The Betsie Shale Member—A Datum for Exploration and Stratigraphic Analysis of the Lower Part of the Pennsylvanian in the Central Appalachian Basin

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The Betsie Shale Member (Breathitt Formation, Middle Pennsylvanian) is correlated in the Central Appalachian basin by means of gamma-ray logs of oil and gas wells

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The Betsie Shale Member—A Datum for Exploration and Stratigraphic Analysis of the Lower Part of the Pennsylvanian in the Central Appalachian Basin

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Abstract

An upward-coarsening bay-fill sequence of mostly shale and siltstone, here named the Betsie Shale Member of the Breathitt Formation, can be identified in gamma-ray logs of oil and gas test wells in much of the Central Appalachian basin. The relatively high radioactivity of the basal part of the shale is most conspicuous in the deeper and poorly known parts of the Pennsylvanian section within and northwest of the Cumberland overthrust sheet in Tennessee, Kentucky, and Virginia. The Betsie is in the lower part of the Middle Pennsylvanian sequence, and this position makes the Betsie invaluable as a datum for coal exploration of that part of the section, as well as for regional stratigraphic analyses of the controversial Lower and Middle Pennsylvanian quartz arenites.

INTRODUCTION

Geologic mapping in southeastern Kentucky has identified a distinctive thick marine shale and siltstone unit in the lower part of the Middle Pennsylvanian. This unit, the Betsie Shale Member (new name), is an upward-coarsening bay-fill sequence as much as 150 ft (46 m) thick that occurs above the Matewan, Clintwood, Hance, or equivalent coal beds or coal zones in a large part of the Central Appalachian basin. In many geologic reports for southwestern West Virginia (for example, Hennen and Reger, 1914) and eastern Kentucky (for example, Trent, 1965), the unit has been informally and, as we will show, incorrectly designated the Cannelton Limestone of White (1885).

This distinctive shale and siltstone unit has been recognized and mapped for many years in outcrop in West Virginia and in easternmost Kentucky and as an important element in the stratigraphic framework of these areas. However, in other parts of the Central Appalachian basin, the unit is in the subsurface, is too poorly exposed, or is not visually distinctive enough to have been recognized and named. Wanless (1946) gave the name Whetstone Creek shale to equivalent strata near Williamsburg, Ky. (fig. 1), and suggested that the dark shale unit (about 71 ft (22 m) thick) was so uniform in bedding, and the occurrence of ironstone bands was so persistent, that the unit must have formed in an extensive body of water such as a large lake or bay.

The probable wide extent of the unit was suggested by Rice and Smith (1980), who correlated the unit as the "Cannelton Shale" from easternmost Kentucky to a sparsely fossiliferous unnamed marine zone in the lower part of the Breathitt Formation along the Cumberland Escarpment in Kentucky on the northwestern margin of the basin. Outcrops of the unnamed marine zone extend about 150 mi (390 km) along the escarpment and occur locally above the Corbin Sandstone Tongue of the Lee Formation or above the overlying coal bed. The correlation of these marine units was based on very sparse surface and subsurface data, and the tentative nature of the correlation was emphasized by the fact that no equivalent unit had been recognized in the thicker stratigraphic sequences of the Middle Pennsylvanian on the Cumberland overthrust sheet in southeastern Kentucky.

Geophysical logs from oil and gas test holes have provided a valuable new source of stratigraphic data for the Pennsylvanian in recent years. Additionally, coal exploration and development programs increasingly have used gamma-ray and bulk density (gamma-gamma) logs for supplemental stratigraphic data and as a backup for traditional lithologic and core logging methods. Such exploration in the vicinity of Middlesboro, Ky. (fig. 1), identified a thick (as much as 140 ft (43 m)) shale sequence at the stratigraphic position of the Betsie Shale Member above the Hance or Bennetts Fork coal zone (Rice and Smith, 1980). Gamma-ray logs of that interval

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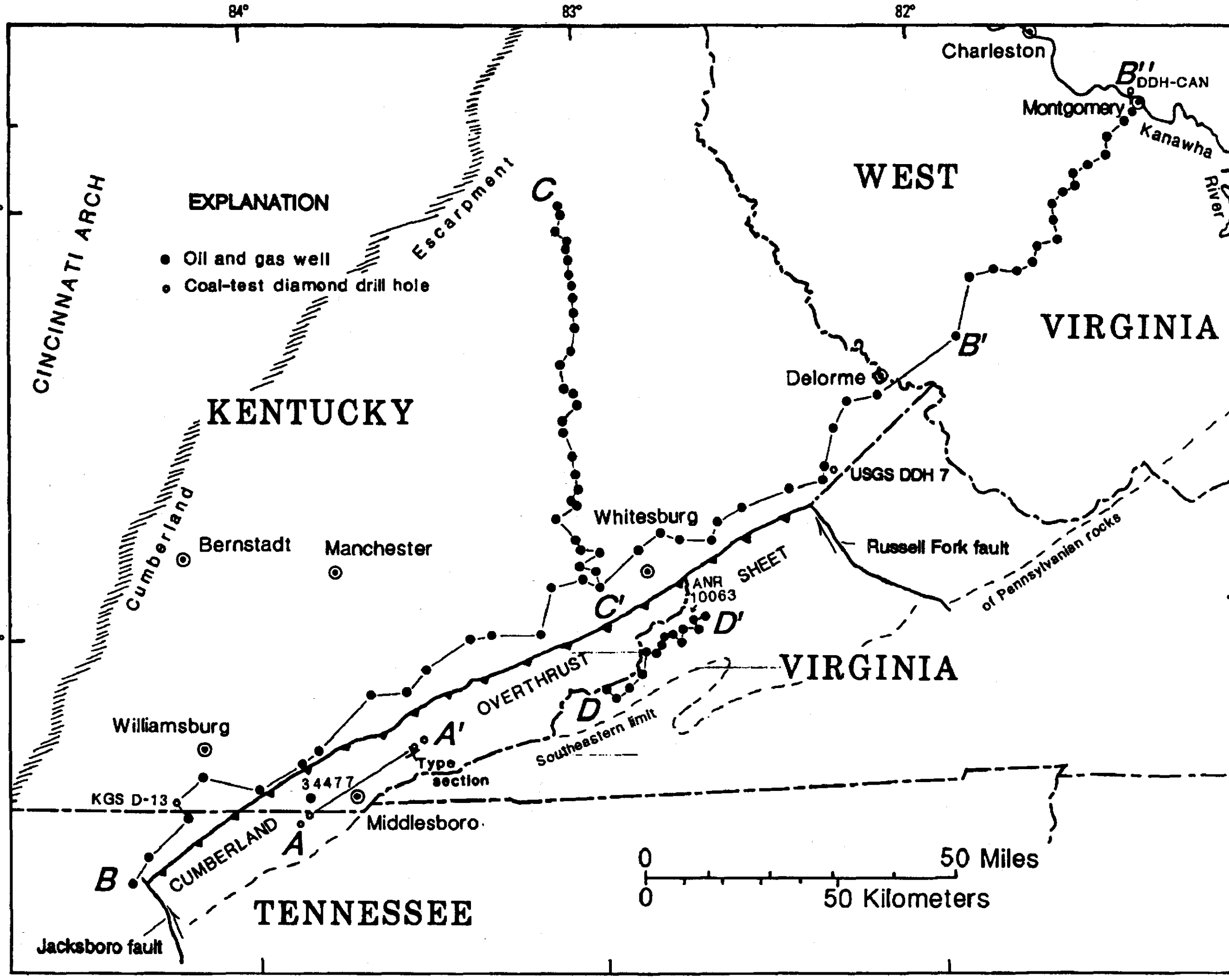

Figure 1. Index map showing locations of sections and wells.

show that the sequence is characterized by a relatively thin basal shale that deflects the curve as much as 100 American Petroleum Institute (API) units above the gray-shale base line (see fig. 2, well 1). In a pioneering subsurface study of coal-bearing Pennsylvanian strata in Kentucky in the area between Manchester and Whitesburg (see fig. 1), Currens (1978) used, almost exclusively, geophysical logs of oil and gas wells to provide subsurface stratigraphic data. Currens traced an unidentified marker bed in his cross sections that was the basal bed of a thick shale sequence distinguished by a high gamma-ray response. Comparison of Currens' sections with the gamma-ray logs from the Middlesboro area suggests that the marker bed and overlying shale sequence are also the Betsie Shale Member. Further study of oil and gas logs confirmed that the Betsie can be recognized by its distinctive gamma-ray signature over a wide area and that its signature is particularly distinctive in the subsurface in the deeper part of the basin northwest of the Cumberland overthrust sheet (Rice and others, 1986). Moreover, our investigations suggest that the member extends throughout the Central Appalachian basin and that its base is a datum unmatched for its usefulness in coal exploration and stratigraphic analysis of the lower part of the Pennsylvanian.

