Attachment 6
The Central Appalachian Coal Basin

The Central Appalachian Coal Basin is the middle basin of three basins that comprise the Appalachian Coal Region of the eastern United States. It includes parts of Kentucky, Tennessee, Virginia, and West Virginia (Figure A6-1). It covers approximately 23,000 square miles, contains six major Pennsylvanian age coal seams, and contains an estimated 5 trillion cubic feet (Tcf) of coalbed methane (Zebrowitz et al., 1991; Zuber, 1998). These coal seams typically contain multiple coalbeds that are widely distributed (Zuber, 1998). The coals seams, from oldest to youngest (West Virginia/Virginia name), are the Pocahontas No. 3, Pocahontas No. 4, Fire Creek/Lower Horsepen, Beckley/War Creek, Sewell/Lower Seaboard, and Iager/Jawbone (Kelafant et al., 1988). The Pocahontas coal seams include the Squire Jim and Nos. 1 to 7 and Nos. 3 and 4 are the thickest and most areally extensive. The majority of the coalbed methane (2.7 Tcf) occurs in the Pocahontas seams (Kelafant et al., 1988). The highest potential for methane development is in a small, 3,000 square mile area in southwest Virginia and south central West Virginia, where target coal seams achieve their greatest thickness and occur at depths of about 1,000 to 2,000 feet (Kelafant et al., 1988). The Gas Technology Institute (GTI) reported that the entire basin's annual production was 52.9 billion cubic feet (Bcf) of gas in 2000 (GTI, 2002).

6.1 Basin Geology

The Central Appalachian Basin is characterized structurally by broad, open, northeast-southwest trending folds that typically dip less than five degrees (Kelafant et al., 1988) (Figure A6-2). The only documented exception to this is the Pine Mountain Overthrust Block in the southeast portion of the basin (Kelafant et al., 1988). Faults and folds associated with this 25 mile-wide and 125 mile-long structural feature are more intense as evidenced by overturned beds and even brecciated zones in some locations (Kelafant et al., 1988). The overthrust block is believed to have been transported about five miles from the southeast to the northwest (Kelafant et al., 1988). The two dominant joint patterns within the coals are most likely due to the basin having undergone two distinct patterns of structural deformation. These deformations include the Appalachian Orogeny and the tectonic event associated with development of the Pine Mountain overthrust (Kelafant et al., 1988).

The regional dip of coal-bearing Pennsylvanian strata is to the northwest at a rate of 75 feet per mile (Kelafant et al., 1988). Sedimentation within the Central Appalachian Basin was influenced somewhat by the Rome Trough, an Early Cambrian graben structure. Sediment deposition during early Pennsylvanian time (about 320 million years ago) occurred to the southeast of the Rome Trough in a rapidly but intermittently subsiding basin (Kelafant et al., 1988). As this tectonic activity began to abate in the Central Appalachian Basin, subsidence to the northeast of the Rome Trough began to form the Northern Appalachian Basin. However, subsidence rates in the Northern Appalachian Basin were comparatively slower, enabling the formation of more regionally extensive coalbeds (Kelafant et al., 1988).

There are three coal-bearing formations in the Central Appalachian Basin (Kelafant et al., 1988). From deepest to shallowest, they are the Pocahontas Formation, the New River/Lee Formation, and the Kanawha/Norton Formation. Each formation [Pennsylvanian in age (approximately 320 to 290 million years old)] is part of the Pottsville Group, and has varying nomenclature from state to state (Kelafant et al., 1988).

The Pocahontas Formation directly overlies the Mississippian Bluestone Formation, and was deposited in an unstable basin that was rapidly subsiding to the southeast (Kelafant et al., 1988). This is reflected in the thickness of the formation, which is thickest in the southeast and thins to the northwest. It also thins to the south and west due to erosion caused by the basal sandstone member of the overlying New River/Lee Formation (Kelafant et al., 1988). The Pocahontas Formation reaches its maximum thickness of 750 feet near Pocahontas, Virginia (Kelafant et al., 1988). The formation consists mostly of massively bedded, medium-grained subgraywacke, which can be locally conglomeratic (Kelafant, 1988). Gray siltstones and shales are interbedded within the sandstone (subgraywacke) unit, and coal seams comprise about two percent of the total thickness of the Pocahontas Formation (Kelafant et al., 1988).

The New River/Lee Formation conformably overlies the Pocahontas Formation in the northeastern portions of the basin (i.e., there are no time gaps in the depositional record), but there is an unconformity in the east-central portion of the basin (Kelafant et al., 1988). In the southern portion of the basin, the New River/Lee Formation unconformably overlies the Bluestone Formation. It is difficult to correlate this formation across state boundaries as nomenclature varies (Kelafant et al., 1988). The overall thickness of the formation decreases from east to west, with the thickest portion (1,000 feet) in parts of Virginia and West Virginia, lessening to fewer than 100 feet along the Ohio River in Kentucky (Kelafant et al., 1988). Coalbeds encountered in the New River/Lee Formation include the Fire Creek/Lower Horsepen, Beckley/War Creek, Sewell/Lower Seaboard, and the Iager/Jawbone (Kelafant et al., 1988). These coalbeds thin and pinch-out towards the south and west; therefore, there are no equivalent coalbeds in Kentucky and Tennessee (Kelafant et al., 1988).

The Kanawha/Norton Formation varies from a maximum thickness of 2,000 feet in West Virginia to less than 600 feet in portions of Dickenson and Wise Counties, Virginia (Kelafant et al., 1988). The formation is composed of irregular, thin- to massively-bedded subgraywackes interbedded with shale. Several thin carbonate units also occur within the formation as well as over 40 multi-bedded coalbeds.

All coal seams within the basin occur within the Pennsylvanian Pottsville Group (Figure A6-3). Specific stratigraphic nomenclature varies from state to state within the basin. (Names used in this summary are consistent with the West Virginia/Virginia nomenclature).

The Pocahontas No. 3 coal seam ranges in depth from outcrop along the northeastern edge of the basin to about 2,500 feet, with a thickness ranging up to seven feet (Kelafant et al., 1988). Depths to the Pocahontas No. 4 coal seam are somewhat similar to those for the Pocahontas No. 3 coal seam, as the No. 4 seam overlies the No. 3 seam by roughly 30 to 100 feet. The thickness of the No. 3 coal seam varies, with a maximum of approximately seven feet (Kelafant et al., 1988). The Fire Creek/Lower Horsepen coalbed ranges in depth from roughly 500 feet over half of its area, to a maximum depth of approximately 1,500 feet, with a maximum thickness of roughly six feet (Kelafant et al., 1988). The Beckley/War Creek coalbed is approximately two to five feet thick, and reaches to a maximum depth of about 2,000 feet (Kelafant et al., 1988). The Sewell/Lower Seaboard coalbed is fairly shallow, less than 500 feet in depth over half the area it covers, reaching to a depth over 1,000 feet in one small area. While this coal ranges in thickness from two to six feet, it averages about two feet in West Virginia and one foot in Virginia (Kelafant et al., 1988). The youngest targeted coal seam, the Iaeger/Jawbone, is generally less than 500 feet in depth, reaching its maximum depth of over 1,000 feet in two Virginia Counties. The thickness of the Iaeger/Jawbone coal ranges from two to six feet (Kelafant et al., 1988). Figures A6-4 through A6-9 are isopach maps for the six major coal groups of the Appalachian Coal Basin (adapted from Kelafant, et al., 1988).

