Figure 23. Structure-contour map on the Fire Clay coal bed of the Hyden formation (Breathitt Group). This map was produced by Mr. Richard Sergeant (Kentucky Geological Survey) and computer-generated from approximately 2,000 data points obtained by the Kentucky Geological Survey.


Ohio
Kentucky
Ohio
West Virginia
Allegheny Synclinorum
Cincinnati Arch
Eastern Limb of Cincinnati Arch
Paint Creek Uplift
northern limb
Eastern Kentucky Syncline
Kentucky-Virginia Monocline
Pine Mountain Thrust Fault
Artemus Uplift
Virginia
Kentucky
Virginia
Tennessee
N
10 Miles
16 Kilometers
600
600
800
800
800
1000
1000
1000
1200
1200
1200
1400
1400
1600
1600
1800
1800
1800
2000
2200

Only structures encountered in the cross sections will be described.

## Folds

The most obvious feature on the Fire Clay structure map (Fig. 23) is an anastomosing synclinal structure oriented generally northeast-southwest. This structure actually consists of two previously recognized synclines (Fig. 22), the Allegheny synclinorium and the Eastern Kentucky syncline. The Allegheny synclinorium is a synclinal structure located in the northeastern third of the structure-contour map and in the northwestern thirds of the Catlettsburg (Fig. 12) and the Grundy (Fig. 13) cross sections. In West Virginia (Fig. 22) the northeast-trending Allegheny synclinorium is known as the Parkersburg syncline.

The Eastern Kentucky syncline occurs in the southern two-thirds of the structural map (Figs. 22, 23). The axis of this syncline bends near the center of the map, so that, to the south, the axis is oriented north-south, and to the east, it is oriented northeast-southwest. The Eastern Kentucky syncline is recognized in the central parts of the Catlettsburg, Grundy, and Booneville (Fig. 14) dip sections and in the central parts of the strike sections (Figs. 16-18). The Allegheny and the Eastern Kentucky synclines are separated by the Irvine-Paint Creek and Walbridge faults, by the Paint Creek uplift, and by the Paintsville-

Warfield anticline (Fig. 13, 22). Carboniferous strata do not thicken in the Eastern Kentucky syncline (Figs. 16-22), whereas, Middle and Late Pennsylvanian-age strata thicken in the Allegheny synclinorium (Sergeant, 1979). These thickness trends indicate that the Allegheny synclinorium was apparently active during the Carboniferous, while the Eastern Kentucky syncline was not, and, therefore, they were probably not related features.

Northwest of the Allegheny synclinoriurn and the Eastern Kentucky syncline the outcrops consists of the east or southeast-dipping beds of the southeastern limb of the Cincinnati arch (Fig. 23). This feature is more easily recognized in the northwestern parts of the dip cross sections (Figs. 12-15), because the sections include data farther to the northwest than the structure contour map.

The Middlesboro syncline, located between Cumberland Mountain and Pine Mountain, and between the Jacksboro and Russell Fork faults in the southern part of the study area, was formed by movement of the Pine Mountain thrust fault. This northeast-southwest striking syncline is encountered in the southeastern part of the Booneville dip section. The central part of the Harlan strike section (Fig. 18) is located along the axis of this syncline.

Many smaller synclinal and anticlinal features were encountered in the cross sections. In the Catlettsburg dip section, the Warfield anticline occurs in the central part of the section, and the Coalburg syncline is just south of the anticline. An unnamed anticline and syncline occur in the southern quarter of the section. In the Grundy dip section, an anticlinal feature called the Paint Creek uplift is located just south of the Walbridge fault. The large, but weakly developed anticlinal feature east of the Eastern Kentucky syncline in the Hazard strike section (Fig. 16) is also part of the Paint Creek uplift. A small anticline known as the Rockcastle River uplift is present in the northern part of the Booneville dip section.

In the central part of the Pineville strike section (Fig. 17), an unnamed, steeply dipping anticline is located just southwest of the White Mountain-Dorton Branch fault zone. A similar and possibly related anticline is located just southwest of the Rocky Face fault in the central part of the Harlan strike section. This anticline in the Harlan section, is also near the Middlesboro cryptoexplosive structure, a probable meteor-impact structure mapped by Englund and other (1964).

