DEPOSITIONAL ENVIRONMENTS AND STRATIGRAPHY OF THE PENNINGTON FORMATION (UPPER VISEAN-NAMURIAN A), EAST-CENTRAL AND EASTERN KENTUCKY, U. S. A.

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The Pennington Formation is an Upper Mississippian mixed clastic-carbonate sequence that is transitional between dominantly transgressive Middic and Upper Mississippian carbonates below and dominantly regressive Pennsylvanian clasfics above in eastern Kentucky. The unit crops out in two belts: a western belt in east-central Kentucky and an eastern belt in southeastern Kentucky and adjacent states.

The Pennington Formation is the distal edge of an Upper Mississippian progradation that began in late Middle Mississippian time on the eastern edge of the Appalachian Basin. The milder, early phases of progradation apparently were related to a transcurrent tectonic regime that continued from the Acadian. More rapid progradation in latest Mississippian time continued into earliest Pennsylvanian time and was related to a collisional regime. Actual collision with a trench probably occurred in the Early Pennsylvanian Period and was represented by rcgional Uplift, cratonic emergencc, and erosion, which have left a prominent unconformity. In central parts of the Appalachian Basin (eastern belt), the Pennington is gradational with Pennsylvanian rocks, but progressively older Pennington rocks are truncated westward along the unconformity toward the basin margins. Hence, in the western belt, very little Pennington exists.

The Pennington, together with the underlying Bluefield Formation (upper Newman) and upper parts of the Greenbrier (Newman) Limestone, represents two westward-prograding environmental continua separated by a period of transgression. The Pennington of the western belt, however, represents only parts of the early progradation and is largely correlative with the Bluefield (upper Newman) Formation of thc eastern belt.

INTRODUCTION

Throughout much of the eastern United States the Mississippian System (lower Carboniferous) is known for its thick sequences of relatively pure carbonate rocks, whereas the Pennsylvanian System (upper Carboniferous) is known for its thick sequences of coal-bearing clastic rocks. Most of the carbonates are of Middle and Late Mississipian age (Valmeyeran and Chesterian-Tournaisian and Visean), while the coal-bearing rocks are of Pennsylvanian age (Morrowan and younger-late Namurian and younger). Not so well known, however, are the mixed carbonate-clastic sequences of latest Missisaipian age (Visean-Namurian A) that overlie the carbonates and underlic the major coal-bearing rocks in the eastern and east-central United States. The Pennington Formation is the stratigraphic unit that contains this sequence in east-central and eastern Kentucky (Fig. 1).

The Pennington Formation has remained poorly known for a long time for a number of reasons. It is a heterogeneous and complex unit dominated by shales, with lesser amounts of sandstone, siltstone, dolastone and limestone; many lithologic units are not continuous. The unit is poorly exposed because of the dominance of shale. The shales are commonly cut out by Early Pennsylvanian erosion along the Mississippian-Pennsylvanian unconformity; the entire Pennington and large parts of the underlying carbonate sequence may be absent along this unconformity (ETTENSOHN, 1979, 1980, 1981). No single model explains the unit. And there is little economic interest in the unit.

Despite these difficulties, a greater knowledge of the Pennington is essential to resolve two major problems. The first problem is the nature of the transition between the tectonically quiescent Middle and Late Mississippian and the tectonically active latest Mississippian and Pennsylvanian. The mixed clastic-carbonate sequence of the Pennington is clearly transitional between the shallow-shelf

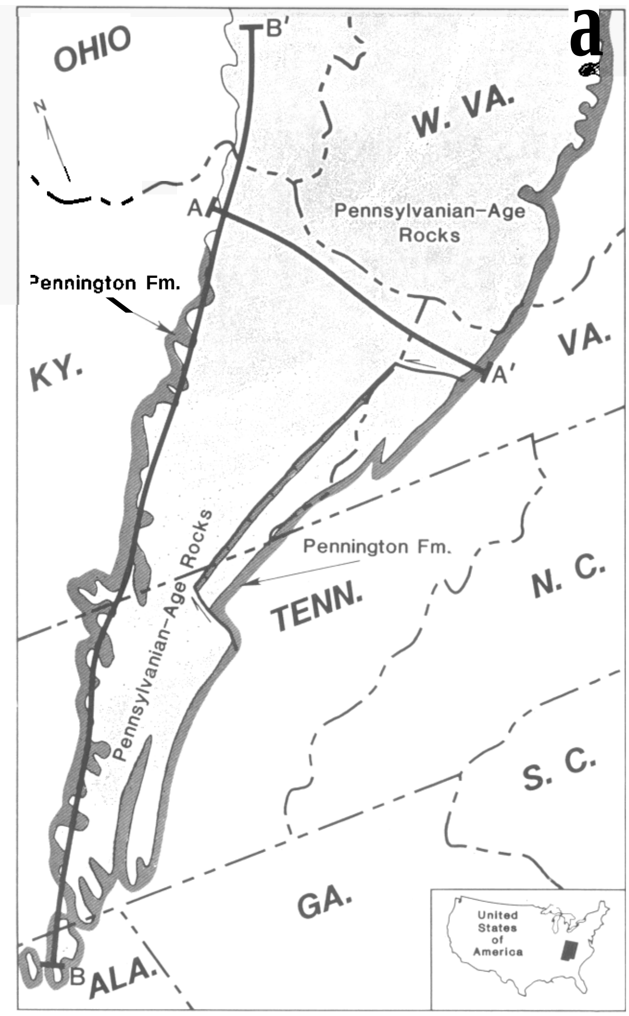

Figure 1. Map showing the two Pennington outcrop belts and the two lines of section used in the study. The two outcrop belts (dark stipple) are separated by up to 200 km of Pennsylvanian rocks (light stipple) in eastern Kentucky.

bonates of the Middle and Late Mississippian and the fluvial and deltaic clastics of the Pennsylvanian. A study of these units should help elucidate the nature of the transition.

The second problem is the stratigraphic relationship between the Pennsylvanian clastics and the underlying Mississippian carbonates and clastics. The major controversy is the presence or absence of a systemic unconformity. One model (FERM *et al.*, 1971: FERM, 1974; HORNE *et al.*, 1974) contends that Mississippian and Pennsylvanian rocks form a continuous, complexly intcrtongued sequence with no systemic unconformity. The other major model (MCFARLAN, 1943; PRYOR & SABLE, 1974): RICE *et al.*, 1979) contends that approximately tabular Mississippian and Pennsylvanian units are separated by a major systemic unconformity. Variations on the latter model involve episodes of synsedimentary tectonism (ETTENSOHN, 1977, 1980, 1981) and the presence of stratigraphically distinct transgressive and progradational cycles (MILLER, 1974; CHESNUT, 1982).