This paper describes the Betsie, illustrates its wide distribution by using several lines of sections, and shows how gamma-ray logs can be used for analysis of the lower part of the Pennsylvanian in the Central Appalachian basin. In respect to the latter, one of the main purposes of the paper is to investigate the subsurface continuity and distribution of sandstone units in the Lee Formation and the equivalent New River Formation to help determine whether these units were deposited in fluvial or marine environments. Because of the importance of the Betsie in developing a coherent stratigraphic framework for the Pennsylvanian, we here formally designate it as the Betsie Shale Member of the Breathitt Formation in Kentucky and Tennessee, of the Kanawha Formation in West Virginia, and of the Wise Formation in Virginia. (In some areas discussed in this report, the Breathitt has been raised to the rank of group; for purposes of consistency and clarity, this report follows the suggestions of Rice (1984a) and McDowell and others (1985) and treats the Breathitt as a formation.) The type section of the Betsie Member (fig. 1) is in exposures above a mine in the Hance coal bed located about 3,200 ft (975 m) north-northwest of Betsie Gap between Blacklick and Coal Stone Branches of Brownies Creek, Varilla 7 1/2-minute quadrangle, Bell County, southeastern Kentucky.

This study is dependent almost completely on the analysis of gamma-ray logs and on the accompanying bulk density logs where available. The gamma-ray log is ideally suited for description of Pennsylvanian strata of the Appalachian basin because these strata consist mostly of sandstone that has low natural radioactivity (producing a left-hand curve deflection; see fig. 2, wells 3 and 4, above the Betsie Shale Member) and of shale that has relatively high natural radioactivity (producing a right-hand deflection). Furthermore, the increase of organic content with the decrease of grain size in these rocks produces a very useful relation. Because uranium (the major radioactive element in the rocks) is associated with the organic material in the shale (Potter and others, 1984), the amount of radioactivity of the rock can be used in general as a measure of its grain size. The strong deflection of the gamma-ray curve at the base of the Betsie shown in figure 2, well 1, is caused by a distinctive 3-ft-thick (1-m-thick) laminated black clay shale bed. The bed contains about 30 ppm uranium (D. McKown and R. Vaughn, written commun., 1986) and probably was deposited in anoxic conditions well below wave base on the floor of a bay. Turekian and Wedepohl (1961) indicate that the average uranium content of shale is 3.7 ppm. Coal beds, which commonly underlie the black shales, were deposited in uranium-poor terrestrial conditions and, like sandstone, may have little natural radiation and a gamma-ray response similar to that of sandstone. As a result, bulk density logs are useful, particularly in analyzing coal-bearing strata and distinguishing coal beds from thin sandstone beds. Coal has approximately half the density of the enclosing rocks, and coal beds produce a low density spike from which bed thickness and even ash content can be estimated. For example, the low density spike in well 1 (fig. 2) about 40 ft (12 m) below the base of the Betsie illustrates a coal bed that has many shale partings. The comparable coal bed in well 2 (fig. 2) is low in ash and free of shale partings. Detailed lithologic logs rarely accompanied the geophysical logs; however, when available, they were useful in the study to confirm lithic interpretations. These lithologic logs were particularly useful for distinguishing the unconformable boundary between Mississippian red and green shales and the overlying Pennsylvanian gray shales.

ACKNOWLEDGMENTS

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DESCRIPTION OF THE BETSIE SHALE MEMBER

Most bay-fill sequences in the Pennsylvanian of the Appalachian basin are upward-coarsening terrigenous clastic accumulations deposited by deltas prograding into a shallow bay or subsiding basin. Such sequences commonly rest directly on a coal bed or on the underlying underclay or seat rock where the coal bed was not preserved. The basal part of the sequences commonly is marked by a dark-gray bioturbated clay shale 1–3 ft (0.3–1 m) thick that represents distal bottomset or toe deposits. The boundary between the bottomset beds and the overlying lighter colored, coarser grained, and more rapidly deposited foreset beds is either sharp or gradational with respect to color or grain size. The delta sequences commonly show an upward thickening of beds and have an upward increase in grain size. Where the entire bay-fill sequence is preserved, the upper part contains beds of flaggy sandstone that represent deposition of the upper parts of the foreset beds at or near the top of the distributary mouth bar (see fig. 5); complete sequences generally are capped by a coal bed. In many places, however, bay-fill sequences are relatively thin (less than 20 ft (6 m) thick) because of truncation of the upper parts by channel-fill sandstone of the overlying progradational fluvial system. Where present, marine fossils and fossiliferous limestone commonly are found in the bottomset dark-gray shales. Limestone concretions that occur in the middle and upper parts of the bay-fill

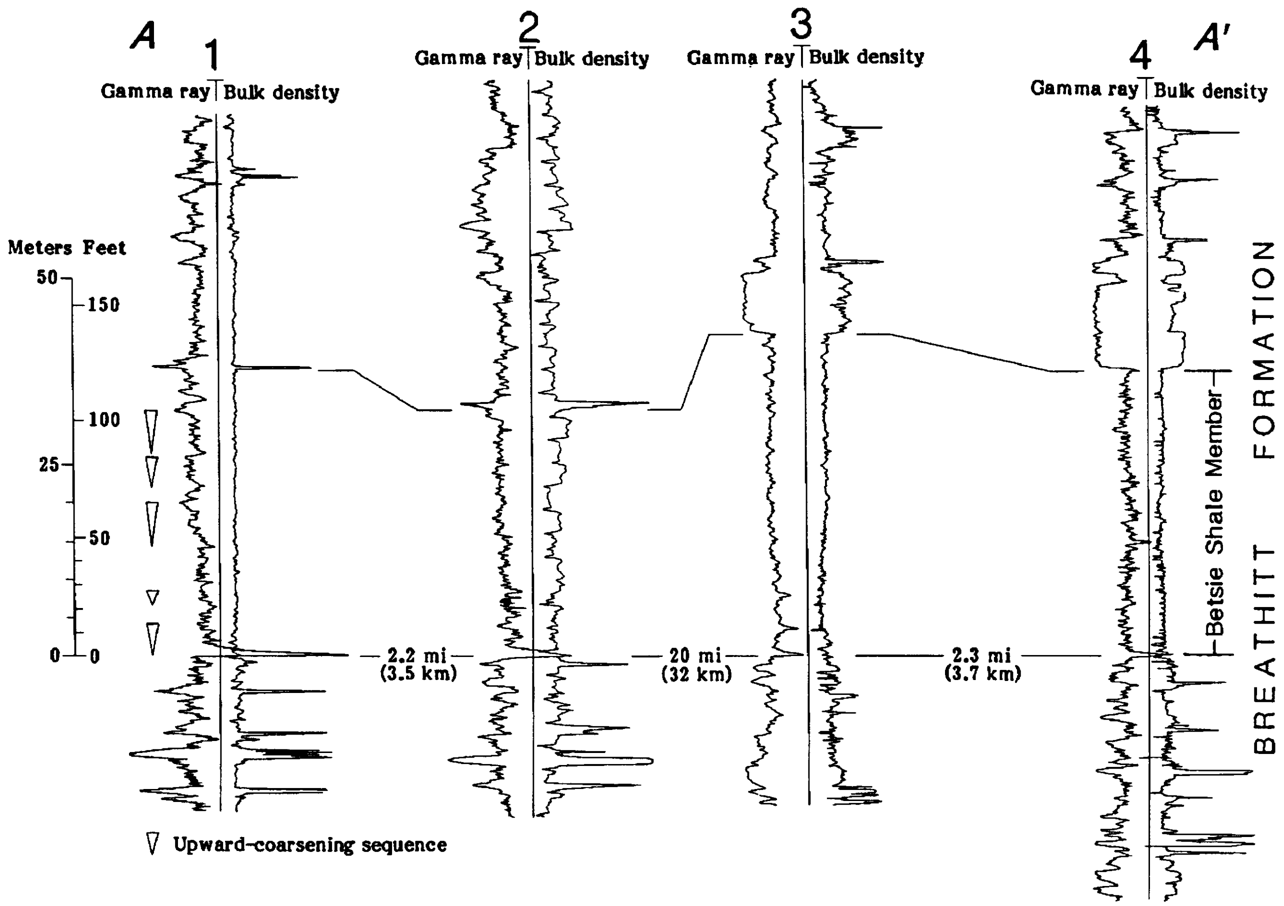

Figure 2. Gamma-ray and bulk density logs of coal-test wells (1–4) in the vicinity of Middlesboro, Ky., showing details of the Betsie Shale Member (see fig. 1 for location of section). Logs show mostly shale. Low bulk density spikes are coal beds. Channel sandstone units cap the Betsie in wells 3 and 4.

sequences are mostly barren of marine fossils. Discontinuous thin lenses or diffused bands of siderite, generally less than an inch (2.5 cm) thick, are common features of the prodelta shales (Weller, 1930).

