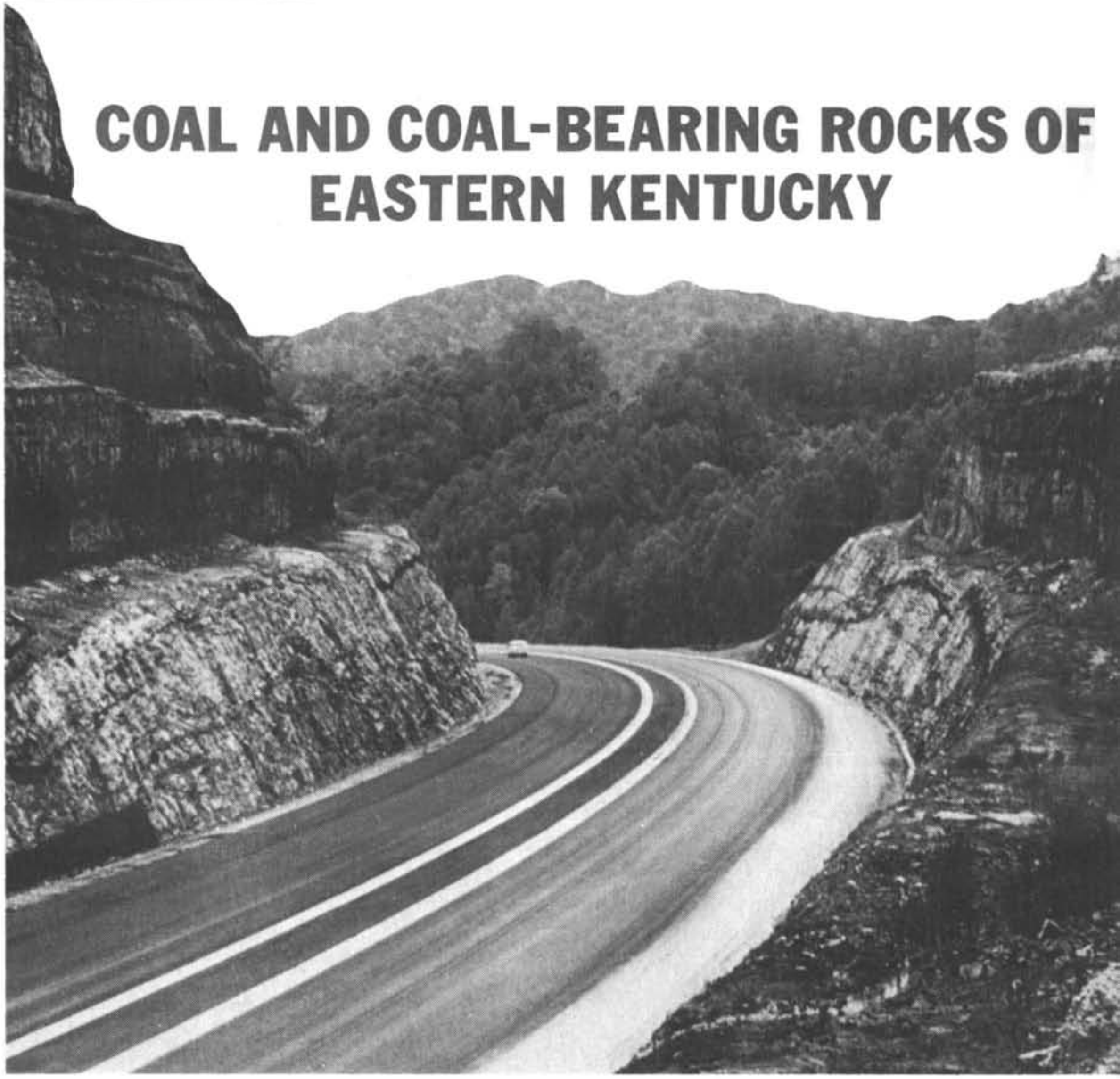
COAL AND COAL-BEARING ROCKS OF EASTERN KENTUCKY



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ANNUAL GEOLOGICAL SOCIETY OF AMERICA COAL DIVISION FIELD TRIP
November 5-8, 1981

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KENTUCKY GEOLOGICAL SURVEY
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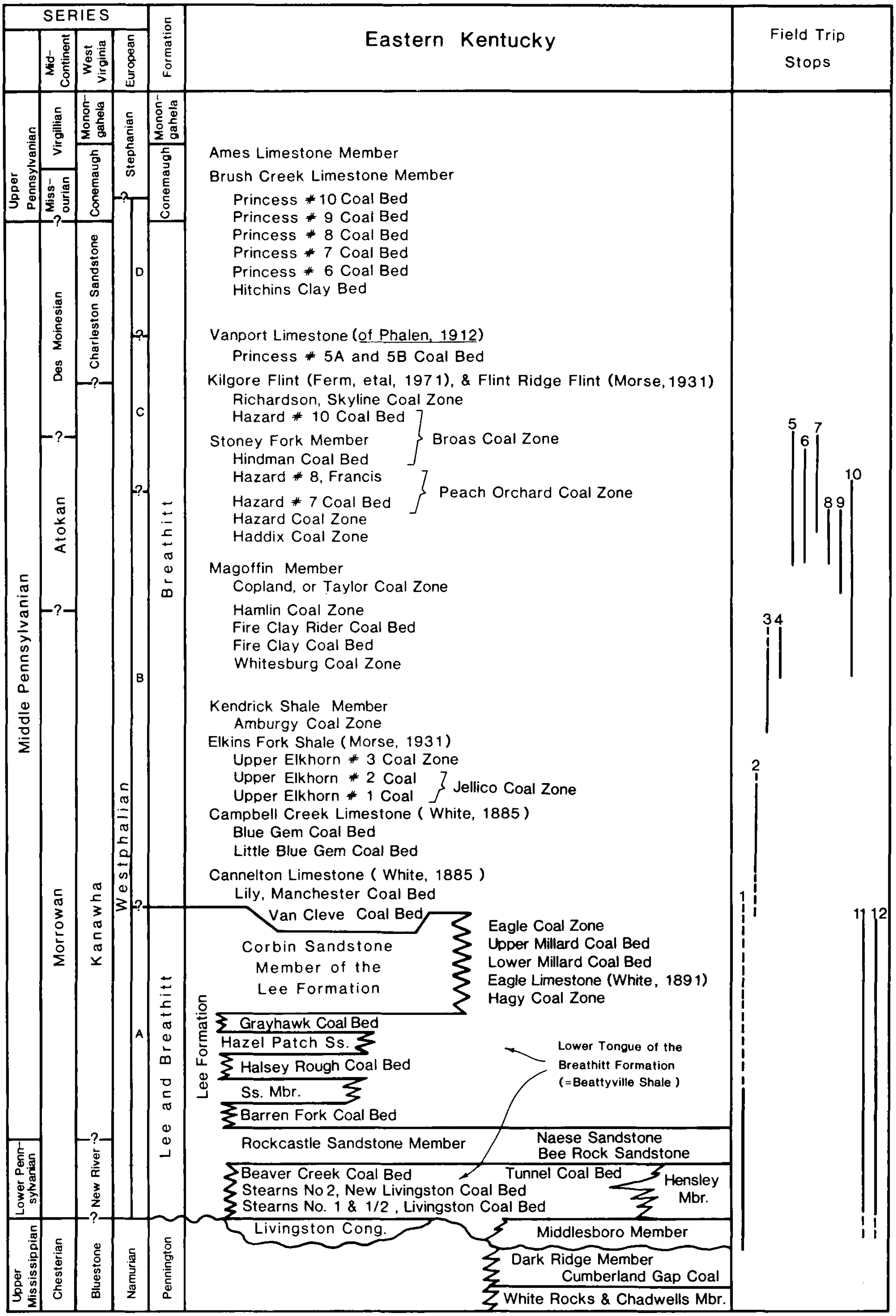

SERIES
Mid-Continent
West Virginia
European
Formation
Eastern Kentucky
Field Trip Stops
Upper Pennsylvanian
Virgillian
Miss-ourian
Monon-gahela
Conemaugh
Stephanian
Monon-gahela
Conemaugh
Ames Limestone Member
Brush Creek Limestone Member
Princess # 10 Coal Bed
Princess # 9 Coal Bed
Princess # 8 Coal Bed
Princess # 7 Coal Bed
Princess # 6 Coal Bed
Hitchins Clay Bed
Middle Pennsylvanian
Des Moinesian
Charleston Sandstone
D
Vanport Limestone (of Phalen, 1912)
Princess # 5A and 5B Coal Bed
Kilgore Flint (Ferm, etal, 1971), & Flint Ridge Flint (Morse, 1931)
Richardson, Skyline Coal Zone
Hazard # 10 Coal Bed
Stoney Fork Member
Hindman Coal Bed
Broas Coal Zone
C
Hazard # 8, Francis
Hazard # 7 Coal Bed
Peach Orchard Coal Zone
Hazard Coal Zone
Haddix Coal Zone
Atokan
Breathitt
Magoffin Member
Copland, or Taylor Coal Zone
Hamlin Coal Zone
Fire Clay Rider Coal Bed
Fire Clay Coal Bed
Whitesburg Coal Zone
B
Kendrick Shale Member
Amburgy Coal Zone
Elkins Fork Shale (Morse, 1931)
Upper Elkhorn # 3 Coal Zone
Upper Elkhorn # 2 Coal
Upper Elkhorn # 1 Coal
Jellico Coal Zone
Campbell Creek Limestone (White, 1885)
Blue Gem Coal Bed
Little Blue Gem Coal Bed
Cannelton Limestone (White, 1885)
Lily, Manchester Coal Bed
Morrowan
Kanawha
Westphalian
Van Cleve Coal Bed
Corbin Sandstone Member of the Lee Formation
Eagle Coal Zone
Upper Millard Coal Bed
Lower Millard Coal Bed
Eagle Limestone (White, 1891)
Hagy Coal Zone
A
Lee and Breathitt
Lee Formation
Grayhawk Coal Bed
Hazel Patch Ss.
Halsey Rough Coal Bed
Ss. Mbr.
Barren Fork Coal Bed
Lower Tongue of the Breathitt Formation (=Beattyville Shale)
Rockcastle Sandstone Member
Naese Sandstone
Bee Rock Sandstone
Lower Pennsylvanian
New River
Beaver Creek Coal Bed
Stearns No 2, New Livingston Coal Bed
Stearns No. 1 & 1/2 , Livingston Coal Bed
Tunnel Coal Bed
Hensley Mbr.
Upper Mississippian
Chesterian
Bluestone
Namurian
Pennington
Livingston Cong.
Middlesboro Member
Dark Ridge Member
Cumberland Gap Coal
White Rocks & Chadwells Mbr.
1
2
3 4
5
6
7
8 9
10
11
12

COAL AND COAL-BEARING ROCKS OF EASTERN KENTUCKY

FIELD TRIP LEADERS
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Annual Geological Society of America Coal Division Field Trip
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FOREWORD

The Kentucky Geological Survey and the field trip leaders welcome you to the 1981 Geological Society of America Coal Division field trip. We hope to give those of you on your first geologic trip to eastern Kentucky a thorough introduction to the geology of coals in one of the world's most productive regions. We hope to give those of you already familiar with eastern Kentucky new data on the coals and new information on a wide variety of coal-related geology.

