XI^e Congrès International de Stratigraphie et de Géologie du Carbonifère Beijing 1987,
Compte Rendu 4 (1989): 145-159

NATURE AND PROBABLE ORIGIN OF THE MISSISSIPPIAN-PENNSYLVANIAN UNCONFORMITY IN THE EASTERN UNITED STATES

Frank R. Ettensohn
(Department of Geological Sciences, University of Kentucky, Lexington, KY 40506, USA)
Donald R. Chesnut, Jr.
(Kentucky Geological Survey, University of Kentucky, Lexington, KY 40506, USA)

ABSTRACT

Throughout most of the eastern United States, Mississippian and Pennsylvanian rocks are separated by the so-called Mississippian-Pennsylvanian unconformity. Recent stratigraphic analysis in the central Appalachian Basin, however, suggests that the unconformity is a product of Early Pennsylvanian (Namurian C) erosion. We suggest that this erosion was largely produced by a northwestward-migrating peripheral bulge accompanying inception of an Early Pennsylvanian phase of Alleghanian Orogeny. As the migrating deformational load pushed the bulge cratonward, uplift and erosion on the bulge progressively truncated earliest Pennsylvanian and Mississippian rocks, so that late Early Pennsylvanian sediments progressively overstepped Mississippian rocks to the northwest on the unconformity.

In the three Appalachian areas, east-central Pennsylvania, western Virginia and southern West Virginia, and northern Alabama and adjacent parts of Georgia and Tennessee, no mid-Carboniferous unconformity is present. These conformable sequences occur in major depocenters cratonward of continental promontories, where residual deformational loading continually produced sufficient subsidence to offset bulge uplift.

Although an eustatic component may have contributed to unconformity development, in tectonically active periods and places like the mid-Carboniferous of the Appalachian Basin, it is unlikely that eustacy was the major cause of unconformity development.

INTRODUCTION

The so-called Mississippian-Pennsylvanian unconformity is a major interregional surface separating Mississippian and Pennsylvanian rocks throughout much of North America; this surface is also commonly used as the boundary between rocks of the Kaskaskia and overlying Absaroka sequences.' In the 1970's and early 1980's, however, the exact

nature of this boundary in the Appalachian Basin of eastern United States became the subject of considerable controversy.[2,3] The proponents of one interpretation contended that Mississippian and Pennsylvanian rocks are gradational and that no major unconformity exists.[4,5] whereas proponents of theother interpretation maintained the existence of a major unconformity and lacuna separating Mississippian and Pennsylvanian rocks.[6,10] In the Appalachian Basin, the controversy has subsided considerably, and the growing consensus of the geologists working in the area is to accept the presence of a major unconformity.

Despite the consensus, however, the nature, age, and origin of this extensive surface are largely unknown. In the following study, we would like to briefly characterize this surface in the Appalachian Basin and integrate the resulting data with some recently developed models in order to suggest an origin for the unconformity.

DEFINING THE UNCONFORMITY

The Mississippian-Pennsylvanian boundary has been treated as an unconformity throughout most of eastern United Stares since the early 1800's largely because it was viewed as an irregular surface separating a mostly marine Mississippian sequence from a mostly terrestrial Pennsylvanian sequence. On the outcrop such criteria may seem unequivocal, but over the extent of the Appalachian Basin, we agree with Ferm,[2,11] Ferm *et al.*,[4] and Horne *et al.*[5] that these criteria by themselves are no longer adequate for defining such an extensive surface. Rather, we suggest the use of a series of geologic and paleontologic criteria for defining this surface. Specifically, we have examined the nature in which underlying beds have been truncated, the character of the surface itself, the nature of overlapping beds, the geometrical relationships between beds above and below the surface, as well as the biostratigraphic significance of faunas on either side of the surface. We cannot claim to have examined these aspects over the entire extent of the unconformity, for it is mostly present in the subsurface where it is poorly known. However, we have examined the surface in some detail in eastern Kentucky, where surface exposures[11] and subsurface data[13] are abundant. Hence, most of our observations are based on criteria derived from eastern Kentucky and parts of adjacent states.

Truncation of underlying beds along the unconformity is an important characteristic, and it occurs in a systematic fashion. Construction of detailed cross sections perpendicular to strike in Kentucky[13] shows that the unconformity truncates progressively older rocks cratonward toward the northwest (Fig. 1). Thus, the surface begins near the center of the Appalachian Basin with truncation of Lower Pennsylvanian rocks (Fig. 1) and continues northwestward into northeastern Kentucky where rocks in the Borden Formation as old as Osagian (Tournaisian) age have been cut.[9,11] Much of this deep northwestward truncation was apparently related tn uplift on the Cincinnati Arch, which defines the western margin of much of the Appalachian Basin. Cross sections parallel to strike along the western margin of the basin similarly show a progressive truncation of older Mississippian rocks to the northeast (Fig. 2). Much of the northeastward truncation may be re-

lated to uplift on a series of up-to-the-north basement faults in Kentucky and Ohio.[14]

The nature of the surface itself also suggests an unconformity. The surface shows evidence of subaerial exposure in the form of paleokarst, probable paleosols and erosional relief.[15] The presence of intense oxidation, leaching, bleaching, and rooting along the surface suggests the former occurrence of subaerial exposure and upland-soil development.[15] Elsewhere, the presence of well-developed underclays or fire-clays on this surface suggests the development of swampy lowland soils.[11,16,17] Cross sections and a structure-contour map on this surface in Kentucky[18] also indicate topographic relief of nearly 70m, which locally controlled some aspects of subsequent Pennsylvanian deposition. In fact, Rice[19] has suggested that cuesta-like erosional features on this surface controlled the distribution of some overlying Pennsylvanian channel sands.

The cross sections[13] also reveal definite relationships within the overlapping Pennsy1vanian sequence. Successively younger Pennsylvanian units overlap each other and progressively overstep older Mississippian units below (Figs. 1, 2). Moreover, the cross sections[13] also show that though both Mississippian and Pennsylvanian rocks dip to the southeast, Pennsylvanian rocks above the unconformity dip at a lesser angle.