6.2 Basin Hydrology and USDW Identification

The primary aquifer in the Kentucky portion of the Central Appalachian Basin is a Pennsylvanian sandstone aquifer underlain by limestone aquifers (National Water Summary, 1984). Water wells are typically 75 to 100 feet deep in the Pennsylvanian aquifer and commonly produce one to five gallons per minute of water (National Water Summary, 1984). The basin is located in a portion of the Cumberland Plateau physiographic province in Tennessee (National Water Summary, 1984). The primary aquifer in this area is a Pennsylvanian sandstone aquifer, comprising water-bearing sandstone and conglomerate subunits with interbedded shale and coal (National Water Summary, 1984). Water wells are typically 100 to 200 feet deep and usually produce 5 to 50 gallons per minute of water (National Water Summary, 1984). In Virginia, the basin is located in a portion of the Appalachian Plateau physiographic province. The primary aquifer in this region is the Appalachian Plateau Aquifer, a consolidated sedimentary aquifer consisting of sandstone, shale, siltstone, and coal (National Water Summary, 1984). Water wells are typically 50 to 200 feet deep, and commonly produce one to 50 gallons per minute of water (National Water Summary, 1984). In West Virginia, the basin is in a portion of the Appalachian Plateaus physiographic province of that state. The primary aquifers in this area are Lower Pennsylvanian aquifers, which include the Pottsville Group (National Water Summary, 1984). Wells are commonly 50 to 300 feet deep and typically produce one to 100 gallons per minute of water (National Water Summary, 1984).

Produced water volumes from coal seams within the Central Appalachian Basin are relatively small, typically only several barrels or less per day per well, with high total dissolved solid (TDS) levels, usually greater than 30,000 milligrams per liter (mg/L) (Quarterly Review, 1993). Half the states (Kentucky and Ohio) within the Central Appalachian Basin have maps to locate the undulating interface between saline and freshwater aquifers. The remaining states (Tennessee and Virginia) have no maps defining this interface. Mike Burton (2001), a geologist with the Oil and Gas Office of the Tennessee Geology Division (TGD), reports that the state has no data relating to coalbed methane, which suggests that little or no coalbed methane extraction occurs inside Tennessee's borders (Burton, 2001). Luke Ewing (Ewing, 2001) of the TGD reported that the state had no aquifer maps. Scotty Sorles (Sorles, 2001) of Tennessee's Underground Injection Control Program mentioned that within the state, produced water disposal methods vary on a site-by-site basis. Depending on site characteristics, all injected waters must either be returned to the formation from which they came, or be treated to drinking water levels prior to injection elsewhere (Sorles, 2001).

Robert Wilson, Director of the Virginia's Division of Gas & Oil, stated that there is no mapping program for underground sources of drinking water (USDWs) or for the fresh/saline groundwater interface in Virginia. He reported that the most potable water is found far above the coal zones used for coalbed methane extraction, with fresh water typically found at less than 300 feet deep. He believes most drinking water in southwestern Virginia comes from wells in fractured bedrock aquifers or shallow coal aquifers, or, in some areas, directly from springs. Mr. Wilson also stated that some coalbed methane exploration has moved to shallower coal seams. The Commonwealth of Virginia has instituted a voluntary program concerning depths at which hydraulic fracturing may be performed (Virginia Division of Oil and Gas, 2002). This program involves an operator's determination of the elevations of the lowest topographic point and the deepest water well within a 1,500-foot radius of any proposed extraction well (Wilson, 2001). Hydraulic fracturing should occur at least 500 feet deeper than the lower of these two points (Wilson, 2001).

According to Mr. Tony Scales of the Virginia Department of Mines, Minerals and Energy, coal seams are the most permeable layers in the geologic subsurface in Virginia. For this reason, many private wells in the coalbed methane-producing counties are finished within the coalbeds. Mr. Scales stated that impacts to water supplies have occurred if the coal seams have been punctured by coalbed methane well drilling. The puncture hole acts as a conduit for the flow of water out of the coals and into lower formations. The puncture hole also allows methane to rise up to the surface (Virginia Department of Mines, Minerals, and Energy, 2002).

The following table contains information concerning the relative locations of the base of the zone of fresh water and potential methane-bearing coalbeds in the Central Appalachian Coal Basin. The table provides useful information that can help in determining whether coalbeds being used or slated for methane development lie within USDWs. Note that the 10,000 mg/L level of TDS in groundwater is the water quality criterion for a USDW. The depth to the USDW will thus lie well below the fresh water/ saline water interface. The area of focus for coalbed methane exploration in the basin only covers parts of Virginia and West Virginia (Figure A6-1). In Virginia, the depth to the base of fresh water is approximately 300 feet, whereas the depths to the bases of USDWs are greater. Thus, as can be seen in Table A6-1, methane-producing coalbeds could lie within USDWs in Virginia. West Virginia's interface between fresh and saline water (Foster, 1980) is based on a qualitative assessment, and is estimated at 280 to 730 feet. Again, the depths to USDWs are greater, and thus the coalbeds of interest could lie within potential USDWs in West Virginia. Finally, in Kentucky the interface between fresh water and saline water is based on a TDS level of 1,000 mg/L (Hopkins, 1966). Although the depths to methane-producing coalbeds in Kentucky are not listed in the Table A6-1, it is possible that, as in Virginia and West Virginia, such depths could be lower than the base of USDWs in Kentucky.

Table A6-1. Relative Locations of USDWs and Methane-Bearing Coalbeds

Central Appalachian Coal Basin, States and Coal Groups	Tennessee		Virginia		West Virginia		Kentucky	
	Depth to top of Coal (ft)	Depth to Base of Fresh Water[1] (ft)	Depth to top of Coal[2] (ft)	Depth to Base[1] of Fresh Water[3] (ft)	Depth to top of Coal[2] (ft)	Depth to Base[4] of Fresh Water[1] (ft)	Depth to top of Coal[2] (ft)	Depth to Base[5] of Fresh Water[1] (ft)
Iaeger/Jawbone	N/A[6]	N/A	0 to 1000	~ 300	0 to < 1000	~ 280 to 730	N/A[6]	~ 700 to 1000
Sewell/Lower Seaboard	N/A		500 to 1000		0 to < 1000		N/A	
Beckley/War Creek	N/A		500 to 2000		< 500 to 1000		N/A	
Fire Creek/Lower Horsepen	N/A		500 to 1500		< 500 to 1000		N/A	
Pocahontas No. 4	N/A		500 to 2000		< 500 to < 2000		N/A	
Pocahontas No. 3	N/A		500 to 2000		< 500 to < 2500		N/A	

[1] Note: The base of "fresh water" is not the base of the USDW (a 10,000 mg/L of TDS contour line would define the base of the USDW). Fresh water is within the USDW and the base of fresh water is above the base of the USDW.
[2] Kelafant et al., 1988
[3] Wilson, DGO, personal communication 2001
[4] Foster, 1980
[5] Hopkins, 1966 and USGS, 1973
[6] Not Available

6.3 Coalbed Methane Production Activity

Coalbed methane operators in the Central Appalachian Basin include Equitable Resources, CONSOL (Consolidation Coal Company), and Pocahontas Gas Partnership, all located in Virginia (Zuber, 1998). GTI reported that the entire basin's annual production was 52.9 Bcf of gas in 2000 (GTI, 2002).