We are fortunate to have new Kentucky Highway 80 available for the field trip. This is the first formal geologic field trip along this highway, which has cuts rising as much as 400 feet above road level. Kentucky Highway 80 was built by the State to serve the needs of eastern Kentucky and its coal industry; therefore, you will see many trucks hauling coal down this road.

A great deal of effort has been made by many people and organizations to fill this guidebook with new coal data and the results of geologic research. Many coals were sampled along the route of the field trip, and analyses of these samples have been made available. We are indebted to the University of Kentucky Institute for Mining and Minerals Research for providing these analyses.

We are indebted to Charles Rice of the U. S. Geological Survey for providing the introduction to this guidebook. His paper, "Stratigraphic Framework of Eastern Kentucky," gives a clear and concise discussion of the stratigraphy of eastern Kentucky coals.

James Jennings of Eastern Kentucky University made several collections of plant fossils from along the route and has contributed numerous identifications as well as a paper for the guidebook. We wish to thank him for his special efforts.

We wish to thank the authors of the 18 papers contributed to the guidebook. They are, in alphabetical order: Alan E. Bland, Bruce F. Bohor, Russell A. Brant, Donald R. Chesnut, Jr., James C. Cobb, Gary A. Cole, Steven Cordiviola, James C. Currens, James Dinger, Faith L. Fiene, Charles T. Helfrich, Norman C. Hester, James C. Hower, James R. Jennings, Raphael V. Ketani, John Kiefer, James Kipp, David W. Koppenaal, Robert M. Kosanke, Fred Lawrence, Charles L. Rice, Richard Smath, Frederick Taylor, Don M. Triplehorn, and David A. Williams. These papers make this guidebook an excellent overview of new research on coal and coal-bearing rocks of eastern Kentucky.

We wish to express our thanks to the Kentucky Geological Survey, the University of Kentucky Institute for Mining and Minerals Research, and Consolidated Resources of America, Inc., for allowing the authors the time and support to work on this guidebook, and to the University of Kentucky for the facilities to publish it.

Last but not least, we wish to acknowledge the fine help and assistance rendered by the Kentucky Geological Survey's editors and illustrators who formed this diverse collection of information into a comprehensible volume. These indispensible and invaluable workers are: Don Hutcheson, Meg Luther (editors); Roger Potts, Lynn Guindon, Freda Harris (illustrators); and Norma Reynolds (manuscript typist). Thanks are also expressed to Brandon Nuttall for computer typesetting assistance.

One final word—we realize that eastern Kentucky has been the subject of many previous field trips. These trips have concentrated mainly on sedimentary rocks associated with coal and not on the coal itself. The main focus of this trip is *coal:* coal petrography, coal quality, and coal chemistry, with emphasis also being placed on factors pertinent to coal deposition such as paleontology, palynology, paleobotany, and stratigraphy. We hope this approach will be of interest and benefit to all participants.

J. C. Cobb
D. C. Chesnut
N. C. Hester
J. C. Hower.

INTRODUCTION: THE STRATIGRAPHIC FRAMEWORK OF THE PENNSYLVANIAN ROCKS IN EASTERN KENTUCKY

Charles L. Rice
U. S. Geological Survey

In eastern Kentucky rocks of the Pennsylvanian System are in the central part of the Appalachian Basin and crop out in an area of about 27,000 km^2 (10,000 $mi.^2$). The Pennsylvanian is a wedge of strata composed largely of sandstone, siltstone, shale, and coal; it is as much as 1,400 m (4,600 ft.) thick along the Kentucky-Virginia border, but thins to the northwest. For example, the interval between the Fire Clay coal bed and the base of the Magoffin Member of the Breathitt Formation (Fig. 1) thins from a maximum of about 135 m (450 ft.) in the southeast to less than 10 m (30 ft.) near the northwestern margin of the basin.

The Pennsylvanian rocks have divided into three major units in eastern Kentucky. The Lee Formation, characterized by pebbly quartzarenite, is in the lower part of the sequence and is commonly at the base. The Breathitt Formation, characterized by subgraywacke, gray siltstone and shale, and coal beds, generally overlies and in tertongues with the Lee Formation. The Conemaugh and Monongahela Formations (undivided), characterized by variegated red and green siltstone and shale, are at the top of the section and occur only in northeastern Kentucky. The Breathitt has locally been raised in rank to group and subdivided into the Hance, Mingo, Catron, Hignite, and Bryson Formations. Divisions of the Breathitt, both formal and informal, generally have been made at commercially important coal beds. However, because coal beds do not persist, cannot be traced, or tend to split into coal zones, they are not easily identified or correlated throughout the coal field. Some stratigraphic units have been given member rank, but few of those are distinctive or persistent enough to be extended far from their type areas. Thus, the lack of easily recognized and persistent key beds, the great lateral facies variations, and the changes in interval thickness have discouraged further formal lithostratigraphic subdivision of the Pennsylvanian section.

Key beds and sequences of beds have, nevertheless, been used to establish a more comprehensive stratigraphic framework by which coal beds can be correlated across the basin. One of the most important key beds has been the Fire Clay coal bed, which has distinctive flint-clay parting. This bed and its correlatives,

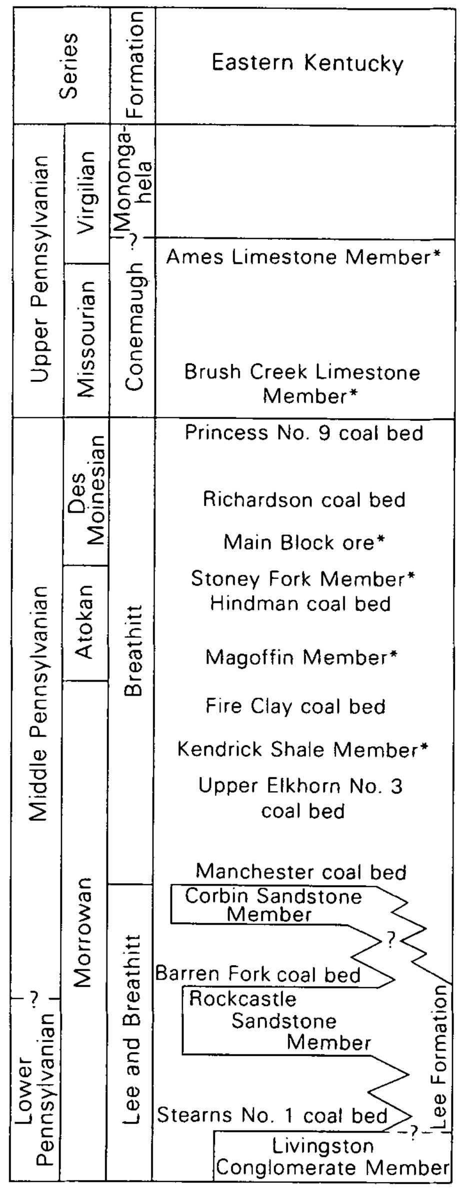

Figure 1. Generalized geologic column for the Pennsylvanian rocks of eastern Kentucky, showing selected members and key beds. * = members and beds that contain marine fauna.

though not continuous, have been identified in Virginia, West Virginia, Tennessee, and eastern Kentucky. Most early geologic reports and county maps in eastern Kentucky used the Fire Clay coal bed as the datum for contouring structure. The flint-clay parting, or tonstein, ranges from a fraction of a centimeter to as much as 35 cm (14 in.) in thickness and is generally dark brown, microcrystalline, hard, and fractures conchoidally. The parting may represent a volcanic ash fall (Seiders, 1965). However, similar partings are associated with at least five other coal beds in the middle part of the Breathitt Formation. Where the principal or "real" parting is missing or poorly exposed, these other coal beds have been misidentified locally as the Fire Clay coal bed.

Marine units have also become progressively more important for stratigraphic analyses of the Pennsylvanian section. They range in thickness from about 1 m to more than 30 m (100 ft.) and generally consist of coarsening-upward, bayfill sequences of shale, siltstone, and sandy siltstone in which the basal meter is sparsely to abundantly fossiliferous. The marine units are commonly not well exposed, and their importance has been realized only as a result of regional investigations (Wanless, 1939, p. 40), particularly of coal resources (Huddle and others, 1963), and as greater amounts of data (particularly drill-hole) have become available. The cooperative geologic mapping program of the U. S. Geological Survey and the Kentucky Geological Survey has shown further the utility of marine units for stratigraphic subdivision of much of the Middle and Upper Pennsylvanian sequence. The Magoffin Member is the most widespread and persistent marine unit in eastern Kentucky and commonly contains abundantly fossiliferous beds at its base that are easily recognized in drill cores. In fact, since about 1960, the Magoffin has become the most used datum for subsurface coal exploration and correlation. The Kendrick Shale and the Stoney Fork Members of the Breathitt Formation are two other marine units that have been widely recognized. In northeastern Kentucky, the Brush Creek Limestone Member and the Ames Limestone Member are the only persistent stratigraphic units of the Conemaugh Formation.

Many marine units, however, are less well known than the members mentioned above. These less-well-known units are generally less fossiliferous and have been largely overlooked by the stratigraphers. Some important units are identified only by the coal bed over which they are found, such as the Fire Clay rider marine zone; however, at least six marine units described in the literature are informally identified by the name of their discoverers. One of the most important of these is the Cannelton Limestone of White (1885). It was first identified in central West Virginia and later mapped locally in easternmost Kentucky. This marine unit is under drainage across much of eastern Kentucky but has been correlated with the sparsely fossiliferous marine unit that is directly above the Manchester coal bed (or its rider coal bed) and its equivalents along the western margin of the basin (Rice and Smith, 1980). Unfortunately, such correlations are tentative, and additional data are needed concerning the distribution and faunal content of the marine beds. Because none of the key beds of the Pennsylvanian coal-bearing section can be readily identified without reference to other beds, the framework of the stratigraphy is a detailed composite of many thin units, the Fire Clay coal bed, the marine units, and the thicker coal beds; locally, thick and cliff-forming sandstone beds are also important datums.