In general, the Betsie Shale Member follows the foregoing description of marine bay-fill sequences. Figure 2 shows that, in the area of Middlesboro, Ky., the Betsie overlies a coal zone, which consists of as many as six coal beds in an interval as thick as 85 ft (26 m). The Betsie is overlain by a coal bed in wells 1 and 2 and by sandstone in wells 3 and 4 (fig. 2). In the Middlesboro area, the unit is mostly a mudstone, but the gamma-ray logs, particularly of wells 1 and 2, show that the unit not only coarsens upward, but that it consists of five or more upward-coarsening sequences (fig. 2, well 1). The latter sequences cannot be traced between wells or far along the outcrop; they probably result from delta lobe switching or channel avulsion rather than from subsidence or sea-level change.

Field studies suggest that the Betsie Member generally does not contain marine body fossils on the Cumberland overthrust sheet, and not even limestone concretions were observed in the unit in the Middlesboro area. Sparse brachiopods, bivalves, and ostracodes were found in the unit locally in southwestern Virginia; a fragment of the goniatite *Gastrioceras* of probable early Middle Pennsylvanian (late Morrowan) age was identified in the basal dark clay shale of the Betsie in southwestern Virginia about 15 mi (24 km) east of Whitesburg, Ky. (T.W. Henry and M. Gordon, Jr., written commun., 1981). Henry and Gordon (1979) give an extensive list of marine taxa from collections from the type locality of the Eagle Limestone of White (1891) near Montgomery, W. Va. (fig. 1); we project the Eagle to be equivalent in part to the Betsie Shale Member (see fig. 11). In other parts of the Appalachian basin, marine fossils generally are sparse in the Betsie. The basal, highly radioactive bed illustrated in well 1 (fig. 2) contains masses and disseminated grains of pyrite and, locally, pyritized plant material. These contents indicate deposition in anoxic conditions.

Figure 3 shows the type section of the Betsie Shale Member in its entirety in the highwall above the proposed entrance of a new mine that is being developed in the

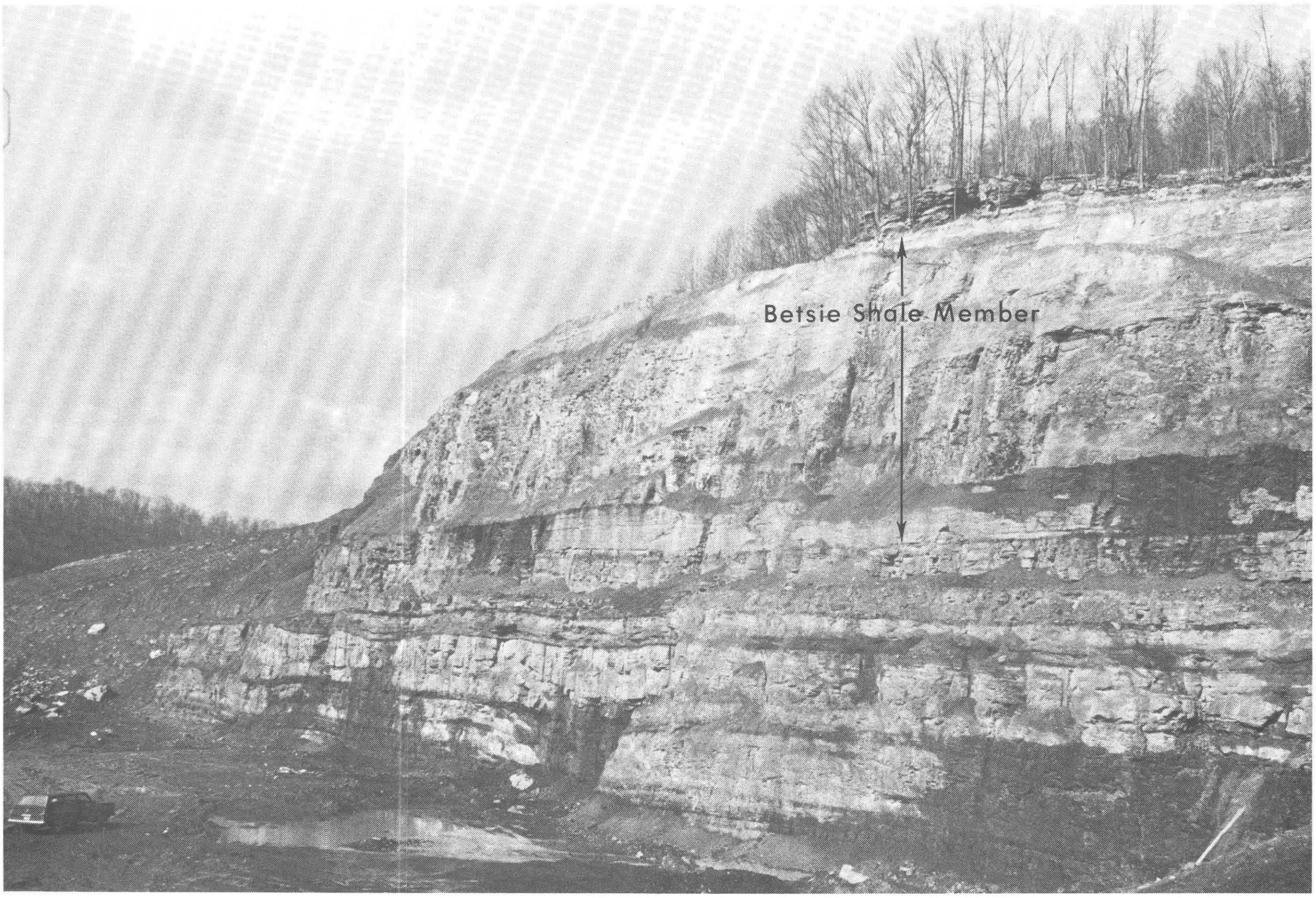

Figure 3. Highwall above new coal mine east of Oaks on Brownies Creek, Varilla quadrangle, Ky., showing the type section for the Betsie Shale Member of the Breathitt Formation on the Cumberland overthrust sheet. Top of the Betsie is base of sandstone-filled channel at tree line at top of highwall.

Lower Hance coal bed about 3/4 mi (1.2 km) east of the community of Oaks on Brownies Creek, Varilla quadrangle, Kentucky. The member is here about 140 ft (43 m) thick and consists mostly of a dark-gray silty shale having thin laminae and lenses of siltstone and very fine grained sandstone. The strata in the highwall show a close correspondence with the geophysical logs illustrated in well 3 (fig. 2), which is only about 500 ft (152 m) east of the highwall. Directly underlying the Betsie (figs. 3, 4) is a rooted silty sandstone about 10 ft (3 m) thick. Locally, a thin film of coal separates the sandstone from the overlying shale of the Betsie Member. The basalmost upward-coarsening unit of the Betsie is a dark clay shale or siltstone that is also about 10 ft (3 m) thick and that contains irregular, flat concretions of siderite 1–2 in. (2.5–5 cm) thick. The basal unit is overlain by a second upward-coarsening sequence that is clearly illustrated in figures 2 (well 3), 3, and 4. Because of homogeneity of overlying lithologies, other such sequences in figures 3 and 4 are impossible to distinguish. The upper part of the Betsie shown in figure 4 is mainly a siltstone; the member is overlain by a 25-ft-thick (8-m-thick), medium-grained, crossbedded sandstone. Figure 5 depicts a haul road section about 0.75 mi (1.2 km) northeast of the outcrop in figure 3 and shows the proximal flaggy sandstone facies in the upper part of the Betsie where the Betsie is truncated by a sandstone-filled channel. An easily accessible reference section for the Betsie, similar to those sections shown in wells 1 and 2 (fig. 2), is found in the highwall behind the Bell County High School about 6 mi (10 km) north of Middlesboro, Ky., on the eastern side of U.S. Highway 25E.