In the northeastern part of the Harlan strike section, two closely related anticlines southwest of the Russell Fork fault are recognized. The easternmost and best developed of these is the Buck Knob anticline (Miller, 1974, p. 14); the other is unnamed. Other small anticlines and synclines occurring between the Jacksboro fault and the Russell Fork fault may be more apparent than real, due to the zig-zag traverse of the section along the Middlesboro syncline. True anticlines and synclines could be masked by these apparent structures.

## Monocline

The northwest-dipping beds of a previously unnamed monocline occur southeast of the Eastern Kentucky syncline on the structure-contour map (Fig. 23). The monocline occurs in the southeastern parts of the Catlettsburg and Grundy dip sections (Figs. 12, 13) and the northeastern parts of the Pineville (Fig. 17) and Harlan (Fig. 18) strike sections. The monocline is, here, called the Kentucky-Virginia monocline.

In the area of the Kentucky-Virginia monocline, an interesting structural relationship between older and younger rocks is detected. The strata of Pennsylvanian age dip to the northwest, as shown by the structure contour map on the Fire Clay coal bed, but the Mississippian and older strata dip to the southeast, an apparent reversal of the trend of the overlying strata. In the southern half of the Catlettsburg dip section, the Slade Formation and lower units are nearly horizontal or dip to the southeast, whereas the units above the Slade dip to the northwest. In the Grundy section, surface rocks in the southern half of the section dip to the northwest, and subsurface units below the Pennsylvanian formations dip to the southeast, away from the Cincinnati arch. In the Booneville dip section (Fig. 14), dip of the Lee Formation and overlying rocks is nearly horizontal north of the Pine Mountain fault, whereas rocks below the Lee dip to the southeast. In the Lake City section (Fig. 15), the subsurface rocks dip away from the Cincinnati arch toward the southeast. Surface rocks, however, are nearly horizontal in the Pikeville and Hyden formations, whereas rocks above the Hyden dip to the northwest.

The southeastern dip of the older beds is part of a regional trend of beds dipping from the Cincinnati Arch toward the Appalachian basin. The difference in dip direction from older to younger strata, may be due to a combination of two processes: partial uplift of basinal strata, and regional erosion followed by a shift in the position of the basin. Where a basin subsides more along its axis than its margin, the strata deposited in the basin will have divergent dip from bottom to top. When uplift occurs, such that the strata in the central part of the section are horizontal, then overlying strata will dip in a direction opposite that of the underlying strata. This process may explain most of the divergences in dip in the study area, but another process may explain part of the divergences as well. Most of the Carboniferous rocks show a gradual change in dip up-section. A more abrupt change in dip can be recognized between Pennsylvanian and subjacent Mississippian strata in each of the dip cross sections (Figs. 12-15). This change in dip occurs at an unconformity near the Pennsylvanian-Mississippian boundary and is caused by erosion and shift of the depositional basin.

## Faults

The Pine Mountain thrust fault is located in the southern part of the study area. The thrust fault is encountered in the southeastern end of the Booneville dip section (Fig. 14) and in the central part of the Harlan strike section (Fig. 18). The Middlesboro syncline, a feature associated with the thrust fault and represented in the Booneville dip section, is discussed above. The Harlan section is more complex than the other sections, because it traverses the full length of the Pine Mountain thrust sheet. In the southwestern part of the section, the southwestern limit of the thrust sheet is the Jacksboro fault, apparently a lateral ramp with left-lateral displacement. The lateral displacement along the Jacksboro fault is reported to be about 11 miles (17.7 km) (Wentworth, 1921; Englund, 1968).

Farther east in the central part of the section, the Rocky Face fault occurs in the thrust sheet. This fault is upthrown to the northeast. The Rocky Face fault and the anticline just to the southwest are reminiscent of similar structures just north of Pine Mountain (Pineville Strike Section, Fig. 17) and are probably related. In the northeastern part of the Harlan strike section, the northeastern end of the Pine Mountain thrust sheet is marked by the Russell Fork fault. The lateral displacement along the Russel Fork fault is reported to be about 4 miles (6.4 km)(Wentworth, 1921; Englund, 1968; Miller, 1974).