Most of the rocks traversed by the field trip are Middle Pennsylvanian in age. These strata contain almost all the economic deposits of coal in eastern Kentucky. Figure 2 is a generalized cross section extending from the Rockcastle River to Dewey Lake, and another section extending from Dewey Lake to Natural Bridge. Because the sections subparallel the strike of the basin and are northwest of the major Pennsylvanian depositional hinge-line, stratigraphic intervals show only a small amount of thickening toward the southeast. In addition to showing the coal beds and key beds that have been mapped along the route of the field trip, the cross sections indicate some of the many names that have been applied to individual coal beds. More than a dozen names have been given in various geologic reports to coal beds in the Eastern Kentucky Coal Field (Rice and Smith, 1980). In parts of the cross sections, coal "zones" are indicated where the same coal name is shown for more than one bed. The concept of a coal zone has been utilized where coal beds split into several beds and where those beds are perceived to constitute a zone whose members are not readily distinguishable. In some places, a member bed of a coal zone also has a distinct name as, for instance, the Hazard No. 7 and Francis coal beds, which have been mapped as members of the Peach Orchard coal zone. In other places, the principal coal beds are indicated by numbers, as are the coal beds of the Upper Elkhorn coal zone.

The high roadcuts and broad exposures, particularly along the Daniel Boone Parkway, afford a partial view of the facies changes that take place laterally and vertically within the Pennsylvanian strata. Although the size, thickness, and complexity of the sediments prohibit easy analysis, the field trip will traverse a large area rapidly. The general coarsening-upward succession of sediments characteristic of the Breathitt Formation will be most apparent from the vicinity of London to the area between Kentucky Highway 15 and Hindman (Fig. 2). The sediments above the Corbin Sandstone Member

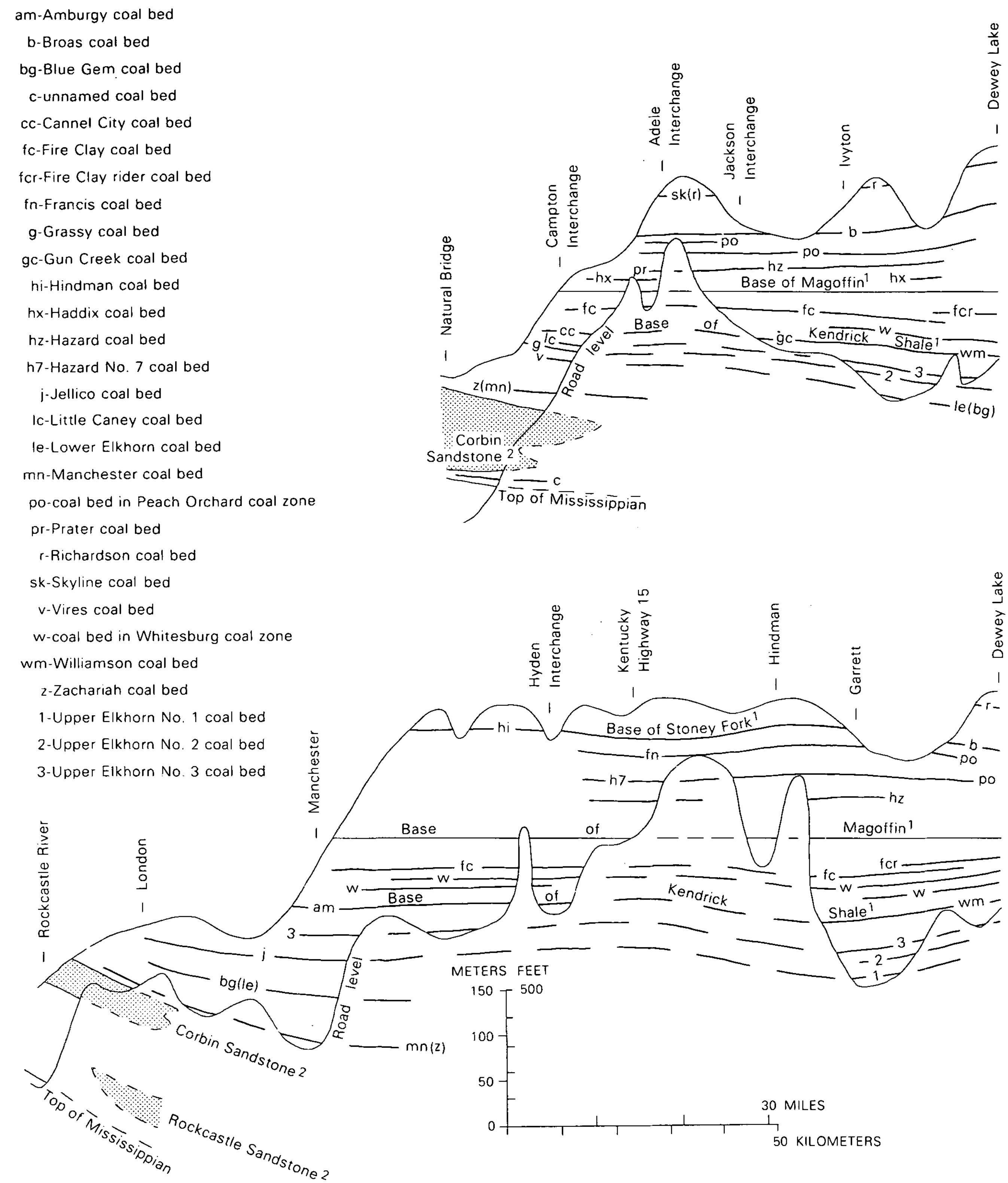

Figure 2. Generalized cross sections along the Mountain Parkway (Natural Bridge to Dewey Lake), Interstate Highway 75, and Daniel Boone Parkway (Rockcastle River to Dewey Lake). Topography and road level generalized. Coal bed names (listed alphabetically and numerically) are local usage from U. S. Geological Survey geologic quadrangle maps. Datum is base of Magoffin Member of Breathitt Formation.

of the Lee, and below the Amburgy or Cannel City coal bed east and west of the Campton interchange and between London and Manchester are fine grained (Fig. 2); equivalent stratigraphic intervals between Garrett and Dewey Lake and Dewey Lake and Ivyton are significantly sandier, suggesting an eastern or northeastern source for the clastic deposits. The Middle Pennsylvanian delta would thus have been a prograding system whose source was generally in the east, or perhaps in the northeast.

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FIELD TRIP ROADLOG

Thursday, November 5, 1981

Buses will depart the Convention Center about 6:15 p.m. and will proceed to London, Kentucky, for the first night's lodging. There will be no geology stops until the following morning, Friday, November 6. The roadlog begins at the Rockcastle River Bridge on Interstate Highway 75 at milepost 45.

Friday, November 6, 1981

Mileage **Description**

Coal Analysis. Three coal beds were sampled along Interstate Highway 75, in Carter coordinate section 3-J-63, 7 miles north of Stop 1. The coal beds were tentatively identified as the New Livingston coal bed and two riders, although the correlation is uncertain. The average rank (vitrinite reflectance) of the three coals is high volatile B bituminous (0.71 percent R_{max}. Both the lower and upper coals have greater than 82 percent total vitrinite (the second rider having 91 percent vitrinite plus liptinite), and the middle coal has 73 percent total vitrinite and 11.1 percent total liptinite. The lower two coals have less than 0.7 percent total sulfur (quoted ash and sulfur values on as-received basis), while the upper coal has 5.86 percent total sulfur, an exceptionally high value for eastern Kentucky coal and the highest value among the analyses to be reported in the roadlog and stop descriptions.

00 **Stop 1: Rockcastle River**

Purpose

The purpose of this stop is to examine Upper Mississippian and Lower Pennsylvanian rocks and the problematic unconformity which marks their boundary.

Location

This stop includes a series of three adjacent roadcuts at milepost 51 north of, and adjacent to, the Rockcastle River Bridge on Interstate Highway 75, Bernstadt Quadrangle, Rockcastle County, Carter coordinate location 5-I-64, 3,000 ft. FSL X 2,000 ft. FEL. This stop is shown on the field trip route map (Fig. 3).

Stratigraphy

Exposed in the three roadcuts, from road level upward, is the Upper Shale Member of the Pennington Formation (Upper Mississippian) and the lowermost portion of the Lower Tongue of the Breathitt Formation (Lower Pennsylvanian). These two formations are separated by an unconformity at this locality. Below road level of Interstate Highway 75 to the gravel road below the bridge over the Rockcastle is the Upper Shale Member and the underlying thin Limestone Member of the Pennington Formation. The figure on the inside front and outside back covers shows the stratigraphic interval and geologic position of this stop within the Appalachian Basin.

Description

The exposures described at this stop are shown in Plate 1, (in pocket) a diagrammatic sketch of the exposures. The Pennington Formation (Upper Chesterian) is a heterogenous unit of calcareous shales, siltstones, sandstones, dolostones, thin limestones, and characteristically red and green shales. In vertical sequence these rocks generally grade from more open marine at the base to nonmarine at the top. This formation overlies a thick sequence of limestones known as the Newman Limestone (lower and middle Chesterian and upper Meramecian). The Pennington is divided into four members by Ettensohn and Chesnut (1979). The sequence of red and green shales and siltstones with sporadic thin lenses of dolostone and a persistent bed