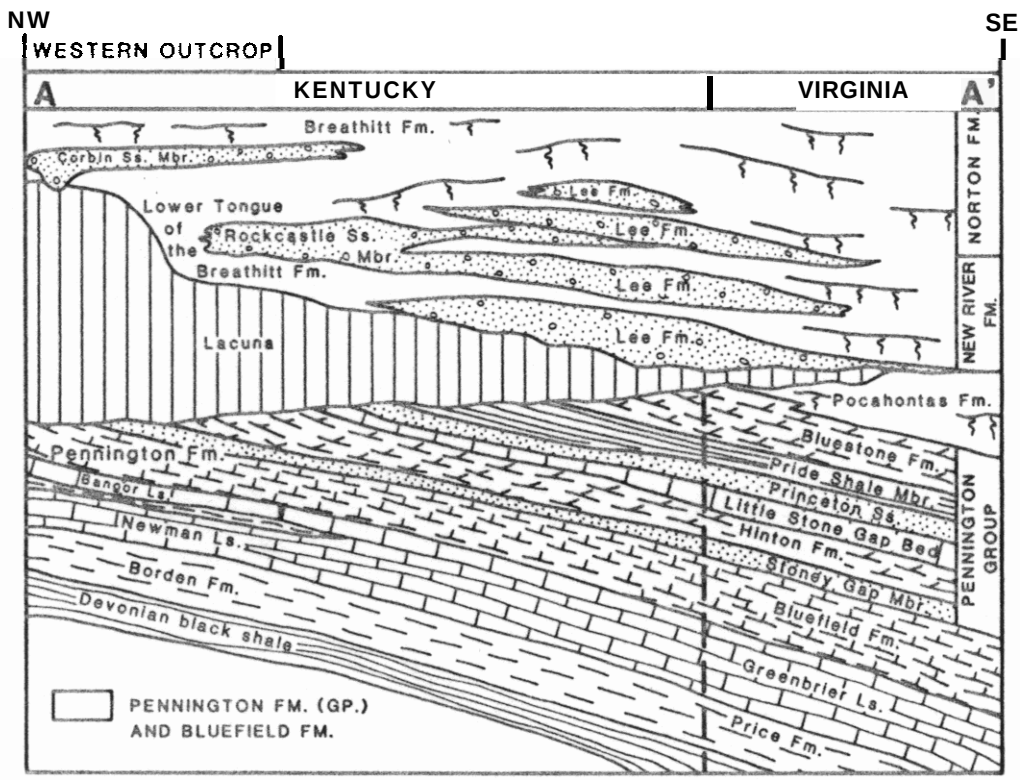

Fig. 1 Schematic area-time expansion of the mid-Carboniferous section along a northwest-southeast cross-section line in the central Appalachian Basin

Note the nature of the lacuna along systemic and intra-systemic parts of the unconformity. See Fig. 3 for location; not drawn to scale.

Biostratigraphic studies across the unconformity are few in number and hampered by difficulties in trying to correlate between dominantly marine and nonmarine faunas on respective sides of the surface. The hiatus hetween rocks containing Middle and Late Mississippian marine guide fossils and those containing Early and Middle Pennsylvanian palynomorphs and plants is obvious and well founded in northeastern Kentucky.[10] but the extent of the hiatus is difficult to assess because of the markedly different nature of biostratigraphic indicators on either side of the surface. Palynology offers some hope of resolving this problem, but there are few studies. Kosanke[20] indicated a definite change in palynomorphs at the unconformity in eastern Kentucky, but only in northeastern Kentucky has the presence of a hiatus at the unconformity been demonstrated through palynology.[21]

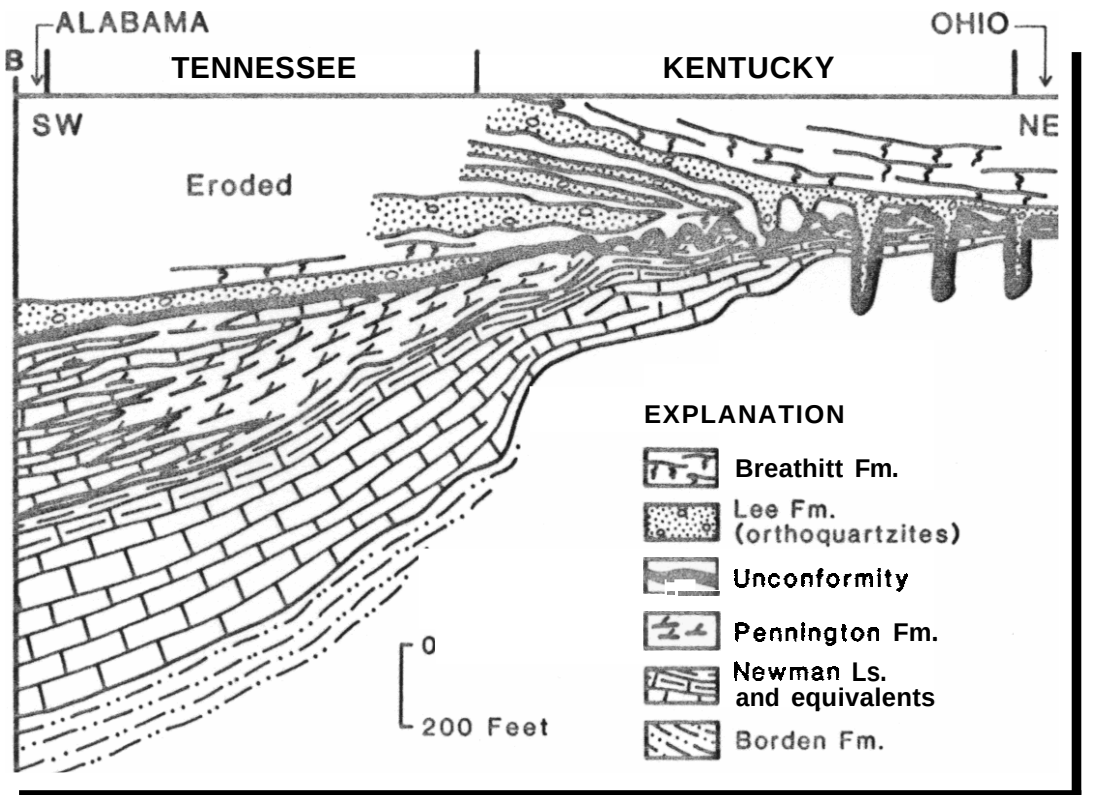

Fig. 2 Schematic cross-section approximately parallel to the western margin of the Appalachian Basin The systemic unconformity truncates progressively older Mississippian rocks to the northeast so that almost no Pennington remains in northeastern Kentucky and southern Ohio. See Fig. 3 for location; not drawn to scale.