The base of the Pine Mountain thrust fault occurs in the Chattanooga Shale. Slickensides and gas "blowouts", occurrences of over-pressured gas, are reported in the shale in this region. In the Chattanooga, they are associated with fractures or slip surfaces, and in the thrust sheet, they indicate presence of the thrust fault (Brandon Nuttall, Kentucky Geological Survey, personal communication, 1986).

Many other faults were also recorded in the cross sections. The Walbridge fault, a normal fault with the downthrow to the south, was traversed in the northeastern part of the Grundy dip section (Fig. 13).

At the southeasternmost part of the Lake City section (Fig.

15) at Walden Ridge, the rocks dip to the northwest. This ridge marks the Eastern Cumberland escarpment and the eastern belt of outcrop of Carboniferous rocks. A thrust fault is mapped at this ridge on the Lake City geological quadrangle map (Swingle, 1960). Unmapped thrust faults in the Breathitt Group northwest of Walden Ridge may account for difficulties in correlation of strata in this area.

In the Pineville section (Fig. 17), several faults were recognized. Faults, such as the Lick Ridge, and the Little Peavine thrust faults, the Fox Creek, Otter Creek, Yellow Creek, and other lateral faults (Stearns, 1954), were mapped in the southwestern end of the cross section. These closely-associated faults are illustrated collectively in the section. The westernmost block reportedly contains several repeated sections of Pennsylvanian sandstones. Correlations were not extended west of these faults.

In the southwestern third of the Pineville strike section, the Terry Creek Fault is present in the Pioneer Quadrangle (Englund, 1968). The southern part of the scissor-fault is mapped as upthrown to the northeast, whereas the northern part is upthrown to the southwest. In the area of the cross section, the upthrown side is to the southwest, and very little displacement occurs across this fault in this section.

In the central part of the Pineville strike section, a steeply dipping anticline and associated fault zone just to the east of the anticline are recognized. This anticline and fault zone are part of the White Mountain-Dorton Branch fault zone. The similar and probably related Rocky Face fault and associated anticline are located in the central part of the Harlan strike section.

A new structural feature, disclosed in these cross sections is the subsurface Dorton-Hellier fault between Dorton and Hellier quadrangles, Kentucky (Pineville strike section). A structural declivity can be seen in the subsurface in the northeastern part of the cross section. This declivity appears to be a subsurface fault that offsets the Pride Shale Member (Pennington Group) and older strata. The Warren Point Sandstone Member of the Lee Formation is largely restricted to the downthrown side of the fault. The Bee Rock and Sewanee members of the Lee Formation overlie the fault, but do not appear to be much affected by the fault. Therefore, faulting would have occurred after deposition of the Pride Shale (Late Mississippian) and before or during the deposition of this lower member of the Lee Formation (Early Pennsylvanian). This fault is herein called the Dorton-Hellier Fault. Because this feature is found in only one cross section, its trend is not known.

If the Dorton-Hellier fault extends beneath the Pine Mountain Thrust Sheet, then it may have acted as a lateral ramp. Such a lateral ramp would have produced a lateral ramp anticline on the thrust sheet. In fact, an unnamed anticline (Miller, 1974, fig. 11) on the thrust sheet in the western part of Dickenson County, Virginia (Fig. 22) trends northwest-southeast, and, if projected farther north along its trend, would approximately intersect the fault on the Pineville cross section. Perhaps this anticline reflects a northwest-southeast trend for the Dorton-Hellier fault.