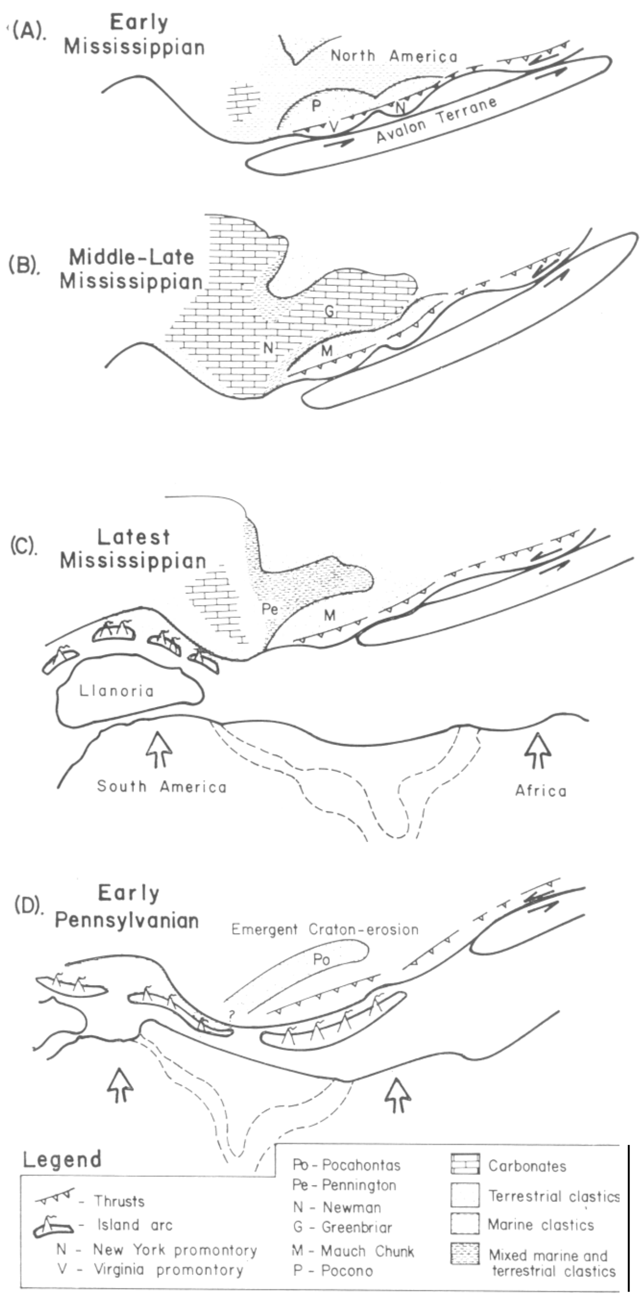

Figure 2. A series of four schematic diagrams in time showing the inferred tectonic framework and development of the Pennington-Mauch Chunk clastic wedge. A and B reflect a dominant transcurrent tectonic regime; C and D reflect a dominant collisional regime. D represents the time of probable collision with the subduction trench, the beginning of subduction on the eastern margin of the North American craton, and a period of cratonic emergence and erosion. Erosion during this time destroyed much of the Pennington. Not drawn to scale.

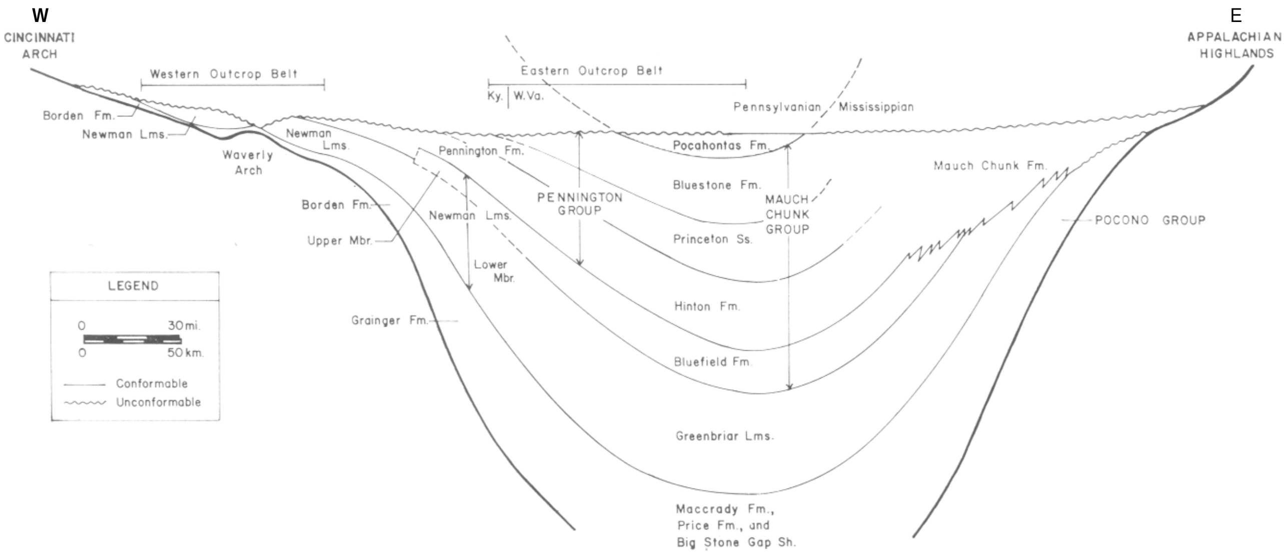

Figure 3. Schematic east-west cross section of the Appalachian Basin in Kentucky and West Virginia showing the regional stratigraphic relationships between the Pennington and related units and the position of the two outcrop belts. All units except the Pocahontas Formation (stippled) are Mississippian in age.

This paper will examine lithologies, stratigraphy, and depositional environments of the Pennington Formation to gain insight into the two problems. Particular attention will be given to tectonic implications and evidence far a systemic unconformity and its significance.

PREVIOUS WORK

The Pennington Formation is known from two outcrop belts in eastern Kentucky, one in extreme southeastern Kentucky, called the "eastern belt", and the other in east-central Kentucky, called the "western belt", (Fig. 1). The formation was described by CAMPBELL (1983) based on an extension of the eastern belt in Virginia. CAMPBELL (1898a, b) introduced the unit to the western belt, but the stratigraphic limits were uncertain until they were defined by MILLER (1917, 1919) and BUTTS (1922). Most of the subsequent work on the Pennington has been confined to local studies of the western belt.

The stratigraphy and depositional environments of the eastern belt are not as well known as the western belt because of the greater thicknesses and increased complexity of the eastern belt.

TECTONIC FRAMEWORK

The fine-grained Pecnnington clastics represent a transition between relative tectonic quiescence in the Middle and early Late Mississippian and increased tectonic activity in the Pennsylvanian. Two separate tectonic regimes are involved.

The earlier regime began in the Devonian with Acadian tectonism and extended into the Carboniferous. WILLIAMS & HATCHER (1982) suggested that the Acadian orogeny was the product of oblique convergence or major transcurrent movement along a sinistral strike-slip fault zone separating the North American craton from a linear microcontinent called the Avalon terrane (Fig. 2a). This interpretation is supported by paleomagnetic differences between the two terranes (KENT & OPYYKE, 1978). Major phases in the Acadian orogeny taking place from the Middle Devonian to the Early Mississippian were apparently related to sequential collisions between the Avalon terrane and promontories on the eastern margin of the North American craton (ETTENSOHN, in press). Hence, the Middle and Late Devonian clastic wedges were largely derived from the New York promotory, and the Early Mississippian clastic wedge (Pocono. Grainger, Borden; Fig. 2A) emanates from the Virginia promontory. Major collision and rapid clastic progradation ended by the Middle Mississippian (Figs. 2 and 3). when carbonate deposition (Greenbrier, Newman) spread throughout the Appalachian Basin and onto the craton. The partially coeval Mauch Chunk clastic wedge indicates, however, that strike-slip movement and resulting uplift along the fault zone had not ceased. In fact, isopach maps of the Mauch Chunk (MECKEL, 1970) indicate the greatest thicknesses near the New York and Virginia promontories, where convergence would have continued to be greater.

By the latest Mississippian, increased subsidence and progradation of the Mauch Chunk-Pennington clastic wedge (Fig. 3) reflect the beginning of a second, collisional tectonic regime. The inpending collision involved the Gond-