DISTRIBUTION AND STRATIGRAPHIC ANALYSES

Four lines of sections have been constructed by using gamma-ray logs to illustrate the continuity and distribution of the Betsie Shale Member and to show its usefulness for stratigraphic analysis in the Central Appalachian basin. Only a small percentage of the oil and gas test holes have been logged by gamma-ray methods in the study area, and only the deeper parts of the Paleozoic

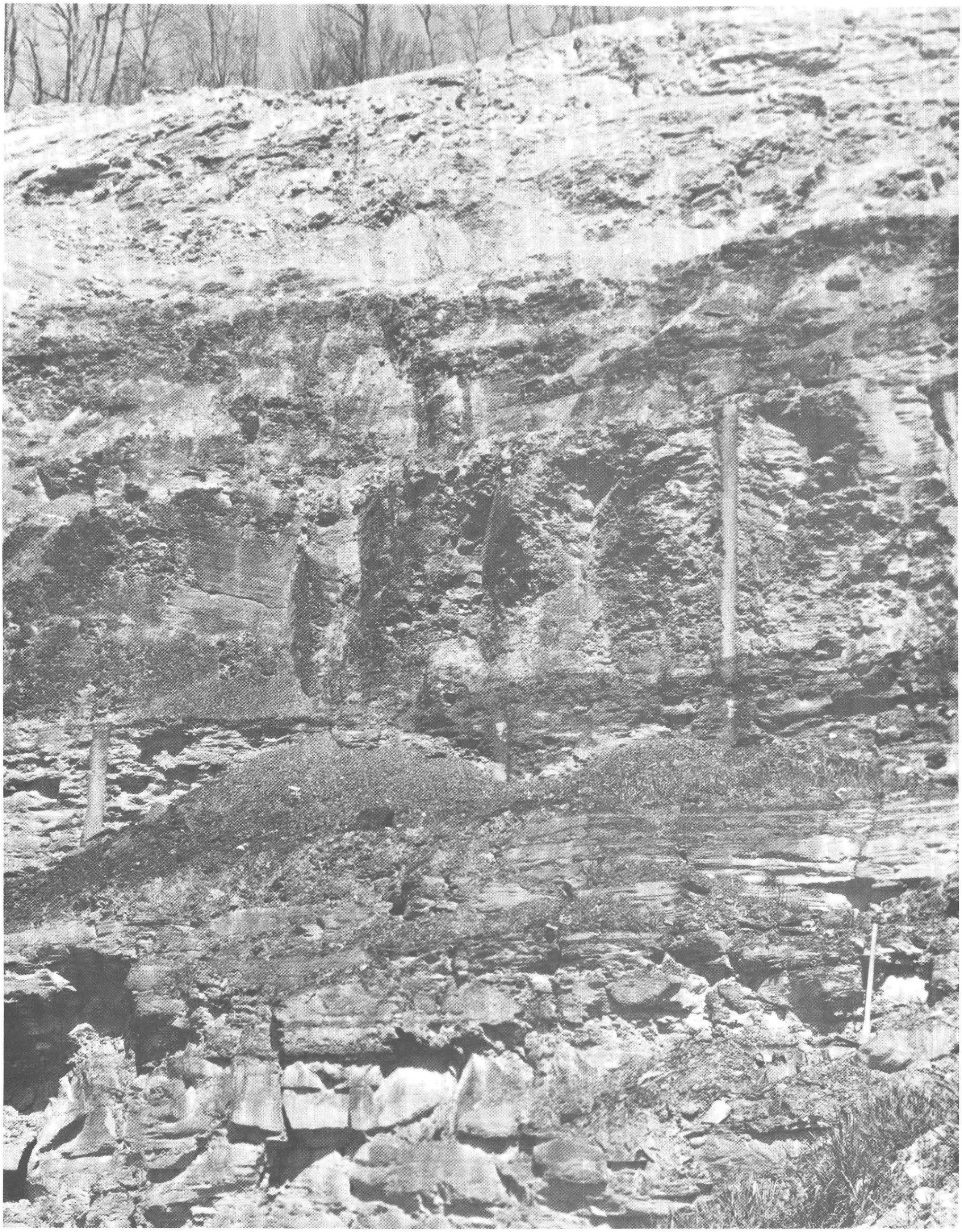

Figure 4. Closeup of the type section showing the base of Betsie Shale Member (base of mattock) over a rooted silty sandstone. The basal unit, about 10 ft (3 m) thick, coarsens upward to base of second upward-coarsening unit (see left side of photograph).

Figure 5. Haul road about 0.75 mi (1.2 km) northeast of the type section of the Betsie Shale Member showing the proximal flaggy sandstone facies in the upper part of the Betsie where the member is truncated by a sandstone-filled channel.

section were logged in many of these holes. All available records were used in the construction of the sections; most records were taken from the public files of the State geological surveys, and all are identified for reference purposes. Differences in quality of the logs are due largely to differences of logging speed and calibration; gamma-ray logs of holes lined with steel casing lose precision but are used here in the absence of better data. Reduction to publication scale of slowly run logs, such as coal-test logs that have large vertical scales, results in a horizontal compression that is hard to read and that misrepresents the excellence of the log. Where well records include the bulk density logs, we show our interpreted positions of coal beds.

Section *B–B'*

Figure 6 shows gamma-ray logs of wells extending from northeastern Tennessee to southwestern West Virginia (fig. 1) located on the autochthonous plate as close to the Cumberland overthrust sheet as data allowed. The subsurface Pennsylvanian strata virtually were unstudied by previous work in this area. The datum in this cross section, as well as in the other cross sections, is the radioactive marker bed at the base of the Betsie Shale Member. The gamma-ray logs suggest that the Betsie, which is below drainage in much of southeastern Kentucky, is 50–150 ft (15–46 m) thick. The identification of the Betsie in the logs of figure 6 is certain; however, for corroboration, the base of the Kendrick Shale Member (Breathitt Formation and equivalent strata), which occurs 550–750 ft (166–229 m) above the Betsie, also is identified in the well logs. Pennsylvanian strata form a southeastward-thickening wedge, and thickness variations of the interval between the base of the Betsie and the base of the Kendrick are due largely to the relative position of the wells with respect to this wedge.

The base of the Pennsylvanian in the study area is an unconformity; only the upper 100 ft (30 m) or so of Mississippian strata are shown in figure 6. The line of section appears to cross several paleovalleys cut into Mississippian strata at the base of the Pennsylvanian. The largest and deepest paleovalley has its axis near wells 20457 and 33267 (fig. 6). That feature has been interpreted as a paleovalley (Rice, p. 13, 1984b) and named the Middlesboro Valley (Rice, 1985). The quartz arenites (greater than 95 percent quartz) of the Lee Formation and equivalent strata are shaded in figure 6 (as well as in figs. 7, 8, and 10) to distinguish them from silty sandstone and finer grained rocks and to help emphasize their depositional character. More than 90 percent of the quartz arenite units have sharp bases and become finer grained upward. These two characteristics commonly are associated with fluvial deposits. The available bulk density logs show that coal beds occur within and commonly between the major quartz arenite units. The irregularity of the top and bottom of the Lee strata and the lack of continuity of units within the Lee Formation and equivalent formations give added value to the Betsie as a datum for analyses of that part of the Pennsylvanian section. The interval between the base of the Betsie and the base of the Kendrick (see Rice and others (1979) for the overlying stratigraphic interval) is relatively constant along the line of section *B–B′*, whereas the underlying Pennsylvanian stratigraphic intervals expand to the northeast. This difference suggests that the axis of the depositional basin shifted slightly from a more northerly orientation during earlier Pennsylvanian time to an orientation after deposition of the Betsie Member that is more closely parallel to the present structural grain, as represented by the orientation of the northwest edge of the Cumberland overthrust sheet. Englund and others (1979, 1985, 1986), Ferm (1974), and Miller (1974) have interpreted the quartz arenites of the Lee Formation as linear barrier, beach, or offshore-bar deposits oriented northeast-southwest that intertongue westward or northwestward with marine deposits. Figure 6, however, suggests a terrestrial environment of deposition for these rocks where the quartz arenites alternate with relatively thin coal-bearing sequences of shale and siltstone. Given a fluvial interpretation for deposition of the Lee strata, the lack of continuity of the quartz arenite units suggests that section *B–B′* was oriented obliquely to transport direction.