# ANALYSIS OF CROSS SECTIONS

## Structural History of the Basin

Interpretations of the structural history of the Central Appalachian basin are made from relationships shown in the cross sections. Changes in the thickness of strata are used to interpret basin development, especially if it is accepted that depositional depth despite minor fluctuations was constant. However, three complicating factors affecting thickness must be considered: underfilled basins, carbonate build-ups, and differential compaction. An underfilled basin may contain deposits which have a surface of variable depositional depth. Differences in depositional depth of units can lead to differences in thickness of the units that are independent of basin subsidence. For example, the change in thickness of the Borden Formation in south-central Kentucky and north-eastern Tennessee is not due to basin subsidence, but is caused by differences in depth of deposition of the subaqueous Borden delta (Discussed in later section). Thin shales of the Borden (Maury Sh.) Formation in Tennessee were deposited as prodelta shales, whereas thick Borden shales, siltstones, and sandstones to the northeast were deposited in delta front and delta top environments. In the case of the Borden delta, the Fort

Payne Formation filled the remnant basin when Borden deposition ceased. The combined thickness of the Borden and Fort Payne formations, therefore, compensate for the differences in depositional depth, and can be used to determine basin subsidence.

Thicknesses of carbonate strata can also be controlled by factors other than basin subsidence. Carbonate producing organisms avoid areas of clastic influx and deposition, and are attracted to clear, shallow, oxygenated waters, which are commonly associated with structural highs. In addition, chemically precipitated carbonates, such as oolites, are formed in similar environments. Build-ups of carbonates at structural highs, however, are probably not significant at the scale of the cross sections in this study. On the other hand, differences in carbonate thicknesses due to the influence of clastic deposition lateral to carbonate deposition, may be an appropriate consideration in this basin.

An increase in thickness of rocks of uniform composition, originally deposited at a constant depositional depth, such as near sea level, must indicate an increase in basin subsidence. Stratigraphic units of non-uniform composition, however, may complicate the analysis of basin subsidence because of differential compaction. For example, a unit composed largely of sandstone in one area will remain thicker in that area after compaction than in an area composed largely of shale. However, the largest amount of compaction occurs soon after deposition, and, therefore, topographic lows are quickly filled, so that the surface occurs at a nearly uniform level if the supply of sediment is adequate. The subsiding Atchafalaya Basin in Louisiana, for example, is attracting drainage from the Mississippi River, and, were it not for the the attempts of the Army Corps of Engineers to control the flow of the Mississippi River, much of its flow would divert to the Atchafalaya. The shifting of drainage in lower delta plains tends to keep the surface near sea level (Coleman, 1988, p. 1000-1002). Differences in compaction, therefore, should not interfere in the analysis of basin subsidence if compaction is early and there is an adequate supply of sediment to infill the topographic lows produced by the compaction. Syndepositional basin subsidence of the Carboniferous and Late Devonian formations discussed below, is based on thickness changes.

## Chattanooga Shale

The exact depth of deposition of the strata of Late Devonian age in the Central Appalachian basin is not known, although Ettensohn (1985a,b) reports a deep-water origin, largely below the pycnocline (between anaerobic and dysaerobic conditions), because the black, organic-rich shales of the Chattanooga Shale were deposited and preserved under reducing conditions. Since the thickness of Late Devonian rocks increases to the east (discussed in the section on the Chattanooga Shale), and deposition in the study area was largely below the pycnocline, the basin is infered to have had more subsidence to the east.

## Borden-Fort Payne

The top of the combined Borden-Fort Payne formations is overlain by shallow-water carbonates of the Slade Formation. The cross sections indicate a slight easterly thickening of the Borden-Fort Payne formations (compared to the Chattanooga Shale), suggesting that the basin subsided to the east, although much less so than during the Late Devonian.

## Slade

The only large increase in thickness of the Slade Formation occurs in the southeastern part of the Catlettsburg Dip Section (Fig. 12). The Catlettsburg, Grundy, and Booneville Dip sections (Figs. 12-14), show a general increase in thickness of the Slade to the southeast, The northeastern parts of each of the strike cross sections (Figs. 16-18) also indicate a slight increase in the same area. This increase in thickness to the east or southeast in the study area is part of a general trend of Carboniferous units. In the Lake City Dip Section (Fig. 15), however, the Slade Formation increases in thickness to the northwest. Moreover, each of the strike sections show an increase in thickness of the Slade Formation to the southwest. This increase in thickness to the northwest or southwest in the southwestern part of the study area is atypical for the other Carboniferous units. Either the basin subsided in this area during Slade deposition, an unexpected phenomenon, or clastic influx prevented continuing carbonate deposition in the rest of the study area. Information gathered in this study is insufficent to determine the controlling factor of this anomalous thickness.

