# TIMING OF ALLEGHANIAN TECTONICS DETERMINED BY CENTRAL APPALACHIAN FORELAND BASIN ANALYSIS

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## ABSTRACT

A revised stratigraphic and structural framework of the Central Appalachian Basin is used to interpret the timing of tectonic activity during the Alleghanian orogeny. The stratigraphic framework indicates that clastics with an eastern source were deposited in a basin subsiding to the east in the Late Devonian and in a very slightly subsiding basin in the Early Mississippian. During mid-Mississippian time, clastic sedimentation and basin subsidence were minimal, and a broad carbonate platform was developed. During the latter part of the Late Mississippian, clastic deposition and basin subsidence were renewed and persisted into the Permian. Subsidence was greatest to the southeast.

The occurrence of the clastic wedges and timing of basin subsidence, as well as the occurrence of a regional unconformity, structural features, and tonsteins, are. related to events occumng in the Alleghany orogen. The timing of these basinal features is compared with tectonic events reported in the literature. Subduction along the eastern margin of North America during the latest Mississippian through Middle Pennsylvanian time is suggested. Subduction was followed by continent-continent collision during the Early Permian.

## INTRODUCTION

The Alleghanian orogeny was the last great orogeny to affect eastern North America. The timing of the events that occurred in this orogeny is controversial. However, the response to Alleghanian tectonism in the craton and foreland basin can be used to infer the timing of events within the orogen itself.

Large-scale tectonic events must affect crustal rocks in the vicinity of the orogen. Clastic wedges and basin subsidence among other responses are assumed to occur at about the same time as tectonism. In this paper evidence from a new stratigraphic and structural framework of the Carboniferous rocks of the Central Appalachian Basin (Figure 1) is examined to infer the timing of Alleghanian orogenic events.

### Stratigraphic and Structural Frameworks

A new lithostratigraphic and structural framework of the Central Appalachian Basin, based on detailed cross sections constructed through the Carboniferous rocks, was developed by Chesnut (1988, in press A). The cross sections were constructed from descriptions of approximately 2,000 boreholes and oil and gas wells collected from coal companies, land companies. state geological surveys, published literature, and engineering reports. Thickness trends, regional unconformities, and onlap/offlap relationships of units in these sections (Chesnut, 1988, in press A) have been used to infer stratigraphic relationships that aid in determining the timing of Alleghanian orogenic events.

Results from this study and from the published literature are summarized in the following section.

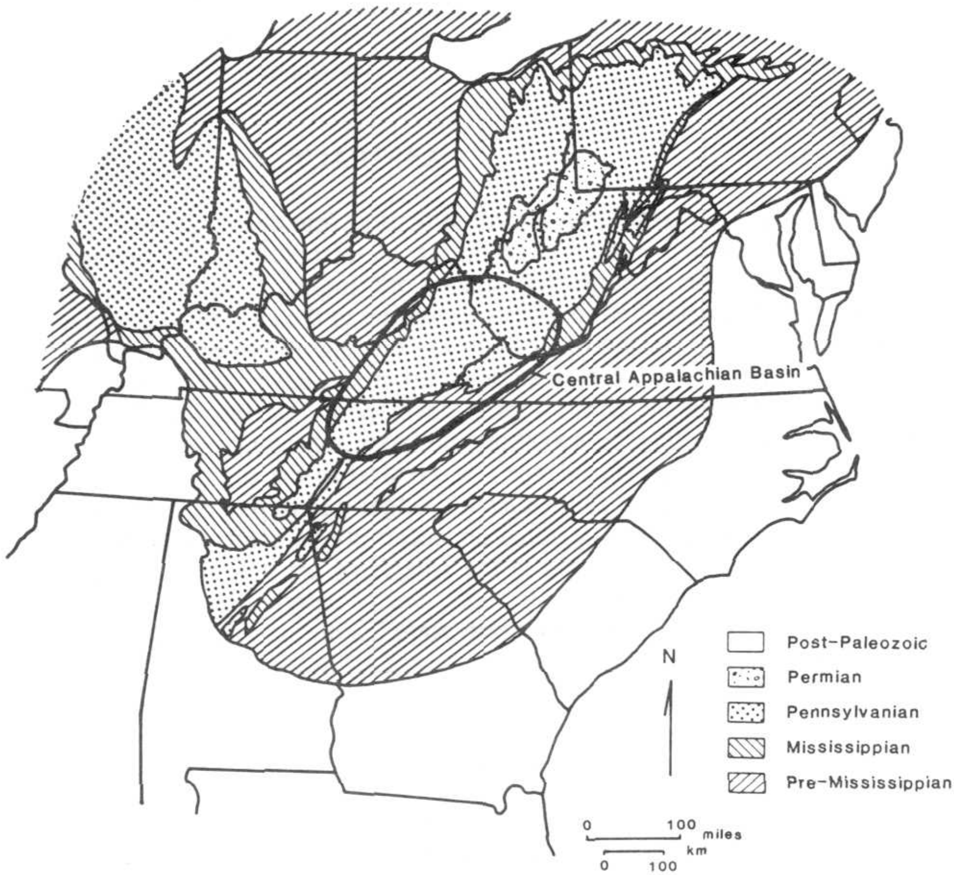



Figure1. Location of the Central Appalachian Basin in the eastern United States.

## REGIONAL FEATURES OF THE CENTRAL APPALACHIAN BASIN

Some features in the Appalachian foreland basin that record Alleghanian stresses or other Alleghanian events occurring in the orogen are difficult to date. These include (a) development of jointing, (b) remagnetization of red beds by movement of orogenic fluids (Miller and Kent, 1988), (c) twinning of calcite crystals in carbonate rocks (Craddock and van der Pluijm, 1989), (d) cementation patterns in carbonate sequences (Nelson and Read, 1990, fig. 4), and (e) development of pedogenic slickensides (Gray and Nickelsen, 1989). However, other basinal features such as clastic wedges, basin subsidence, the presence of regional unconformities, fault and arch movements, tonsteins and bentonites, and the dating of fluid migration can used to infer the timing of events within the orogen.