Section *B′–B″*

Figure 7 shows the extension of the Betsie Shale Member into the type area of the Cannelton Limestone of White (1885), which is just across the Kanawha River from Montgomery, W. Va., and the Eagle Limestone of White (1891), which is about 2 mi (3.2 km) south-southeast of Montgomery (fig. 1). The Cannelton and Eagle units designate key marine horizons of Middle Pennsylvanian age that have been used extensively for regional correlation (Wanless, 1939). In the type area and as identified in drill hole DDH–CAN, the Cannelton occurs 45–50 ft (13.7–15.2 m) above the Eagle coal bed, and the Eagle Limestone occurs 90–100 ft (27.4–30.5 m) below the Eagle coal bed (see fig. 11 and Hennen and Teets, 1919). Although the name Cannelton has been applied to strata here identified as the Betsie Shale Member in southwestern West Virginia and easternmost Kentucky, figure 7 shows that the Betsie is stratigraphically below the Eagle coal bed and that the Betsie probably includes strata identified by White (1891) as Eagle Limestone. The position of the Eagle coal bed in the oil and gas wells (fig. 7) is projected from nearby outcrop or drill hole data and is also confirmed by open-file structure contour maps and coal bed maps constructed by the Coal Resources Group of the West Virginia Geological and Economic Survey. Those maps, at 7 1/2-minute-quadrangle scale, indicate that some coal beds have been miscorrelated in the County Reports across the Boone (Krebs and Teets, 1915) and Logan County (Hennen and Reger, 1914) boundary in the area of section *B′–B″* (M. Blake and A. Keiser, oral commun., 1986). The section (fig. 7) illustrates the difficulty in recognizing and tracing thin stratigraphic units by gamma-ray logs into marginal parts of the basin that are strongly influenced by sandstone deposition in delta plain environments. The Betsie locally is less than 30 ft (9.1 m) thick northeast of well 955 in Boone County (fig. 7) and would be difficult to trace in the wells without outcrop and core hole data.

Section *C–C′*

Section *C–C′* (figs. 1 and 8) extends almost due north in Kentucky away from the axis and toward the thinnest part of the depositional basin. The Betsie, the base of which is the datum, is increasingly more difficult to identify northward because the unit thins from about 125 ft (38 m) at the southern end to locally only a few feet thick at the northern end of the section. The base of the Kendrick Shale Member is identified in the logs, as it was in figure 6, to reinforce the identification of the Betsie in the well logs. An extensive unnamed fossiliferous marine zone is reported to directly overlie the Lee quartz arenites in the area, particularly north of point *C* (for example,

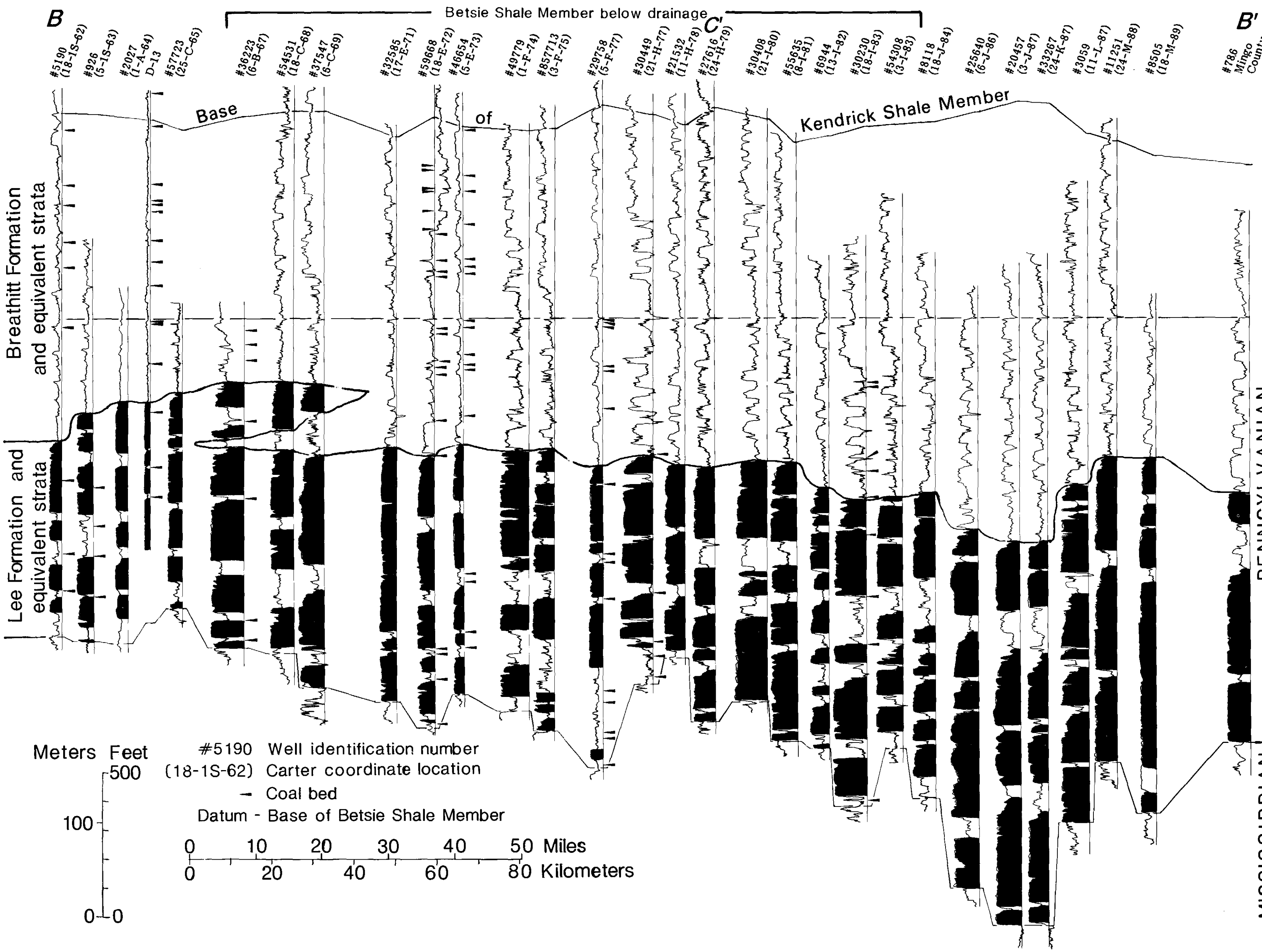

Figure 6. Gamma-ray logs of wells extending from northeastern Tennessee northeastward to southwestern West Virginia (see fig. 1 for location of section). The quartz arenite units of the Lee Formation and equivalent strata are shaded to show their sharp bases and upward-fining habit. Coal beds are indicated by wedge marks where data were available from bulk density logs.

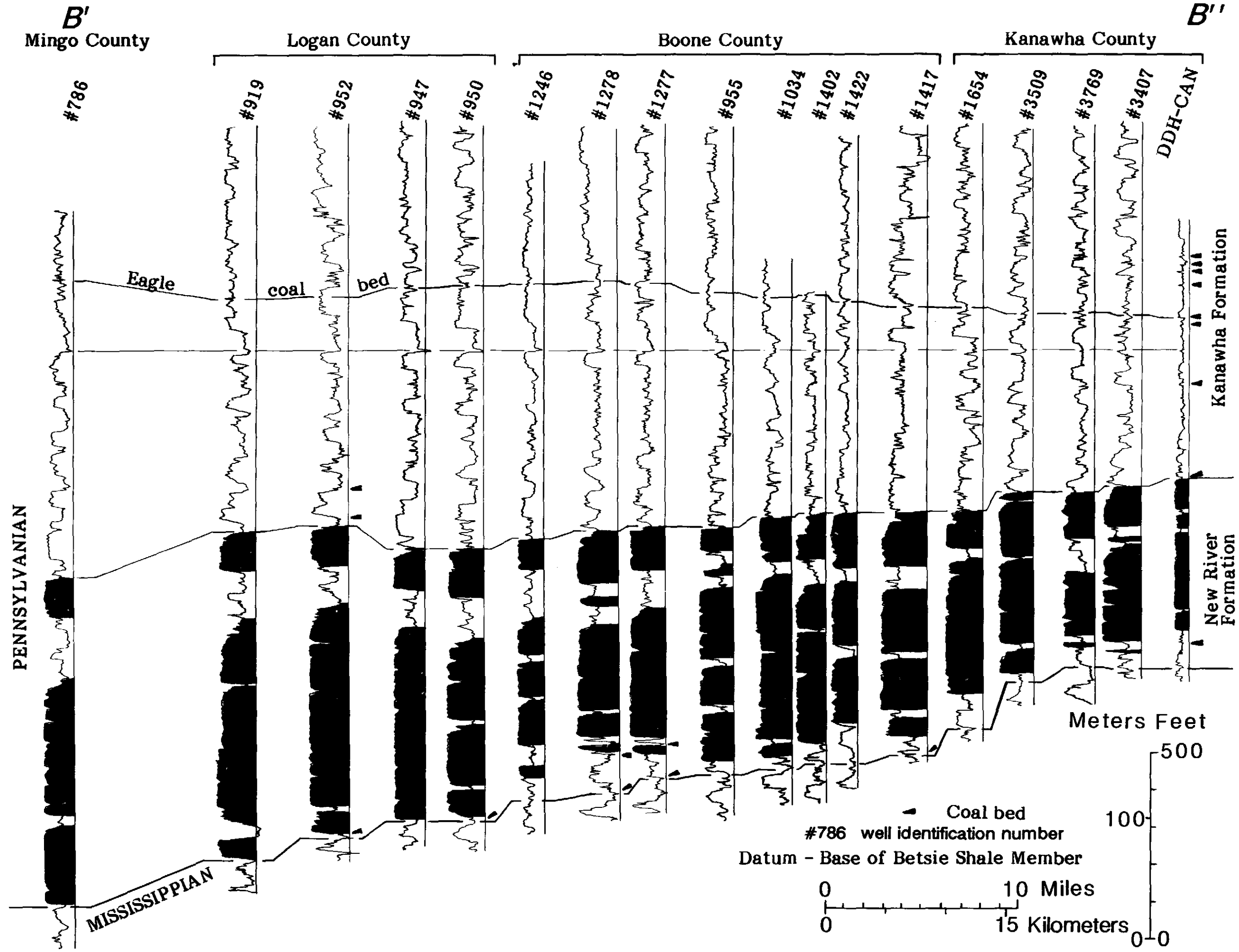

Figure 7. Gamma-ray logs showing the correlation of the Betsie Shale Member of the Kanawha Formation from southwestern to central West Virginia. Note that this figure is an extension of figure 6 (common *B'*) (see fig. 1 for location of section). The quartz arenite units of the New River Formation are shaded.