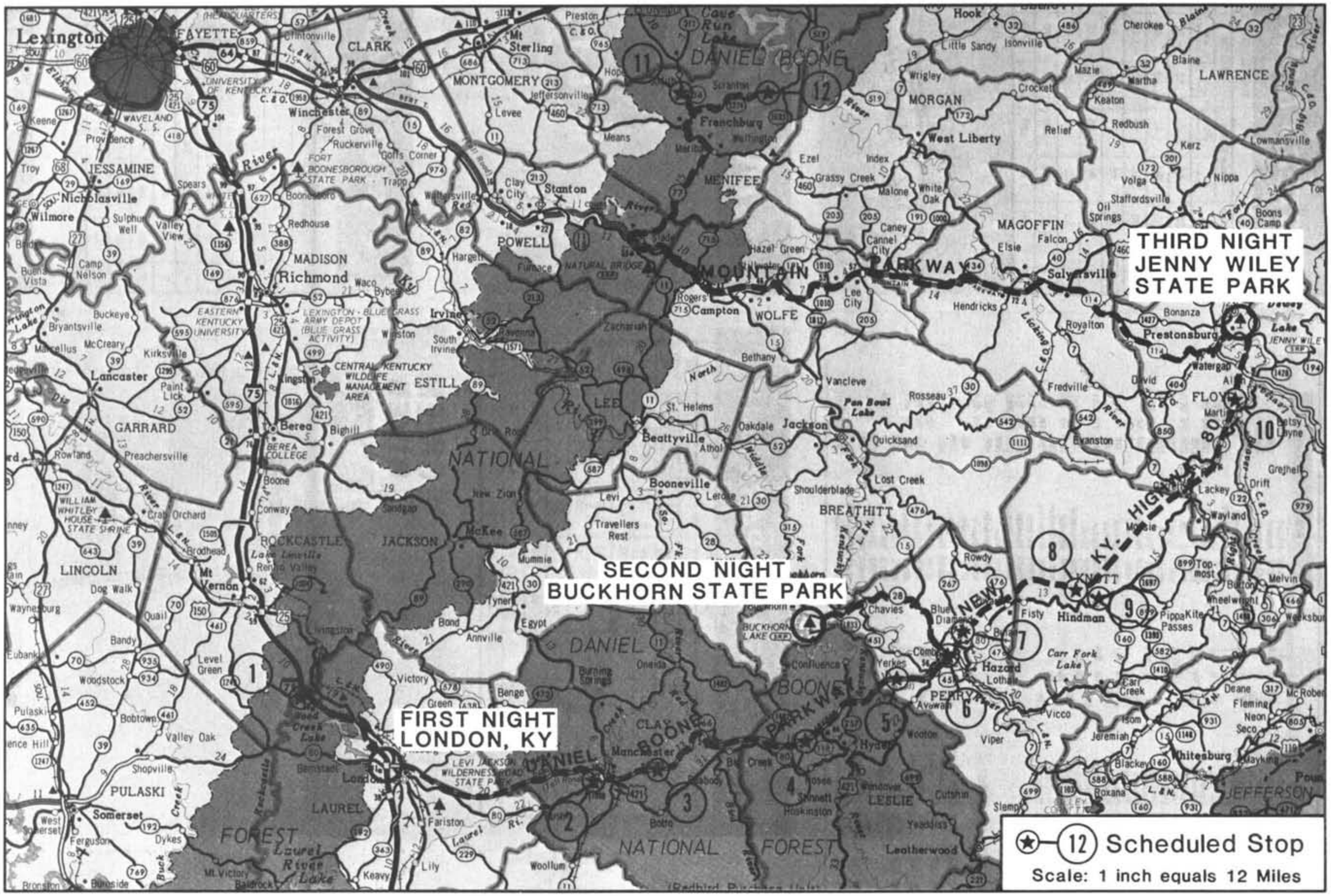


Figure 3. Map of field trip route showing stop locations.

of dolomitic siltstone and sandstone in the upper part is known as the Upper Shale Member of the Pennington Formation. This member is usually barren of fossils except for a few thin beds which have abundant but monotypic marine fossils.

The contact between the Pennington Formation (Mississippian) and the Lower Tongue of the Breathitt Formation (Pennsylvanian) is unconformable at this stop. For a detailed discussion of the unconformity *see* Chesnut (this volume). At first glance, the exposure nearest the bridge may appear to be conformable, but if one follows the difference in lithologies (red and green shales, coals, gray to black shales, and sandstones) across all three sections of this large roadcut, the erosional nature of the contact can be seen (Plate 1; in pocket). Pennington-type lithologies are not found above the unconformity. A variety of lithologies lie above the unconformity. These lithologies consist of black and gray shales, siltstones, thin sandstones, and coals. They belong to the Lower Tongue of the Breathitt Formation. The base of the Breathitt Formation is mapped at the base of the lowermost coal for convenience (Livingston? coal), though a channel fill can be seen just below the coal at the northern end of the middle roadcut that may belong to the Breathitt Formation. Usually 1 to 2 feet of the Pennington Formation green shale underlying the coal is leached to a light-gray, rooted claystone. At the southern end of the southern roadcut of this stop, the coal contains unusual coal balls. Faith Fiene (personal commun., 1981) of the Institute for Mining and Minerals Research determined by diffraction that the coal balls are composed of silica. Lace-like texture is preserved and may be preserved plant texture, but this has not been verified. Within a few feet above the coal at the southern end of the roadcut is thin lens of a dark sandstone, conglomeratic in part, heavily bioturbated, and composed of variable-size quartz pebbles ($\geq$1.75 inches), lithoclasts of shale, siderite, and sandstone, cemented by a dark, ferruginous cement. At the northernmost of the three roadcuts, a sandstone occupying part of a channel can be seen a few feet above this coal. The sandstone is overlain by a thin bed of dark, ferruginous sandstone and conglomerate which is correlated with the previous conglomerate. Above these two sandstones are several coarsening-upward sequences of shale, shale with lenticular-bedded sandy shale (ripples) with abundant trace fossils, flaserbedded clayey sandstone with very abundant trace fossils, ripple-bedded sandstone, crossbedded sandstone locally rooted at the top, followed locally by thin coals. The thin sandstones are irregular in thickness and are difficult to correlate from one roadcut to another.

The coals belong to the Livingston coal zone which includes the Livingston coal, the New Livingston coal, and several unnamed coals. The Livingston and New Livingston coals are irregular in thickness but are locally important in Rockcastle County (*see* Hower and others, this volume, Table 6, for analyses). Across the Rockcastle River at the next series of roadcuts, dark shale with sandstones overlying the bioturbated sandstones and shales previously described are exposed. This shale also belongs to the Lower Tongue of the Breathitt Formation.

Overlying the shale is the Hazel Patch Sandstone. Locally, below the Hazel Patch Sandstone, is the Halsey Rough(?) coal which is mined in Laurel and Pulaski Counties. The Hazel Patch Sandstone in this area was studied by Blancher (1970). This sandstone is typically thin to medium bedded, with thin sets of crossbeds. Blancher interpreted the origin of this sandstone as a fluvial sandstone reworked by marine processes or a distributary sandstone near the strand line. Blancher's paleocurrent analyses indicate a southwesterly direction of transport.

Above the Hazel Patch Sandstone is a shale which locally contains the Grayhawk coal. Plant fossils were collected above the coal at the top of the hill south of our first stop and were field identified by James Jennings. The flora is listed below.

Above the shale at the top of the hill is the Corbin Sandstone Member of the Lee

Formation. It is massive, crossbedded, and weathers to a pink, friable sandstone. Just south of here (2 to 3 miles) the Rockcastle Sandstone Member of the Lee Formation is found. It is a conglomeratic sandstone that occurs below the Hazel Patch Sandstone. It was either not deposited or was eroded at the stop area and northward, but is widespread southward into Tennessee and to extreme southeastern Kentucky where it is known as the Bee Rock and Naese Sandstone Members of the Lee Formation (Rice and Smith, 1980). The three sandstones (the Rockcastle, the Hazel Patch, and the Corbin) are all mapped as members of the Lee Formation. These semi-orthoquartzite sandstones are different from the thick sandstones of the Upper Tongue of the Breathitt Formation (*see* Stop 6 and the Stops of Day 2), which are more poorly sorted and more variable in composition.

Interpretation

Ettensohn and Chesnut (1980), and Chesnut (1979) discussed the depositional environments of the Pennington Formation. According to their interpretation, the Upper Shale Member represents distal prodelta clays deposited by a westerly progradation that began in Late Mississippian time. The delta front and more shoreward deltaic facies were probably deposited further east in extreme southeastern Kentucky and in western Virginia and Tennessee. Thin dolostone beds and lenses in the Upper Shale Member may represent shallow-water carbonate deposition during times of reduced clastic input. A few of these beds contain marine fossils. The laminated, dolomitic siltstone contains ripple marks, mud cracks, and rip-up clasts. This unit was probably formed as a terrigenous clastic tidal flat. The laminated dolostone, of probable algal origin, represents supratidal origin for a portion of this sequence. Small tidal channel-fill sediments are commonly represented in the upper portions of the Upper Shale Member.

The unconformity (*see* Chesnut, this volume) between the Pennington Formation and Lower Pennsylvanian rocks may be regional in extent, and is generally undulating.

The portion of the Lower Tongue of the Breathitt Formation at this locality is interpreted as a marginal, channel fill at the southern extent of a large paleochannel system called the Livingston Channel. A large paleochannel system ($\gtrsim$3.3 miles wide; Brown and Wixted, 1979a, 1979b) to the north of this stop contains a conglomerate and sandstone known as the Livingston Conglomerate (Pennsylvanian). Paleocurrent indicators measured by Wixted (1977) and Brown and Wixted (1979a, 1979b) indicate a southerly transport direction. They reported that up to 66 feet of channel-fill sediment occurs above the conglomerate and includes coal, black shale, and bioturbated siltstone. This stop may be marginal to the paleochannel and the Pennsylvanian rocks at this stop may be these channel-fill sediments minus the Livingston Conglomerate. Livingston coal apparently is present only within the channel and above the level of the conglomerate (Brown and Osolnik, 1974). The sand and pebbles of the Livingston Conglomerate were carried south by the river which eroded the channel. After the river was diverted and the channel was abandoned, the channel-fill process began. Marine waters periodically entered the abandoned channel, depositing clays and sands. These are the thin, coarsening-upward sequences. At other times, marshes developed within the channel and later their peat formed coals in the channel. These peats were perhaps formed in brackish conditions; only lycopod leaves and rare lycopod cones are found in associated sediments. Monotypic assemblages often indicate stressful environments. According to James Jennings (personal commun., 1981) *Lepidodendron* could tolerate brackish conditions, which suggests that *Lepidodendron* rather than *Calamites* was the true pioneer species.

The depositional environment of the Hazel Patch Sandstone may be in tidal flat or other near-shore, shallow-water conditions.

The Corbin Sandstone Member and other members of the Lee Formation *see*

Hester and Taylor, this volume) are fluvial in origin. Their orthoquartzitic nature can be explained by quartzitic source area, reworking of previously deposited sands, or intense leaching in a tropical climate.

Paleontology

The brachiopod *Anthracospirifer* sp. was found in a siderite layer above the lowermost Livingston coal. Sparse fragments of brachiopod were also found but not identified. Nearby, on U. S. Highway 25, which is the road paralleling the river below the Interstate highway bridge, a moderately large *Lingula* and an as yet unidentified plano-convex brachiopod were found in bioturbated sandstones between the unconformity and the New Livingston? coal. A small lycopod cone? *(Lepidostrobus?)* was found in a siderite nodule almost directly overlying the Livingston coal at this stop. Some of the sandstones contain *Stigmaria*.