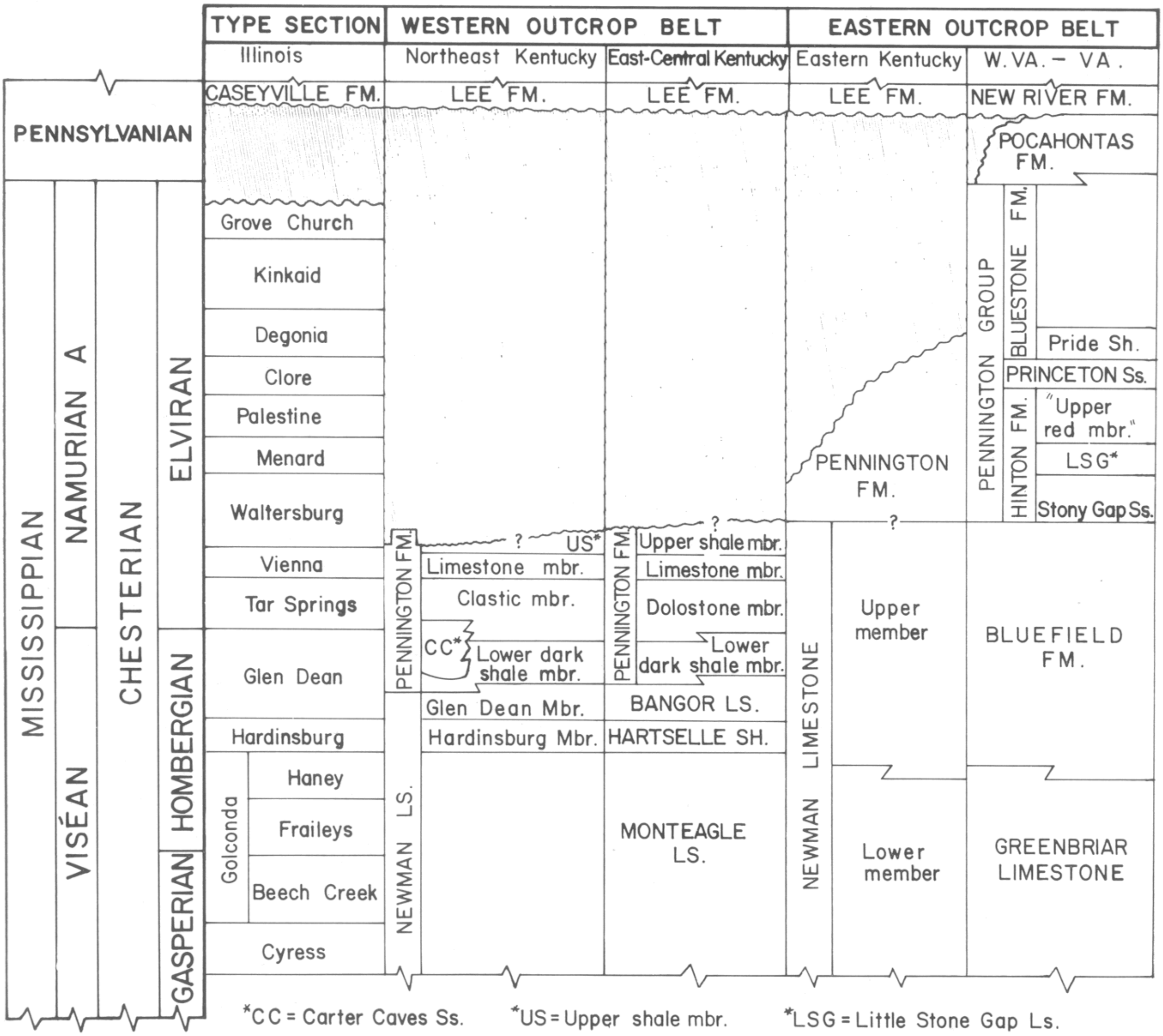

Figure 4. Nomenclature and approximate correlations of the Pennington and related units between western outcrop belt, eastern outcrop belt, and type Mississippian section. Note that the Pennington of the western outcrop belt and that of the eastern outcrop belt are probably not equivalent. Not drawn to scale.

wana (South America, Africa) and North American plates, with the Avalon terrane intervening in the north (Fig. 2c). As transcurrent movement was replaced by subduction, collision with the subduction trench and development of a volcanic arc occurred south of the Avalon terrane during the Early and Middle Pennsylvanian (SINHA & ZIETZ, 1982; RAST, in press). This event may be represented by a major regional unconformity.

Regional Setting

The Pennington Formation is prominent in the subsurface throughout most of eastern Kentucky (Fig. 1). The formation also crops out in the western belt and the eastern belt. The eastern belt of outcrop, in which the type section for the Pennington is located, is in extreme southeastern Kentucky, western Virginia, and southern West Virginia,

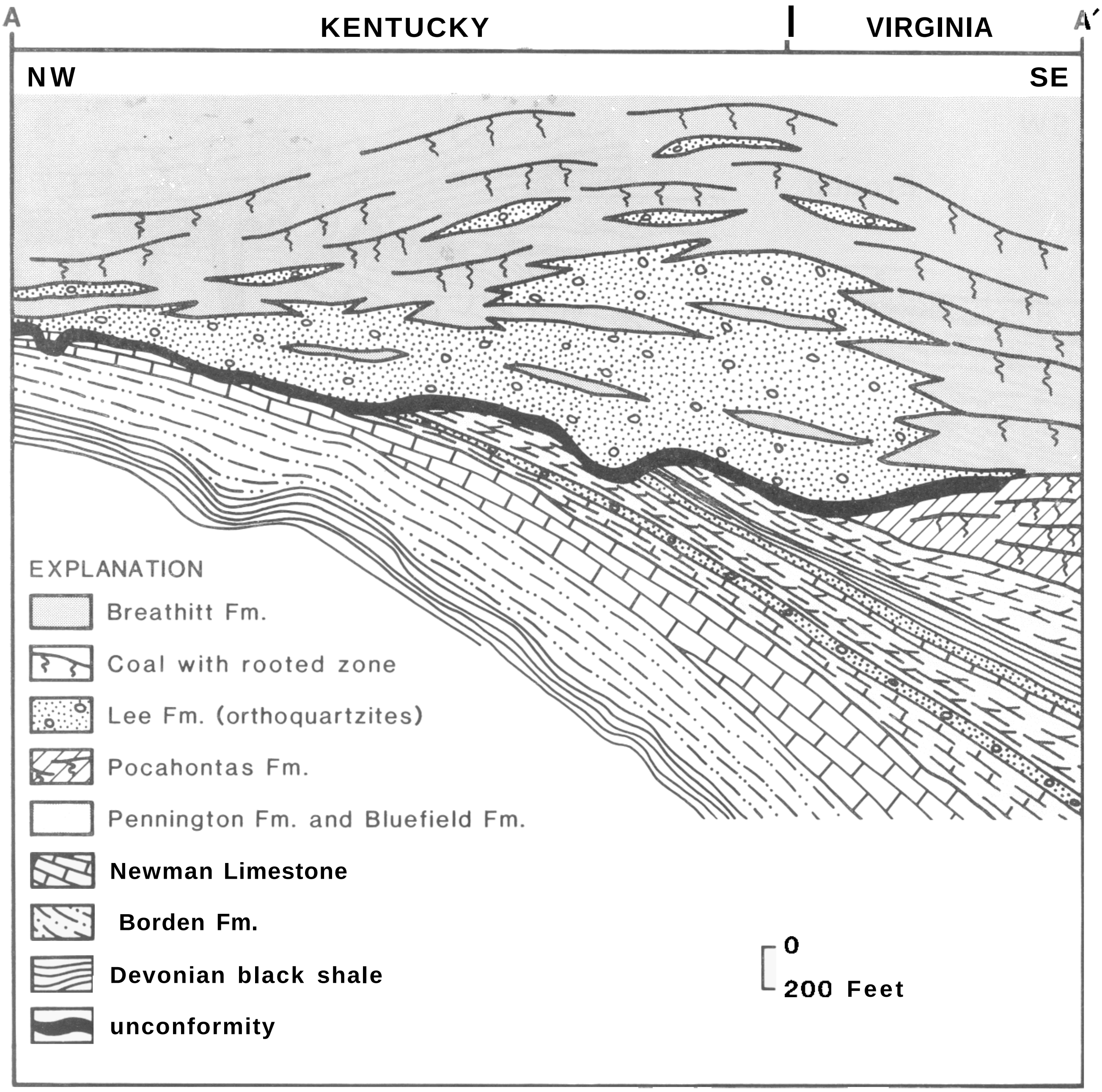

Figure 5. Schematic down-dip cross section between the western and eastern outcrop belts. The Pocahontas and overlying formations are Pennsylvanian in age. What begins as an intrasystemic unconformity in Pennsylvanian rocks to the southeast becomes a systemic unconformity to the northwest as progressively older rocks are truncated toward the margin of the basin. Vertical scale shown; no horizontal scale intendcd. See Figure 1 for location of section.

where it is as much as 750 meters thick. Along the western belt of outcrop the Pennington is as much as 60 meters thick, but is usually much thinner. The western belt of outcrop coincides with the western margin of the Appalachian Basin and the eastern flank of the Cincinnati Arch (Fig. 3).

Methods of Study

The eastern belt of outcrop, separated from the western belt by as much as 200 kilometers, is nearer to the axis of the Appalachian Basin (Fig. 3) and is therefore thicker.