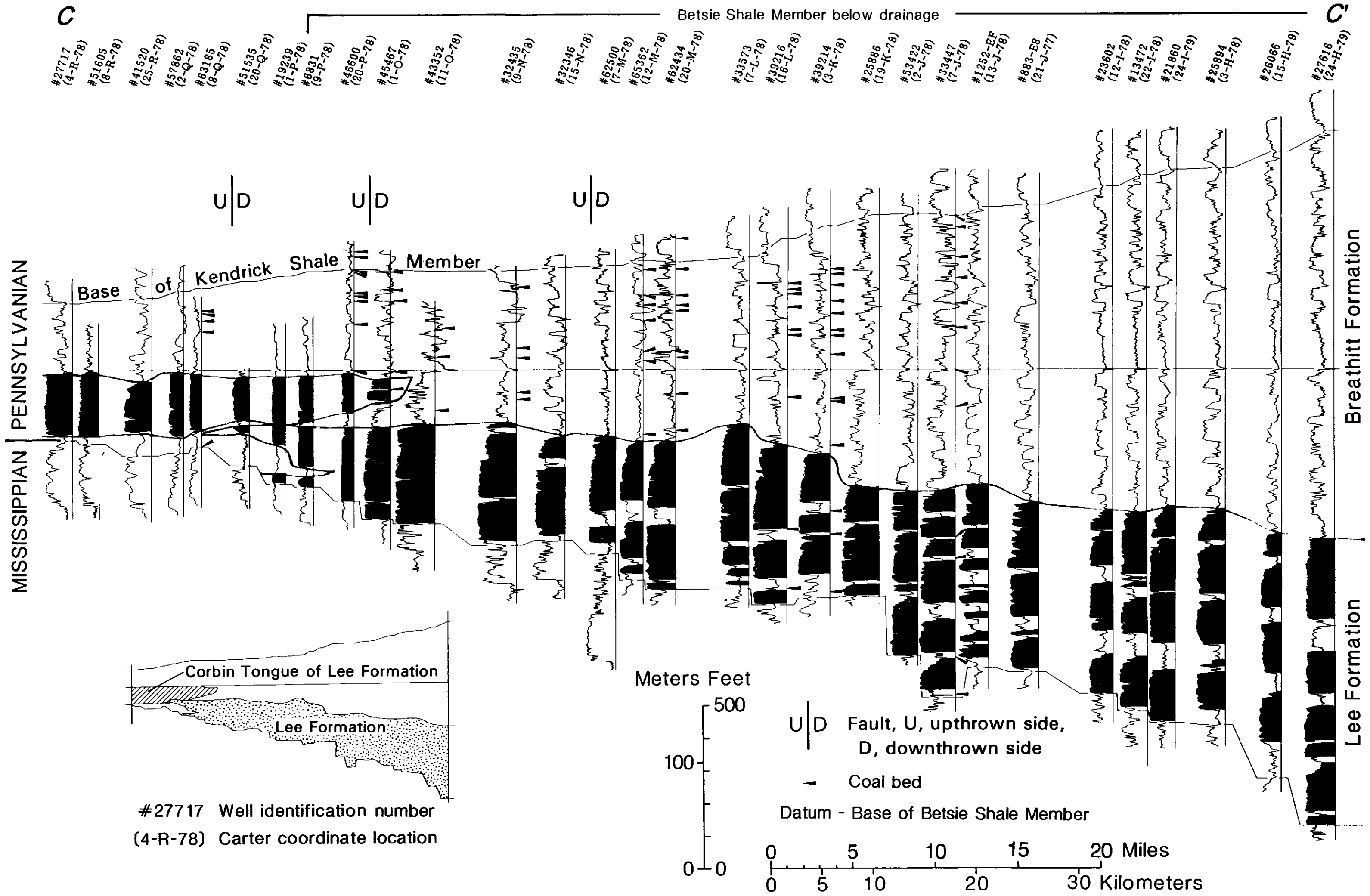

Figure 8. A line of gamma-ray logs of wells extending into northeastern Kentucky showing northward thinning of the Pennsylvanian section and onlap of the underlying eroded Mississippian surface (see fig. 1 for location of section). Quartz arenites of the Lee Formation are shaded. The main body of the Lee pinches out north of well 51535; the overlying tongue of the Lee just below the Betsie is the Corbin Sandstone Tongue of the Lee Formation. Upper Mississippian strata, consisting largely of limestone below and shale above, are shown in their entirety north of well 62500; the few feet of shale indicated below the limestone belongs to the Borden Formation, Early Mississippian in age. No Upper Mississippian strata are present in well 45467.

Englund and Delaney, 1966); our cross section shows this marine unit to be the Betsie Shale Member.

Figure 8 includes the Mississippian-Pennsylvanian unconformity, which truncates progressively older rocks northward, and shows the northward intertonguing of the Lee and Breathitt Formations (see also fig. 9). The entire Upper Mississippian section (Slade and Paragon Formations, equivalents of the Greenbrier Limestone and the Mauch Chunk Formation; see Ettensohn and others, 1984) is shown in well 62500 and north of the well to illustrate the effects of faulting on preservation of Mississippian strata and Pennsylvanian deposition. Limestone, like sandstone, generally produces little natural radioactivity and produces a left-hand deflection of the gamma-ray curve with respect to shale. The few feet of shale shown below the Mississippian Slade limestone in these logs belong to the upper part of the Borden Formation (Lower Mississippian, fig. 9). The faults shown crossing the section in figure 8 are oriented approximately east-west and represent reactivation of a fault system associated with the Rome trough (McDowell, 1986). Wanless (1946, fig. 1) suggested that the northernmost fault was a major hingeline, and Horne (*in* Smith and others, 1971, fig. 1) characterized the faults as growth faults that had significantly greater sediment accumulation during the Pennsylvanian on the southern or downthrown sides of the faults. Although the Upper Mississippian strata show a great variation in thickness in the faulted area (no Upper Mississippian strata are present in well 45467), the Pennsylvanian strata appear to thicken more or less uniformly southward irrespective of the unconformity at the base.

The Lee Formation as shown at *C'* (fig. 8) is approximately equivalent to the New River Formation of West Virginia. The top of the New River Formation is, by definition, the boundary between the Lower and Middle Pennsylvanian Series. Figure 8 shows the main body of the Lee strata both onlapping the eroded Mississippian surface and thinning northward, pinching out north of well 51535. The upper tongue of the Lee at the north end of section *C–C'* is the Corbin Sandstone Tongue; it is also a quartz arenite, and it pinches out in the section south of well 45467. The Corbin is Middle Pennsylvanian in age and locally rests unconformably on the Slade Formation north and west of section *C–C'*.

Figure 8 shows that the Corbin Tongue, in part, directly overlies the main body of the Lee, a relation that was surmised but never before demonstrated. Transport directions and bed geometries indicate that the Corbin was deposited by west-flowing streams in the area of the section, whereas the main part of the Lee was deposited by southwest-flowing streams (Rice, 1984b). Thus, the two quartz arenite units diverge westward of section *C–C'* to a point along the Cumberland Escarpment outcrop belt. There the Corbin diverts southward along the eastern flank of the Cincinnati Arch and again crosses the northwestern pinchout of the main body of the Lee (the Rockcastle Conglomerate Member of the Lee Formation) in the area near Bernstadt, Ky. (Hatch, 1963) (see fig. 1 for location). In that area, the Corbin is as much as 240 ft (73 m) above the top of the Rockcastle Member and about 425 ft (130 m) above the top of the Mississippian (Paragon Formation).