## Clastic Wedges and Basin Subsidence

Clastic wedges in sedimentary basins record the influx of sediment from uplifted source areas. The variation in thickness of the wedges can be used to infer the accommodation space of sediment deposited, and from this the degree of differential basin subsidence can be inferred. The first clastic wedge occurring in the Carboniferous was deposited from the Late Devonian through Early Mississippian (Figure 2). The Chattanooga Shale (Late Devonian and Early Mississippian) and the Borden (Grainger and Maccrady Formations) and Fort Payne Formations (both Early Mississippian) represent a largely siliciclastic sequence in the Central Appalachian Basin (Figure 3a). Based on grain size and paleocurrent indicators, the dominant clastic source for the Chattanooga and Borden was from the east (Kepferle, 1977; Ettensohn, 1985). Thickness trends of the clastic wedge indicate that basin subsidence was greater to the east and had a strike oriented roughly north to south (Dillman, 1980; Chesnut, 1988; in press A). Basin subsidence was greater during the Late Devonian and much reduced during the Early Mississippian (Figure 3c), as indicated by the greater thickness variations from basin margin to axis of the Late Devonian sediment package compared to the Early Mississippian package.

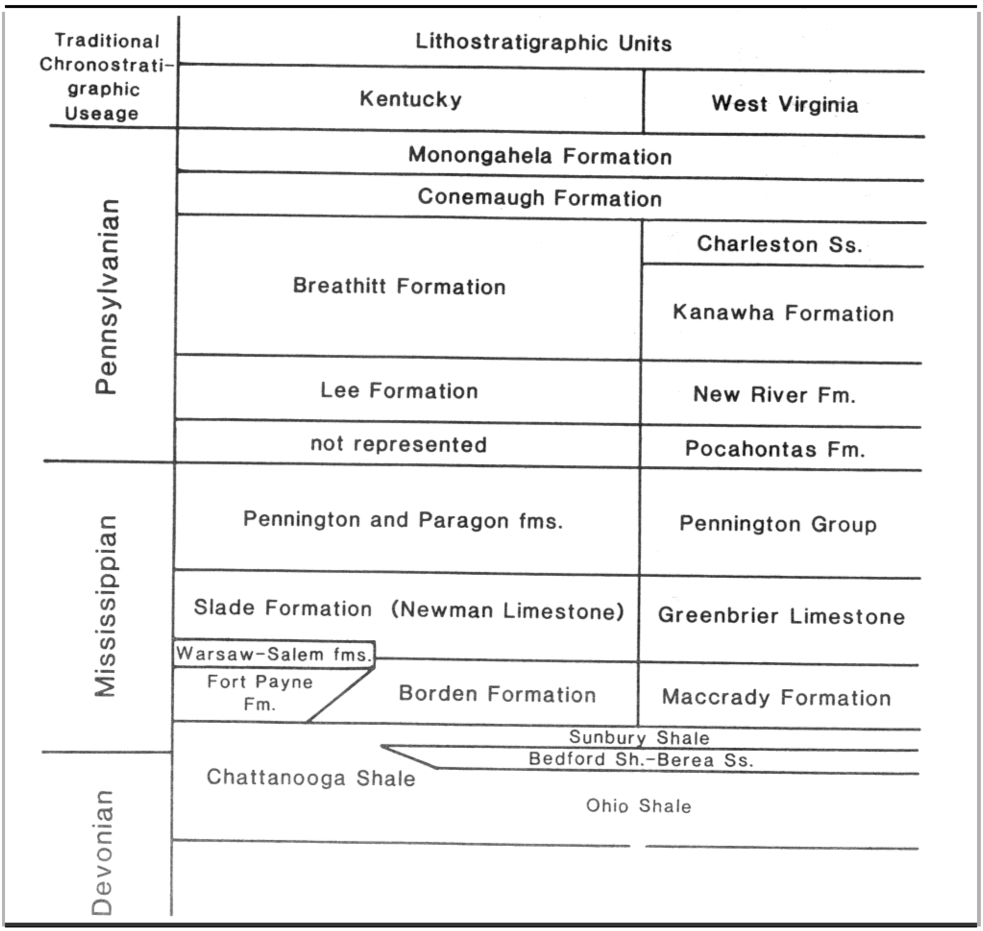
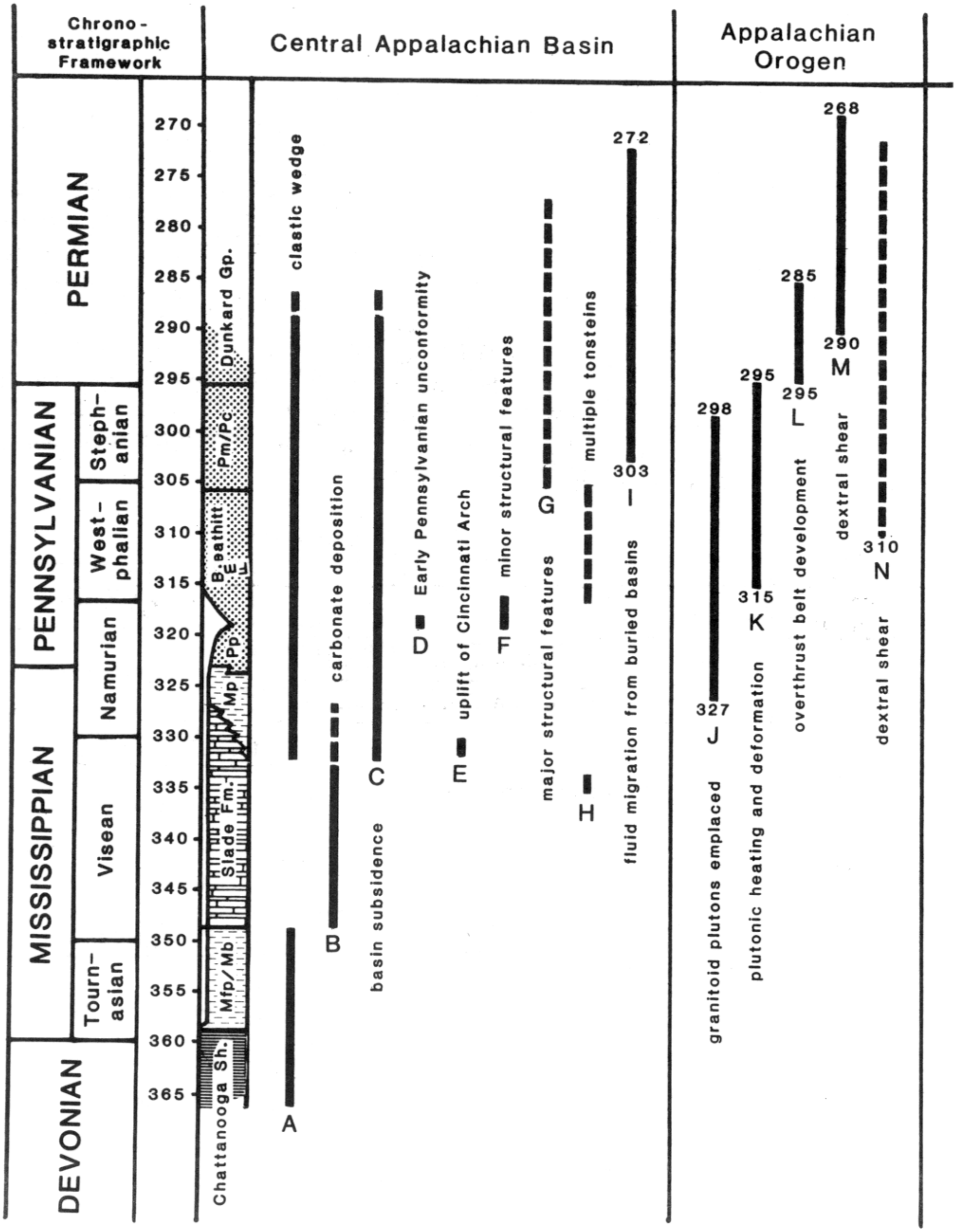