The following methods were used to study the eastern

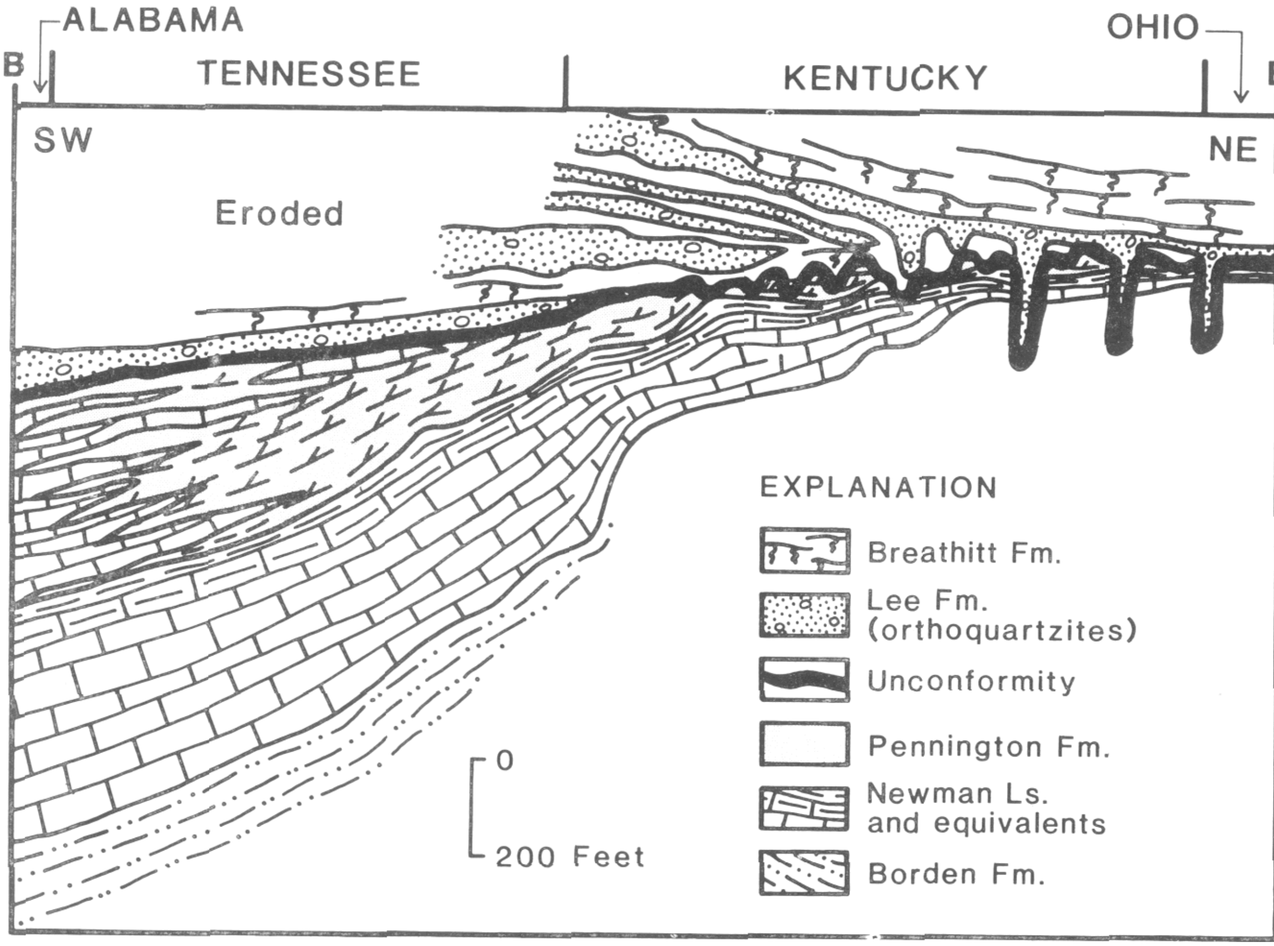

Figure 6. Schematic cross section approximately parallel to strike on the western margin of the Appalachian Basin. The systemic unconforrnity truncates progressively older Mississippian rocks to the northeast so that almost no Pennington remains in northeastern Kentucky and southern Ohio. No horizontal scale. *See* Figure 1 for location of section.

belt of outcrop. Regional lithologic and stratigraphic synthesis (WILPOLT & MARDEN, 1949, 1959; MILLER, 1974; ENGLUND *et al.*, 1979; ENGLUND & HENRY, 1981) were used for environmental inferences. Also, in order to evaluate the relationship between the two outcrop belts, five stratigraphic cross sections. two parallel to strike and three perpendicular to strike, were constructed, using measured sections from previous work, the literature, and the files of the Kentucky Geological Survey. The sections were examined for evidence of regional unconformities and facies change. Because of space limitations only two sections are presented here; the others can be found in CHESNUT (1982). In addition, the nomenclature used in the two outcrop belts was examined to determine if inconsistencies existed between the two belts. Finally. depositional sequences were modeled for the eastern belt of outcrop.

Detailed studies of the western belt of outcrop have been made by ETTENSOHN (1975, 1980, 1981), ETTENSOHN & CHESNUT (1979a, b), CHESNUT (1980), and FISHER (1981). Only a summary of the results and their implications are presentcd here. Using these studies, a detailed environmental model was constructed for the Pennington of the western outcrop belt.

STRATIGRAPHY

Eastern Outcrop Belt

The generalized stratigraphy along the eastern belt of outcrop is shown in Figure 4. The units of interest in this study are the Greenbrier Limestone, the Princeton Sandstone, and the Bluefield, Hinton (and its members), Bluestone, Pocahontas, Lee, and New River (Breathitt) Formations. The Greenbrier Limestone is a massive sequence of limestone with minor beds of shale, dolostone, and sandstone. The Bluefield Formation contains primarily fossiliferous, calcareous shales and shaly limestones. Its base

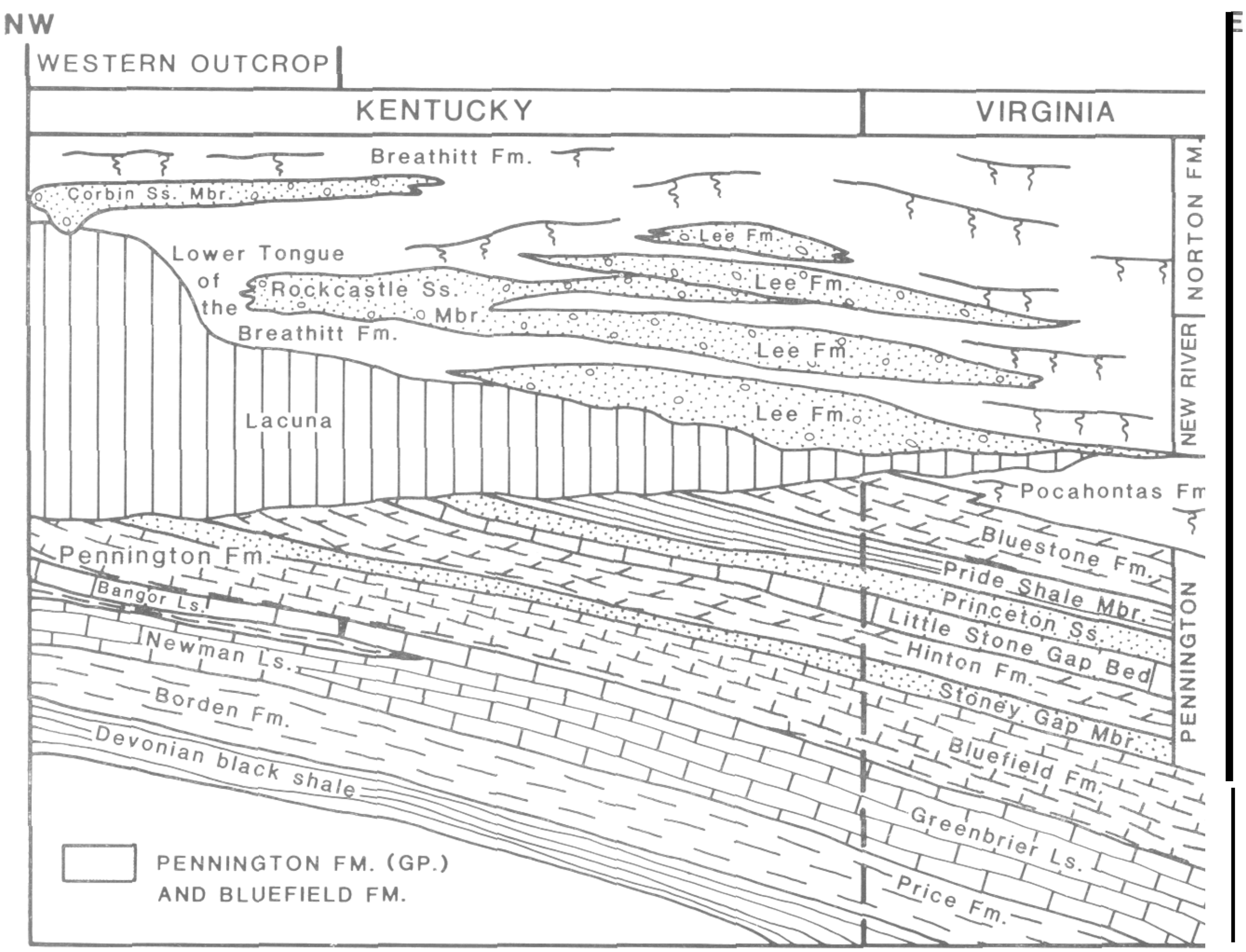

Figure 7, An area-time expansion of Figure 5 showing the approximate extent of the lacuna along systemic and intra-systemic parts of the unconformity. Not drawn to scale.