The Nora Field in southwestern Virginia is one of the better known coalbed methane production fields. Equitable Resources operates the Nora Field in southwestern Virginia. According to the

Virginia Division of Gas and Oil, over 700 coalbed methane wells were drilled in the Nora Field in 2002 and more than 1,800 coalbed methane wells were drilled in southwestern Virginia's Buchanan County (VA Division of Gas and Oil, 2002). Foam or water is used as the fracturing fluid and about 70,000 to 100,000 pounds of sand per well serve as proppant (Zuber, 1998). CONSOL and Pocahontas Gas Partnership produce coal methane from coal mine developments in Buchanan County, in southwestern Virginia (Zuber, 1998).

Many other smaller test projects were carried out in the basin in the 1970s, including the New River Coal Company/Lick Run Mine Project, Department of Energy (DOE)/Clinchfield Coal Company Project, U.S. Bureau of Mines (USBM)/Occidental Research/Island Creek Coal Company Project, Gas Research Institute/Wyoming County Co-op Project, USBM Federal No. 1 Project, and the Consolidation Coal Company/ Kepler Mine Project (Hunt and Steele, 1991). These projects were very small (five wells or fewer) and achieved limited success in terms of production. During development of some wells in the DOE/Clinchfield Coal Company project and the USBM Federal Project No. 1, fracture treatments "screened out" (i.e., the proppant placement failed), affecting those coalbed methane wells' production viability.

No coalbed methane production occurred in Tennessee between 1995 and 1997 (Lyons, 1997). Three coalbed methane wells produced gas from 1957 to 1980 in Harlan County, Kentucky, and only one test well was in production in the early 1990s in eastern Kentucky (Lyons, 1997). The Kentucky Department of Mines and Minerals website (2002) indicated that 1,338 gas wells were in operation in Kentucky at the end of 2000, but no indication was given whether these were coalbed methane wells or conventional gas wells.

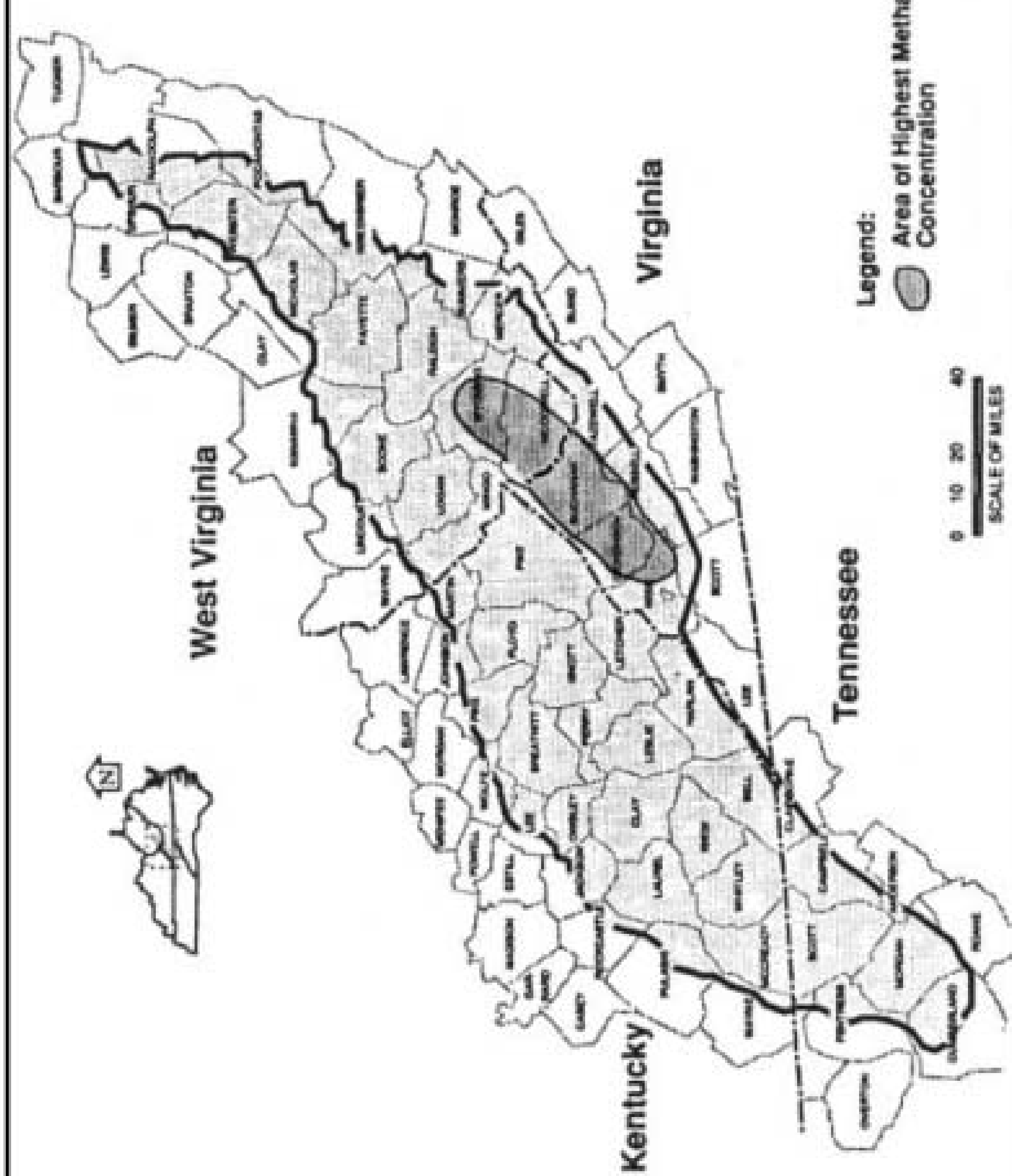
In August 2001, EPA attended a hydraulic fracturing field visit in the Central Appalachian coal basin in Virginia. Pocahontas Oil & Gas, a subsidiary of Consol Energy, Inc., invited EPA personnel to a well location where a hydraulic fracturing treatment was being performed by Halliburton Energy Services, Inc. This treatment employed a variety of fluids and additives to create fractures in select coal seams at various depths. The main fracturing fluid was nitrogen foam (70% nitrogen / 30% water mixture). Prior to injection of the foam, 6 barrels of 15 percent hydrochloric acid were introduced into the well to dissolve the grout surrounding the injection perforations. Once the fracture was propagated to its maximum extent, 16/30 sand suspended in a 10-pound linear gel was injected to prop the fracture open. All the fluids and additives used were produced by Halliburton, including a scale inhibitor and a microbicide additive. Halliburton staff stated that typical fractures range in length from 300 to 600 feet from the well bore in either direction, but that fractures have been known to extend from as few as 150 feet to as many as 1,500 feet in length. According to the fracturing engineer on-site, fracture widths range from one eighth of an inch to almost one and a half inches (Virginia Site Visit, 2001).