Figure 2. Carboniferous lithostratigraphic units of the Central Appalachian Basin.



Chrono-stratigraphic Framework
Central Appalachian Basin
Appalachian Orogen
PERMIAN
PENNSYLVANIAN
MISSISSIPPIAN
DEVONIAN
Steph-anian
West-phalian
Namurian
Visean
Tourn-asian
270
275
280
285
290
295
300
305
310
315
320
325
330
335
340
345
350
355
360
365
Dunkard Gp.
Pm/Pc
B.eathitt
E
L
Pp
Mp
Slade Fm.
Mfp/Mb
Chattanooga Sh.
A
clastic wedge
B
carbonate deposition
C
basin subsidence
D
Early Pennsylvanian unconformity
E
uplift of Cincinnati Arch
F
minor structural features
G
major structural features
H
multiple tonsteins
I
fluid migration from buried basins
272
303
J
granitoid plutons emplaced
298
327
K
plutonic heating and deformation
295
315
L
overthrust belt development
285
295
M
dextral shear
268
290
N
dextral shear
310

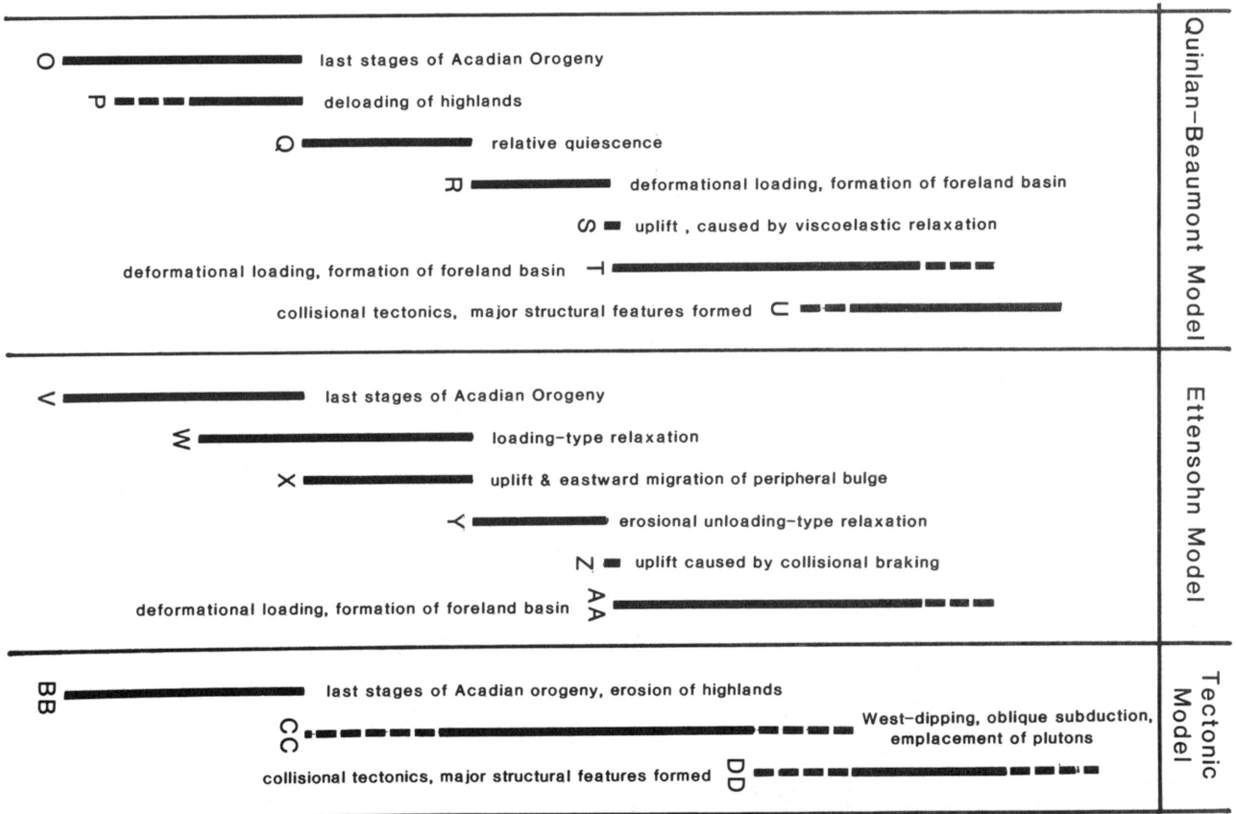



**Figure 3. Comparison of features in the Central Appalachian Basin with coeval events in the Appalachian orogen. Basin development and tectonic models based upon these features are also shown. Chronostratigraphic framework from Menning (1989). Mb, Borden Formation; Mfp, Fort Payne Formation; Mp, Pennington Group; Pc, Conemaugh Formation; Pm, Monongahela Formation; Pp, Pocahontas Formation.**

The Late Devonian and Early Mississippian clastic wedges are overlain by the middle and Late Mississippian Slade Fonnation and equivalent units (Figure 2). This thick, widespread carbonate unit marks a time of very reduced clastic input (Figure 3b) and subsidence in the Central Appalachian Basin (Figure 3c).