In short, the multiple lines of evidence summarized ahove support the presence of a major unconformity surface separating Mississippian and Pennsylvanian rocks in eastern Kentucky and adjacent states, and similar lines of evidence have been used to support its occurrence elsewhere in the basin.[22]

NATURE AND AGE

Not everywhere in the Appalachian Basin, however, are Mississippian and Pennsylvanian rocks separated by an unconformity. In three Appalachian areas (Fig. 3). east-central Pennsylvania,[6] western Virginia and southern West Virginia,[7,15,23,24] and northern Alabama,[25,26] and adjacent parts of Georgia[27] and Tennessee,[26] Mississippian and Pennsylvanian rocks are interpreted to be vertically and laterally gradational. Moreover, in the central Appalachian area where the gradational Mississippian transition is best known, Englund and his co-workers[15,23,24,29] have demonstrated that the so-called Mississippian-Pennsylvanian unconformity originates in the lower part of the Lower Pennsylvanian New River Formation (Namurian C) and truncates the lowest Pennsylvanian Pocahontas Formation (Namurian B) and underlying Upper Mississippian rocks northwestwardly (Fig. 1). Hence, the unconformity must be largely Early Pennsylvanian in age. If the unconformity is of the same age throughout the Appalachian Basin, then the widespread presence of Mississippian rocks below the unconformity is merely the product of Early Pennsylvanian truncation.

POSSIBLE ORIGINS

The two most likely possibilities for the origin of any major episode of unconformity development are eustatic and tectonic, and both mechanisms have been used to explain the origin of the Mississippian-Pennsylvanian unconformity in the Appalachian Basin.

Saunders and Ramsbottom,[30] for example, have suggested that the unconformity coincides with a major worldwide mid-Carboniferous eustatic event. Their event, however. cannot be assumed to have coincided with major unconformity development in the Appalachian Basin, for the timing of the two occurrences does not match. Their eustatic event began at the end of the E2b ammonoid zone in the late Chesterian (Elviran; Namurian A) and at its latest, in most places, persisted to the R1a ammonoid zone at the Mississippian-Pennsylvanian boundary. Although correlations with the Appalachian Basin sequence are poor, their event probably correlates with an unconformity at the base of the Princeton Sandstone and Bluestone Formation,[31] and subsequent regression in the Bluestone and Pocahontas Formations[32] at the Mississippian-Pennsylvanian transition. However, as already indicated,[15,23,24,29] the Mississippian-Pennsylvanian unconformity largely formed during the post-Pocahontas Early Pennsylvanian and appears to have postdated the typical conclusion of the eustatic event, as interpreted by Saunders and Ramshottom.[30]

Possible tectonic causes run the gamut from localized vertical movements to large-scale cratonic flexure caused by convergence at continental margins. The extent of the unconformity in the Appalachian Basin and elsewhere, and the fact that unconformity development coincided with early phases of the Alleghanian Orogeny suggest that large-scale cratonic flexure may provide the best explanation. A model detailing the causes and