Section *D–D'*

Section *D–D'* (figs. 1 and 10) is located on the Cumberland overthrust sheet and extends down the axis of the previously described Middlesboro paleovalley. Gamma-ray logs of wells penetrating the Betsie Shale Member and the lower part of the Pennsylvanian could not be found for the area northeast of *D'* in Virginia or southwest of *D* to near Middlesboro, Ky. The Betsie is easily recognized in the figure as a shale locally more than 150 ft (46 m) thick that has a strongly radioactive bed at its base. The position of the member in the area of section *D–D'* has been confirmed by surface mapping by the Virginia Division of Mineral Resources. In southwestern Virginia, the member is in the middle of an important coal-bearing sequence that includes many named and mined coal beds; in much of the adjacent area of southeastern Kentucky, this stratigraphic interval is in the subsurface and is very poorly known. The basal Betsie datum also is helpful in identifying the thin Gladeville Sandstone, which is easily confused with other more prominent sandstones in this area. The apparent continuity of the quartz arenite units of the Lee Formation in section *D–D'* suggests that the line of the section is nearly parallel to transport direction (BeMent, 1976).

DISCUSSION AND CONCLUSIONS

Pennsylvanian stratigraphers face many important nomenclatural problems in the Central Appalachian basin where one coal bed or marine zone easily might be mistaken for some other. A case in point is the confusion of the identity of the Cannelton Limestone of White (1885) and the Eagle Limestone of White (1891) as they have been projected from the type area along the Kanawha River into southwestern West Virginia and eastern Kentucky. The magnitude of the error introduced by those miscorrelations is evident by comparing drill logs for holes DDH–CAN and USGS DDH 7 (fig. 11). These logs show that the Eagle coal bed of central West Virginia correlates with the Pond Creek coal bed of eastern Kentucky and not with the coal bed about 330 ft (100 m) below, labeled "Eagle." These correlation problems stem largely from a lack of knowledge of the geometry and stratigraphic relations of units within the lower part of the Middle Pennsylvanian and a lack of an easily recognizable reference horizon in the Lower Pennsylvanian. Here, most Early and Middle Pennsylvanian strata are in the subsurface and previously have been known primarily from widely separated outcrop belts. Coal beds, which traditionally have been used as stratigraphic datums in regional framework studies, unfortunately are less persistent in this part of the Pennsylvanian section.

Figure 11 represents the lower part of the Pennsylvanian as a line of section across the central part of the basin from a point near the Kentucky-Tennessee State line northeastward to the Kanawha Valley in central West Virginia (see fig. 1 for location of wells). The figure indicates the great variation in thickness of the Pennsylvanian and shows the uncertainty of regional correlation because of the discontinuity of coal beds and the complexity of coal zones. Huddle and Englund (1966) previously suggested a regional subdivision of the Breathitt Formation in Kentucky and the Kanawha Formation in West Virginia at the horizon of the Harlan (Alma) coal bed, but that bed is not present or cannot be distinguished easily in many parts of the basin and may be miscorrelated across West Virginia. In figure 11, no attempt is made to illustrate the complexity of the top of the Lee or New River Formations. Wanless (1946) recognized that the regionally applied subdivisions of the quartz arenites of the lower part of the Pennsylvanian in Kentucky, Tennessee, and Virginia could not be correlated from region to region and that the tops of sandstone units differed in age from place to place. Many of these relations are still in question.

Although other Pennsylvanian marine or marginal marine units have similar gamma-ray log signatures, none is as distinctive or as thick or has as wide a distribution as the Betsie Shale Member. The Betsie is the one continuous and easily recognizable datum that can be used confidently for coal exploration in the deeper part of the basin and that may result in a comprehensive understanding of this part of the Pennsylvanian section. The use of gamma-ray logs that include the Betsie makes possible subsurface studies that will provide new insights with respect to the relation of Pennsylvanian sedimentology and tectonics in the Central Appalachian basin. For instance, the lithologic sequences illustrated in the gamma-ray logs of sections *B–B′* and *C–C′* (figs. 6 and 8) do not support arguments (Ferm, 1974) that the quartz arenites of the lower part of the Pennsylvanian are beach or longshore barrier-bar deposits that border land to the southeast and intertongue northwestward with marine strata. The logs do indicate that the quartz arenites are upward-fining channel deposits that have limited lateral continuity; these characteristics suggest a fluvial environment of deposition. Furthermore, the logs suggest that the channels became the sites of peat accumulation when filled with sand and then abandoned and that formation of coal beds of the Lee Formation therefore may be controlled by pre-existent channels.

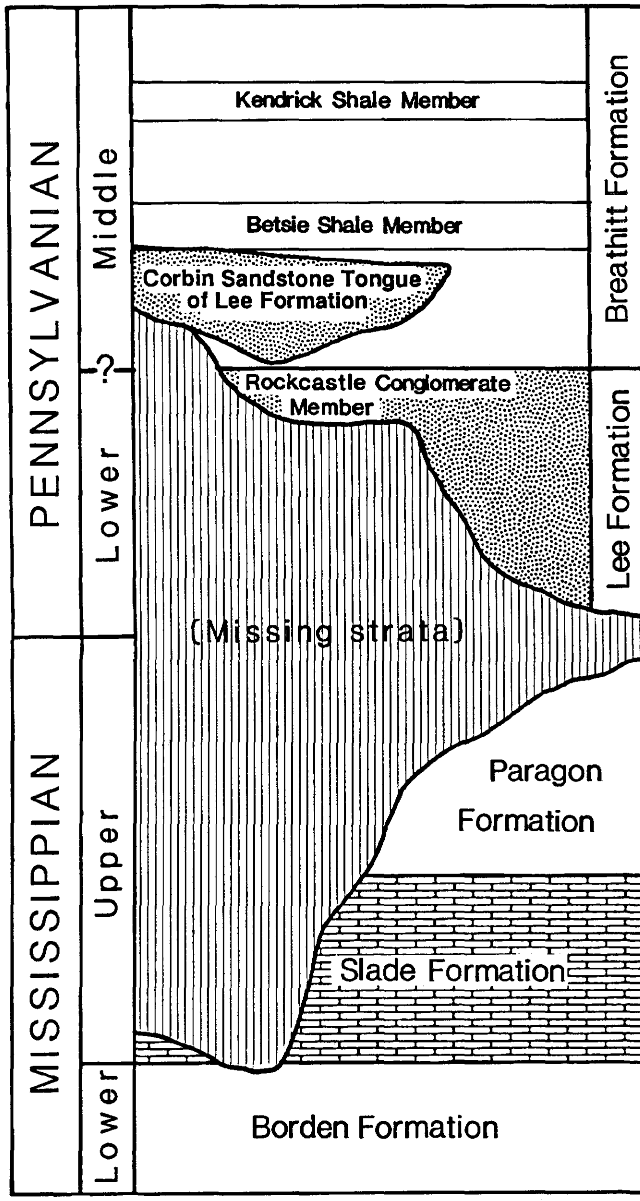

Figure 9. Correlation diagram of Carboniferous stratigraphic units in eastern Kentucky.

A shale unit that commonly occurs at the base of the Pennsylvanian as a rule contains a coal bed or zone of coal beds. The distribution of a single marine unit in the Lower Pennsylvanian of Kentucky has been described by Rice (1984b) from outcrops along the Cumberland Escarpment where the marine unit occurs within this coal-bearing shale and siltstone at the base of the Pennsylvanian. Thus, the northward and westward onlap of the New River and Lee quartz arenites was generally across Pennsylvanian terrestrial deposits and was not a northwestward progradation of beach or barrier-bar sequences into a marine basin. Locally, Pennsylvanian sandstone-