A return to siliciclastic deposition is represented by the Pennington Group (Late Mississippian) and overlying Pocahontas (Early Pennsylvanian), Breathitt (Early and Middle Pennsylvanian), Conemaugh (Late Pennsylvanian), Monongahela (Late Pennsylvanian) Formations, and the Dunkard Group (Early Permian in part)(Figures 2-3a). Grain-size trends indicate a source to the east and southeast for most of the units and a source to the northeast for the Lee Formation (Figure 2)(Bement, 1976), which occurs within the lower part of the Breathitt Formation. Thickness trends of subunits within the Pennington Group and Breathitt Formation indicate greater basin subsidence (Figure 3c) to the southeast, with a strike oriented northeast-southwest (Chesnut. 1988, in press A). Post-Paleozoic erosion has reduced the occurrence of the Conemaugh, Monongahela, and Dunkard in the study area to the Allegheny Synclinorum (Parkersburg Syncline) in northeastern Kentucky, northwestem West Virginia, and southeastern Ohio. Thickness trends of these Late Pennsylvanian and younger units suggest that the Allegheny Synclinorum in and near Kentucky may have been an actively subsiding feature during the Late Pennsylvanian and Permian (Figure 3c)(Sergeant, 1979; Chesnut, 1988, in press A).

## Early Pennsylvanian Unconformity

Regional unconformities indicate periods of relative basin uplift or eustatic regression, when basins are exposed and streams erode to a lower base level. Two thick conformable stratigraphic sequences, separated by a discontinuity, are recognized in the Carboniferous rocks of the Central Appalachian Basin. The lower sequence includes the Pocahontas Formation (Early Pennsylvanian) and underlying Mississippian strata (Pennington Gmup), whereas the upper sequence consists of all Pennsylvanian strata above the Pocahontas Formation. The discontinuity between these sequences is the. Early Pennsylvanian unconformity (Figure 3d), previously called the “Mississippian-Pennsylvanian unconformity” in much of the literature (e.g., Rice and others, 1979). Rocks of the lower sequence are sequentially truncated to the northwest as low as the Borden Formation (Early Mississippian). The overlying Pennsylvanian sequence onlaps the unconformity to the northwest up to the top member of the Lee Formation (Early to lower Middle Pennsylvanian)(Chesnut, 1988, in press A). The contact of the lower and upper sequence is apparently conformable in the southeastem part of the basin in western Virginia and southern West Virginia (Englund and others, 1979). The increase in trucation below the unconfonnity and onlapping above the unconformity toward the northwest, coupled with the probable occurrence of a conformable relationship between the sequences near the axis of the basin, indicates relative uplift (or failure to subside) of the northwestern margin of the Central Appalachian Basin during the Early Pennsylvanian. This unconformity is described in more detail in Chesnut (1988, in preparation).

## Uplift of Cincinnati Arch

Laskowski and others (1980) provided a 337±7 Ma Rb-Sr age

Mississippian) for authigenic glauconite in the Brassfield Formation (Early Silurian) of Ohio (Figure 3e). This age is considerably younger than the 410 Ma Early Silurian Brassfield Formation. Laskowski and others (1980) attributed the younger age to closing of fluid exchange caused by "...changes in fluid-pressure gradients and transport pathways produced by an uplift of the Cincinnati Arch." Although Early Mississippian strata do not appreciably thin toward the Cincinnati Arch, Late Mississippian and Pennsylvanian strata on both sides of the Arch do thin (Chesnut, 1988, in press A; Furer, 1989). Several episodes of uplift focused along the arch probably occurred.

## Movement Along Other Structural Features

Sediment thickness changes and offset of Carboniferous units can be used to infer movement along structural features in the Central Appalachian Basin. Movement along these structures might be related to cratonic stresses caused by events in the Alleghanian orogeny. Stratigraphic analysis indicates that subtle structural activity began as early as mid- Mississippian time in northeastern and south-central Kentucky (Dever and others, 1977, 1990). Larger scale structural features were formed in Early Pennsylvanian times.

Several structural features were produced at the same time the Early Pennsylvanian unconformity was being formed (Figure 3f). The Dorton- Hellier Fault, a subsurface fault in Pike County, Kentucky, described by Chesnut (1988, in press A), was formed in the Early Pennsylvanian after the unconformity; the unconformity surface is offset by the fault.

The Mount Vernon Monocline and the associated Mount Vernon Fault are recognized in roadcuts near Mount Vernon, Rockcastle County, south-central Kentucky (Figure 4)(Chesnut, in press B). Folded rocks of the Paragon Formation (Pennington Group) are progressively truncated northward where deformed rocks of the Breathitt Formation (with a small sliver of Paragon) overlie the Slade Formation. These rocks, in turn, are truncated and overlain by rocks of the Breathitt Formation. In this case, progressive truncation of the Pennington toward the uplifted part of the monocline indicates that initial movement on the monocline occurred after deposition of the Pennington Group. Later movement occurred sometime after deposition of the Corbin Sandstone Member of the Lee Formation (Figure 4), because the Corbin and underlying Breathitt sequences are also inclined. The deformed rocks overlying the Slade are interpreted to represent a paleoslump caused by channeling or seismicity (Dever and others, 1979. p. 179-181), perhaps related to the monocline and fault.