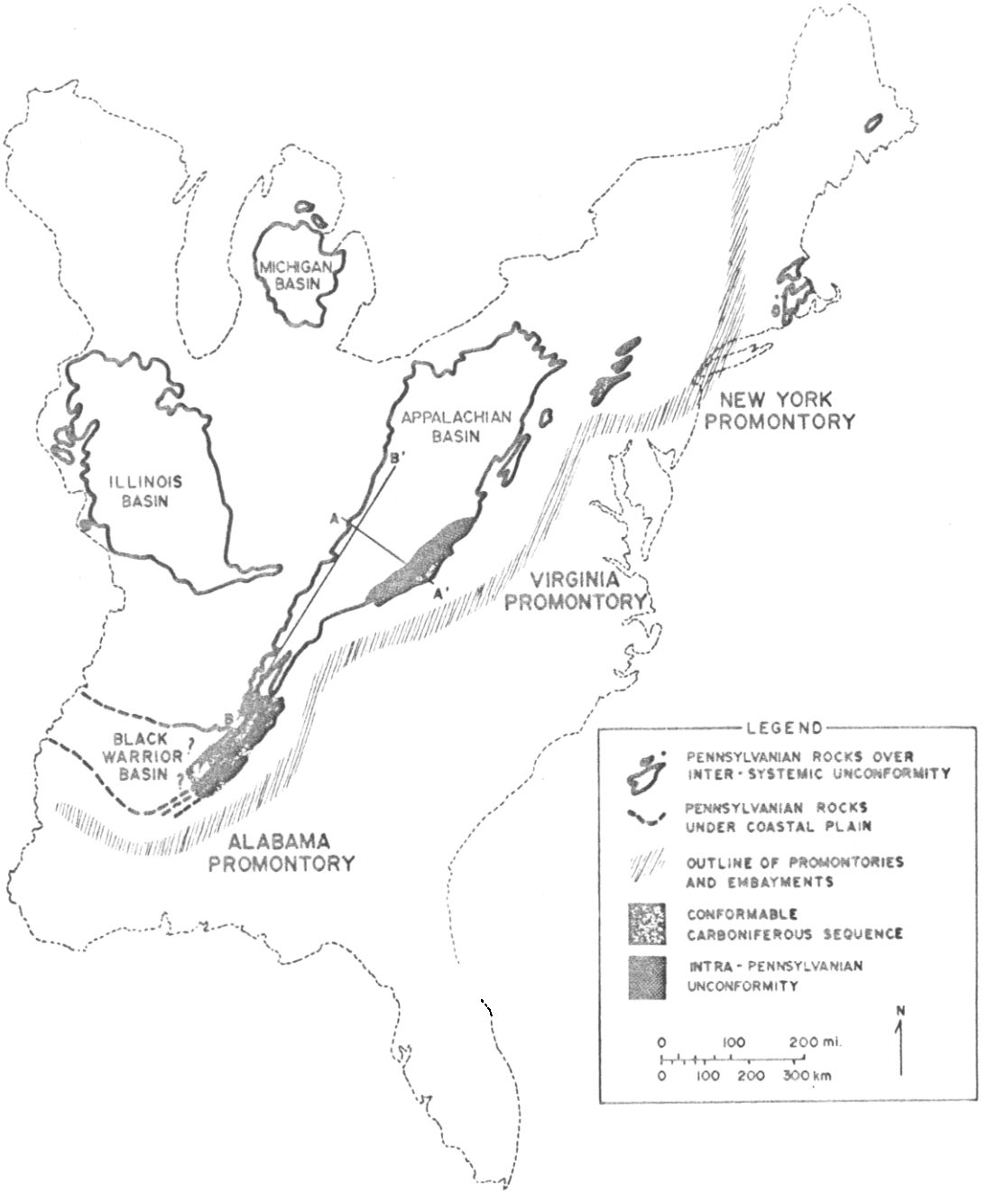

Fig. 3 Map of the eastern United States showing places where the unconformity is thought to separate Mississippian and Pennsylvanian rocks (inter-systemic or systemic), places where the unconformity occurs wholly within the Pennsylvanian (intra-Pennsylvanian), and places where the Carboniferous sequence is wholly gradational. Wholly conformable sequences occur just cratonward of major continental promontories.

effects of such lithospheric flexure[33] in unconformity development is discussed in the following section.

DISCUSSION

The model of Quinlan and Beaumont[33] suggests that deformational loading in an orogen produces a downwarped flexural basin (foreland basin) cratonward of the orogen and a peripheral bulge on the distal (cratonward) margin of the basin (Fig. 4). As orogeny proceeds, and the thrust load continues to migrate cratonward, the foreland basin and peripheral bulge also continue their migration away from the load. The general result of peripheral-bulge migration across the craton is an unconformity that may be very extensive, especially if it records the "initial docking of a substantial overthrust load" against a cratonic mass.[33] However, as orogeny and resultant thrusting cease, lithospheric relaxation causes the peripheral bulge to be uplifted and migrate toward the orogen, while the foreland basin becomes deeper and narrower. As the peripheral bulge migrates back toward the orogen, uplift and erosion of previously deposited sediments creates another unconformity (Fig. 5A).[33]

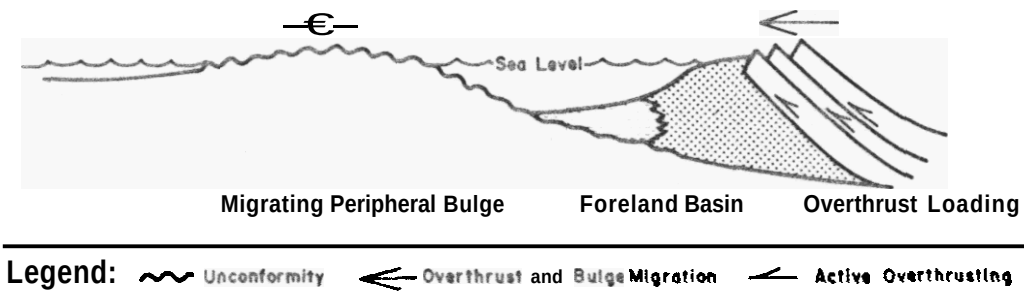

Fig. 4 Schemaiic diagram showing the development of a foreland basin in response to overthrust loading in the orogen

The peripheral bulgeis pushed cratonward hy thrust-sheet migration: uplift and migratiom resultin an unconformity (adopted fromQuinlan and Beaumont[33]).

Lithospheric relaxation may also occur in response to orogenic unloading or erosion, but the flexural response is opposite of that seen above (Fig. 5B).[34] As the orogen is erosionally lowered, it begins to rebound, and lithospheric relaxation progressively uplifts areas adjacent to the unloading while an "anti-peripheral bulge" deepens and moves toward the former load (Fig. 5B).[34] Orogenic unloading also creates a widespread unconformity.

In deeper parts of foreland basins, it is unlikely that erosion accompanying bulge migration and uplift would be effective in generating an unconformity. This is because in parts of the orogen outboard of these deeper basinal areas, enough residual deformational loading remains so that resulting subsidence is always great enough to offset bulge uplift.[33]

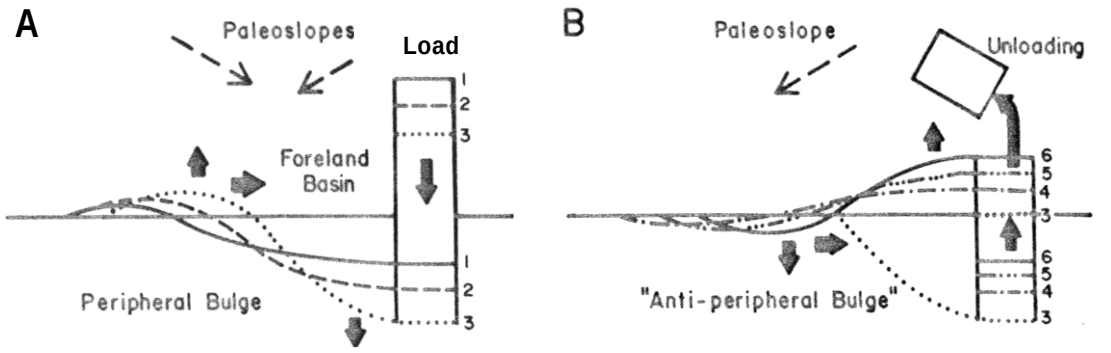

Fig. 5 Two types of flexural response to lithospheric stress relaxation

A. Response to a static load results in a deepening foreland basin and migration of peripheral bulge toward the load:

B. Response to erosional unloading results in rebound or progressive uplift near the unloaded area and an "anti-peripheral bulge" that deepens and migrates toward the former load.[34]

To understand how the above models affect the development of the Mississippian-Pennsylvanian unconformity, we must go back to the advent of lithospheric relaxation following termination of the Acadian Orogeny. The Borden-Price-Grainger-Pocono in our interpretation largely represent synorogenic clastic sediments filling a foreland basin cratonward of the Acadian Orogen during the final tectophase (Fig. 6).[35] As active loading ceased, lithospheric relaxation ensued (Fig. 5A), causing peripheral-bulge migration toward the orogen. We suggest, however, that this migrating peripheral bulge need not have formed an unconformity[33,34] if sea level was rising at the same time, and the sea level curves of Vail *et al.*[36] suggest the presence of such a rise at this time. In fact, the combination of rising bulge **and** rising sea level could have elevated cratonic sea bottoms high enough into the water column to encourage pervasive carbonate deposition, and this is apparently what the Middle and Late Mississippian (Visean-Namurian A) stratigraphic record indicates. At the end of the Acadian Orogeny, much of the craton was an underfilled black-shale basin (Fig. 6A), but apparently in response to bulge uplift and migration, first deep-water (Ft. Payne) and then shallow-water carbonate deposition (Greenbriar, Newman, Monteagle, Bangor, and Slade) ensued and migrated eastward (Fig. 6B). In the east, however, continued relaxation from earlier emplaced loads apparently produced a persistently subsiding basin (Fig. 6B), which filled with Mauch Chunk clastic sediments[34,37] derived from the eroding orogen. Sediment influx apparently was rapid