Once a well is drilled and fractured in Virginia, several weeks might elapse before fracturing fluid flowback is initiated because a pipeline system must be constructed to transport the produced coalbed methane away from the well. Flowback fracturing fluids are collected in lined pits and tanks and transported off-site for disposal. The State of Virginia does not regulate the use of any drilling or fracturing fluids (Wilson, 2001).

6.4 Summary

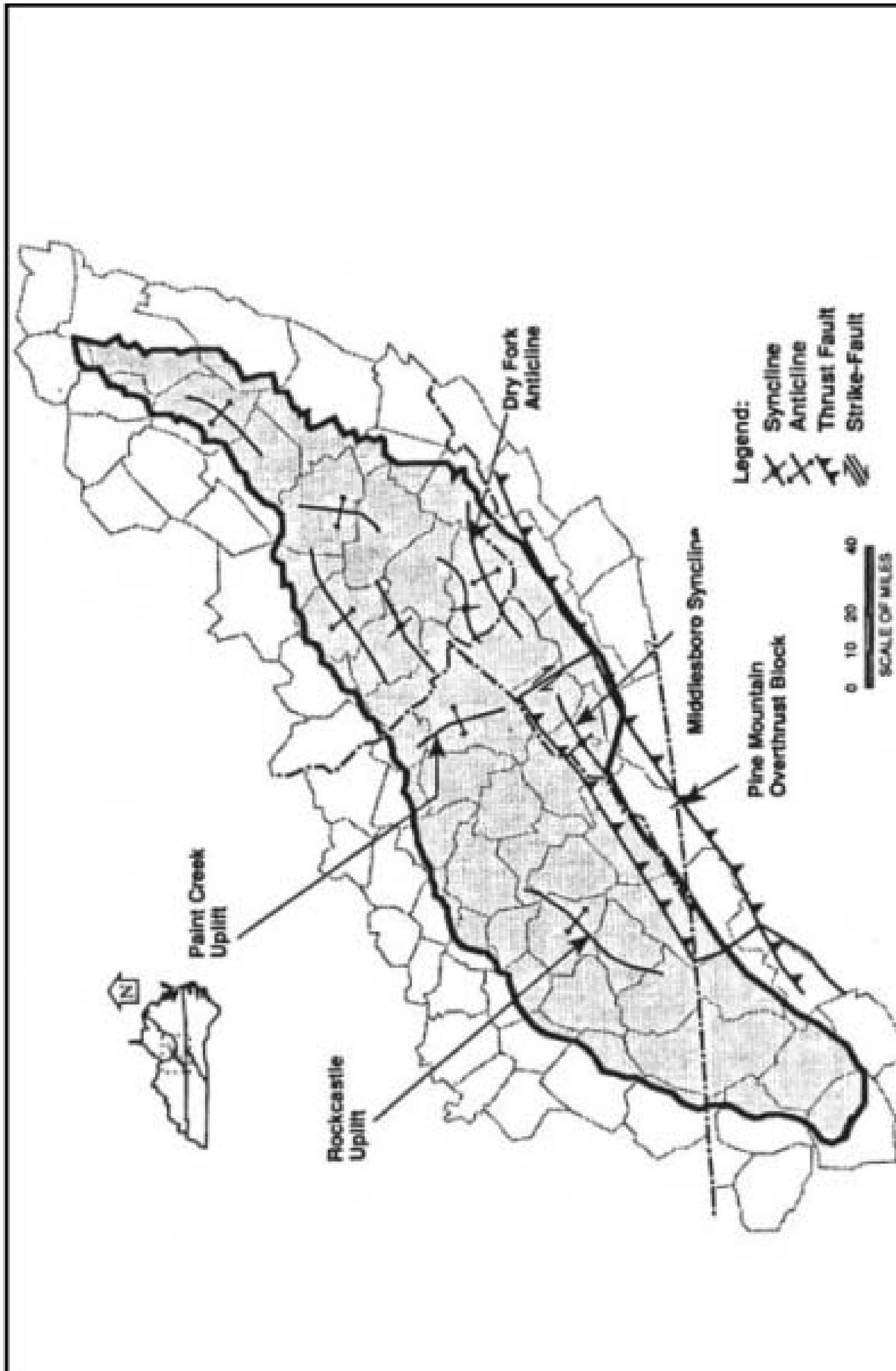
The area with the highest potential for coalbed methane production in the Central Appalachian Coal Basin is southwestern Virginia (Dickenson and Buchanan Counties) and southern West Virginia (Wyoming and McDowell Counties) (Figure A6-1). The coal seams achieve their greatest thickness in these regions and occur at depths of approximately 1,000 to 2,000 feet. Based on Table A6-1, methane-producing coal may lie within a USDW, providing the potential for impact of water supplies.

Hydraulic fracturing is common practice in this region. Foam and water are the fracturing fluids of choice and sand serves as the proppant. Because most of the coal strata dip, a coalbed methane well's location within the basin may determine if hydraulic fracturing during the well's development will likely affect water quality within the surrounding USDW. For instance, on the northeastern side of the basin, the depth to the Pocahontas No. 3 coalbed is less than 500 feet. This depth increases to over 2,000 feet in the western portion of the basin, in the direction of the coal seam dip. Therefore, a well tapping this coal seam in the western portion of the basin may be below the base of a USDW but a well tapping this coal seam in the eastern portion of the basin may be within a USDW. Additionally, the base of the freshwater is not a flat surface, but rather an undulating one. These factors indicate that the relationship between a coalbed and a USDW must be determined on a site-specific basis.