Early Middle Pennsylvanian debris-flow deposits (Poison Honey beds) and contorted sediments in Laurel County, south-central Kentucky, have been reported by Greb and Chesnut (1989a, 1989b) and Greb and others (in press). The beds are situated on the downthrown side of a normal fault, suggesting that they are Middle Pennsylvanian seismites and that the fault was active during the Middle Pennsylvanian.

Major structural features such as the Allegheny Synclinorum (Parkersburg Syncline), Eastern Kentucky Syncline (Coalburg Syncline), Irvine-Paint Creek Fault, Jacksboro Fault, Middlesboro Syncline, Pine Mountain Thrust Fault, Russell Fork Fault, and other features shown by Chesnut (1988, in press A) were active largely after the Pennsylvanian (Figure 3g). Although the Allegheny Synclinorum and the Irvine-Paint Creek Fault show some changes in thickness of Pennsylvanian strata across the structure, most of the major structural features apparently did not affect Pennsylvanian sedimentation.

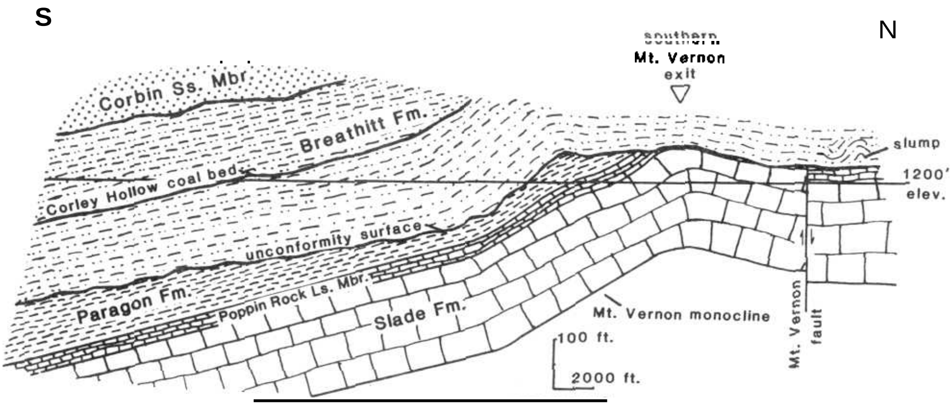



Figure 4. Generalized geology exposed along Interstate Highway 75 in south central Kentucky near the southern Mt. Vernon exit, Rockcastle County. Adapted from Chesnut (in press B).

## Tonsteins and Bentonites

Tonsteins are a type of altered volcanic-ash deposit which, when found in basinal sediments, can be used to infer proximity to rhyolitic vulcanism, probably in the orogen. Tonsteins have been recognized in the Lower Banner, Amburgy, Upper Whitesburg, Fire Clay, Hazard No. 5, Hazard No. 7, Skyline, and Princess No. 6 coals of the Central Appalachian Basin (Slucher, 1982; Chesnut, 1985; Burger and Damberger, 1986, p. 441-442; Outerbridge and others, 1989; Triplehorn and Finkleman, 1989: Triplehorn and others, 1989). These tonsteins (Figure 3h) occur in rocks of Middle Pennsylvanian age (Westphalian A-D). The tonstein in the Fire Clay coal of eastern Kentucky has been radiometrically dated at 311 ±Ma ($Ar^{40}/Ar^{39}$ dates of sanidine by Dr. J. C. Hess of the University of Heidelberg, Germany; personal communication, 1987). Also, glass shards and other features suggesting an altered volcanic ash (bentonite?) have been recognized in a thin shale bed in the Newman Limestone (Figure 2)(Late Mississippian, Visean) in Bell County, Kentucky (F. Ettensohn, 1990, personal communication).

## Fluid Migration

Fluid migration from foreland basin to craton indicates deep burial and perhaps loading of the foreland basin. The general model accepted by most workers, is that as the proximal (to orogen) part of a foreland basin is pushed deeper, lithostatic pressure due to increased depth, tectonic loading, and compression cause a "squee-gee" effect, forcing fluids through the strata toward areas of less pressure. Some of this fluid ends up at the craton. Several reports of basinal fluid migration have been made for the Carboniferous (Elliott and Aronson, 1987; Miller and Kent, 1988; Nelson and Read, 1990). Of these, only Elliott and Aronson's provided radiometric dates. Elliott and Aronson (1987) dated illitization (272-303 Ma) of Ordovician bentonites, and suggested that illitization was caused by migration of fluids from deeply buried foreland basins in the Late

Pennsylvanian and Permian (Figure 3i).

## EVENTS REPORTED IN THE SOUTHERN APPALACHIAN OROGEN

Although many radiometric dates exist for plutons in the Appalachian orogen, chronologic frameworks for development of the Alleghany orogeny are largely unavailable. One chronologic framework was synthesized by Secor and others (1986), involving (1) emplacement of granitoid plutons during the Late Mississippian and throughout the Pennsylvanian (Figure 3j), (2) plutonic heating and deformation during the Middle and Late Pennsylvanian (Figure 3k), (3) development of an overthrust belt (Figure 3l), and large- scale dextral shear during the Permian (Figure 3k). Vauchez (1987) reported that large-scale dextral shear of the Brevard zone occurred as early as the Middle Pennsylvanian (Figure 3n).

## DISCUSSION

### Analysis of Basin Models

The information obtained from the new stratigraphic and structural framework of the basin, clastic-wedge trends, inferred subsidence rates, presence of a regional unconformity, and other basinal features described above was compared to available foreland basin models to determine the relationship between the stratigraphic responses and Alleghanian tectonic events.

Foreland basin models based on deformational loading of an elastic crust (Flemings and Jordan, 1990) and a viscoelastic crust (Quinlan and Beaumont, 1984) have been developed. The Flemings and Jordan model has not been applied to the Central Appalachian Basin; however, the Quinlan and Beaumont model has been applied to this basin. Quinlan and Beaumont (1984) related Appalachian thrusting to development of foreland basins, and movement of a peripheral bulge during the Paleozoic.