## Pennington

The Pennington Group thickens toward the southeast (see discussion in the Pennington Group section). The widespread occurrence in the Pennington of rocks originally deposited in tidal-flat and other shallow-water environments with thin coals deposited in lowland environments (Wilpolt and Marden, 1959; Miller, 1974) indicates deposition near sea level. An increase in thickness indicates that the basin probably underwent greater subsidence toward the southeast.

## Lee-Breathitt

Carboniferous strata younger than the Pennington rocks were also deposited in very shallow environments. The near-surface deposition is indicated by the common occurrence of coals overlain by marine beds. The Pocahontas Formation thickens to the southeast. This thickening is related to greater subsidence of the basin to the southeast, as during Pennington deposition.

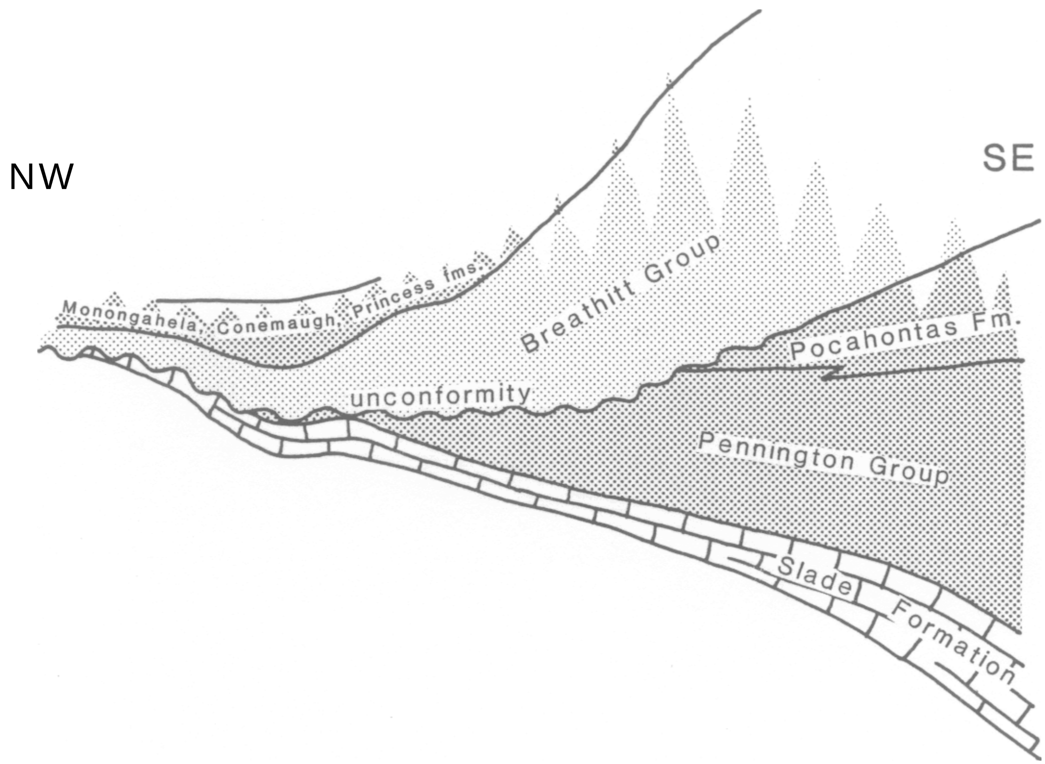
Widespread erosion, discussed in a following section, of underlying units took place near the beginning of Bottom Creek deposition in the southeastern part of the basin. The Dorton-Hellier Fault (Pineville Strike Section, Fig. 17) displaced Pennington Group strata, but Alvy Creek rocks were not displaced: indicating that this fault formed during late Pennington, or Bottom Creek time, approximately the same time as the widespread erosion.