is defined by the top of the massive Greenbrier Limestone (lower member, Newman Limestone). The overlying Hinton Formation consists largely of variegated shales and sandstones with minor amounts of impure limestone. Its base is defined by the quartzose Stony Gap Sandstone Mcmbcr. The Little Stone Gap Member (Avis Limestone of REGER, 1926), which is at or near the top of the Hinton Formation, is the most prominent and widespread limestone above the Bluefield Formation. The overlying Princeton Sandstone is the thinnest of the formations. It ranges from coarse, quartzose sandstone to conglomerate, and is locally calcareous. The overlying Bluestone Formation consists largely of gray and red shales with lesser amounts of sandstones, siltstones, and impure limestones. The basal member of the Bluestone Formation, the Pride Shale Member, consists of a distinctive dark-gray, highly organic shale that contains plant and rare marine fossils. The Bluestone Formation grades laterally into the Pennsylvanian Pocahontas Formation. The Pocahontas Formation consists of sandstones, siltstones, shales and coals; it is an important coal-bearing formation. The overlying New River Formation is lithologically similar to the Pocahontas Formation, and grades laterally into the Lee Formation (Fig. 4). The Lee Formation is predominantly composed of massive orthoquartzitic sandstones and quartzpebble conglomerates. WILPOLT & MARDEN (1949, 1959), MILLER (1974), ENGLUND *et al.* (1979), and ENGLUND & HENRY (1981) have more detailed accounts of these units and their stratigraphic relationships.

Cross Sections

Two of the five cross sections through the basin were selected for use here. Figure 1 shows the locations of these two cross sections. Cross section B-B' is along the western belt of outcrop and is slightly diagonal to the strike of the beds (Fig. 6). Cross section A-A' is oriented perpendicular to strike (Fig. 5). The eastern belt of outcrop is on the right side of cross section A-A'. Examination of this cross section (Fig. 5) reveals that all units thin toward the western belt of outcrop, and, more importantly, that older units are successively truncated toward the western belt. Cross section B-B' (Fig. 6) reveals succesive truncation of these older units to the north. This truncation is interpreted as representing an unconformity. Figure 7 is based on all five cross sections and shows the approximate location of formations directly below the unconformity. In northeastern Kentucky beds as old as Middle Mississippian (Tournaisian) are locally truncated by the unconformity. In the western outcrop belt (Figs. 4 and 7), the unconformity is a systemic unconformity, in which Lower Pennsylvanian rocks overlie Mississippian rocks; in parts of the eastern outcrop belt, however, the unconformity becomes intra-systemic, and the Lower Pennsylvanian Lee Formation overlies the Lower Pennsylvanian Pocahontas Formation (Figs. 4 and 7). To the extreme southeast the unconformity disappears, and the contact between the two Lower Pennsylvanian units becomes conformable. The Pennsylvanian Pocahontas Formation intertongues with the largely Mississippian Bluestone Formation in the area where both are preserved (MILLER, 1974; ENGLUND *et al.,* 1979; ENGLUND, 1979; ARKLE *et al.,* 1979: ENGLUND & HENRY, 1981).

Figure 4 is a graphic representation of the correlations from the eastern belt of outcrop to the western belt of outcrop. Apparently, none of the Mississippian units above the Bluefield Formation are found along the western belt of outcrop in Kentucky. This finding has nomenclatural implications.

NOMENCLATURE

CAMPBELL (1893) named the sequence of largely red and green shales between the Newman Limestone and the Lee (Pottsville) Conglomerate at Big Stone Gap, Virginia (eastern outcrop belt), the Pennington Formation. The Newman Limestone was defined at the same time (Fig. 4). However, the boundaries of these formations. particularly the one separating the Newman and the Pennington, were never well defined. CAMPBELL's (1893) original description of the Newman mentioned a sequence of calcareous shales and shaly limestones in the upper part. CAMPBELL's (1893) definition of the Newman continues to be used in the eastern belt of outcrop in Kentucky, but the upper shaly part (Fig. 4) has been designated as the upper member of the Newman (for example, CSEJTEY, 1971). The upper member is thought to be equivalent to units from upper parts of the Golconda through lower parts of the Waltersburg in the Mississippian type section (Fig. 4). Farther northeast, in the Pocahontas area of Virginia and West Virginia, CAMPBELL (1896) divided strata equivalent to the upper member of the Newman and the Pennington Formation into four units that were defined by prominent marker horizons at their base. These units are the Bluefield Formation, the Hinton Formation, the Princeton Sandstone, and the Bluestone Formation (Fig. 4). The Bluefield Formation is approximately equivalent to the upper member of the Newman Limestone. Its base is defined by the top of the massive Greenbrier Limestone (lower member of the Newman). The base of the overlying Hinton Formation is defined by the quartzose Stony Gap Member. Overlying the Hinton Formation is the Princeton Sandstone, which in turn is overlain by the variegated shales of the Bluestone Formation.

In 1958, HARRIS & MILLER proposed to raise the Pennington in Virginia to the rank of group, including the Hinton, Princeton, and Bluestone Formations. In some reports the Pcnnington Group has also included the Bluefield Formation, but this usage has been discontinued. In southern West Virginia (Fig. 3) the Bluefield, Hinton, Princeton, and Bluestone Formations are considered part of the Mauch Chunk Group (ARHLE *el al.,* 1979). Farther north in east-central West Virginia and western Maryland, where these units can no longer be distinguished, the unit is called the Mauch Chunk Formation (Fig. 3).

In 1898, CAMPBELL introduced the Newman and Pennington terminology into the western outcrop belt of east-central Kentucky (CAMPBELL, 1898a, b), even though the lithologies bore little resemblance to those in the type area. According to MILLER (1910), CAMPBELL (Fig. 4) included rocks as low as the Haney Member (Golconda) within the Pennington. MILLER (1917, 1919) later restricted the Pennington in the western outcrop belt to Chesterian (Upper Mississippian) lithologies above the Glen Dean Member (Bangor Limestone) of the Newman (Fig. 4), and this is still the current usage for most workers.

As a result of our correlations, however, the base of the Pennington in the eastern outcrop bclt (type area) is stratigraphically higher than the base of the western belt (ENGLUND, 1968; Fig. 4). Recent biostratigraphic studies of the western belt (ETTENSOHN &BLIEFNICK, 1982) and areas near the eastern belt (ENGLUND *et al.,* 1979; ENGLUND & HENRY, 1981) have made this inconsistency apparent. Lithologic and probable time equivalents of the Pennington Formation in the western belt arc entirely in the upper member of the Newman or Bluefield Formation in the eastern outcrop belt. Hence, the Pennington in the western belt is older and not at all equivalent to the Pennington in the eastern belt (Fig. 4). Realizing this, some workers (for example, ENGLUND & WINDOLPH, 1975; ENGLUND, 1976) have placed all Pennington lithologies from the western belt into an informal upper member or shale member of the Newman Limestone, but this usage has not gained general acceptance. A complete revision of Newman and Pennington nomenclature in the western belt is called for and is currently in preparation (ETTENSOHN *el al.,* 1984). Correlatives of the Hinton, Princeton, and Bluestone Formations (Pennington Group) do not occur in the western outcrop belt.

