47.9)
Slade Formation (Mississippian):		
Poppin Rock Member type section:		
21. Calcarenite, light-gray, thin-bedded, argillaceous, skeletal; contains thin partings of dark-gray shale, brachiopods, bryozoans, pelecypods, and echinoderm debris; bioturbated	0.5	(1.6)
20. Shale, dark-brownish-gray, silty to sandy; contains thin beds and lenses of argillaceous calcarenite; extremely fossiliferous including brachiopods, rugose corals, ramose and fenestrate bryozoans, crinoid debris and fish-bone fragments; bioturbated	0.8	(2.6)
19. Calcarenite, dark-bluish-gray to medium-gray, thin- to medium-bedded, argillaceous, dense; interbedded with thin beds of dark-gray shale that contain brachiopods (predominantly), bryozoans, rugose corals, and crinoid debris all concentrated on upper bedding planes	3.2	(10.5)
Total thickness of Poppin Rock Member	4.5	(14.8)
Maddox Branch Member:		
18. Dolosiltite and dolarenite, interbedded; dark-yellowish-orange; thin-bedded; contains brachiopods, gastropods, and echinoderm debris; bioturbated	0.2	(0.7)
17. Shale, greenish-gray, silty	0.4	(1.3)
Total thickness of Maddox Branch Member	0.6	(2.0)
Ramey Creek Member:		
16. Calcarenite, brownish-gray, thin- to thick-bedded, finely oolitic, skeletal, crossbedded; contains large echinoderm fragments	2.1	(6.9)
15. Shale, medium-dark-gray, silty; contains calcisiltite nodules containing brachiopods, bryozoans, gastropods, and echinoderm debris; bioturbated	0.4	(1.3)
14. Calcarenite, brownish-gray, thin-bedded and interbedded with medium-dark-gray shale; oolitic; skeletal; contains large chert nodules; unit thins southward	0.5	(1.6)
13. Calcarenite to calcisiltite, light-gray, thin-bedded, argillaceous; contains beds of silty medium-gray shale, rugose corals, brachiopods, pelecypods, gastropods, ramose bryozoans, and echinoderm debris; bioturbated	0.4	(1.3)
12. Shale, medium-dark-gray, silty; contains nodules and lenses of medium-gray calcilutite, rugose corals, brachiopods, ramose and fenestrate bryozoans, and echinoderm debris	0.5	(1.6)
11. Calcarenite, light-olive-gray, medium- to thick-bedded, skeletal, oolitic, crossbedded; contains scour structures; basal part contains dololutite clasts reworked from underlying unit	0.7	(2.3)
10. Dololutite, dark-yellowish-orange, in irregular thin to thick beds; contains birdseyes and "slickensides," sheet cracks, rip-up clasts, breccia, and hummocky laminae; unit fills channels in underlying unit and varies in thickness from 0.1 to 1.4 m (0.3 to 4.6 ft) in outcrop; load structures at base	0.5	(1.6)
9. Calcisiltite and calcilutite, interbedded; light-gray; in irregular thin beds interbedded with partings of medium-dark-gray silty shale; contains gastropods, brachiopods, echinoderm debris, and rare chert nodules; bioturbated; unit deformed by load at base of overlying channels	1.7	(5.6)
8. Shale, greenish-gray, clayey	0.2	(0.7)
Total thickness of Ramey Creek Member	7.0	(22.9)
Tygarts Creek Member:		
7. Calcarenite, white to very light gray, thick-bedded, crossbedded, skeletal, oolitic; contains blastoids, large gastropods, brachiopods, and large crinoid stems; stylolites	2.9	(9.5)