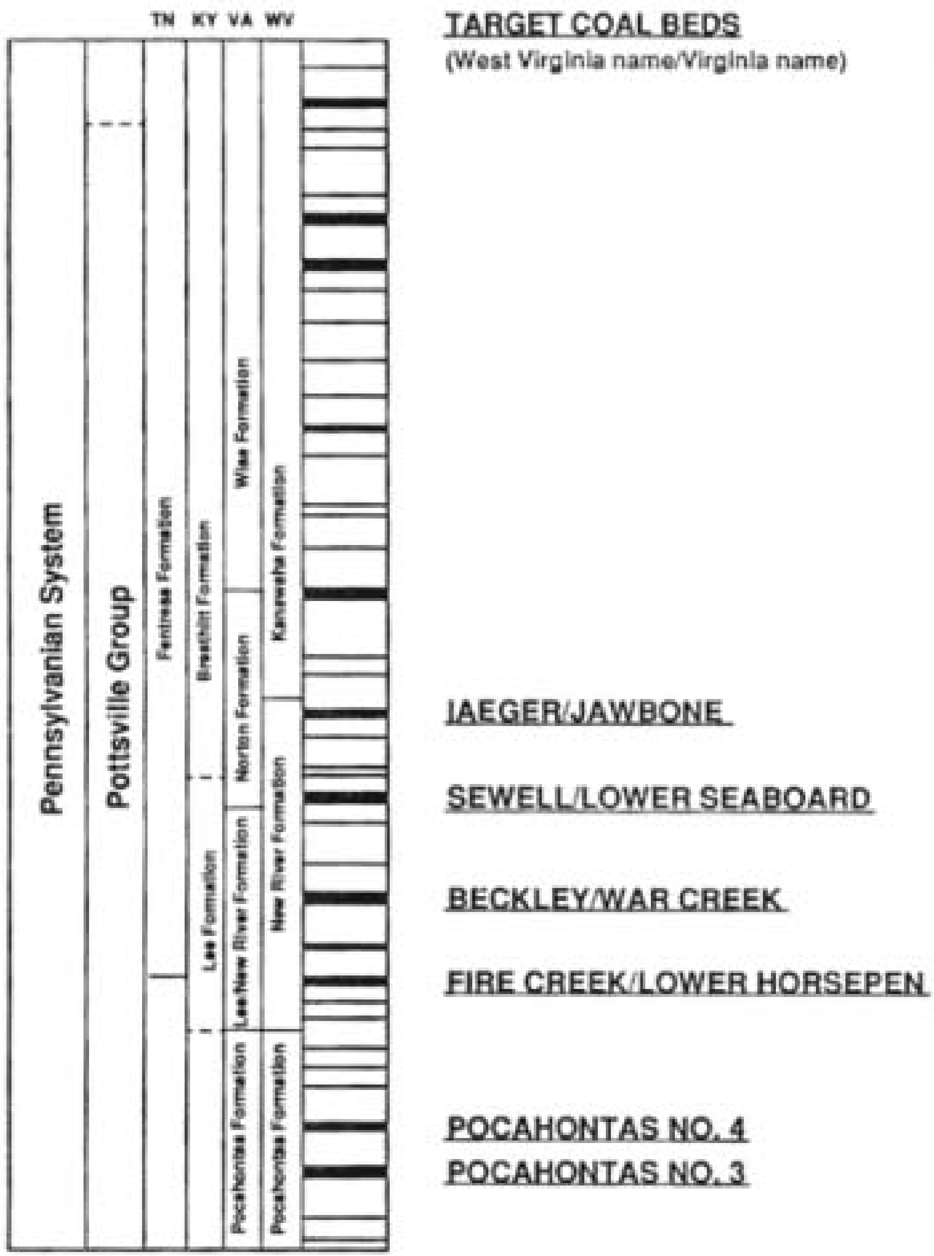
Area of Highest Methane Concentration (Kelafant et al., 1988)

Figure A6-1



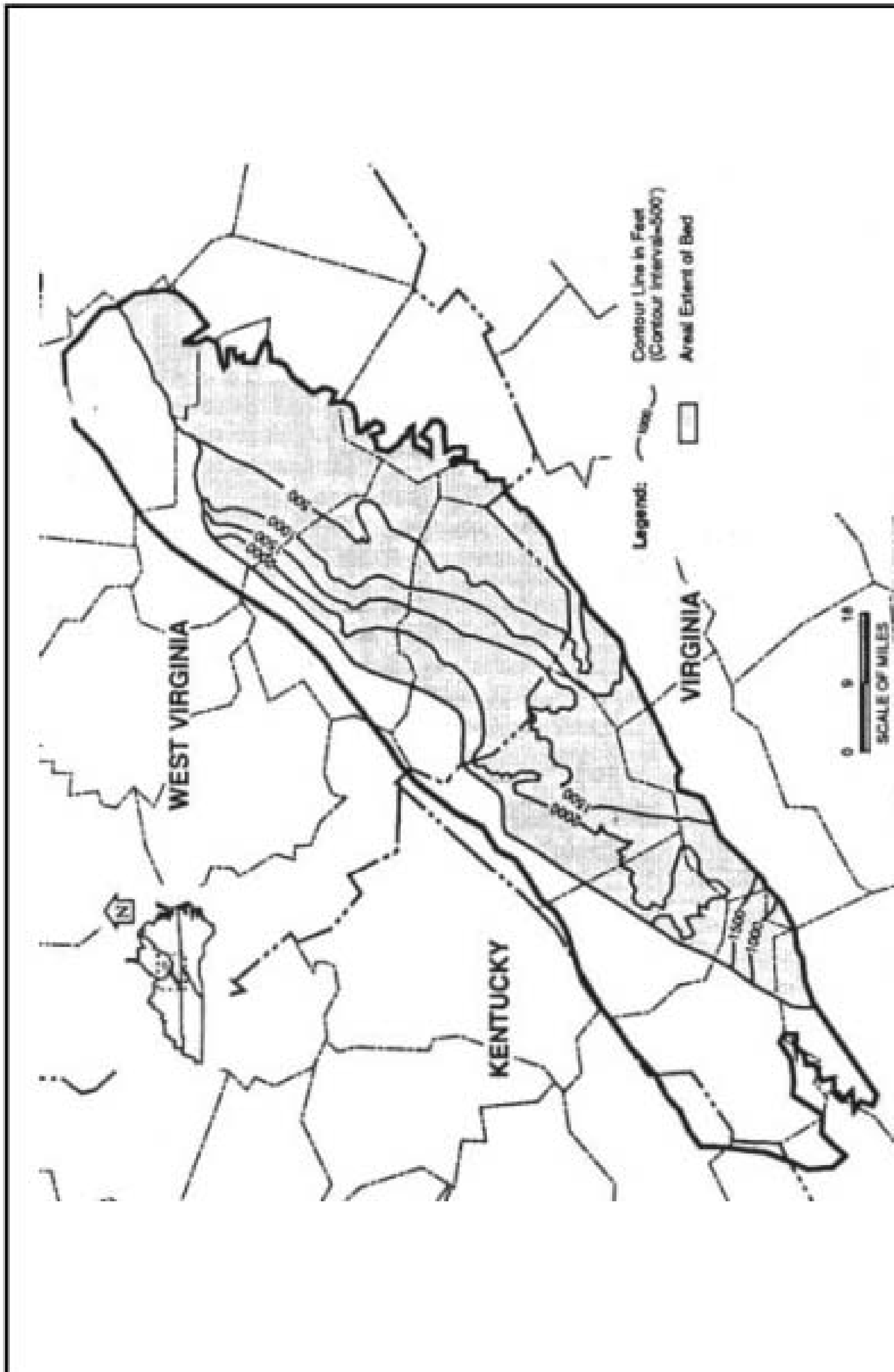
Structural Features (Kelafant et al., 1988)