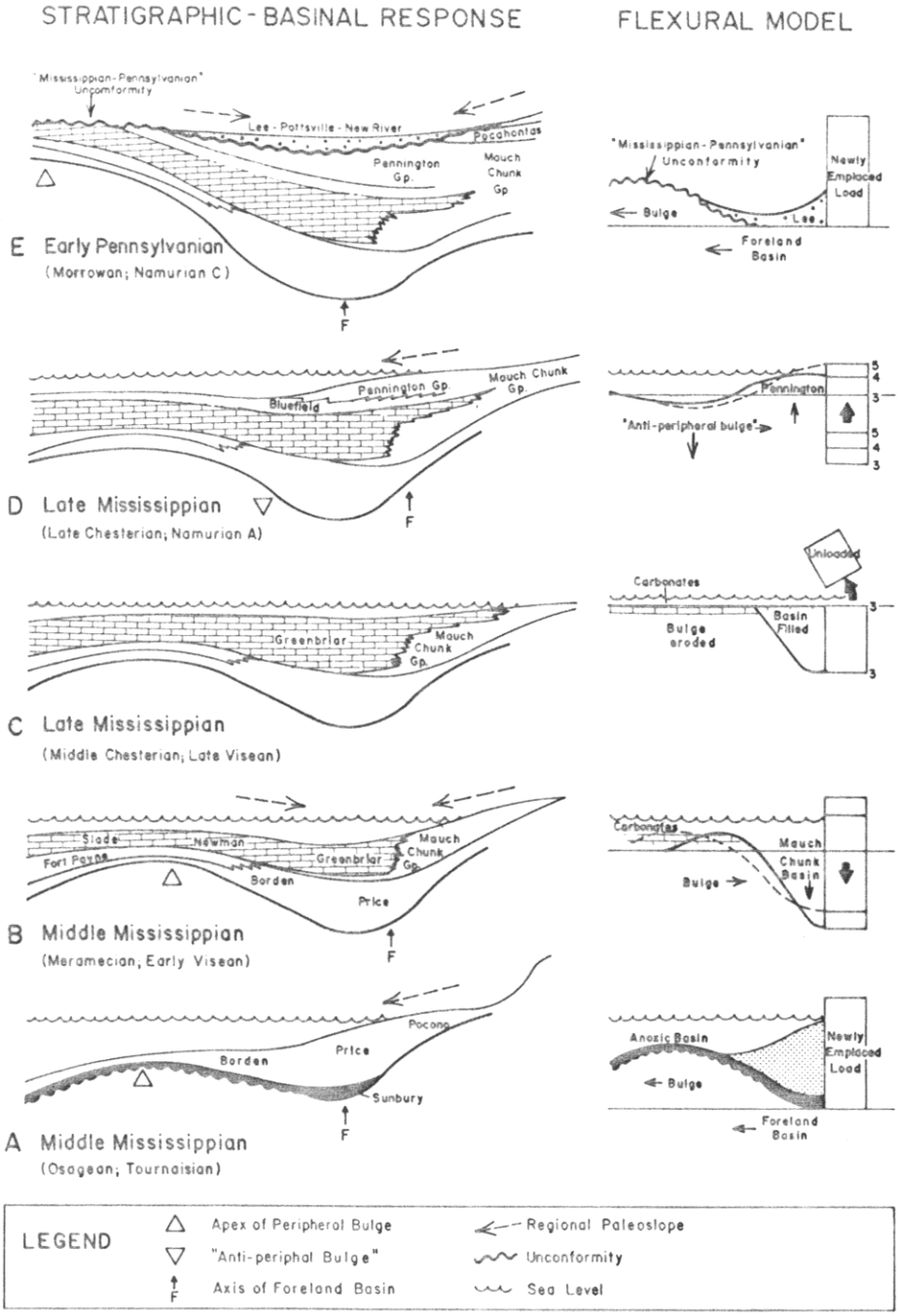

Fig. 6 Schematic sequence of depositional events from the Middle Mississippian to the Early Pennsylvanian showing probable stratigraphic-basinal responses to flexural situations inferred in diagrams on the right

enough to keep pace with or exceed subsidence, for most of the Mauch Chunk was deposited at or slightly above sea level.[38] Even though the erosional unloading that resulted in the basin filling was obviously very effective, the continuation of basin subsidence indicated by the nature and thickness of the Mauch Chunk suggests that loading-type lithospheric relaxation (Figs. 5A, 6B) still predominated. This type of relaxation apparently reached its peak in the late middle Chesterian (Hombergian; late Visean) when a sheet of very shallow-water oolitic sand (part of the lower Newman Limestone, Tygarts Creek and Ramey Creek Members of the Slade Formation;[38] the "Gasper" Limestone or Union Formation; upper Monteagle Limestone) spread across much of the basin and adjacent craton.

Although no regional unconformity developed at this stage, local unconformities did, however, develop in eastern Kentucky,[9,11,14] in eastern Ohio,[41,42] and in east-central West Virginia[43] as the migrating peripheral bulge reactivated old basement structures.

We suggest that loading-type lithospheric relaxation (Fig. 5A) ended following deposition of the ooid sand sheet, for at about this time Mississippian carbonate deposition attained its greatest extent (Fig. 6C) extending nearly across the foreland basin into western Maryland and south-central Pennsylvania.[44] These widespread carbonates imply infilling of the foreland basin and the nearly complete erosion of the formerly loaded orogenic source area (Fig. 6C). Once this situation was attained, the stage was set for an unloading type of lithospheric relaxation (Fig. 5B).