	Thickness (equivalents) Meters	(Feet)
6. Dolarenite and dolosiltite, interbedded; light-brown; thin-bedded; interbedded with light-gray stringers and nodules of calcarenite; crossbedded	0.7	(2.3)
5. Calcarenite, light-gray, medium- to thin-bedded, skeletal, oolitic; contains intraclasts, large gastropods, and brachiopods	0.8	(2.6)
4. Dolosiltite, dark-yellowish-orange, thick- to medium-bedded, interbedded with thin lenses of light-gray, thin- to medium-bedded skeletal calcarenite; unit poorly exposed	2.1	(6.9)
Total thickness of Tygarts Creek Member	6.5	(21.3)
Cave Branch Bed:		
3. Shale (interval covered)	0.4	(1.3)
2. Shale, greenish-gray, rubbly, silty to sandy; unit poorly exposed in drainage ditch	0.9	(3.0)
Total thickness of Cave Branch Bed	1.3	(4.3)
Disconformity.		
Mill Knob Member (not measured):		
1. Calcilutite; unit poorly exposed		
Total measured thickness of Slade Formation	19.7	(64.6)

Section 9

Reference section for the Paragon Formation in south-central Kentucky is a series of roadcuts at Sloans Valley, Ky., between the Sloans Valley U.S. Post Office and a small road cut on the east side of U.S. Highway 27, just north of the junction with the Dixie Bend Road, Burnside (7½-minute) quadrangle, Pulaski County, Ky., lat 36°56′17″ N., long 84°32′10″ W.

	Thickness (equivalents) Meters	(Feet)
Breathitt Formation (incomplete; Pennsylvanian):		
61. Shale, dark-gray, fissile, silty and clayey; contains siderite nodules at base; plant debris	0.9	(2.8)
60. Shale, medium-gray, clayey and silty; poorly bedded at base becoming rubbly at top; plant debris; weathers dark yellowish orange at top	1.0	(3.3)
59. Shale, black, carbonaceous to coaly; sandy	0.3	(1.0)
58. Shale, black at base to white below coaly shale; very sandy, organic rich; weathers rubbly; disconformably overlies Paragon Formation where sandstone is absent	0.6	(2.0)
57. Sandstone, grayish-orange, thick- to thin-bedded, fine- to medium-grained, argillaceous, interbedded with sandy shale layers; channel-fill deposit that truncates as much as 2.7 cm (1 in) of underlying strata of the Paragon Formation	0–3.7	(0–12)
Total measured thickness of Breathitt Formation	2.8–6.5	(9.1–21.1)
Unconformity.		
Paragon Formation (Mississippian):		
Upper shale member:		
56. Shale, olive-green, weathered; missing to south due to channeling from above	0.1	(0.3)
55. Dolosiltite, olive-gray, silty; weathers dark yellowish orange; has a brown ironstone coating where it underlies Pennsylvanian rocks	1.0	(3.3)
54. Shale, olive-green, clayey, silty	0.4	(1.3)
53. Siltstone, dark-green, dolomitic; contains current ripples: weathers dark yellowish orange	0.4	(1.3)
52. Shale, red and green, clayey, silty; contains yellowish-orange dolosiltite stringers	5.1	(16.8)
51. Sandstone, greenish-gray, medium-grained; argillaceous, dolomitic, sparsely micaceous; thin, irregularly bedded; contains current ripples and flaser beds in the middle of unit; bioturbated; weathers dark yellowish orange to olive brown	2.0	(6.6)
50. Shale, maroon and green; silty; rubbly; contains thin dolosiltite stringers and nodules; possible mudcracks in dolosiltites	2.2	(7.2)
49. Covered interval (Dixie Bend Road)	4.1	(13.3)
48. Siltstone, light-olive-gray, argillaceous, dolomitic; poorly bedded; contains pelecypods and vertical burrows; weathers rubbly	0.5	(1.6)
47. Shale, dark-greenish-gray becoming dark-gray and fissile at base; clayey	0.6	(2.0)
46. Dolosiltite, dark-yellowish-orange, silty	0.2	(0.6)
45. Shale, yellowish-green, dolomitic, silty	0.2	(0.6)
44. Dolosiltite, light-gray, silty; laminated at base becoming rubbly at top; weathers dark yellowish brown	0.3	(1.0)
43. Shale, dark-greenish-gray, silty	0.2	(0.6)