Depositional Environments

The Pennington Formation represents the Late Mississippian (Chesterian, late Visean-Namurian A) distal edge of

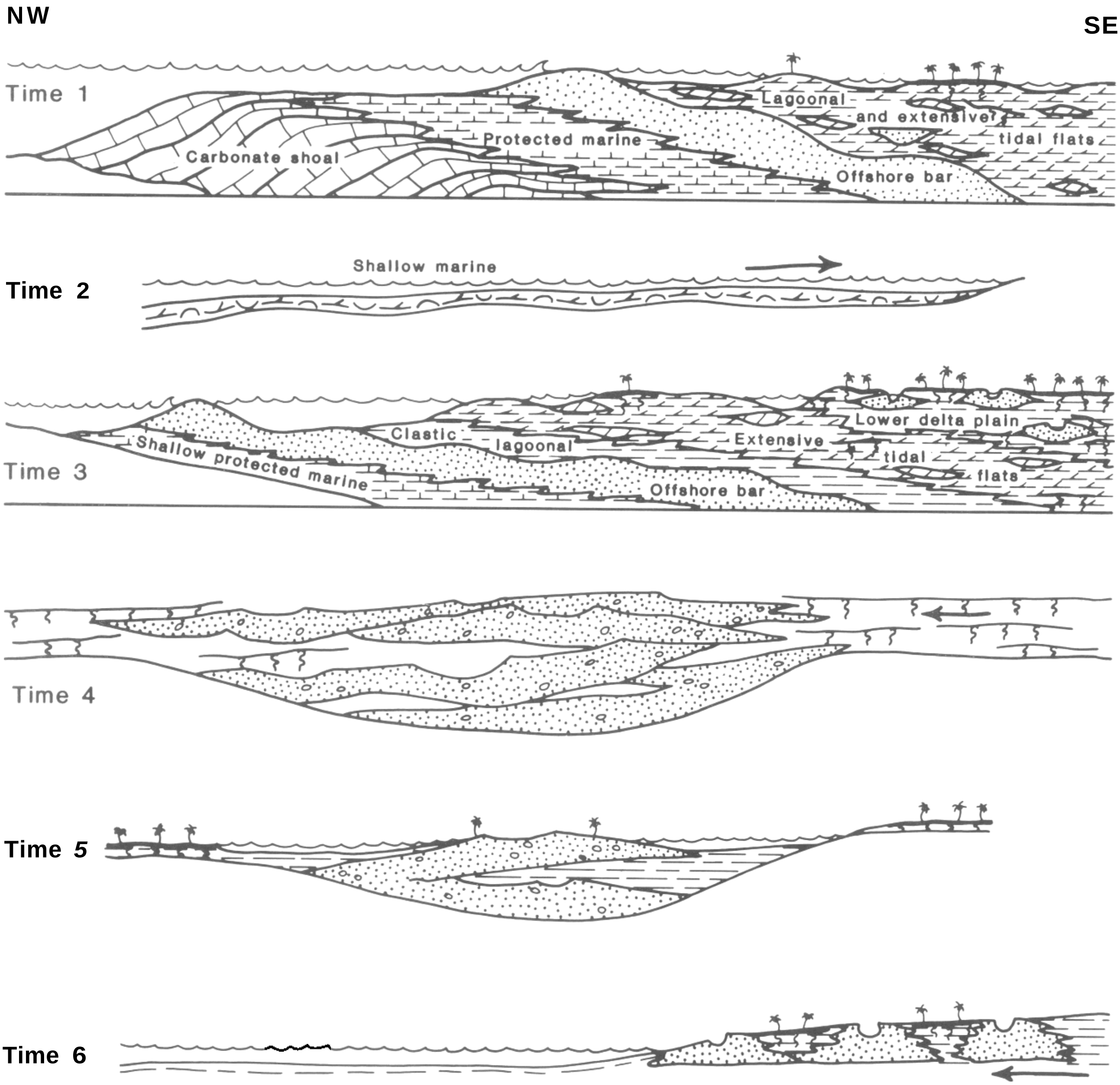

Figure 8. Schematic reconstructions of the scqucnce of environmental continua thought to be represented in upper parts of the Greenbrier ((lower Newman), Bluefield (upper Newman). Pennington Group, Pocahontas, and Lee. The Pennington and adjacent units are interpreted to represent two mixed clastic-carbonate progradations separated by a shallow-marine transgression. Time 4 reflects a major changc in basin subsidence and regional gradient.

progradation that began in the late Middle Mississippian (Meramecian, early Visean). On the eastern side of the wedge is the Mauch Chunk Formation (Fig. 3), which consists of largely terrestrial red and green shales. This progradation represents continued, though mild, uplift at the New York and Virginia promontories; it was caused by transpression along the transcurrent fault zone (Fig. 2b).

Throughout the Meramecian and most of the early Chesterian (Gasperian and Hombergian), uplift and clastic influx from the promontaries were reduced enough for thick carbonates such as the Greenbrier (Newman) to be deposited throughout central and western parts of the basin (Figs. 2b and 3). By the late middle Chesterian (Hombergian, late Visean), clastic influx had increased to the point that a mixed clastic-carbonate environmental continuum prograded westward. The continuum is represented by the Bluefield, upper Newman, and lower Pennington in the western belt of outcrop. During the late Chesterian (Elviran, Namurian A), however, clastic influx increased so much that clastic dominated environmental continua prograded across the Appalachian Basin and probably across the Cincinnati Arch (Figs. 2c and 3); they are represented by the clastics of the Pennington equivalent, the Litchfield Formation in west-central Kentucky. This greatly increased clastic influx was probably related to renewed compression and uplift in the Appalachian highlands, and impending collision.

Eastern Outcrop Belt

Depositional environments in the eastern belt (Fig. 8) are best explained by a two-cycle progradational model (MILLER, 1974; CHESNUT, 1982). The first cycle of progradation is represented by the upper parts of the Newman and Greenbrier Formations through the lower parts of the Hinton Formation (Fig. 8, time I). Crossbedded skeletal and oolitic calcarenites in upper parts of the Newman and Greenbrier are interpreted to represent offshore carbonate shoals and bars from the first progradation. The calcareous shales and siltstones and shaly limestones of the Bluefield and upper member of the Newman intertongue with underlying carbonates and represent a protected shallow-marine environment shoreward of the offshore shoals. A diverse marine fauna reflects normal marine conditions. Locally in middle and upper parts of the Bluefield, thin coals represent brackish or freshwater swamps, which formed near the margin of a beach-barrier system. The Stony Gap Sandstone. the basal member of the Hinton, is a mature, crossbedded sandstone that grades into the underlying Bluefield; it is interpreted to represent an offshore beach-barrier-marine bar system (MILLER, 1974: ENGLUND *et al.*, 1981). The parts of the Hinton Formation overlying the sandstone consist of variegated shales, siltstones. sandstones, coals, underclays, and minor impure limestones. This sequence apparently represent a varying mosaic of near-shore terrestrial and marine environments. Quiet-water, back-barrier lagoon and tidal flats are indicated. Localized fossiliferous limestones reflect the inundation of areas in which sedimentation could not keep pace with subsidence.

The first progradational cycle was ended by a regional transgression, represented by the Little Stone Gap Limestone Member of the Hinton Formation (Fig. 8, time 2). The Little Stone Gap consists of highly fossiliferous, argillaceous limestone and calcareous shale, and represents a shallow, offshore, marine environment. In southeastern parts of the eastern outcrop belt, the Little Stone Gap Member grades upward into a sequence of variegated shales, sandstones, and impure limestones (upper red member of the Hinton Formation, Fig. 4) that are interpreted by ENGLUND *et all.*, (1981) to represent near-shore marine and tidal-flat environments: this sequence does not occur to the northwest, where the Princeton directly overlies the Little Stone Gap (WILPOLT & MARDEN, 1949). If the interpretation of ENGLUND *et al.*, (1981) is correct, then the Little Stone Gap sequence represents a short-lived westward progradation not shown in Figure 8. Alternatively, MILLER (1974) suggested that the sequence represents a series of varying environments transitional between quiet. shallow-marine and high-energy, beach-barrier-bar environments. Our interpretation (Fig. 8, time 3) essentially follows that of MILLER (1974).