Ichnofossils from sandstones, and sandy shales between the New Livingston coal(?) and the unconformity include dwelling places of a sea anemone, *Conostichus* (Plate 2. Fig. 1-2); burrowing traces of worms, *Asterosoma* (Plate 2. Fig. 3-4), *Rosselia, Zoophycos,* and *Teichichnus;* crawling traces of worms, *Scalarituba(?);* and dwelling traces of worms(?), *Skolithos*. These ichnofossils are associated with *Skolithos-Cruziana-Zoophycos* assemblages which have been interpreted as representing shallow-water conditions in the Pennsylvanian rocks of the Ouachita Geosyncline (Chamberlain, 1978). Similar assemblages have occurred in offshore bars (Chamberlain and Basan, 1978, p. 58), near shore (p. 58), and tidal-flat and tidal-channel deposits (p. 43) in the Pennsylvanian of eastern Oklahoma. The abundant size and variety of trace fossils seen at this stop are uncommon in the Pennsylvanian section of eastern Kentucky.

In silty shales above the New Livingston(?) coal, casts of resting places of the small pelecypod *Pelecypodichaus (= Lockeia)* (Plate 2) are found with abundant plant debris. This indicates shore or very near shore conditions (Chamberlain, 1978, p. 24-25). Recognizable plant fragments are sparse but include lycopod leaves *(Lepidophylloides)*, and stems *(Lepidodendron)*.

James Jennings collected and identified plant fossils between the Grayhawk coal and the Corbin Sandstone Member of the Lee Formation. The flora include *Alethopteris decurrens, Alloiopteris* sp., *Artisia transversa, Bowmanites* sp., cf. *Biscalitheca* sp., *Calamites* sp., *Calamostachys* sp., *Eremopteris* sp., *Lepidophylloides* sp., *Mariopteris pygmaea, Neuropteris* cf. N. *gigantea, Neuropteris schlehani, Pecopteris* sp., *Sphenophyllum* sp., *Sphenopteris neuropteroides, Stigmaria ficoides, Trigonocarpus* sp., and *Whittleseya* sp. This is a lower Westphalian flora that is probably middle or upper Westphalian A in age (James Jennings, personal commun., 1981).

0.9 Milepost 49. The Corbin and Hazel Patch Sandstone Members of the Lee Formation are exposed at this exit. *Coal analysis.* A Lee Formation coal (Grayhawk?) was sampled (KGS 63) near Interstate Highway 75 at Carter coordinate location 8-I-64, 4,500 ft. FSL X 3,800 ft. FEL, in the Bernstadt Quadrangle. This coal has 76.1 percent total vitrinite, 9.7 percent total liptinite, and 1.03 percent total sulfur (0.44 percent pyritic sulfur). Coal rank is high volatile B bituminous (0.68 percent R_{max}).

3.4 Wood Creek Lake. The Interstate highway is built upon the dam. The Hazel Patch Sandstone is exposed at road level, and the Rockcastle Sandstone is exposed in the gorge to the left (east).

3.8 Hazel Patch and Corbin Sandstone Members of the Lee Formation.

4.4 Milepost 47. Corbin Sandstone.

4.8 Here begins the extensive plateau on the Corbin Sandstone. There are many canyons and multiple cliffs of Lee Formation sandstones. The plateau is the only extensive flat land in eastern Kentucky, and farming is important here. The principal coal mined here is the Lily coal (average thickness 6 to 18 inches), which lies above the Corbin Sandstone. The first strip mine in Kentucky was in the Lily coal at Lily, Kentucky, near here.

6.7 Corbin Sandstone exposed in small gorge

PLATE 2

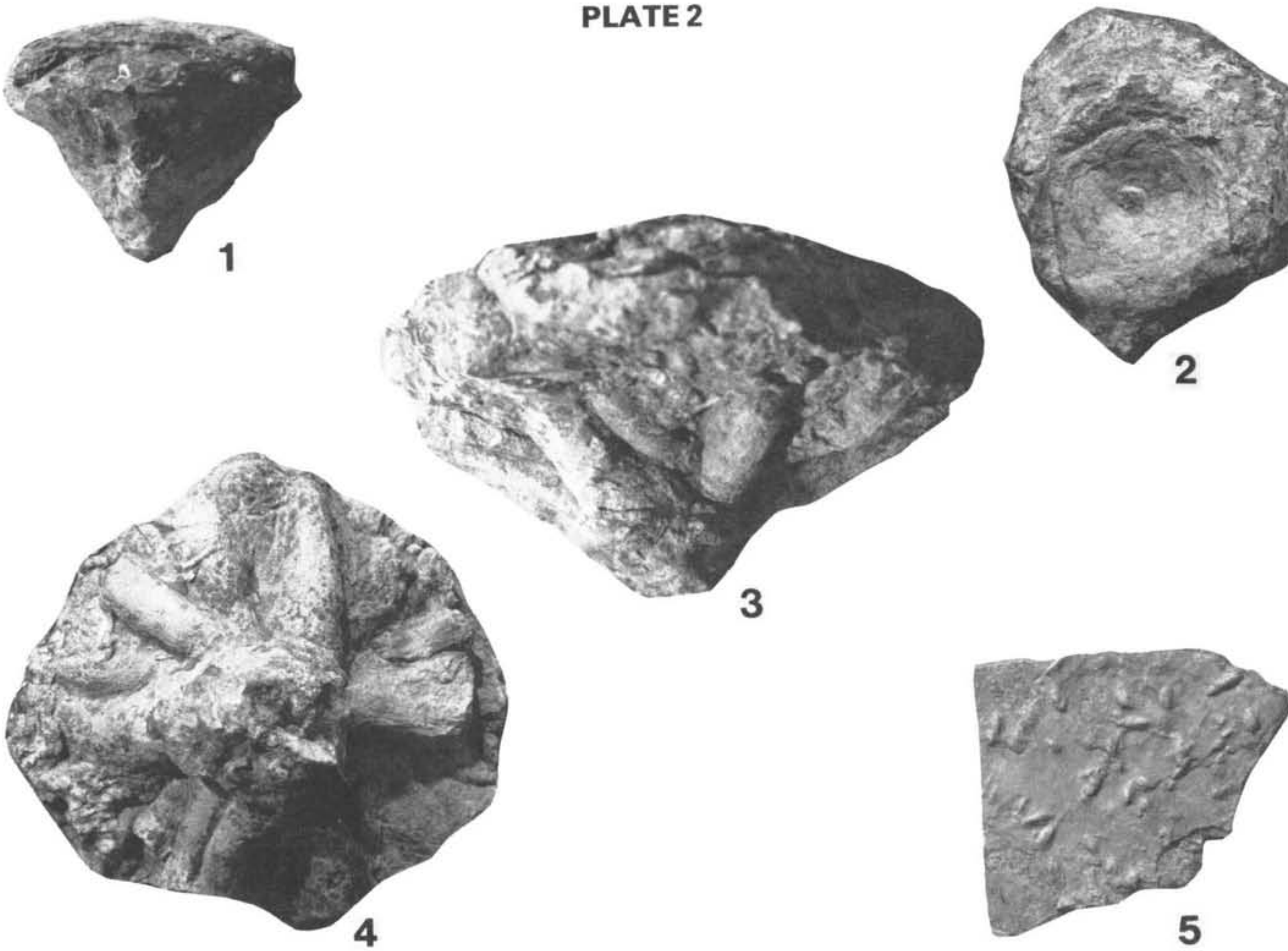


Plate 2. Common trace fossils from Stop 1.

Fig. 1-2. *Conostichus* sp., trace fossil from heavily burrowed sandstone in sequence of sandstones and shales just above the Mississippian-Pennsylvanian unconformity at Stop 1, Rockcastle County, Kentucky x 0.7.

Fig. 3-4. *Asterosoma* sp., trace fossil from same sequence as above, Rockcastle County, x 0.6.

Fig. 5. *Pelecypodichnus* (*Lockeia*) sp. trace fossil from shale sequence just overlying the above sequence at Stop 1, Rockcastle County, Kentucky, x 0.5.

to the right (west).
7.9 Corbin Sandstone.
8.3 Weigh station.
10.7 **Exit Interstate Highway 75; at exit 41; turn left onto Kentucky Highway 80; proceed eastward to the Daniel Boone Parkway.**
11.6 At entrance to the Daniel Boone Parkway, dark-gray to black shale above the Lily coal (not exposed). Herein it is informally designated the "Lily" shale. It is a bayfill-type shale.
12.8 "Lily" shale.
13.9 Cross Kentucky Highway 638.
15.2 "Lily" shale.
15.4 Milepost 3. Mining to the north. Leeco coal preparation plant to the right (south). Junction with new Kentucky Highway 192.
16.5 Near milepost 5. Shale and siltstone capped by sandstone. Above, Blue Gem coal.
17.5 Shale and Blue Gem(?) coal.
19.0 Milepost 8. Blue Gem(?) coal and shale with carbonate concretion, capped by sandstone. The Blue Gem coal is one of the most important coals in eastern Kentucky because of its high quality.
21.2 Blue Gem(?) coal and shale.
21.8 Unnamed sandstone in Breathitt Formation.
22.3 Jellico(?) coal.
23.1 "Lily" shale.
23.6 Lenticular sandstone bodies and thin, lenticular carbonate bodies in shale.
24.5 Large roadcut. Blue Gem(?) and Jellico(?) coals. Carbonate concretions and flow rolls.
25.6 "Lily" shale.
26.1 Milepost 14. Surface mining to the north, Manchester coal (= Lily coal).
27.2 Milepost 15. Massive sandstone at the same stratigraphic level as the Corbin Sandstone Member of the Lee Formation.
27.6 Surface mining of the Manchester coal in this area.
28.9 Large roadcut. Blue Gem(?) coal.
29.9 Mine in Manchester coal to the left (north).
30.3 Milepost 18. Roadcut. Limestone concretions, Blue Gem(?) or Jellico(?) coals.
31.2 Mine to the south.
31.3 Milepost 19. Roadcut. Blue Gem? coal and black shale.

32.2 **Stop 2: Manchester, Kentucky**

Purpose

The purpose of this stop is to compare the section between the Manchester (= Lily) coal and the Blue Gem(?) coal of this locality with the same interval in London, Kentucky. Also discussed here is the small-scale slumping and channel fill, unusual plant flora, and the sandstone below the Manchester coal.

Location

Stop 2 is located on the Daniel Boone Parkway near milepost 20, approximately 0.6 mile west of the intersection with U. S. Highway 421, about 1.5 miles south of Manchester, Kentucky, in Clay County. This roadcut is in the Manchester Quadrangle at Carter coordinate location 9-H-69, 2,000 ft. FSL X 2,000 ft. FEL. It is about 1/4 mile long and has a maximum height of 180 feet. The location of this stop is shown on the field trip route map (Fig. 3).