	Thickness (equivalents) Meters	(Feet)
42. Dolosiltite, light-gray; consists of two dolostone layers separated by green shale that merge to the north	0.4	(1.4)
41. Shale, greenish- to reddish-gray; contains zone of brecciated dolosiltite layers 1.0 m (3.2 ft) from top	1.3	(4.2)
40. Sandstone, grayish-orange, fine-grained, thin-bedded; dolomitic, micaceous; lower part contains ripple marks and flaser beds; upper 0.2 m (0.6 ft) crossbedded and gradational to overlying shale	0.7	(2.3)
39. Dolosiltite, dark-yellowish-orange, thin-bedded; contains fragments of fossils and shale clasts; bioturbated; concretionary	0.2	(0.7)
38. Shale, red and green; silty, dolomitic; contains dolomitic nodules and lenses; clayey, fissile	2.9	(9.4)
37. Shale, dark-gray to black; clayey, fissile, carbonaceous; contains productid brachiopods	4.3	(14.2)
36. Calcarenite, light-olive-gray; in thin irregular beds, interbedded with shale; argillaceous; contains brachiopods and bryozoans (poorly exposed)	0.3	(1.0)
35. Shale, dark-gray; clayey, laminated	1.6	(5.3)
Total thickness of upper shale member	29.0	(95.0)
Limestone member:		
34. Calcarenite, gray to brownish-gray, thin-bedded; oolitic, skeletal; overlies and fills a burrowed, irregular surface on underlying dolostone; crossbedded; contains crinoids, corals, and brachiopods	0.3	(1.0)
Total thickness of limestone member	0.3	(1.0)
Dolostone member (Spann Limestone Member of Munn [1914]):		
33. Dolosiltite and dolomitic calcisiltite, brownish-gray, thin- to thick-bedded; laminated with vugs containing dolomite, calcite, gypsum, barite, strontianite, and celestite; upper 0.8 m (2.6 ft) thin-bedded with shale partings; weathers yellowish brown; forms a prominent ledge together with limestone member	2.2	(7.2)
32. Shale, medium-dark-gray, calcareous, laminated, fissile; three thin dolosiltite beds in upper 0.4 m (1.3 ft); lower parts contain bioturbated and rippled calcisiltite beds and thin dolosiltite lenses	2.0	(6.6)
31. Calcarenite, brownish-gray, thin-bedded, skeletal; contains brachiopods, pelecypods, and burrows; chert clasts at top	0.2	(0.6)
30. Shale, grayish-green at base to black at top; silty; glauconitic(?) at base; weathers rubbly at base	0.4	(1.2)
29. Calcilutite, brownish-gray, thin-bedded; uppermost 0.5 m (1.6 ft) brecciated and fractured with grayish-green shale filling fractures; spar-filled fractures; locally dolomitic; fossil fragments; upper part represents calichified exposure surface	0.9	(3.0)
28. Shale, light-gray, calcareous, silty; weathers rubbly	0.1	(0.4)
27. Calcilutite and calcisiltite, brownish-gray, thick-bedded, argillaceous; rubbly and brecciated at top with glauconitic shale and calcarenite filling fractures; birdseyes; upper part represents calichified exposure surface	0.4	(1.2)
26. Shale, dark-gray, clayey	0.6	(1.8)
25. Dolosiltite and dololutite, greenish-gray, laminated; contorted laminae, mud chips, birdseyes, and breccia; weathers dark yellowish orange	0.3	(1.0)
24. Shale, greenish-gray, with lenses of coarse-grained fossiliferous calcarenite	0.3	(1.0)
23. Calcarenite, brownish-gray, thin-bedded, fine-grained, fossiliferous; brecciated at top representing exposure surface	0.2	(0.5)
22. Shale, gray, silty	0.05	(0.1)
21. Calcisiltite, brownish-gray, thin- to medium-bedded; locally dolomitic; rubbly and shaly toward top; fossiliferous	0.6	(1.8)
20. Shale, light-gray; contains rubbly calcisiltite nodules	0.1	(0.3)
19. Calcarenite, bluish-gray, thin- to thick-bedded; skeletal and oolitic; crossbedded; contains dolomite-filled burrows	1.2	(3.8)
18. Dolosiltite, light-brownish-gray, medium-bedded; vuggy, containing large stylolites; lower 0.8 m (2.6 ft) may be rubbly, shaly dolosiltite grading to massive dolosiltite	1.0	(3.3)