Three lines of evidence support the inception of an unloading type of lithospheric relaxation at this point in the late middle Chesterian (Hombergian; late Visean). First, analyses of depositional continua in the upper Mauch Chunk or Pennington suggest that the regional paleoslope after this point in time was dominantly cratonward or to the west. This single dominant paleoslope direction contrasts sharply with the two dominant directions verging toward the center of a basin characteristic of the other loading and relaxation models (Figs. 4, 5A). Secondly, on the craton and in adjacent parts of the Appalachian Basin, an abrupt deepening of the shallow Mississippian ooid-forming seas is indicated as far east as central West Virginia by deeper water shaley units like the Maddox Branch Member of the Slade Formation in eastern Kentucky, the Hartselle Shale of south-central Kentucky and adjacent Tennessee, the upper Newman Limestone or Bluefield Formation of Pine Mountain and southwestern West Virginia, and the Greenville Shale of central West Virginia (Fig. 6D). This abrupt, but slight deepening was apparently related to the development of an "anti-peripheral bulge"[34](Fig. 5A) in response to unloading. Finally, because the newly uplifted area would have already been beveled nearly flat (Fig. 5B, no. 3), most of the resulting sediment would have been very fine grained. Indeed, all of the abovementioned units, as well as most overlying parts of the Mauch Chunk and Pennington Groups, consist dominantly of mudstone, shale, silty shale, or shaly carbonates, and this kind of deposition apparently continued on largely uninterrupted through the Early Pennsylvanian Pocahontas Formation and its equivalents.

The unloading in this model, however, should have resulted in an unconformity across previously deposited sediments (Fig. 5B), yet none is present. We submit that this is probably because of rising sea level in the Late Mississippian (late Visean-NamurianA).[36] The

presence of an unconformity at the base of the Princeton Sandstone or Pride Shale[31] in the Pennington Group is probably related to the brief Late Mississippian (Chesterian; Namurian A) sea-level fall noted by Vail et al.[36] and Saunders and Ramsbottom.[30]

The unloading phase of lithospheric relaxation apparently continued through the earliest Pennsylvanian, because at least Upper Mississippian (Namurian A) and lowermost Pennsylvanian (Namurian B) rocks are gradational and were parts of westwardly or southwestwardly migrating depositional continua. However, a little later in the Early Pennsylvanian (Namurian C), the lowermost Pennsylvanian and uppermost Mississippian units representing these continua were progressively truncated to the west and northwest along a major unconformity. In the central Appalachian region of western Virginia and southern West Virginia, the unconformity begins in the New River Formation (Namurian C)[46] and progressively truncates the lowermost Pennsylvanian Pocahontas Formation (Namurian B)[46] and underlying Mississippian (Namurian A) units (Fig. 1).[46] In fact, the amount of erosional truncation increases progressively to the northwest (Fig. 1) where in northeastern Kentucky, Lower Pennsylvanian rocks unconformably overlie rocks as old as Middle Mississippian (Osagian; Tournaisian) in parts of the Borden Formation.[3,8-11,32] Even though the unconformity was apparently related to widespread episode of Early Pennsylvanian (Namurian C) erosion, it has been called the Mississippian-Pennsylvanian unconformity because it largely separates Mississippian and Pennsylvanian rocks. Unfortunately, this terminology has led many to assume that the unconformity was a product of erosion at the Mississippian-Pennsylvanian transition. Although erosion may have accompanied an eustatic drop in sea level at this point in time,[30] any evidence of it in the Appalachian Basin would have been destroyed or subsumed by the apparently more intense period of erosion that formed the Mississippian-Pennsylvanian unconformity later in the Early Pennsylvanian.

We suggest that this Early Pennsylvanian period of erosion in the Appalachian Basin was produced largely by northwestward peripheral-bulge migration accompanying a major phase of the Alleghanian Orogeny (Fig. 6E). This phase of the orogeny probably reflects initiation of convergence between Gondwanaland and recently accreted terranes on the southeast margin of Laurentia (Fig. 7) and may represent the Lackawana phase of the Alleghanian Orogeny.[47] The result was the development of a west-directed subduction zone below the newly accreted southeast margin of Laurentia and generation of a magmatic arc (Fig. 7).[48] Dating of granitic plutons from this arc indicates emplacement between approximately 320 and 300 Ma,[49] a time frame that overlaps Early Pennsylvanian unconformity development.

The distribution and age of Late Mississippian and Early Pennsylvanian clastic wedges,[13,32] as well as modelling by Beaumont et al.[34,37] indicate that this orogeny began in the southern Appalachians, accompanied by further development of the Ouachita Orogeny, and migrated northward with time. If indeed the termination of unconformity development by initiation of sedimentation can be assumed to reflect the beginning of overthrusting and orogeny in the orogen,[33] then the migrating nature of the early Alleghanian Orogeny is borne out by the sedimentary record. In northeastern Alabama and adjacent parts of Georgia and Tennessee, no unconformity is present because Missis-

sippian and Pennsylvanian rocks were deposited as part of a single depositional continuum in a rapidly subsiding foreland basin cratonward of the area in which the orogeny began. In the central Appalachian Basin, Pennsylvanian rocks atop the unconformity are Morrowan (Namurian C-Westphalian A), whereas in the northern Appalachian Basin rocks overlying the unconformity may be as young as Atokan (Westphalian B).[44,50]