The Quinlan-Beaumont Model: The Quinlan-Beaumont model of foreland basin development was adapted by Chesnut (1988) to fit the stratigraphic and structural sequences of the Central Appalachian Basin (Figure 30-u). The Borden and Ft. Payne Formations (Early Mississippian) in the Central Appalachian Basin comprise a clastic wedge derived from the erosion of highlands within the orogen. The basin apparently experienced minimal subsidence during deposition of this wedge (Figure 3c). Therefore, the highlands at the source were probably being constantly uplifted by isostatic rebound as they were eroded. Such uplift without concomitant basin subsidence on the craton probably marks the final stages of the Acadian Orogeny (Figure 30-p). The carbonates of the Slade Formation (Late Mississippian) represents a stable period of tectonic quiescence (Figure 3q).

Following the carbonate-platform deposition of the Slade Formation, a southeastern-thickening wedge of Pennington (Late Mississippian) and Pocahontas (Early Pennsylvanian) clastics was deposited. An eastern source for these clastics reflects new thrust faulting (Rast, 1984). The weight of the thrust block loaded the viscoelastic lithosphere, and downwarping of the crust resulted in a foreland basin on the craton adjacent to the thrust (Figure 3r). This basin received the sediments from the newly produced uplands on the thrust block. In addition, a peripheral bulge formed cratonward of the foreland basin because of the eastward downwarping of the stiff crust The foreland basin and peripheral bulge together migrated northwestward as the thrust block moved cratonward. The Pennington Group thins toward the Cincinnati Arch, possibly marking the position of the peripheral bulge.

At the end of Pennington and Pocahontas deposition, widespread uplift of the northwestern part of the Appalachian foreland basin occurred, and erosion created the Early Pennsylvanian unconformity. This uplift was caused by isostatic rebound of part of the lithosphere (Figure 3s), perhaps due to erosional unloading and time-dependent relaxation of stress in the viscoelastic lithosphere.

Emplacement of a new thrust fault cratonward of a previous fault is proposed for renewed depression of the lithosphere, which generated a Lee- Breathitt foreland basin northwest of the Pennington-Pocahontas foreland basin (Figure 3t). Most of the Breathitt and Lee (and equivalent units) were deposited in this basin. Because younger units overlap the unconformity northwestward (as previously described), some migration of the peripheral bulge may have occurred within the vicinity of the Cincinnati Arch.

The emplacement of yet another thrust fault may have led to the formation of another basin, the Allegheny Synclinorum in Kentucky. This structural basin was much smaller than the previous two, and formed just northwest of them, Sediments eroded from the upthrust highlands and deposited in this basin are represented by the uppermost Breathitt, Conemaugh, and Monongahela in Kentucky, and perhaps these strata and the Permian Dunkard in West Virginia.

Each of these basins is apparently smaller than the preceding basin. The position and size of the last basin may have been caused by the reactivation of basement structural features such as the Rome Trough and Irvine-Paint Creek Fault Zones in Kentucky, which restricted the basin to an area between these features.

During the very Late Pennsylvanian or Permian, collision between Gondwana and Laurasia produced a variety of deformational features in the Central Appalachian Basin, including the Alleghany Uplift and the Pine Mountain Fault (Figure 3u)(Rast, 1988). The Alleghany Uplift is seen as the progressive uplift of the proximal (to the orogen) foreland basinal rocks. The uplift brought an end to the Appalachian foreland basin.

The Ettensohn Model: Ettensohn and Chesnut (1987, in press) described a model, here called the Ettensohn Model. The model was further adapted by Ettensohn (1990).

In this model (Figure 3v-aa) the Borden (Early Mississippian) was deposited in a foreland basin as clastics derived from uplifted highlands to the east. Uplift of the highlands was caused by "loading" relaxation following cessation of the Acadian Orogeny (Figure 3v-w). During relaxation, uplift and eastward migration of the peripheral bulge provided ideal conditions for deposition of the Slade Formation carbonates (Late Mississippian)(Figure 3w-x).

Rebound of the former highlands caused by erosional deloading was termed "unloading" relaxation by Ettensohn (1990). This rebound created a low sediment source, which led to a westward-prograding marginal-marine clastic sequence represented by the Pennington Group (Late Mississippian) and Pocahontas Formation (Early Pennsylvanian)(Figure 3y).

The uplift creating the Early Pennsylvanian unconformity was caused by collisional braking between Gondwanaland and Laurasia, which marked the beginning of the Alleghany Orogeny (Figure 32). Intraplate stresses formed by continental collision may have uplifted pans of the peripheral bulge and foreland basin (Cloetingh, 1986).

Deformational loading during the Alleghanian Orogeny led to development of a new foreland basin and peripheral bulge (Figure 3aa). Clastics from the new highlands were deposited in the foreland basin and became the Breathitt Formation (Early and Middle Pennsylvanian), Conemaugh and Monongahela Formations (Late Pennsylvanian), and the Dunkard Group (Permian); this scenario is similar to the basin development suggested in Quinlan and Beaumont (1984).

## Appalachian Tectonic Events

Both basin models suggest tectonic events that explain the stratigraphic responses studied in the Central Appalachian Basin. It is possible to relate some of these basinal features to large-scale tectonic events within the orogen. Figure 3a-i shows basinal features of the Central Appalachian Basin included within the chronostratigraphic framework of Menning (1989). The timing of events in the Appalachian orogen is poorly known, although several plutons have been dated (e.g., Dallmeyer, 1988). The radiometrically dated tectonic events of the southern Appalachians described by Secor and others (1986) and Vauchez (1987) are illustrated in Figure 3j-n. The chronology of events within the orogen are compared below to events within the basin to reveal possible cause and effect relationships.

The Borden and Fort Payne Formations, as well as most of the Slade Formation, represent deposition during the last stages of the Acadian Orogeny (Figure 3bb). A Late Mississippian quiescent period marked by carbonate deposition followed deposition of the Early Mississippian clastics. However, at about 335 Ma, changes began in the Central Appalachian Basin. Laskowski and others (1980) suggested uplift of the Cincinnati Arch at 337 ±27 Ma (Figure 3e). Such an uplift could represent a peripheral bulge, reinforcing the Cincinnati Arch. The date of 335 Ma for uplift of the arch corresponds with basin subsidence and deposition of the Pennington Group clastic wedge, which is dated at about 333 Ma in the Central Appalachian Basin (Figure 3a, c). Corresponding events in the Appalachian orogen are not reported by Secor and others (1986)(Figure 3j-n). leaving open the question of what events in the Appalachian orogen caused these basinal features.