Figure A6-2



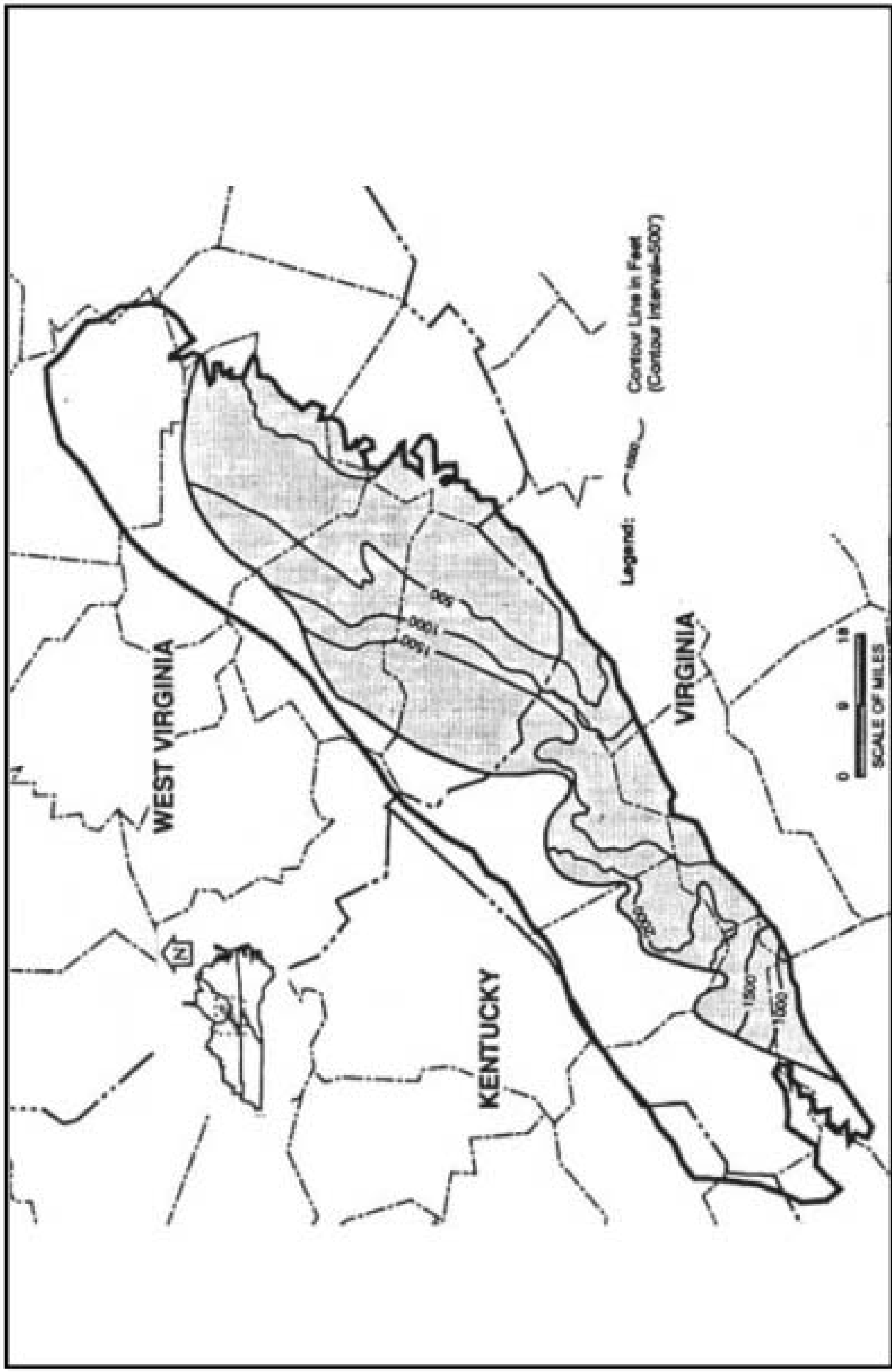
Representative Stratigraphic Column of Pennsylvanian Age Formations
(Kelafant et al., 1988)