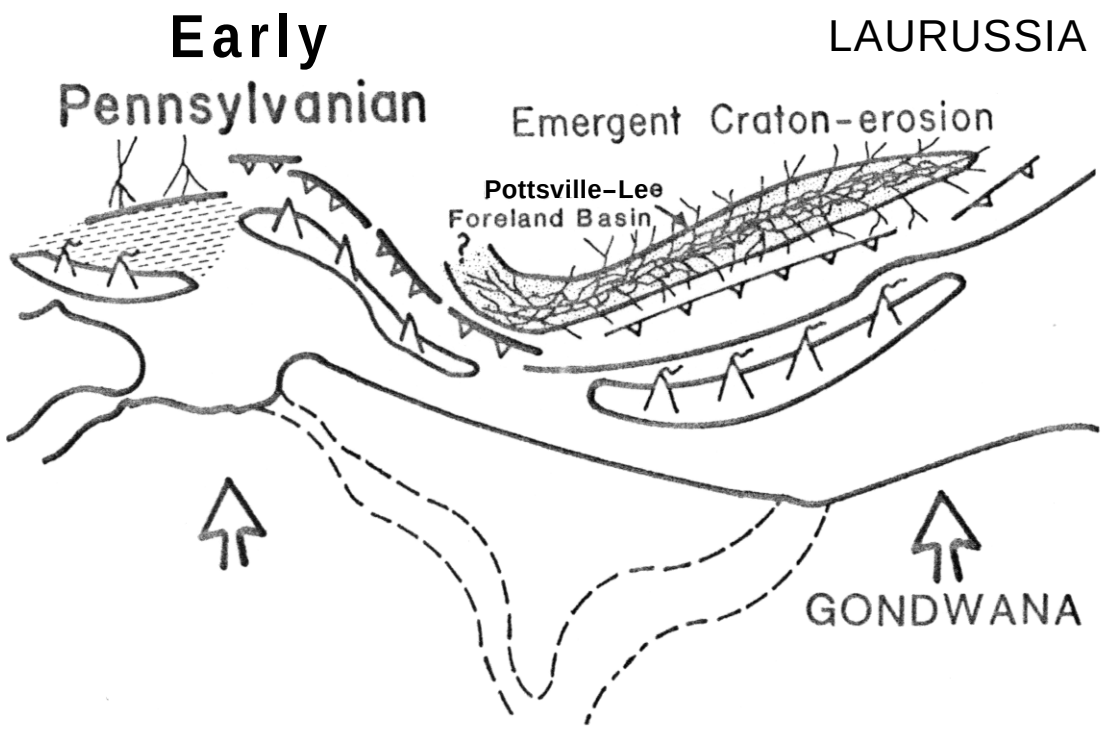

Fig. 7 Reconstruction of the probable plate interactions during the Early Pennsylvanian (Namurian C) which gave rise to erosion forming the Mississippian-Pennsylvanian unconformity and to the Pottsville-Lee Foreland Basin

The peripheral bulge causing the erosion apparently was present northwest of the foreland basin with a northeast-southwest orientation

The unconformity itself can be attributed to progressive emergence accompanying uplift and northwestward migration of a peripheral bulge out of the Appalachian Basin accompanying orogeny (Figs. 4, 6) and a low sea level stand.[36] As the bulge migrated and uplift increased, progressively older Mississippian rocks were truncated (Fig. 1). Moreover, bulge migration also apparently reactivated old basement structures, because Mississippian rocks near these structures in eastern Kentucky show comparatively greater truncation than similar rocks elsewhere along strike.[9-11]

In contrast, the uplift and erosion that generated the unconformity in Ohio, Pennsylvania, and New York must have been caused by lithospheric relaxation due to a lack of thrusting, because orogeny had not yet reached areas so far north this early in the

Pennsylvanian.[37] Nonetheless, coarse clastic sediments derived from the uplifted area to the north, the peripheral bulge to the northwest, and the orogen to the southeast (Pottsville, Lee, New River) subsequently began infilling the newly created foreland basin (Fig. 7)[19,38] and progressively overlapped the unconformity (Figs. 1, 2).

In east-central Pennsylvania, in western Virginia and southern West Virginia, and in northern Alabama and adjacent parts of Georgia and Tennessee (Fig. 3), the wholly gradational Mississippian-Pennsylvanian sequence[51,52] indicates that uplift and truncation by the northwestwardly moving peripheral bulge (Figs. 4, 6) or by subsequent relaxation bulges were ineffective. This was because residual deformational loading in the orogen just outboard of these areas was apparently always sufficient to generate more than enough viscoelastic subsidence to offset the effects of bulge uplift.[33] The location of these areas of residual deformational loading, however, was not merely happenstance. Each of these areas was located cratonward of a continental promontory. Because of the protuberant nature of the promontories, during any convergence event they would have experienced greater compression, the intensity of which would have generated greater deformation and relief.[55,56] The greater amount of deformational loading in these areas, as well as the increased time necessary for inception of any type of lithospheric relaxation within them, would seem to have necessitated the nearly continual loading and resultant foreland-basin suhsidence just cratonward of them. This is borne out by the fact that during the development of major North American cratonic unconformities (Early-Middle Ordovician, Early Devonian, Early Pennsylvanian),[1] parts of the Appalachian Basin just cratonward of the promontories almost always exhibit gradational sequence across the unconformity intervals.[44,50]

CONCLUSIONS

Based on recent stratigraphic analyses of the Carboniferous sequence in the central Appalachian Basin, the so-called Mississippian-PennsyIvanian unconformity is largely an Early Pennsylvanian (Morrowan; Namurian C) erosion surface. The widespread nature of erosion at this time in the Appalachian Basin seems best explained by lithospheric flexure. In the southern two-thirds of the basin, the unconformity apparently developed due to uplift and truncation on a northwestwardly migrating peripheral bulge accompanying a major phase of the Alleghanian Orogeny and deformational loading in the orogen. This phase of orogeny and the unconformity development correlate well with inception of subduction and formation of magmatic arc on the southeast margin of Laurussia, which are dated at approximately 320 to 300 Ma. Because the orogeny began later in the northern Appalachian Basin, Early Pennsylvanian unconformity development here was probably caused by lithospheric relaxation attributable to a lack of deformational loading and thrusting.

The three areas in the Appalachian Basin where the Mississippian-Pennsylvanian sequence is completely gradational occur just cratonward of continental promontories. Because of the greater intensity of orogeny at the promontories, enough residual loading was always present so that resultant foreland-basin suhsidence was more than sufficient to offset

peripheral-bulge uplift. Hence, the location of continental promontories is critical in understanding arid predicting the position of conformable Carboniferous sequence.

Although evidence for an eustatic sea-level drop is present locally at the Mississippian-Pennsylvanian transition in the Appalachian Basin, any resulting unconformity would have been destroyed or subsumed by the later period of tectonically related erosion. Hence, a major eustatic component probably was not necessary for development of the Mississippian-Pennsylvanian unconformity in the Appalachian Basin. In view of the tectonically active margins of Laurussian and Gondwanan continents and microcontinents during the latest Mississippian and Early Pennsylvanian and the probable widespread effects of resulting lithospheric flexure, we believe that it is probably unsound to attribute mid-Carboniferous unconformities on these continents to wholly eustatic causes.