The Early Pennsylvanian unconformity (Figure 3d) represents uplift of a large part of the Central Appalachian Basin adjacent to the craton. In addition to the relative uplift of the basin, several faults (Mt. Vernon and Dorton-Hellier Faults) were produced (Figure 3f). Both the Dorton-Hellier Fault and the Mount Vernon Monocline may have resulted from unidentified stresses originating in the Appalachian orogen.

Tonsteins (Figure 3h) occur in rocks of Middle Pennsylvanian age (Westphalian), and indicate the proximity of vulcanism to the east (Chesnut, 1985), possibly from the Alleghanian volcanic arc suggested by Sinha and Zietz (1982) in the Appalachian orogen. In fact, Secor and others (1986) have indicated that emplacement of granitoid plutons and associated heating and deformation of the Piedmont occurred between 295 and 327 Ma (Late Mississippian and Pennsylvanian) in the orogen (Figure 3j-k). This range corresponds to deposition of part of the Pennington Group and all of the Pennsylvanian units. Secor and others also reported that immediately following this period, from 285 to 295 Ma

(Early Permian), the overthrust belt was developed (Figure 31), approximately coeval with deposition of the Dunkard Group. They indicated large-scale dextral shear in the orogen (Figure 3m) from 268 to 290 Ma (Permian). Vauchez (1987) recognized dextral shear between the Piedmont and Blue Ridge provinces sometime after 310 Ma (Middle Pennsylvanian)(Figure 3n) or concomitantly with the Breathitt and overlying formations. Moreover, dextral shear has been recognized in the Brevard Zone and other fault systems of the Piedmont by Edelman and others (1987) and Bobyarchick (1988). Edelman and others (1987) advanced evidence that suggests that Alleghanian dextral shear of the Brevard was followed by northwestward overthrusting. They did not indicate timing of the events, but perhaps both shear and thrusting events happened in the period of overlap, 285 to 290 Ma Permian), during the time Secor and others reported that both types of deformation occurred together (Figure. 31-m).

Elliott and Aronson (1987) suggested expulsion of fluids from a deeply buried foreland basin between 272 and 303 Ma (Figure 3i). If this hypothesis is true, then proximal foreland basins were deeply buried during deposition of the Conemaugh and overlying units (Late Pennsylvanian and Permian).

Figure 3 indicates that the initiation of the Alleghanian Orogeny is more clearly reflected in rocks from the Appalachian Basin than in rocks from the orogen. The clastic wedges and basin subsidence associated with the Pennington and Breathitt rocks reflect unidentified tectonic events apparently related to emplacement of granitic plutons rather than large- scale overthrusts as suggested by Rast (1984) and Tankard (1986). Large-scale overthrusts were not formed till the Permian, according to Secor and others (1986). If peripheral bulge and foreland basin development occurred during the deposition of the Pennington and Breathitt rocks, then a load must have been emplaced upon the crust. This load may be related to the granitic plutons, unidentified thrust faulting, or other processes.

Sinha and Zietz (1982) described an arc of Alleghanian (Hercynian) plutonic rocks in the Piedmont from Georgia to Maryland. Based on the geometry of the arc and the distribution of certain elements and isotopic ratios, they suggested a westward-dipping subduction zone beneath the Laurasian (North American) continent for the origin of the arc. In addition, they stated that the crustal doming that caused emplacement of the plutons may also have formed thrust faults. If their scenario is correct, then thrusting in response to plutonism may represent the loading of the crust, which, in turn, formed the foreland basin and peripheral bulge. They attributed the Late Pennsylvanian overthrusting of the Valley and Ridge and the Blue Ridge to this process. The timing of plutonism (by ash fall dating) indicates that if any thrust faulting was caused by plutonism, it was probably earlier than the Late Pennsylvanian overthrusting of the Valley and Ridge and the Blue Ridge. Overthrusting of the Valley and Ridge and the Blue Ridge is generally considered to have been caused by other processes, as discussed below.

## PlateTectonic Scenario

Most of the plutons discussed above are allochthonous (e.g., Pratt and others, 1985) and were transported by overthrusting in the Late Pennsylvanian or Permian. The possibility exists that they were formed on another plate or terrane prior to collision with Laurasia. In fact, Pindell and Dewey (1982) suggested that subduction occurred beneath Gondwana (Africa) and was eastward dipping. If this scenario is correct, then the granitic plutons in the Piedmont might represent either (1) subduction-arc vulcanism on Gondwana that was later accreted to Laurasia, or (2) plutonic activity on the Laurasian plate in response to continent-continent collision (Secor and others, 1986). If the second suggestion is true, Secor and others postulated that delamination and subduction of part of the continental crust into the asthenosphere during collision might have produced plutonism in the continental crust. A variety of other plate-tectonic scenarios is illustrated in Secor and others (1986, fig. 6) for the Alleghanian Orogeny. No conclusive evidence is recognized in the Central Appalachian Basin that can determine which scenario is correct. The tonsteins found in the Breathitt Group and the bentonite(?) in the Slade Formation indicate proximity to rhyolitic vulcanism only, and cannot be used to determine which model of plutonic activity occurred.

The development of the Permian overthrust belt (Figure 31) is commonly attributed to continent-continent collision of Laurasia and Gondwana (Secor and others, 1986, p. 1351; Rast, 1988). However. Sinha and Zietz (1982) suggest that the overthrusts were formed in response to plutonic crustal doming.

Any dextral shear in the Appalachian orogen (Figure 3m-n) may be explained by either of two mechanisms: (1) actual dextral motion between Laurasia and Gondwana (Secor and others, 1986, p. 1351), or (2) escape or expulsion tectonics (Vauchez, 1987). Secor and others (1986) asserted that the dextral shear is directly related to dextral oblique convergence and collision of Laurasia and Gondwana. Dextral relative motion of plates is not supported by previous plate-tectonic reconstructions (Figure 5)(Scotese and others, 1979; Scotese, 1986; Van der Voo, 1988), which show an opposite sense of convergence (i.e., sinistral), with Gondwana moving north from the southern latitudes toward Laurasia near the equator.