A section was measured 1.1 miles east of Stop 2 on the Daniel Boone Parkway, where Horse Creek and a roadcut have exposed the Manchester coal and a sandstone that had been considered to be the Corbin sandstone equivalent. This section will be used for part of the description of this stop.

Stratigraphy

The stratigraphic interval to be discussed at this stop includes a sandstone below the Manchester coal, the Manchester coal, and strata below and above the Blue Gem(?) coal. However, at the actual stop location, the Manchester coal and Corbin sandstone are not exposed. The stratigraphic interval exposed at this stop is shown in the figures on the inside of the front and outside back covers.

Description

A diagrammatic sketch of this roadcut is presented in Plate 3 (in pocket). A sandstone unit underlying the Manchester (= Lily) coal and the Manchester coal are exposed near milepost 21 on the east side of the Manchester exit (exit 20). The Manchester coal is exposed near road level, while the underlying sandstone is exposed in the railroad cut in the underpass. This sandstone has been considered to be the equivalent of the Corbin Sandstone Member of the Lee Formation because the sandstone in the London, Kentucky, area directly below the Lily coal is the Corbin Sandstone Member and the Manchester coal is the equivalent of the Lily coal. However, according to Charles Rice (personal commun., 1980), the Corbin sandstone pinches out in the subsurface before it gets to the Manchester area. Rice considers the sandstone below the Manchester coal to be separate from the Corbin sandstone.

The primary roadcut (north side exposure) for this stop, where the buses will stop, is near milepost 20 on the west side of the intersection with U. S. Highway 421. Just above road level from the east side of the roadcut is a coarsening-upward sequence of siltstones and sandstones. These lithologies contain burrows and calcareous concretions. *Zoophycos* and other horizontal and vertical burrows are present. These bayfill-type deposits overlie the Manchester coal and can be traced eastward across the intersection to the roadcut near milepost 21, where the Manchester coal and overlying beds are exposed. In the London, Kentucky, area, to the west, the interval above the Lily coal (= Manchester coal) is a thicker shale unit with much less siltstone and sandstone than at this locality. Eastward, coarser clastics increase in abundance.

Above the bayfill sequence are interbedded silty shale, siltstone, and fine sandstone. These deposits are overbank-type deposits, though perhaps distal in origin. Several poorly preserved vertical tree(?) stumps can be seen here. They appear to be cemented with siderite, as if they were concretions. Near the top of this interval, as marked on the accompanying outcrop sketch, James Jennings collected and tentatively identified plant fossils, including *Alethopteris arbori, Alloiopteris* cf. *A. gracillema, Annularia* sp., *Artisia* sp., *Calamites* sp., *Calamostachys* sp.?, *Cordaites principalis, Cordiacarpis* sp., *Eremopteris* sp., *Lacoea* sp., Lepidophylloides sp., *Lonchopteris* sp., *Megalopteris* sp., *Neuropteris* cf. *N. heterophylla, Neuropteris* cf. *N. tenuifolia, Paleopteridum (Rhacopteris)* sp., *Pecopteris* cf. *P. plumosa, Sphenopteris* spp., *Trigonocarpus* cf. *T. parkinsoni,* and *Whittleseya* sp. This is a unique flora. According to Jennings, this is the first reported occurrence of *Lonchopteris* west of Nova Scotia, although it is common in Europe. Jennings also states that the floral associations of *Cordiates, Megalopteris,* and noeggerathiaphytes (*Lacoea* and *Paleopteridium*) occurring here are rare and are not known at any other locations in eastern Kentucky. While *Megalopteris* was considered to usually grow in sinkholes (James Jennings, personal commun., 1981), this occurrence is definitely not related to limestone and sinkholes.

Channel fills which contain slump blocks and coal stringers are apparent upon close examination just above the first bench. The channel fill is difficult to distinguish, because the fill and the channel bank are similar in grain size and appearance. Contorted and oversteepened beds are seen in small slump blocks in the channel fill. The channel erosion appears to truncate two of the vertical tree(?) stumps preserved in the channel bank material. The largest slump block is capped by what is tentatively identified as the Little Blue Gem(?) coal. It is evident that slumping did not occur until a thickness of peat had accumulated on the overbank deposits and streams began eroding into the peat and underlying deposits. The Little Blue Gem(?) coal is preserved in only a few places here because it has been removed by subsequent erosion.

Overlying the channel-fill sediments containing the disturbed coal is a thicker coal bed (Blue Gem(?) coal) overlain by a black, fissile carbonaceous shale. This black shale is rich in sulfur, as evidenced by its weathering and smell. Following deposition in the channel, a poorly drained swamp or marsh developed and peat accumulated (Blue Gem(?) coal). Continued subsidence brought on by dewatering and compaction of sediments allowed the encroachment of brackish water, which caused the swamp to die out. Carbonaceous clays and iron sulfides were deposited in this isolated and protected environment. In the roadcut at milepost 21, neither the coal nor the carbonaceous shale are found, though they can be traced for several miles back to the west.

Above the coal and carbonaceous shale is a thick unit of probable bayfill-type deposits. A conspicuous thin sandstone in the lower part exhibits rippling and contorted bedding. In the roadcut near milepost 21, this sandstone is much thicker.

A thick sandstone sequence occurs above the shales.

Interpretation

Following deposition of the Corbin Sandstone Member equivalent(?), which probably resulted from fluvial systems, a swamp was established in which peat accumulated. This peat deposit became the Manchester coal. Subsequent subsidence allowed marine transgression which drowned the swamp. Marine- or brackish-water conditions developed. As the bay expanded it eventually attracted a fluvial system and its associated terrigenous clastics which began to fill the bay. Sedimentary structures indicate that the sediment source was to the east.

Progradation of clastics into the developing bay continued, and a river system deposited silts and fine sands onto what was probably its distal levees. These overbank deposits buried and preserved the abundant plant life that had established itself on the levees. Swamp conditions began and peat accumulated. This peat deposit is now the Little Blue Gem(?) coal. Rivers then cut away much of the peat and eroded the underlying sediments. This downcutting caused slumping and resulted in the displaced and disrupted coal bed.

As the river continued depositing sediments, the slumped peat was buried. Conditions suitable for peat accumulation were again established. In what may have been atypically rapid subsidence, a brackish-water bay developed, drowning out the peat swamp. The bay continued to subside, and clays were deposited. Abundant sulfides were also precipitated. As the bay became deeper, better circulation was restored and subsequent clay and silt deposition was low in sulfur content. It appears that distributary systems eventually advanced into the brackish bay and deposited sands and silts.

Coal Characterization

The Manchester coal from this locality analyzed by the Institute for Mining and Minerals Research (*see* Hower and others, this volume) has 77.3 percent total vitrinite and 10.4 percent total liptinite, both of which are above average for the Manchester coal in the area in which it is mined. The rank of the coal, based on vitrinite reflectance (0.78 percent R), is high volatile A bituminous. The total sulfur of 1.39 percent (0.67 percent pyritic sulfur) is slightly below the average of the analyzed Manchester samples.

32.6 Manchester exit.

33.3 Manchester coal is exposed near road level on south side of road. This section is discussed in Stop 2 description, and is shown in Plate 3 (in pocket) *Coal analysis.* A sample of the Manchester coal from this site (Carter coordinate section 10-H-69) has 73.6 percent total vitrinite and 9.6 percent total liptinite, and is high volatile A bituminous rank (0.84 percent R_{max}). The chemistry of this and other Manchester samples is discussed by Cole and Williams (this volume).

35.2 Large roadcut. Mostly shale and some sandstone. Blue Gem(?) and Jellico(?) coals.

37.8 **Stop 3: Road Gap, Kentucky**

Purpose

The purpose for this stop is to show marine zones at many stratigraphic positions. Other points of discussion are the channel and channel-fill deposits at the western end of the roadcut; the insect wing found at this locality; and the truncation of marine, near-marine clastic sediments, and brackish-water peats by a meandering fluvial system.

Location

Stop 3 is approximately 2.75 miles west of Hector, Kentucky, in Clay County. This stop is located at milepost 25 on the

Daniel Boone Parkway at Road Gap in Barcreek Quadrangle. Carter coordinate location is 9-H-70, 1,400 ft. FSL X 2,300 ft. FEL. The stop location is shown on the field trip route map (Fig. 3).

Stratigraphy

The stratigraphic interval and geologic setting of this stop are shown on the inside front and outside back covers. Units include (from road level upwards) the Elkins Fork Shale, Amburgy coal zone, Kendrick Shale Member, Whitesburg coal zone, Fire Clay coal(?), and Fire Clay rider(?).

Description

Plate 4 (in pocket) is a detailed sketch of the strata exposed at Stop 3. At the base of the roadcut, below the Amburgy coal, is a coarsening- upward sequence (Plate 4 (in pocket), coarsening-upward sequence 1) of siltstones and sandstones. These beds contain burrows, convoluted bedding, ripples, limestone concretions, siderite nodules, and the pelecypod *Astartella* (Currens, 1978). The presence of marine fossils, limestone concretions, and abundant burrows is evidence to identify this as a marine (or brackish) zone. It has been named the Elkins Fork Shale. Many clastic marine units in eastern Kentucky that contain marine fossils have these large limestone concretions, but they also occur in sequences in which marine fossils are sparse to absent. The calcareous concretions, sometimes up to 15 feet long and 6 feet high, are thought to have been formed by early diagenetic concentration of calcite from the water column or the calcareous sediment.

Currens (1978) identified the sandstone at the top of this coarsening-upward sequence as an overbank deposit. He also found burrows and a pelecypod cast in this sandstone. Adjacent to this coarsening-upward sequence is a channel cut filled with shale which is seen near road level. Sandstone in the ditch line, adjacent and east of the channel, contains current ripples, bedding dipping toward the channel, and abundant trace fossils including *Arenicolites(?)*, *Stelloglyphus(?)*, *Zoophycos*, and escape burrows. Above the channel-fill deposits are sandstones, shales, siltstones, and coals of the Amburgy coal zone. Three rooted sandstone beds occur in this interval; two are overlain by Lower Amburgy coals and the upper one is at the approximate position of the Upper Amburgy coal, which is missing here (Currens, 1978). James Jennings field identified plant fossils from this interval; these include *Artisia* sp., *Cordiates principalis, Lepidodenron* sp., *Lepidophylloides* sp., a lycopod branch, *Pecopteris plumosa, Sphenopteris* sp., and *Lepidostrobophyllum*. This is a flora dominated by cordaitean and lycopod trees. Cordaitean and some lycopod trees were apparently tolerant of brackish-water conditions. The Amburgy coals are typically characterized as high sulfur (2 to 4 percent sulfur; Jim Currens, personal commun., 1981). The Amburgy coal zone is bound above and below by marine sediments.