Figure A6-3

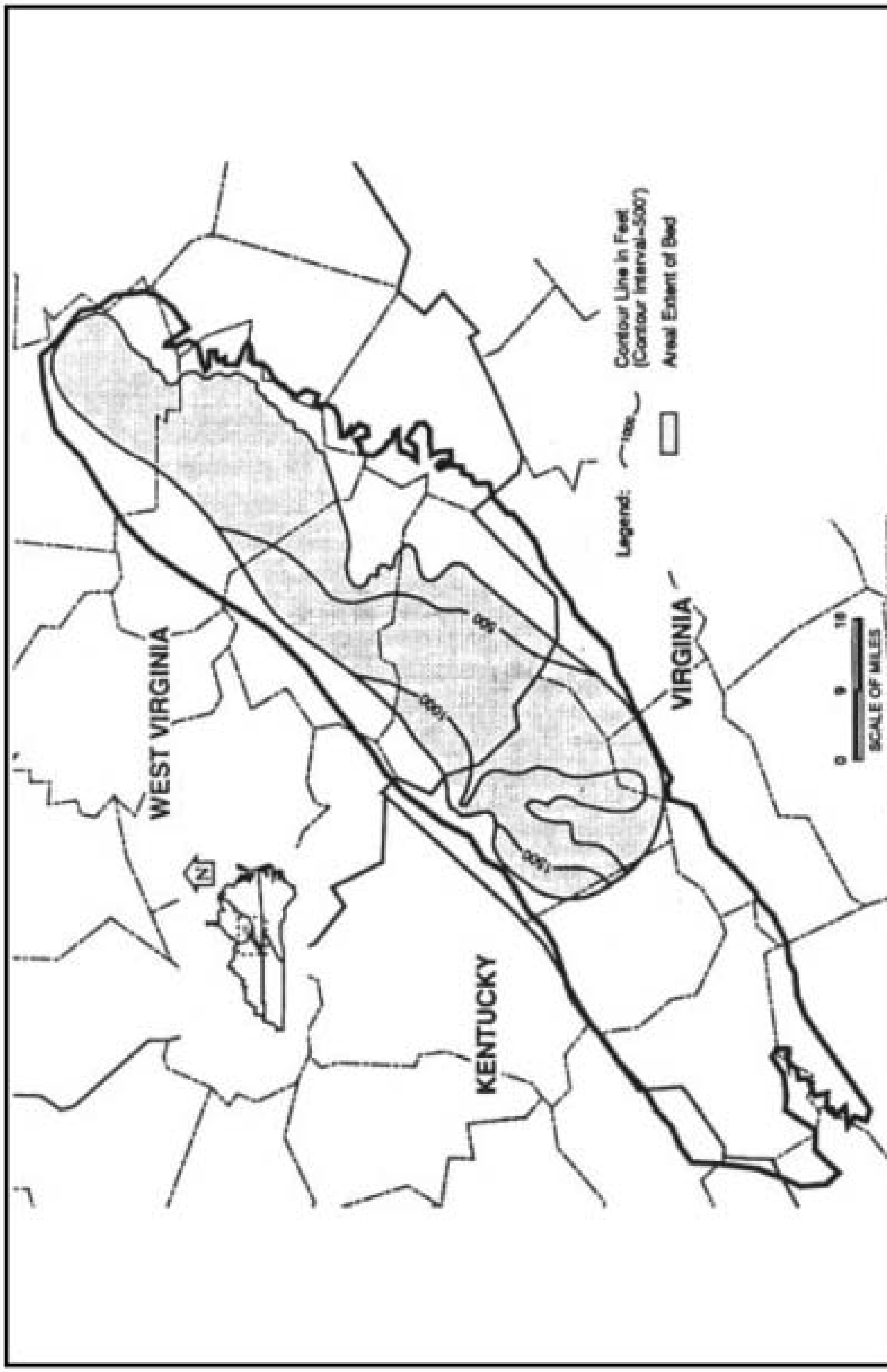


Isopach Map: Thickness of Cover Over the Pocahontas No. 3 Coalbed (Kelafant et al., 1988)

Figure A6-4

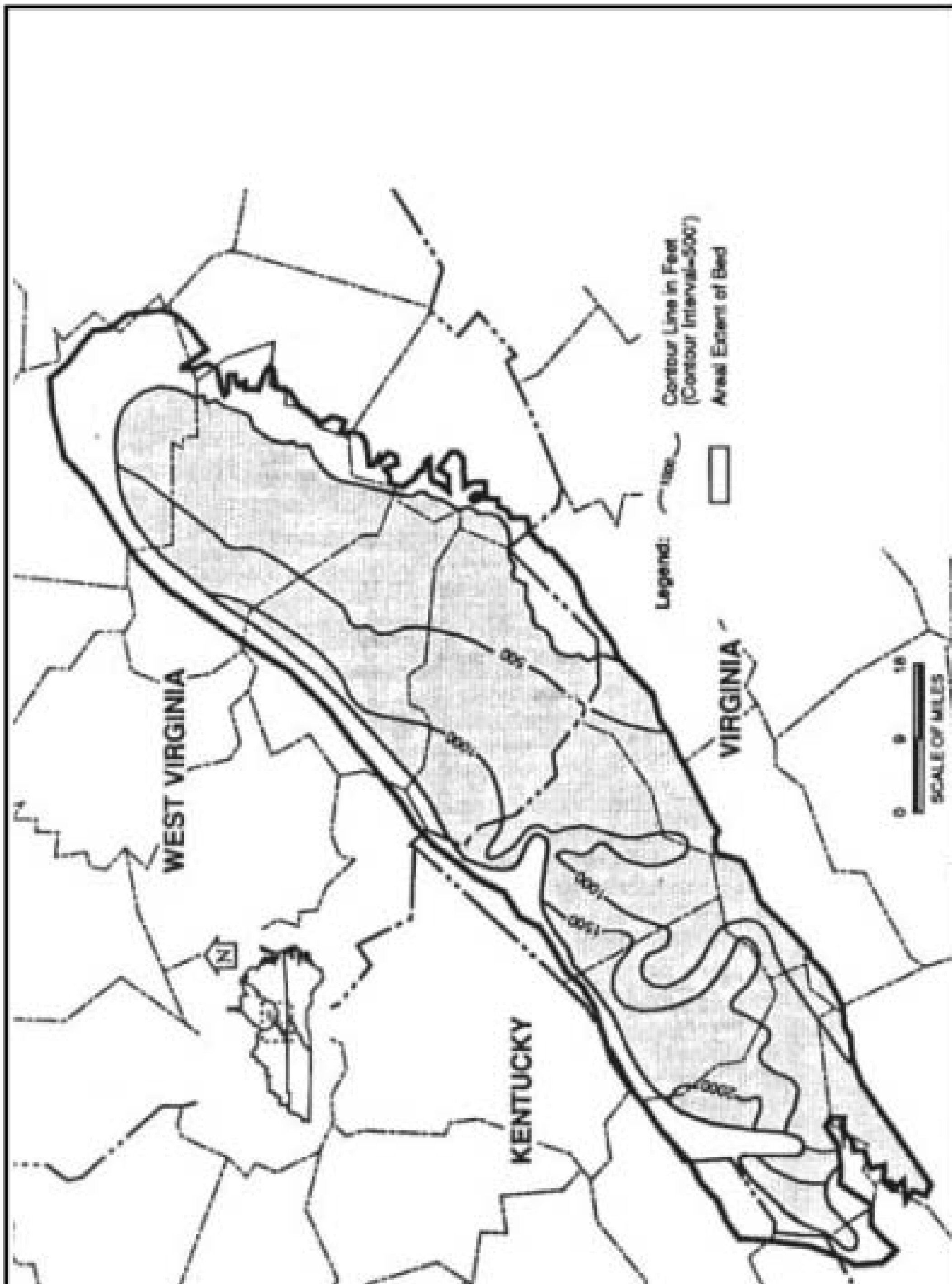


Isopach Map: Thickness of Cover Over the Pocahontas No. 4 Coalbed (Kelafant et al., 1988)