After the Little Stone Gap transgression, a second major progradational continuum migrated northwestward (Fig. 8, time 3). Shallow open-marine and near-shore protected marine environments are represented by upper parts of the Little Stone Gap Member and the transitional lithologies of the upper red member. The Princeton Sandstone conformably overlies the red member to the southeast and the Little Stone Gap to the northwest. The sandstone is mature, calcareous, and quartzose, with molds of marine fossils; it is interpreted as representing an offshore beach-barrier-bar complex (MILLER, 1974). The overlying Pride Shale is the basal member of the Bluestone Formation and consist of dark-gray, highly organic shales with interlaminated siltstones and sandstones, and contains only rare fossil:: it is interpreted as representing a quiet-water marine embayment or lagoon behind the Princeton barrier-bar system (Fig. 8, time 3). The overlying variegated shales, siltstones, sandstones, and impure limestones of the upper Bluestone are interpreted as representing a mosaic of near-shore terrestrial and marine environments similar to upper parts of the Hinton Formation in the earlier progradational cycle. Unlike the earlier cycle, howcver, this cycle ended with lower delta-plain and alluvial-plain environments, represented by the Pocahontas Formation (Fig. 8, timc 3).

After the Pocahontas Formation was deposited during the Early Pennsylvanian, much of eastern North America was subjected to regional uplift, which probably reflects collision with the subduction trench and the beginning of subduction on the southeastern margin of the North American craton (Fig. 2d). Resulting emergence and erosion formed a prominent unconformity along which much of the Pennington was destroyed. Erosion progressively truncated older Mississippian rocks toward the margins of the basin, where uplift was greatest. Hence, in the western outcrop belt the youngest rocks remaining are equivalent to the Bluefield Formation in the east (Figs. 3 and 4). Although the uplift and erosion were wholly Pennsylvanian events, erosion through the thin Pennsylvanian Pocahontas Formation into Mississippian strata resulted in a systemic unconformity nearly everywhere in the Appalachian Basin and adjacent parts of the craton.

The change in tectonic regime caused the locus of basin subsidence temporarily to shift to the northwest (Fig. 8, time 4); regional gradient to change from the northwest to the southwest; and sedimentation to change from near-shore muds, silts, and sands to coarse, conglomeratic,

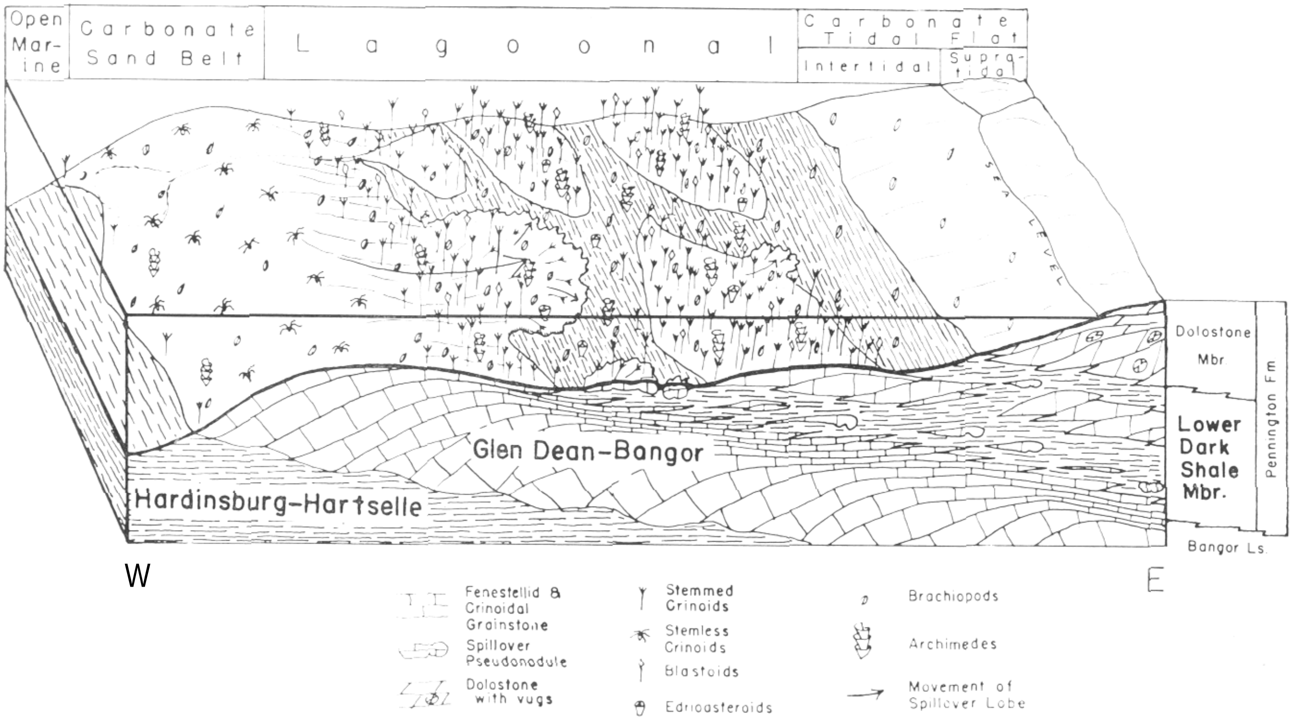

Figure 9. Environmental reconstruction of the progradational sequence represented by the upper Newman and lower Pennington on the western outcrop bclt in south-central Kentucky. This progradation is approximately equivalent to that in Time 1, Figure 8. (Modified from ETTENSOHN & CHESNUT, 1979b).

sands, represented by the Lee Formation (Fig. 8, time 4). The Lee is interpreted as representing braided-river systems that flowed generally southwestward (HESTER, 1981; BEMENT, 1976). These river systems were highly erosive, and contributed to the erosional truncation on the unconformity.

Western Outcrop Belt

The Pennington of the western belt, together with upper parts of the Newman (Glen Dean Member or Bangor Limestone), represents the westward migration of the progradational continuum in cycle one (Fig. 8, time 1). The depositional environments in the west (Fig. 9) were similar to the environments in the east (Fig. 9) but less complex because of decreased subsidence and increased distance from clastic source areas. An environmental equivalent of the Stony Gap Sandstone Member is missing, probably due to erosion.

Where preserved along the western belt, the Pennington Formation can be divided into four lithologic members: (1) lower dark shale member, (2) clastic or dolostone member, (3) limestone member, and (4) upper shale member (Fig. 4). These units overlie the Glen Dean Member (Bangor Limestone).

The Glen Dean (Bangor) is composed of massive, cross-bedded, skeletal calcarenite that is locally oolitic. It contains a sparse, thick-shelled fauna indicative of high-energy conditions. The Glen Dean is interpretcd as representing a shallow, high-energy carbonate sand belt of migrating shoals at or near wave base (Figs. 9 and 10).

The Glen Dean (Bangor) intertongues with the overlying lower dark-shale member (Sloans Valley Member of ETTENSOHN & CHESNUT, 1979a, b) of the Pennington; the lower dark-shale member consists of dark-gray shale with lenses and shoal-like bodies of calcarenite. The member (0-9 m thick) contains a diverse fauna, most of which is associated with the limestone lenses (CHESNUT, 1980). It thickens to the south and becomes more calcareous and fossiliferous. This member is interpreted as representing a somewhat deeper (than the Glen Dean sand belt), protected lagoon environment shoreward of the sand bclt (Fig. 9). The firm substrates provided by these shoals, their protected position shoreward of the sand belt, and access to land-derived nutrients apparently provided optimal environmental conditions for the proliferation of faunas. This environment was similar to the quiet, protected marine environment represented by the upper Bluefield (Fig. 8, time 1).