Above the Amburgy coal zone lies the Kendrick Shale, another coarsening-upward sequence (Plate 4, (in pocket) coarsening-upward sequence 2). This is an extensive marine shale known as the Kendrick Shale. It is a key stratigraphic bed used for coal correlations over much of eastern Kentucky. At many localities the Kendrick Shale is fossiliferous, but in this area, fossils are uncommon. The Kendrick Shale is a dark-gray, clayey shale containing calcareous concretions. The pectenid pelecypod, *Dunbarella knighti,* is the only fossil found at this locale to date. The Kendrick Shale coarsens upward into sandstone seen at the western end of the outcrop, but this is truncated by erosion from channels contemporaneous with the Whitesburg coal zone for the rest of the outcrop.

Above the Kendrick Shale is an interval of sandstones, siltstones, shales, and coals. The coals are part of the Whitesburg coal zone. There is repeated channel erosion in this interval, which makes it difficult to trace a bed from one end of the roadcut to the other. Most of the erosion is at the eastern end of the roadcut. At the western end of the roadcut, an interval of siltstones and shales with large calcareous concretions is preserved. This is a marine zone that is sometimes associated with the Whitesburg coal zone. Plant fossils are abundant in the shales, siltstones, and fine sandstones at the eastern end of the outcrop, and an insect wing was recovered from this interval (Chesnut, this volume, and Jennings, this volume).

Overlying and truncating large portions of the previously described interval is a massive sandstone with interbedded shales and coals. The erosional base of this sandstone begins a fining-upward sequence (Plate 4 (in pocket) fining-upward sequence 3) capped by a coal bed. Horizontal logs (some are *Sigillaria*, an upland or dryland tree) occur at the scoured base of the sandstone. Clasts of siderite, shale, and coal spar (transported peat mats?), and trough and planar crossbeds are observed in the sandstone. Above the massive sandstone are two other fining-upward sequences capped by thin coals (Plate 4 (in pocket)fining-upward sequences 4 and 5). These coals may be part of the Fire Clay coal zone, but this has not been confirmed.

Interpretation

The three marine zones, the Elkins Fork Shale, the Kendrick Shale, and the marine zone associated with the Whitesburg coal zone, indicate frequent marine conditions during deposition of the sediments represented by the rocks below the massive sandstone. Marine, brackish, and fresh-water conditions occurred repeatedly as bays developed, then filled, with sediment. Brackish swamps developed and peats accumulated, but were eroded by contemporaneous channels. The swamps then became flooded by marine waters and the cycle repeated itself.

The thick sandstone above the Whitesburg coal zone is of fluvial origin, an interpretation supported by its erosional base, coal spar, log impressions, large-scale crossbeds, erosion of a coal bed, and fining-upward grain size. As the river migrated away from this area, swamp conditions developed and peat began to accumulate. River migration again brought in sediments, burying the peat. A series of river-channel, point-bar, and overbank deposits in fining-upward sequences 4 and 5 indicates that the fluvial deposition continued, interrupted by periods of peat accumulation.

Paleontology

A pectenid pelecypod, *Dunbarella knighti* (Fig. 6), was found in dark-gray Kendrick shale.

James Jennings made a field identification of the plant fossils associated with the Whitesburg coal zone, including *Alethopteris lonchitica, Annularia* sp., *Annularia radiata, Artisia* sp., *Asterophyllites charaeformis, Bothrodendron* sp., *Calamites cistii, Calamites undulatus, Calamites* sp., *Cordaites principalis, Cordaites* ovule, *Eremopteris* sp., *Lepidodendron aculeatum, Lepidodendron* sp., *Lepidophylloides* sp., *Lepidostrobophyllum* sp., *Lepidostribus* sp., *Mariopteris nervosa, Neuropteris tenuifolis, Pecopteris pennaeformis, Sphenophyllum* sp., *Sphenopteris elegans, Sphenopteris obtusiloba* group, *Sphenopteris* sp., *Trigonocarpis* sp., and *Ulodendron* sp. Found with these plants were small unidentified myalinid(?) pelecypods that probably lived in brackish or fresh water.

In the course of collecting fossil plants within the lower part of the Whitesburg coal zone at Road Gap, a fossil insect wing was found. A detailed description of this fossil and its importance is given by Chesnut (this volume) and Jennings (this volume). Insect wings are quite rare and few are known from the Lower Pennsylvanian. This is the first Pennsylvanian insect wing reported from Kentucky.

Figure 6. *Dunbarella knighti* specimen.

38.8 Roadcut, Elkins Fork Shale, Kendrick Shale, and Amburgy coal zone.

39.0 Milepost 26. Bridge over river.

39.6 Milepost 27. Upper Elkhorn No. 3 coal and Elkins Fork Shale with large limestone concretions in siltstone.

41.3 Upper Elkhorn No. 3 coal zone.

42.3 Small reverse fault displaces Upper Elkhorn No. 3 by 2 to 20 inches.

45.2 Large roadcut. Upper Elkhorn No. 3 coal at base of cut.

46.5 Bridge over Red Bird River.

46.8 Toll booth.

47.0 Upper Elkhorn No. 3 coal exposed.

48.4 Mining on hills in Fire Clay coal.

49.0 Thin coal in Upper Elkhorn No. 3 coal zone.

51.3 Milepost 38. Roadcut. Coarsening-upward sequence. Thin coaly zone is Amburgy coal zone. Limestone concretions in Kendrick Shale.

52.5 "Whitesburg Sandstone" and Whitesburg coal zone.

53.4 Milepost 40. Fire Clay coal with flint clay (tonstein) parting. *Coal analysis*. The Fire Clay (Hazard No. 4) coal sampled in the roadcut has 86.2 percent total vitrinite (the highest of any Fire Clay sample in the area) and 4.9 percent total liptinite, and has a high volatile A bituminous rank (0.77 percent R_{max}).

53.8 Fire Clay rider coal in stream cut to left (north).

55.1 Milepost 42. Large roadcut. Hazard coals above sandstone.

55.4 Magoffin Member. Abundant marine fossils. Copland coal.

56.3 Stop 4: Thousandsticks School, Kentucky

Purpose

The purpose of this stop is to see the Fire Clay and Whitesburg coals and their enclosing strata. (These strata are mostly fine-grained with abundant shale including black fissile shale.) We will also examine the flint clay associated with the Fire Clay coal.

Location

This stop is located on the Daniel Boone Parkway about 2 miles west of the Hyden Spur toll plaza at milepost 43. It is on the Hyden West Quadrangle in Carter coordinate section 22-I-73. The roadcut is about 200 yards long and reaches a maximum height of about 170 feet. The location of this stop is shown in Figure 3.

Stratigraphy

The named stratigraphic units exposed in this roadcut are Whitesburg coal zone, Fire Clay coal, and Fire Clay rider. The geologic setting and stratigraphic interval exposed at this stop are shown in the inside front and outside back covers.

Description

The strata in this exposure are shown in the sketch in Plate 5 (in pocket). The Whitesburg coal zone occurs here at road level. This coal zone overlies the Kendrick Shale, which is exposed in the stream cut on the opposite side of the road. As seen in the previous stop (Stop 3), the Kendrick is a marine shale. The strata composing the Whitesburg coal zone are fine-grained clastics, particularly siltstone and shale with fine sandstone and thin coals. Rooting and burrowing are common. A black fissile shale below the major coal bed contains the fossil *Lingula*. Calcareous concretions occur in the sandstone. The Upper Whitesburg coal bed occupies a channel scour. It thickens from 1.3 feet outside the channel to 2.0 feet in the channel. Siltstone with sandstone lenses composes the channel fill.

The Fire Clay coal also occupies a channel scour that cuts into the channel fill above the Whitesburg coal. The Fire clay coal ranges in thickness from 1.9 feet on the west side to 2.2 feet in the channel to 1.7 feet on the east side of the channel. A flint clay occurs within the Fire Clay coal (*see* Bohor and Triplehorn, this volume). The Fire Clay coal has 0.4 foot of coal below the flint clay parting, which is 0.5 foot thick. Pyrite occurs on the cleats of this coal. Overlying the coal is the black fissile shale. Lycopod cones, *Cordaites* leaves, and horizontal burrows occur in this black shale. Part of this section is covered, but claystones and siltstones extend up to the Fire Clay rider.

The Fire Clay rider is 1.8 feet thick. A black fissile shale just below the rider contains the pelecypod *Naiadites*. A thin coal occurs above the rider. Rippled and cross-bedded sandstone, shale, and abundant siltstone extend to the top of this roadcut.

Interpretation

The coals and strata exposed at this stop indicate similar depositional processes for both coal zones. Sedimentation was dominated by deposition of fine clastics into shallow, slack-water environments of low relief. Erosion by channel scour was minimal but important as sites of peat accumulation. Occasional periods of marine- to brackish-water conditions were followed by periods of emergence and peat accumulation.

The Kendrick Shale underlies the strata exposed at this stop. The Kendrick Shale has a marine fauna and commonly coarsens upward into the Whitesburg coal zone. The environments of deposition suggested for these coal zones are interdistributary bay, crevasse, splay, splay channel, and brackish bay to restricted-marine bay.

The flint clay parting (tonstein) within the Fire Clay is interpreted as resulting from a volcanic ash fall.

57.6 Milepost 44. Toll booth. Level of Kendrick Shale.

59.6 Milepost 46. Amburgy coal at base of Kendrick Shale. Whitesburg coal zone above the Kendrick Shale. Fire Clay coal thins to zero in this area.

61.6 Milepost 48. Whitesburg coal zone, Fire Clay, and Fire Clay rider coals. Crossing Middle Fork of Kentucky River.

62.2 Whitesburg coal zone to Magoffin Member.

63.5 Milepost 50. Coarsening upward Magoffin Member. Hazard through Hazard No. 7 coals.

64.2 Coals in channel fill. Hazard through Hazard No. 8 coals.

64.7 Milepost 51. Large roadcut. Enter Perry County. Hazard through Hindman coals (Hazard No. 9 coal). Hazard No. 7 eroded.

66.0 Milepost 52. Large roadcut. Magoffin Member. Hazard through Hindman coals. Hazard No. 7 eroded.

67.0 Milepost 53. Magoffin Member. Hazard to Francis coals.

68.1 Bone, 3 feet thick, in the Hamlin coal zone.

68.9 **Stop 5: Milepost 55, Daniel Boone Parkway**

Purpose

The feature of particular interest exposed in the roadcut is the cut out of the Hazard No. 7 coal which is seen here only as an erosional remnant. The Magoffin Member will be seen at road level on the west side of the roadcut, and collecting of its abundant fauna will be possible. The destructional effects of large rivers will be emphasized.