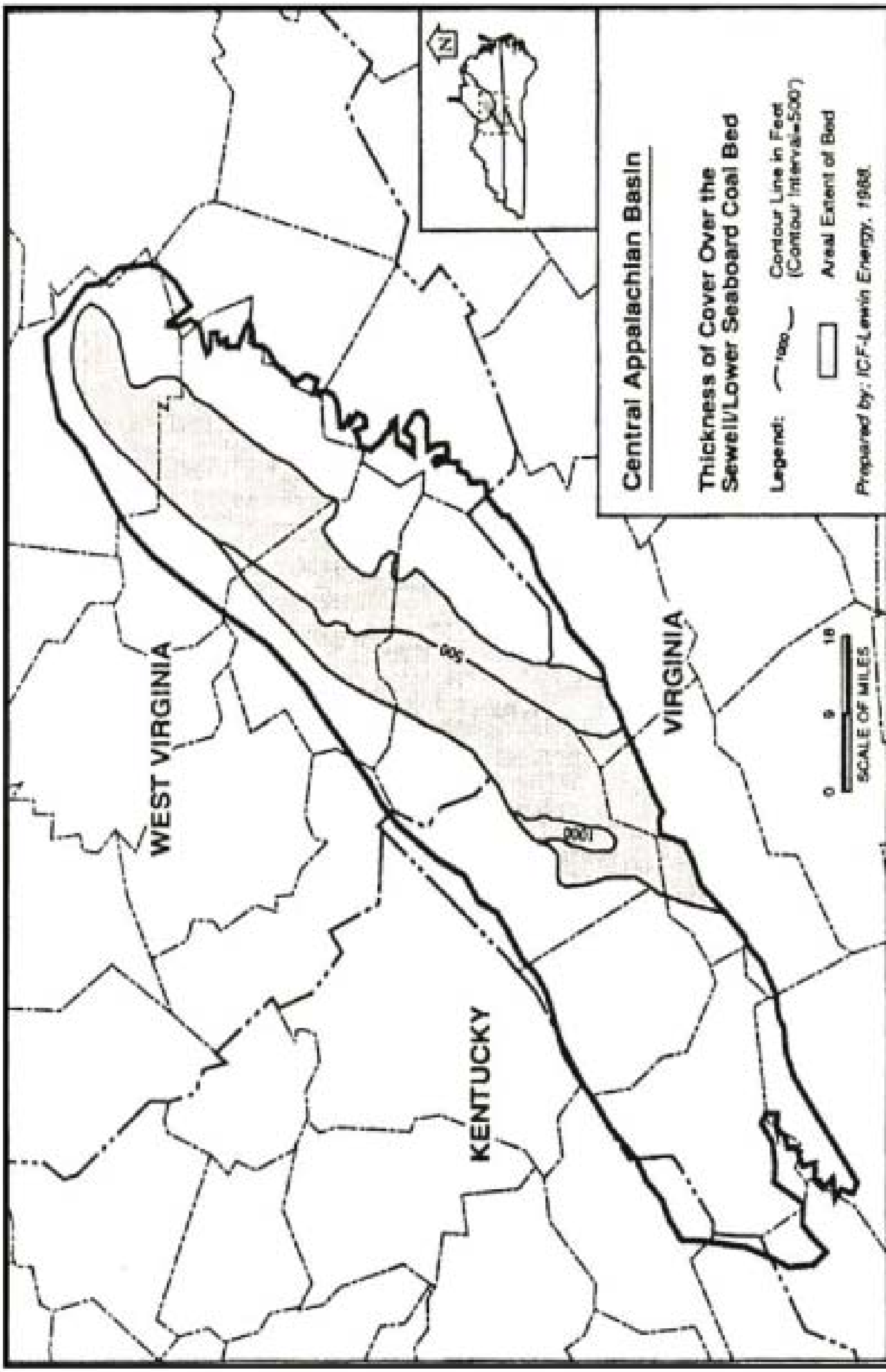
Isopach Map: Thickness of Cover Over the Fire Creek - Lower Horsepen Coalbed (Kelafant et al., 1988)

Figure A6-6



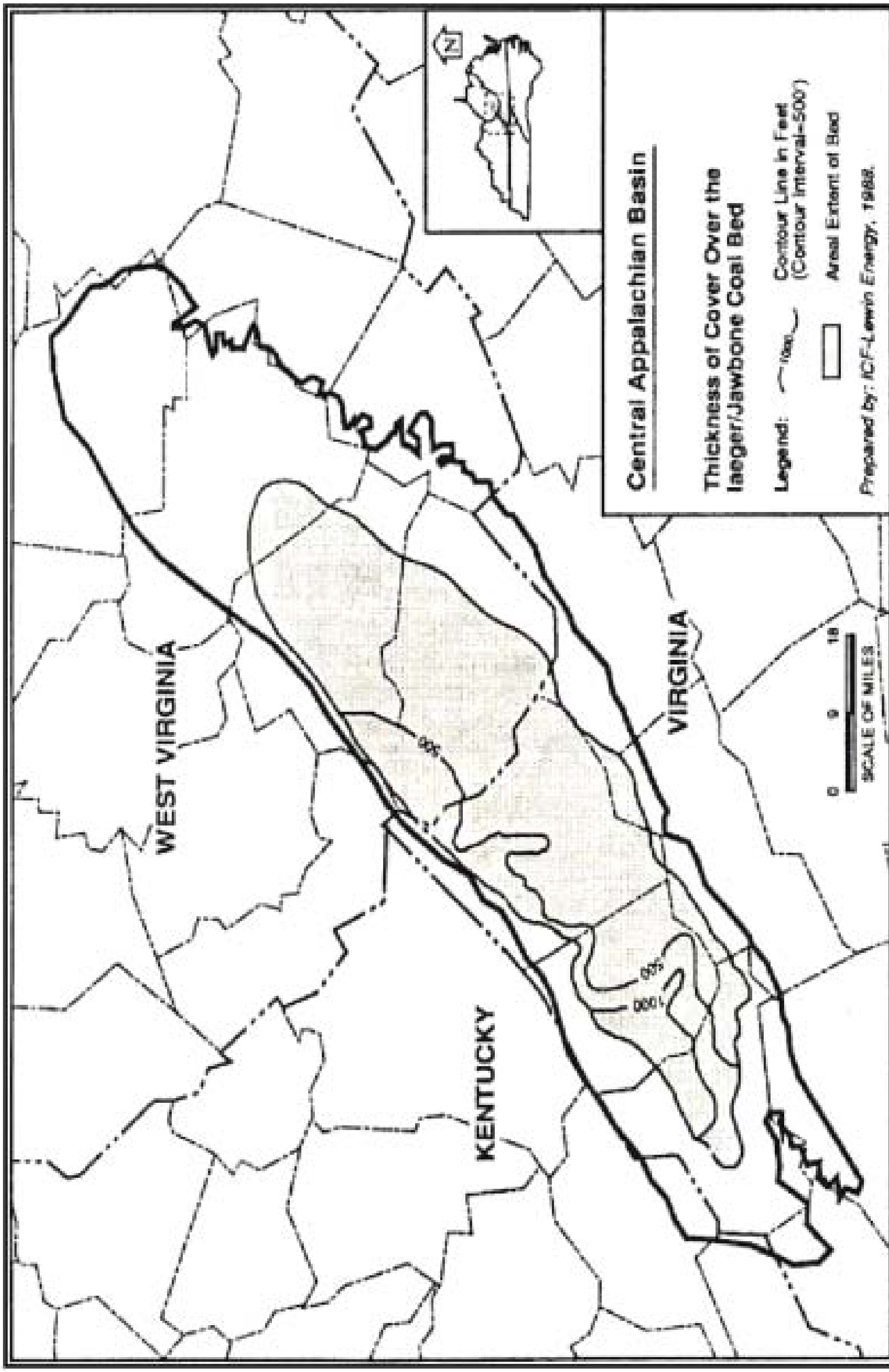
Isopach Map: Thickness of Cover Over Beckley - War Creek Coalbed (Kelafant et al., 1988)

Figure A6-7



Isopach Map: Thickness of Cover Over the Sewell/Lower Seaboard Coalbed
(Kelafant et al., 1988)

Figure A6-8



Isopach Map: Thickness of Cover Over the Leager/Jawbone Coalbed (Kelafant et al., 1988)

Figure A6-8

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