The Breathitt Group above the Pocahontas Formation also increases in thickness toward the southeast. The occurrence of many coal beds and marine units (all deposited near sea level) throughout this group suggests that the thickening is related to basin subsidence. Widespread erosion of the upper part of the Breathitt Group and the overlying Conemaugh and Monongahela formations precludes a complete determination of the basin structure during deposition.

## Basin Shift

The Catlettsburg (Fig. 12) and Grundy (Fig. 13) cross sections show Pocahontas and Pennington formations rapidly thickening to the southeast; therefore, the axis of the depocenter and the basin during deposition must have been much farther to the southeast. Except for the Pocahontas and Princess formations, the axis of the Breathitt and Lee depositional basin appears to be at the southeastern end of these cross sections. Farther to the northwest (north of the Paint Creek Uplift), Breathitt and Lee (below the Princess formation) units are very thin, coal beds are reduced in thickness, and distinctive stratigraphic horizons are lost, indicating little subsidence in this area. From the Four Corners formation upward, however, Pennsylvanian units increase in thickness in the area of the Allegheny synclinorum (Sergeant, 1979). Unfortunately, outside the synclinorum most of these units have been eroded, and so it is not known whether this thickening represents a general shifting of the regional depositional basin into the area or whether it represents a local feature controlled by basement faulting. If thickening represents a shifting of the regional depositional basin, then it can be argued that there was a general shift of depositional basins during much of the Carboniferous toward the northwest, as indicated in Figure 24. The basins appear to be smaller northwestward,

Figure 24. Cartoon diagram, similar to the Grundy dip section, showing the progressive shift in basins to the northwest. The first basin development occured during deposition of the Pennington and Pocahontas; the next basin developed during deposition of the Breathitt and Lee: while the last basin formed during deposition of the Conemaugh, Mononhagela and Princess formations.


NW
SE
Monongahela, Conemaugh, Princess fms.
Breathitt Group
Pocahontas Fm.
unconformity
Pennington Group
Slade Formation

and the first two basins are separated (in part, at least) by a possible sedimentary discontinuity.

## Carboniferous Basin Development

In conclusion, the structural history of the basin indicates changing orientation from maximum subsidence in the east (axis of basin oriented north-south in the study area) during Late Devonian and Early Mississippian times to maximum subsidence in the southeast, while the axis of basin was oriented northeast-southwest, during Late Mississippian and Early and Middle Pennsylvanian times. Basinal subsidence was minimal during mid-Mississippian time and greater during the rest of the Carboniferous. A shifting of progressively smaller basins to the northwest during the Late Mississippian and Pennsylvanian is inferred.

## Description of Discontinuity

The examination of the cross sections (Figs. 12-18) shows two thick conformable stratigraphic sequences separated by a discontinuity. The lower sequence includes the Pocahontas Formation and underlying Mississippian strata, whereas the upper sequence consists of all Pennsylvanian strata above the Pocahontas Formation. The discontinuity between these sequences must be examined in detail to determine its nature. In this section the geometric grounds for testing the possibility of an unconformity will be discussed; paleontologic evidence will be included in a following section.

Basin-scale relationships which may be expected with an unconformity include the presence of a systematic truncation of beds below the discontinuity, indications of topographic relief at the discontinuity, a higher dip of beds below the discontinuity than for those above it, and the progressive onlap of beds over the discontinuity.

## Systematic Truncation

A systematic truncation of units toward the limbs of the depositional basin can be expected below an unconformity. In the Catlettsburg and Grundy dip sections (Figs. 25, 26), the upper and lower sequence may be conformable at the southeastern end of the sections; truncation is not apparent. Elsewhere, in the Catlettsburg, Grundy and Booneville dip sections (Fig. 27), the beds of the underlying sequence are progressively truncated northwestwardly to levels as low as the Borden Formation in the Catlettsburg and Grundy sections, and as low as the Slade Formation in the Booneville section.

Moreover, in some of the cross sections, several units are absent. The Pocahontas and most of the Bluestone

Figure 25. Catlettsburg dip section showing the Late Mississippian- and Early Pennsylvanian-age rocks. Datum is on the uppermost Lee member.