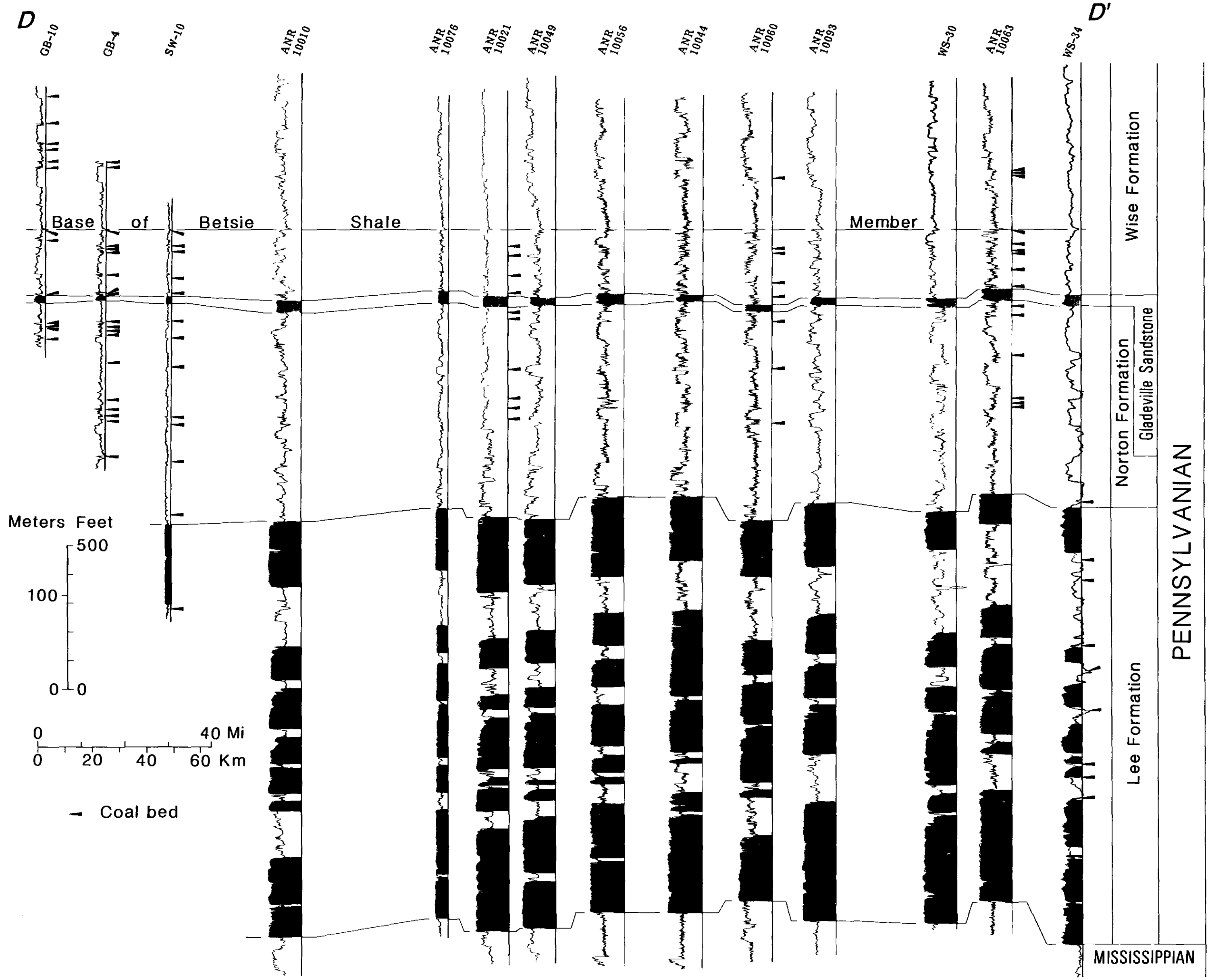

Figure 10. Gamma-ray logs of wells in southwestern Virginia showing the relation of the base (datum) of the Betsie Shale Member of the Wise Formation to the Pennsylvanian formations of that area (see fig. 1 for location of section). The quartz arenites of the Lee Formation and the Gladeville Sandstone are shaded.

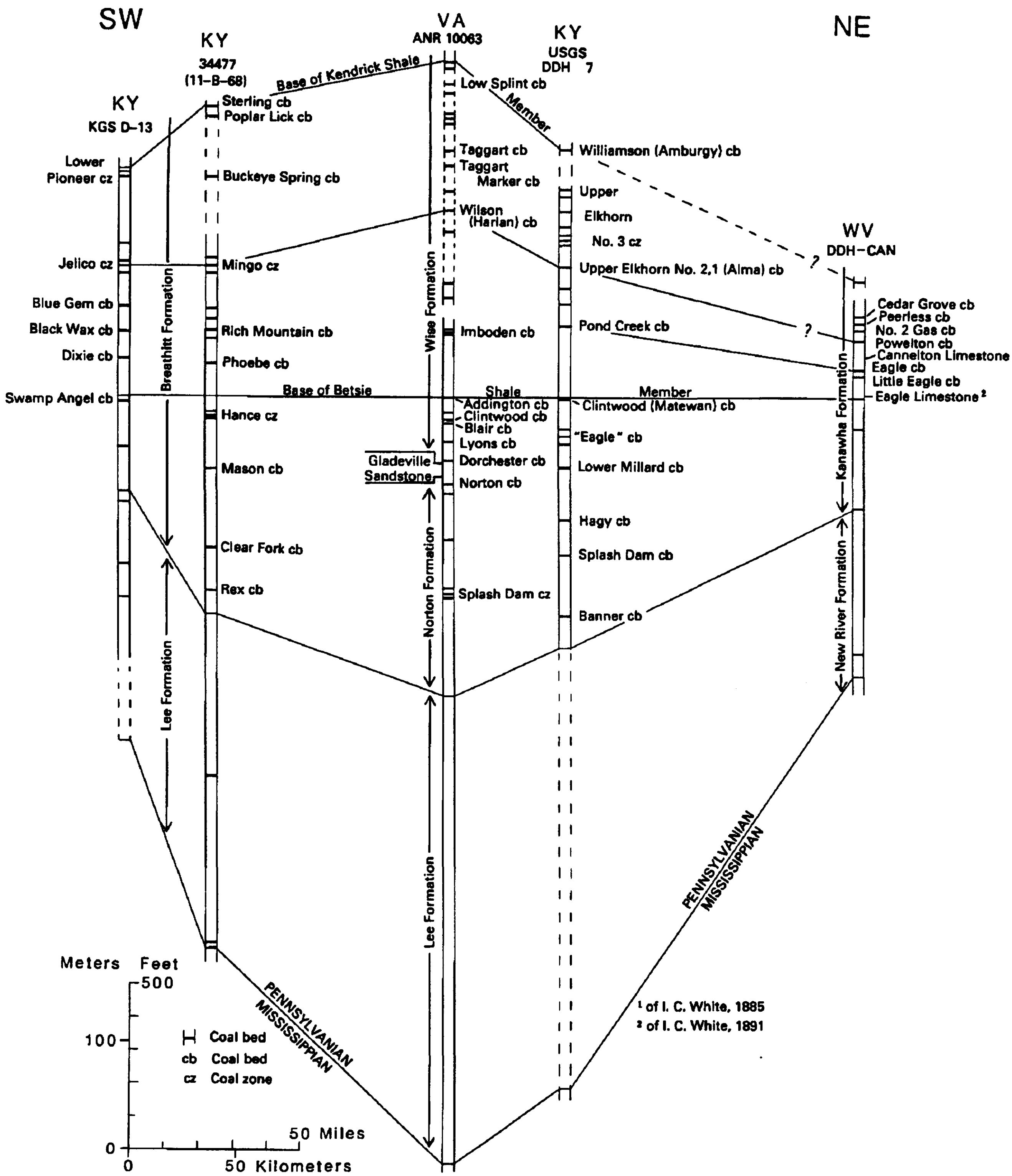

Figure 11. Line of section extending from near the Kentucky-Tennessee State line to central West Virginia showing correlations of major coal beds, coal zones, and marine units (see fig. 1 for location of drill holes and wells). Logs KGS D-13 and USGS DDH 7 are from Bergeron and others (1983) and Alvord (1970), respectively. DDH-CAN was drilled in Dunn Hollow, Montgomery quadrangle, W. Va., about 0.7 mi (1.1 km) west-northwest of the type section of the Cannelton Limestone of White (1885). Logs are shown as dashed where data are projected from outcrop or from nearby drill holes. The coal bed labeled "Eagle" in USGS DDH 7 has been incorrectly named in eastern Kentucky.

filled channels are cut into underlying Mississippian strata, but some paleovalleys at the base of the Pennsylvanian are filled mostly with coal-bearing shale (see fig. 6, wells 29758 and 30449). Marine strata may be more prevalent in areas closer to the Pennsylvanian depocenters to the south and southwest, but no evidence exists in this study area that the quartz arenites intertongue with marine deposits.

The Betsie Shale Member appears to be more highly fossiliferous along the Cumberland Escarpment, particularly in northern Kentucky, and in central West Virginia, and to contain few or no marine fossils in the southern or southeastern part of the basin. The subsidence responsible for Betsie deposition probably first resulted in the upstream retreat of distributaries of the Corbin and other fluvial systems; this retreat was followed by the establishment of widespread swamps in the central part of the basin and finally by the formation of a large lake or bay. The deposition of the Betsie resulted largely from deltas prograding into the basin from a rising land mass to the east and southeast. Marine water, as a result of continued subsidence, appears to have spread from the west or northwest across northern Kentucky and southward and eastward into West Virginia and Virginia. This transgression essentially ended quartz arenite deposition in Kentucky and culminated in the deposition of sparsely fossiliferous shales of the Betsie Shale Member.

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