Vauchez (1987) suggested that the Piedmont terrane was forced southwestward when a promontory on the African craton collided with the North American craton. Perhaps the escaping Piedmont terrane became firmly trapped between the two cratons, and compressional forces reactivated the dextral shears into northwestward-verging thrust faults. This scenario may explain the sequence of Alleghanian faulting events found in the Brevard Zone, although it does not explain how dextral shear continued into the Permian after overthrusting, as suggested by Secor and others (1986)(Figure 31-m).

Convergence between continents is accomplished by subduction or transcurrent motion, or both. The relative positions of Laurasia and Gondwana in the plate-tectonic reconstructions of Scotese and others (1979) indicate that subduction rather than transcurrent motion must have been the dominant cause for convergence of the two plates in the Carboniferous (Figure 5). This convergence, however, may have been oblique.

Some aspects of these models for Carboniferous plate motion and Alleghanian thrusting may be inferred from the Central Appalachian foreland basin. Basin development (Figure 3c), clastic wedges (Figure 3a), tonsteins (Figure 3h) in the Central Appalachian Basin, and emplacement of granitic plutons along an arc in the Piedmont (Figure 3j) are evidence that the margin of the Laurasian continent was active during the Carboniferous. The most likely explanation for the active margin is that an active subduction arc existed along the southeastern edge of Laurasia, with a westward-dipping Benioff zone (Figure 3cc). The deposition of the Pennington Group and overlying Pennsylvanian rocks would then be the result of this subduction.

Continent-continent collision began in the Permian (Figure 3dd). Deposition of the Dunkard Group and formation of the Pine Mountain Thrust, Allegheny Synclinorum, and other major structural features in the Central Appalachian Basin resulted from deformation, chiefly overthrusting, caused by this collision.

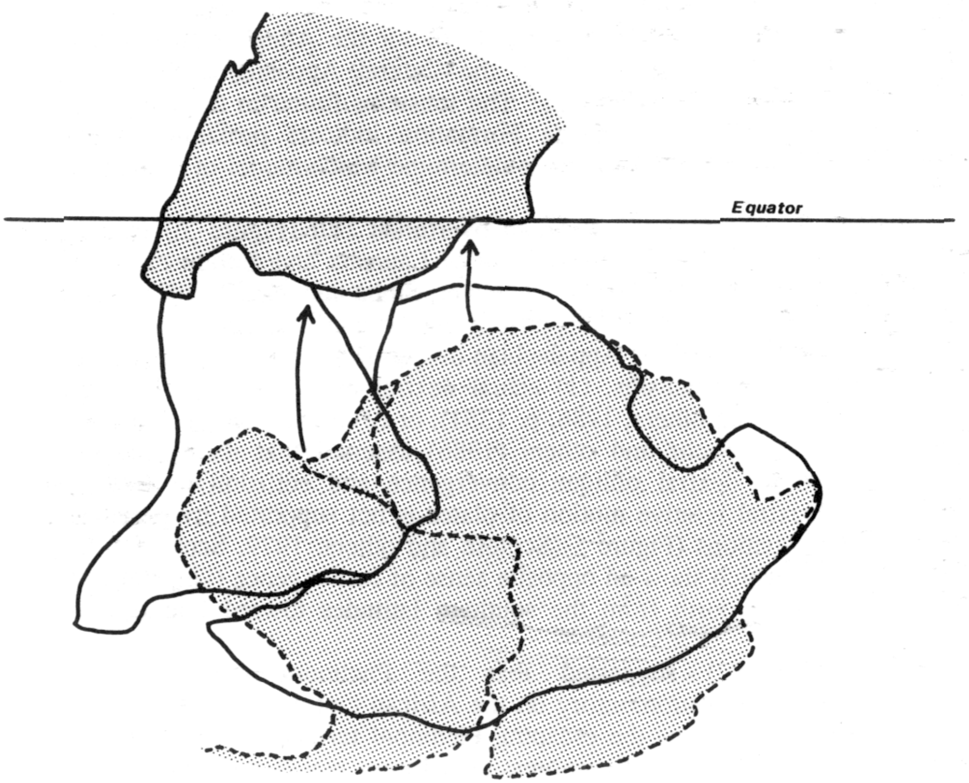



Figure5. Plate reconstructions during the Carboniferous. Adapted from Scotese and others (1979). Northern stippled area is Laurasia. Southern stippled area is the South American and African part of Gondwana during the Visean (Mississippian). Solid lines represent part of Gondwana and Laurasia during the Westphalian C and D. The position of Laurasia is unchanged. Arrows represent motion necessary for Carboniferous placement of the plates.

## CONCLUSIONS

(1) Decreasing basin subsidence and clastic deposition during the Early Mississippian represent the waning stages of the Acadian Orogeny (Figure 3bb). The clastics were derived from the rebounding Acadian mountains. Rebound was caused by erosional unloading of the mountains (Figure 30-p, v-w).
(2) Widespread carbonate-platform development during mid-Mississippian time marks a period of tectonic quiescence (Figure 3q).
(3) Increasing basin subsidence (Figure 3c) and clastic deposition (Figure 3a) starting in the Late Mississippian and continuing through the Pennsylvanian-Permian indicates the increasing development of the Alleghanian Orogeny. Basin shift parallels progressive thrust fault(?) movement and consequent loading of the

lithosphere.
(4) The Early Pennsylvanian regional unconformity was formed by uplift of the northwestern part of the Central Appalachian foreland basin (Figure 3d). This uplift may have been produced by relaxation of stress in the lithosphere (Figure 3s) or by collisional braking (Figure 3z). Onlap over the unconformity and the formation of structural deformation in the foreland basin mark renewed tectonic activity in the orogen (Figure 3t, aa).
(5) The cause of progressive thrust fault(?) movement during the Early and Middle Pennsylvanian is poorly understood, but may have been emplacement of granitic plutons in the orogen. In turn, westward- dipping subduction along the eastern margin of the North American plate may have produced the granitic plutons (Figure 3cc).
(6) Widespread thrust faulting and deformation began in the Permian. This major phase of deformation was caused by oblique collision with the African block (Figure 3dd).

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