To the north the lower dark-shale member is conformably or disconformably overlain by the clastic member (0-38 m); the clastic member consists of a fining-upward sequence of

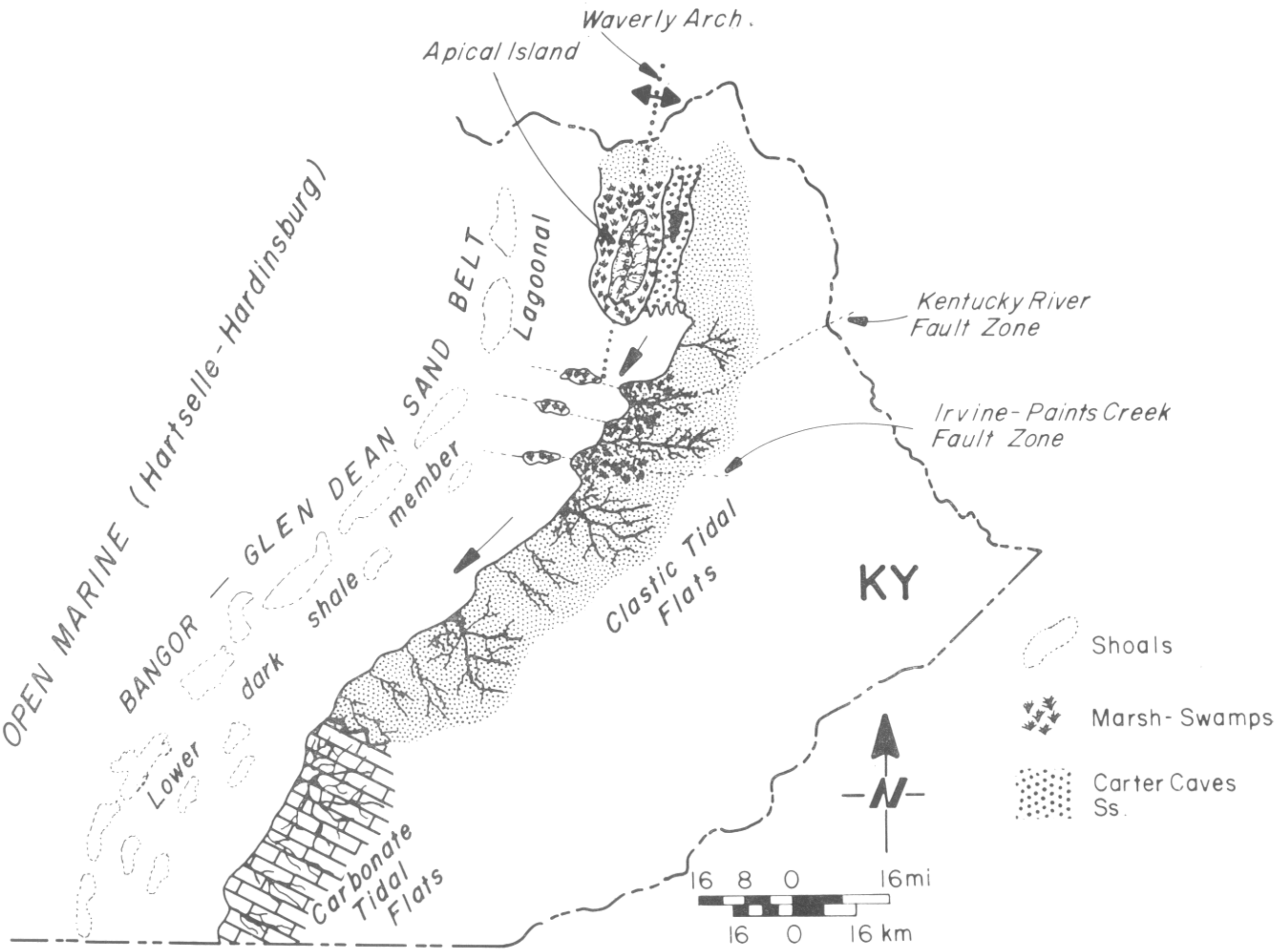

Figure 10. Schematic diagram of major progradational environments along a late middle to early late Chesterian tidal shoreline in the western outcrop belt during Pennington deposition in central Kentucky. (Adapted from ETTENSOHN & CHESNUT, 1979b).

coarse clastics (Fig. 4). The sequence begins with a well bedded to lenticular quartrose sandstone with high-angle crossbedding. The basal sandstone grades upward into rippled or lenticular micaceous sands with flaser beds of highly organic shale; the micaceous sands continue upward into laminated highly organic shale with lenses of argillaceous or calcareous siltstone. Fossils are rare, although bioturbation in common in parts of the sequence. The sequence is interpreted as representing a clastic tidal flat. The Carter Caves Sandstone of Englund & Windolph (1971) is considered to be a channel-shaped lens within the clastic member (ETTENSOHN, 1979, 1980, 1981; Fig. 4).

In south-central Kentucky the lower dark-shale member grades upward into the dolostone member (ETTENSOHN & CHESNUT, 1979a, b). The dolostone member (0-15 m thick) consists largely of massive dolostones interbedded with red, green, and gray shales. The dolostones are laminated and contain vugs filled with calcite, dolomite, celestite, strontianite, and barite. Some dolostone exhibit vertical burrows and fenestral fabric. Calcilutites, calcisiltites, and oolitic calcarenites occur locally but are not as abundant as dolostone. Two of the limestones exhibit irregular, brecciated surfaces, which suggests subaerial exposure. Fossil fragments are round throughout the member, but fossil assemblages containing complete, untransported forms are rare. Only two such assemblages from this section are known, one containing pelecypods and the other brachiopods. The dolostone member is interpreted as representing intertidal-supratidal deposition at the interface of lagoonal and tidal-flat environments (Fig. 9). The presence of laminated dolostones (some with fenestral fabric), the predominance of vertical burrowing, and the presence of a sparse, restricted fauna suggest intertidal environments. Some of the sulfates filling the vugs have been interpreted as anhydrite replacements (FRAZIER, 1975), suggesting the local presence of evaporites. The calcilutites and calcisiltites in the sequence apparently reflect subtidal conditions resulting from local marine incursions onto the tidal flats. The brecciated, irregular surfaces found on some of these limestones seem to reflect exposure accompanying the abrupt withdrawal of seas from the tidal flats. Crossbedded oolitic calcarenites occur locally in this part of the Pennington and may reflect accumulation in agitated subtidal conditions an tidal deltas. tidal bars, or in open coastal embayments. Somewhat similar coastal oolite deposits occur with tidal-flat sediments in the Persian Gulf (LOREAU & PURSER, 1973).

During the late middle and early late Chesterian, a westward-prograding tidal shoreline seems to have dominated eastern Kentucky (Fig. 10). Paleocurrent studies in sediments that the authors regard to be Pennington (FERM *et al.,* 1971; ETTENSOHN, 1975; SHORT, 1978) suggest a northern source for clastic of the Lower Pennington. If SHORT'S (1978) interpretation of the Carter Caves Sandstone as a distributary channel is correct, then many of the clastics occurring in the clastic member in northeastern Kentucky may have been derived from this channel system (Fig. 10). After sediments were transported to coastal waters by the disttributary channel, they must have been transported southward and reworked into the clastic tidal flats (Fig. 10). Coastal areas near the Waverly Arch apical island and basement fault zone (Fig. 10) were apparently slightly higher than other parts of the tidal coastline and supported paralic marshes (indicated by thin coals). Pennington coals in east-central Kentucky are restricted to the clastic member and occur only in the thinned sequence on local structural highs (ETTENSOHN & PEPPERS, 1979). To the north this part of the Pennington is characterized by a fining-upward clastic sequence with numerous tidal features; the sequence extends as far south as Rockcastle County in south-central Kentucky. Rockcastle County apparently was as far south as the coarser clastics were transported. South of this point, carbonate muds, silts, and sands replaced clastic sediments on the tidal flats. Carbonate sedimentation in this area apparently outstripped any clastic influx into the area. The predominance of carbonate sedimentation is also reflected in the greater abundance of carbonates found in the lower dark-shale member to the south than to the north

The limestone member is a bluish or brownish-gray calcarenite or calcisiltite that is extremely fossiliferous. The limestone member overlies the clastic or dolostone members along the entire length of the outcrop belt in Kentucky; it is probably equivalent to the Vienna Limestone (Fig. 4) in the type section of the Mississippian System, based on conodont evidence (CARL REXROAD, written communication, 1982).

The limestone member reflects a brief, but extensive, easterly transgression from open seas to the west. It is the only limestone that can be traced througout the Pennington of the western belt, but it is not possible to determine an equivalent among the many limestones of the Bluefield Formation in the eastern belt.

The overlying upper shale member (0-35 m) is the highest Mississippian unit in east-central Kentucky. The unit consists largely of silty red and green shales containing layers and lenses of brecciatcd dolostones, crossbedded sandstones, and siltstone. Mud cracks occur in some of the dolostones, and ripple marks and flaser beds are common in the siltstones. The shales contain abundant macerated plant debris and bioturbation, but invertebrate fossils are rare. The sequence is interpreted as representing the return of extensive tidal mud flats, but the flats were dominated by clastic muds this time, with only local accumulations of carbonate muds. The brecciation in these carbonates probably represents subaerial exposure and vadose diagenesis (FISHER, 1981).

Although overlying Pennington strata were apparently once present, they have been destroyed by Early Pennsylvanian erosion along the systemic unconformity, represented by the lacuna in Figure 7.

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