# CATLETTSBURG DIP SECTION

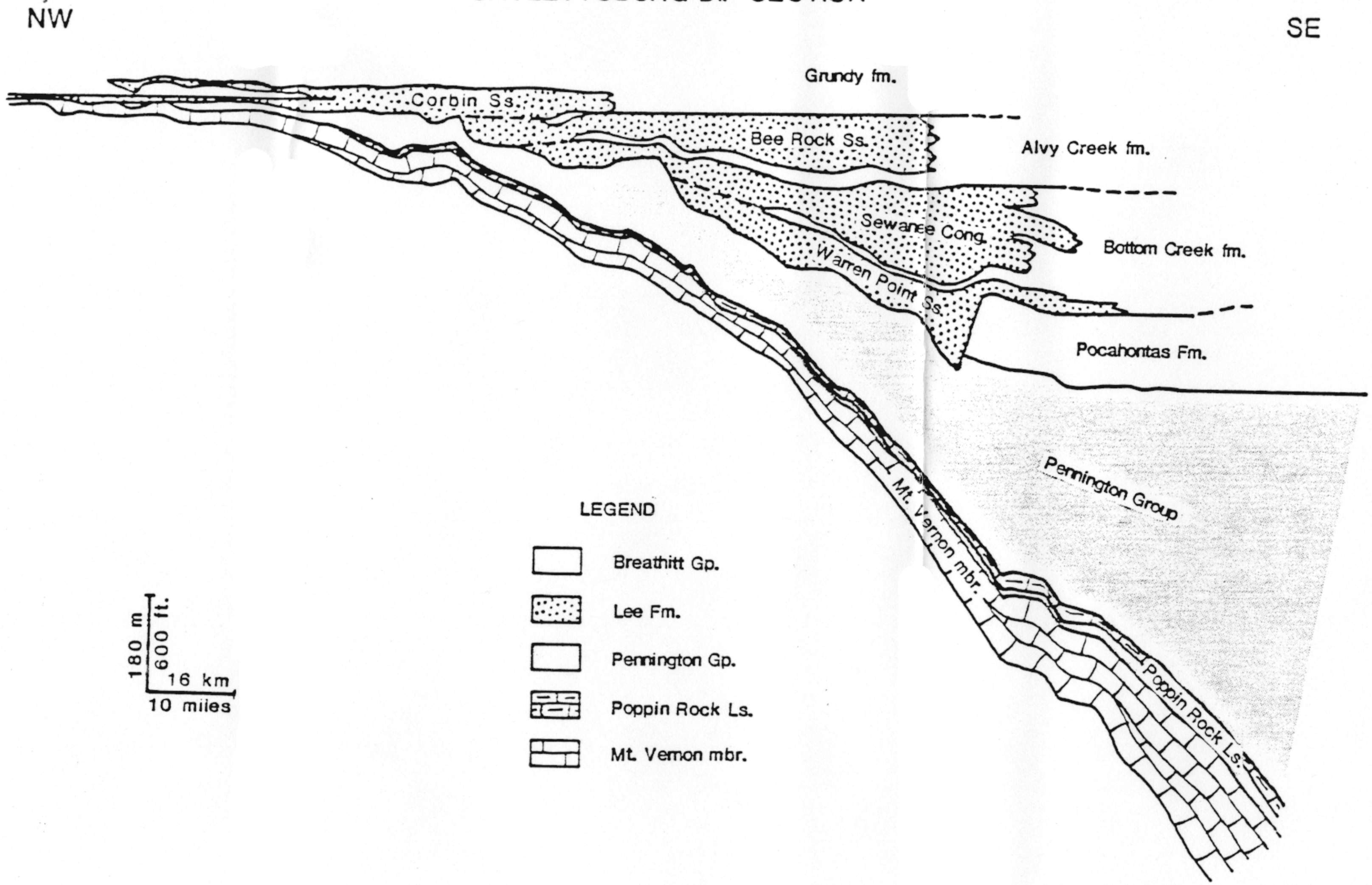


**Figure 26. Grundy dip section showing the Late Mississippian- and Early Pennsylvanian-age rocks. Datum is on the uppermost Lee member.**

# GRUNDY DIP SECTION