	Thickness (equivalents) Meters	(Feet)
17. Dolosiltite and calcisiltite, light-brownish-gray, thick-bedded; exhibits some laminae, vugs, and fossil fragments	1.3	(4.4)
Total thickness of dolostone member	11.85	(38.2)
Lower dark shale member:		
16. Shale, dark-gray, silty, calcareous; contains lenses of argillaceous calcarenite; extremely fossiliferous including bryozoans, brachiopods, pelecypods, and crinoids	0.6	(2.0)
15. Calcarenite, brownish-gray, thick-bedded, argillaceous, skeletal; crossbedded; contains intraclasts, brachiopods, bryozoans, and crinoids	0.6	(2.0)
14. Shale, greenish-gray, clayey, calcareous; contains a few argillaceous calcarenite lenses; extremely fossiliferous including bryozoans, brachiopods, corals, and crinoids	1.7	(5.4)
13. Shale, bluish- to brownish-gray; marly; interbedded with argillaceous nodules and stringers; extremely fossiliferous including bryozoans, brachiopods, corals, and crinoids	1.1	(3.6)
12. Shale, bluish-gray, interbedded with thin-bedded argillaceous calcarenite lenses; fossiliferous	1.0	(3.3)
11. Calcarenite, white to light-gray, thick-bedded; skeletal and oolitic; composed of two channel-fill sequences that pinch out into shale toward northwest and southeast; crossbedded; scours; intraclasts; foreset beds graded	0–4.9	(0–16)
10. Shale, bluish-gray to greenish-black; interbedded with thin argillaceous calcarenite and calcisiltite lenses; extremely fossiliferous including crinoids, bryozoans, brachiopods, pelecypods, trilobites, and corals	1.4–2.1	(4.5–7.0)
Total lower dark shale member	6.4–12.0	(20.8–39.3)
Total thickness of Paragon Formation	47.3–52.9	(155.0–174.5)
Bangor Limestone (Mississippian):		
9. Calcarenite, bluish-gray, thin- to thick-bedded; argillaceous; skeletal; thin shale partings with most prominent one at base; crossbedded; scours; bryozoans; chert nodules at top	4.3	(14.2)
8. Calcarenite, light-gray, thin- to medium-bedded; coarse skeletal grains; contains crossbedding, intraclasts and shale partings; crinoids, corals, and bryozoans; weathers reddish gray	1.0	(3.3)
7. Calcarenite, bluish-gray, thin- to thick-bedded; skeletal; thin shale partings; bryozoans, corals, brachiopods, and crinoids	2.1	(7.0)
6. Calcarenite, dark-brownish-gray, thick-bedded; skeletal; crossbedded; intraclasts; corals, bryozoans, blastoids, and brachiopods	0.9	(2.9)
5. Calcarenite, dark-brownish-gray, thin- to medium-bedded, interbedded with dark-gray shale; skeletal; forms prominent reentrant; crinoids, blastoids	0.6	(1.8)
4. Calcarenite, brownish-gray, in thin irregular beds; shaly; bioturbated; brachiopods, bryozoans, and echinoderms; weathers light yellowish gray	0.1	(0.3)
3. Calcarenite, dark-bluish-gray, thick-bedded becoming thin-bedded and shaly at top; argillaceous; skeletal; abundant crinoidal debris	0.3	(1.0)
Total thickness of Bangor Limestone	9.3	(30.5)
Hartselle Formation (incomplete; Mississippian):		
2. Dolosiltite and calcisiltite, grayish-orange, in thin irregular beds; bioturbated; spiriferid and productid brachiopods	0.2	(0.5)
1. Shale, dark-gray, clayey, micaceous, laminated with thin silty laminae; grayish green, rubbly, and silty in upper 0.5 m (1.6 ft); rare pelecypods	1.1	(4.1)
Total measured thickness of Hartselle Formation	1.3	(4.6)

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