REFERENCES

1. Sloss LL, Bull Geol Soc Amer, 74 (1963), 93.
2. Ferm JC, Geol Soc Amer Abstr with Prog, 13 (1981), 450.
3. Ettensohn FR, In: Centennial Field Guide Southeastern Sec, Geol Soc Amer, 6 (1986), 37.
4. Ferm JC, Horne JC, Swinchatt JP et al, In: Guidebook, Geol Soc Kentucky Ann Spring Field Conf, Kentucky Geol Surv, (1971).
5. Horne JC, Ferm JC and Swinchatt JP, Geol Soc Amer Spec Pap, 148 (1974), 97.
6. Edmunds WE, Berg TM, Sevon WD et al, US Geol Surv Prof Pap 1110-B (1979), B1.
7. Arkle T, Beissel DR, Larese RE et al, Ibid, 1110-D (1979), D1.
8. Rice CL, Sable EG, Dever GR, Jr and Kenhn TM, Ibid, 1110-F (1979), F1.
9. Ettensohn FR, In: IX ICC Field Trip No 4, Univ Kentucky (1979), 64.
10. ——, Geol Soc Amer Bull, 91 (1980), pt 1, 130; pt 2, 934.
11. ——, In: GSA Cincinnati '81 Field Trip Guidebooks, Amer Geol Instit, 1 (1980), 195.
12. Ferm JC, Geol Soc Amer Spec Pap, 148 (1974), 79.
13. Chesnut DR, Ph D dissertation, Univ Kentucky (in prep).
14. *Dever GR, Jr, Hoge HP, Hester NC and Ettensohn FR, In: Field Trip Guidebook*, AAPG Eastern Sec Ann Mtg, Kentucky Geol Surv (1977).
15. Englund KJ and Thomas RE, In: Guidebook, Geol Soc Amer 1985 Ann Mtg, US Geol Surv Open-File Rept, 85-577 (1985), 1.
16. Patterson SH and Hosterman JW, US Geol Surv Bull, 1122-F (1961), F1.
17. Ettensohn FR and Dever GR, Jr, In: IX ICC Field Trip No 4, Univ Kentucky (1979), 108.
18. Coskren TD and Rice CL, US Geol Surv Miscel Field Studies Map MF-1100 (1979).
19. Rice CL, US Geol Surv Prof Pap 1151-G (1984), G1.
20. Kosanke RM, In: Biostratigraphic Data for A Mid-Carboniferous Boundary (1982), 27.
21. Ettensohn FR and Peppers RA, J Palaeont, 53 (1979), 453.
22. Colton GW, In: Studies of Appalachian Geology: Central and Southern, Interscience Publishers (1970), 5.
23. Englund KJ, In: IX ICC Field Trip no 1, AGI Selected Guidebook Ser No 1, Amer Geol Instit (1979), 69.
24. —— and Henry TW, In: GSA Cincinnati '81 Field Trip Guidebooks, Amer Geol Instit, (1981), 153.

25. Thomas WA, US Geol Surv Prof Pap 1110-I (1979), I1.
26. Henry TW, Gillespie WH, Gordon M, Jr and Schweinfurth SP, Geol Soc Amer Abstr with Prog, 13 (1981), 471.
27. Thomas WA and Cramer HR, US Geol Surv Prof Pap 1110-H (1979), H1.
28. Milici RC et al, US Geol Surv Prof Pap 1110-G (1979), G1.
29. Englund KJ, Arndt HH and Henry TW, IX ICC Field Trip no 1, AGI Selected Guidebook Ser No 1, Amer Geol Instit (1979).
30. Saunders WG and Ramsbottom WHC, Geology, 14 (1986), 208.
31. Englund KJ, Dillespie WH, Cecil CB et al, In: Guidebook, Geol Soc Amer 1985 Ann Mtg, US Geol Surv Open-File Rept, 85-577 (1985), 35.
32. Ettensohn FR and Chesnut DR, 9th Congr Int Strat Geol Carb Washington and Champaign-Urbana, 1979, C R 3 (1985), 269.
33. Quinlan GM and Beaumont C, Can J Earth Sci, 21 (1984), 973.
34. Beaumont C, Quinlan G and Hamilton J, Tectonics (in press).
35. Ettensohn FR, Geol Soc Amer Spec Pap, 201 (1985), 39.
36. Vail PR, Mitchum RM, Jr and Thompson S, III, Mem Amer Assoc Petrol Geol, 26 (1977), 83.
37. Beaumont C, Quinlan GM and Hamilton J, Mem Can Soc Petrol Geol, 12 (in press).
38. Donaldson AC and Shumaker RC, Geol Assoc Can Spec Pap, 23 (1981), 99.
39. Ettensohn FR, Rice CL, Dever GR, Jr and Chesnut DR, US Geol Surv Bull 1605 (1984).
40. Tankard AJ, Bull Amer Assoc Petrol Geol, 70 (1986), 853.
41. Scatterday JW, Ph D Dissertation, Ohio State Univ (1966).
42. Anderson RJ, In: Northern Appalachian Region, COSUNA Project, AAPG (1985).
43. Yielding CA, Sullivan EM, Dennison JM and Textoris DA, Program-Fall Mtg, 1984, Appalachian Basin Industrial Assoc, 7 (1984), 92.
44. Patchen DG, Avary KL and Erwin RB, Northern Appalachian Region, COSUNA Project, AAPG (1985).
45. Miller MS, Va Div Min Resour Bull, 84 (1974).
46. Gillespie WH, Crawford TJ and Rheams LJ, In: Guidebook, Geol Soc Amer: 1985 Ann Mtg, US Geol Surv Open-File Rept, 85-577 (1985).
47. Geiser P and Engelder T, Geol Soc Amer Mem, 158 (1983), 161.
48. Sinha AK and Zietz I, Geology, 10 (1982), 593.
49. Dallmeyer RD, Geol Soc Amer Abstr with Prog, 18 (1986), 579.
50. Patchen DG, Avary KL and Erwin RB, Southern Appalachian Region, COSUNA Project, AAPG (1985).
51. Ettensohn FR and Chesmut DR, Geol Soc Amer Abstr with Prog, 16 (1984), 137.
52. Sutherland PK and Manger WL, 9th Congr Int Strat Geol Carb Washington and Champaign-Urbana, 1979, C R 2 (1984), 319.
53. Thomas WA, Amer J Sci, 277 (1977), 1233.
54. ——, Geology, 11 (1983), 270.
55. Dewey JF and Burke KCA, Ibid, 2 (1974), 57.
56. —— JF and Kidd WSF, Ibid, 2 (1974), 543.