Location

This stop is located at milepost 55 on the Daniel Boone Parkway. It is 4 miles west of the intersection of the Daniel Boone Parkway and Kentucky Highway 15 in the Krypton Quadrangle at Carter coordinate location 22-J-75, 2,100 ft. FSL X 1,500 ft. FEL. The roadcut is 0.75 mile in length and reaches a maximum vertical height of 380 feet. The location of this stop is shown in the field trip route map (Fig. 3).

Stratigraphy

The stratigraphy exposed in this roadcut from road level upward includes the Magoffin Member, Hazard (Hazard No. 5A) coal, Hazard No. 7 coal, Francis (Hazard No. 8) coal, the Hindman (Hazard No. 9) coal, and the Stoney Fork Member of the Breathitt Formation. The geologic setting and stratigraphy exposed at this stop are shown in the inside front and outside back covers.

Description

The descriptions to follow are keyed to a diagrammatic sketch of the roadcut shown in Plate 6 (in pocket).

The Magoffin Member of the Breathitt Formation is exposed at road level at the western end of the roadcut. The Magoffin Member is a medium-gray, silty, calcareous, fossiliferous shale. A description of Magoffin fossils follows below in this section. It contains large calcareous concretions that are also fossiliferous. The shale has zones of fossils that persist laterally for many feet, but the entire unit is fossiliferous throughout (*see* Chesnut, this volume). The shale coarsens upward (Plate 6 (in pocket) coarsening-upward sequence 1) into a sandstone, but at the level of the first bench it is truncated by a scour surface.

A scour surface with conglomerate lag indicates erosion of the coarsening-upward shale sequence. Sandstone overlies the scour surface. This sandstone interfingers to the east with siltstone and shale. A second scour surface truncates the sandstone and shale. In a repetition of the interfingering of sandstone and shale, these same types of deposits overlie the second scour. Erosion cut into both of the underlying, interfingered deposits. Several disturbed beds that are oversteepened and have contorted bedding occur directly above the scour surface. These beds of siltstone and sandstone with some shale reside on an incline that dips to the east. They are in turn truncated by the thick sandstone with trough crossbeds that extend upward to about the level of the second bench on the west end of the outcrop. This sandstone also interfingers to the east with shale, and the shale contains calcareous concretions. This sandstone begins a fining-upward sequence (Plate 6 (in pocket) fining-upward sequence 2). These beds are the third repetition of sandstone-shale facies changes in about 35 feet of the section above the marine shale; in this case, however, the sequence is completed by coal beds.

A scour surface near the level of the second bench is overlain by medium-gray, silty shale with irregular siderite nodules and thin sandstone lenses. A vertical stump 4 feet tall occurs in the interbedded units. The thin coals which are less than 0.6 foot in thickness are in the Hazard (Hazard No. 5A) coal zone. At this location the main coal bed of the Hazard coal zone is 3.6 feet thick.

A medium-gray shale with siltstone and fine sandstone occurs above the Hazard coal at or near the level of the third bench. Plant fossils found in this unit were field identified by James Jennings (Plates 7-9). These fossils are *Alethopteris lonchitica, A.* cf. *A. serlii, Annularia galliodes, A. radiata, Asterophyllites charaeformis, Calamites cistii, C. undulatus, Eremopteris gracilis, Lepidophylloides* sp., *Lepidostrobophyllum* sp., *Lepidostrobus* sp., *Mariopteris* cf. *M. nervosa, Neuropteris* cf. *N. tenuifolia, Palmatopteris furcata, Paracalamostachys* sp., and *Sphenophyllum cuneifolium.* A rooted vertical *Calamites* trunk was found in a siltstone lens in the medium-gray shale. Several thin coals occur and are overlain by sandstone and shale. These sandstones and shales extend up to about the level of the third bench, interfinger, and pinch out laterally.

Shale with sandstone and large sandstone lenses occurs above the third bench. This shale contains abundant siderite and burrows. A very irregular erosional surface is cut into the shale and sandstone. Above the erosional surface is nearly 70 feet of crossbedded sandstone in a fining-upward sequence (Plate 6 (in pocket) fining-upward sequence 3). Trough crossbeds, conglomeratic lags, and coal spar are abundant in this thick sandstone. One of the most obvious features in this sandstone is the large coal remnant. This coal is at the stratigraphic position of the Hazard No. 7 coal bed. It attains a thickness of more than 6 feet less than 1 mile east of here.

About 1 foot of sandstone occurs below the coal remnant. The remnant also occurs above a topographic high of the channel bottom. Unfortunately, we could not get close enough to check for rooting below the coal, but the other evidence seems to indicate that this coal remnant was stream transported and came to rest on this high in the channel. An alternate explanation could be that the Hazard No. 7 coal was originally deposited here and then stream erosion removed all but this remnant. It might also be said that both explanations are in part correct. The Hazard No. 7 coal may have been deposited here but subsequently destroyed by the action of stream erosion. The remnant may then have been transported in, while the stream was still actively cutting away peat in other areas. It is apparent from the compactional features seen in the sandstone enclosing the coal and in the coal itself that a consider-

PLATE 7

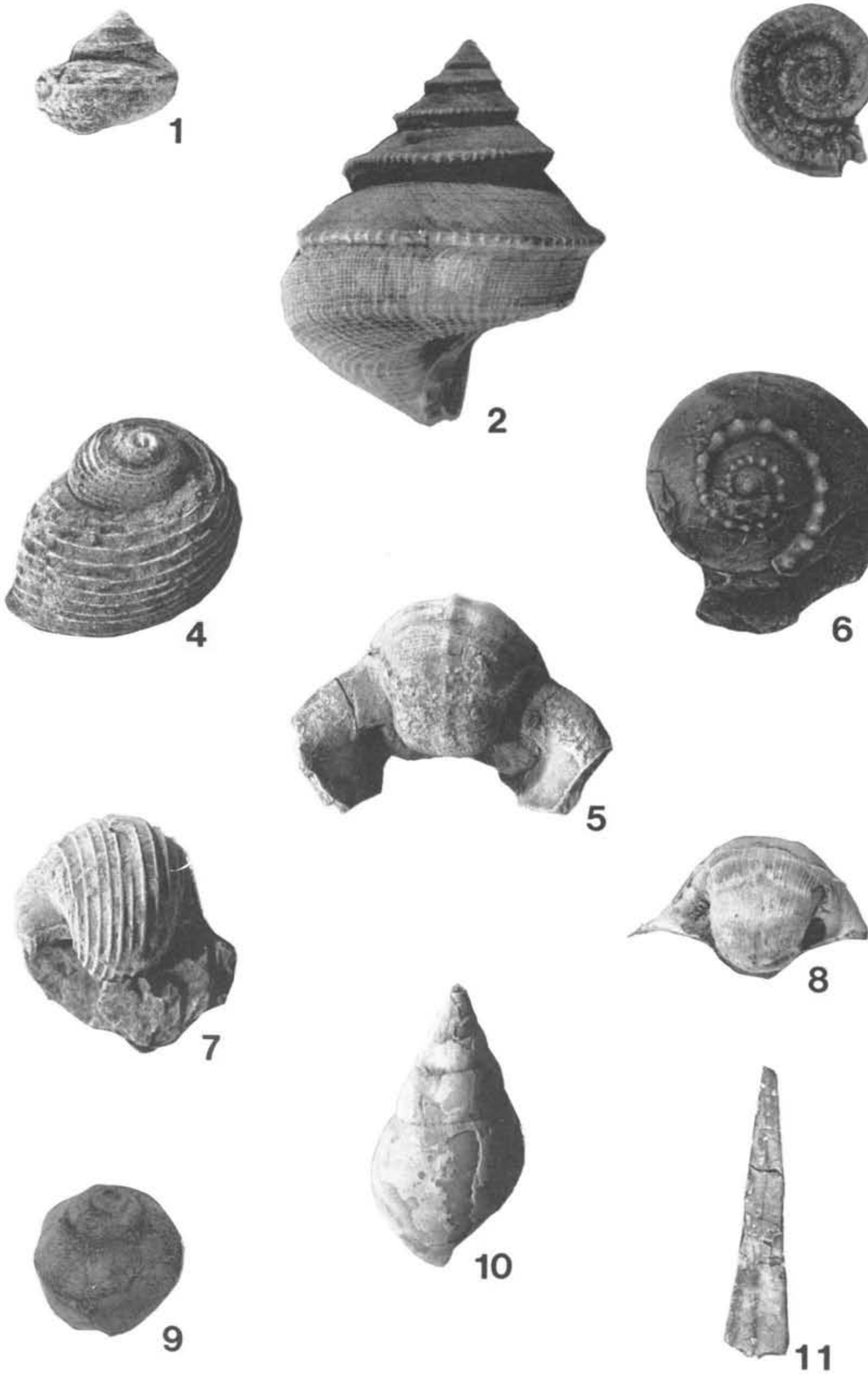


Plate 7. Common fossils from the Magoffin Member along field trip route. All specimens coated lightly with ammonium chloride.

Figure 1. *Glabrocingulum* cf. *G. wannense,* poor specimen from Daniel Boone Parkway, near Hyden, Leslie County, Kentucky. X1.2.

Figure 2. *Worthenia tabulata,* at Stop 10, Martin Cut, Floyd County, Kentucky. X1.8.

Figure 3. *Straparollus catilloides,* along Daniel Boone Parkway, near Hyden, Leslie County, Kentucky. X2.3.

Figure 4. *Shansiella carbonaria,* at Stop 5, Perry County, Kentucky. X1.7.

Figure 5. *Bellerophon (Pharkidonatus) percarinatus,* at Stop 5, Perry County, Kentucky. X1.3.

Figure 6. *Trepospira illinoiensis,* very common, along Daniel Boone Parkway, near Hyden, Leslie County, Kentucky. X2.3.

Figure 7. *Euphemites enodis,* along Daniel Boone Parkway, near Hyden, Leslie County, Kentucky. X2.5.

Figure 8. *Knightites (Cymatospira) montfortianus,* at Stop 10, Martin Cut, Floyd County, Kentucky. X1.9.

Figure 9. *Strobeus* cf. *S. brevis,* along Daniel Boone Parkway, near Hyden, Leslie County, Kentucky. X1.

Figure 10. *Strobeus* cf. *S. regularis,* at Stop 10, Martin Cut, Floyd County, Kentucky. X2.4.

Figure 11. *Plagioglypta* sp., a scaphopod, from black shales near base of Magoffin Member, Hindman Access Cut, Knott County, Kentucky. X2.5.

PLATE 8

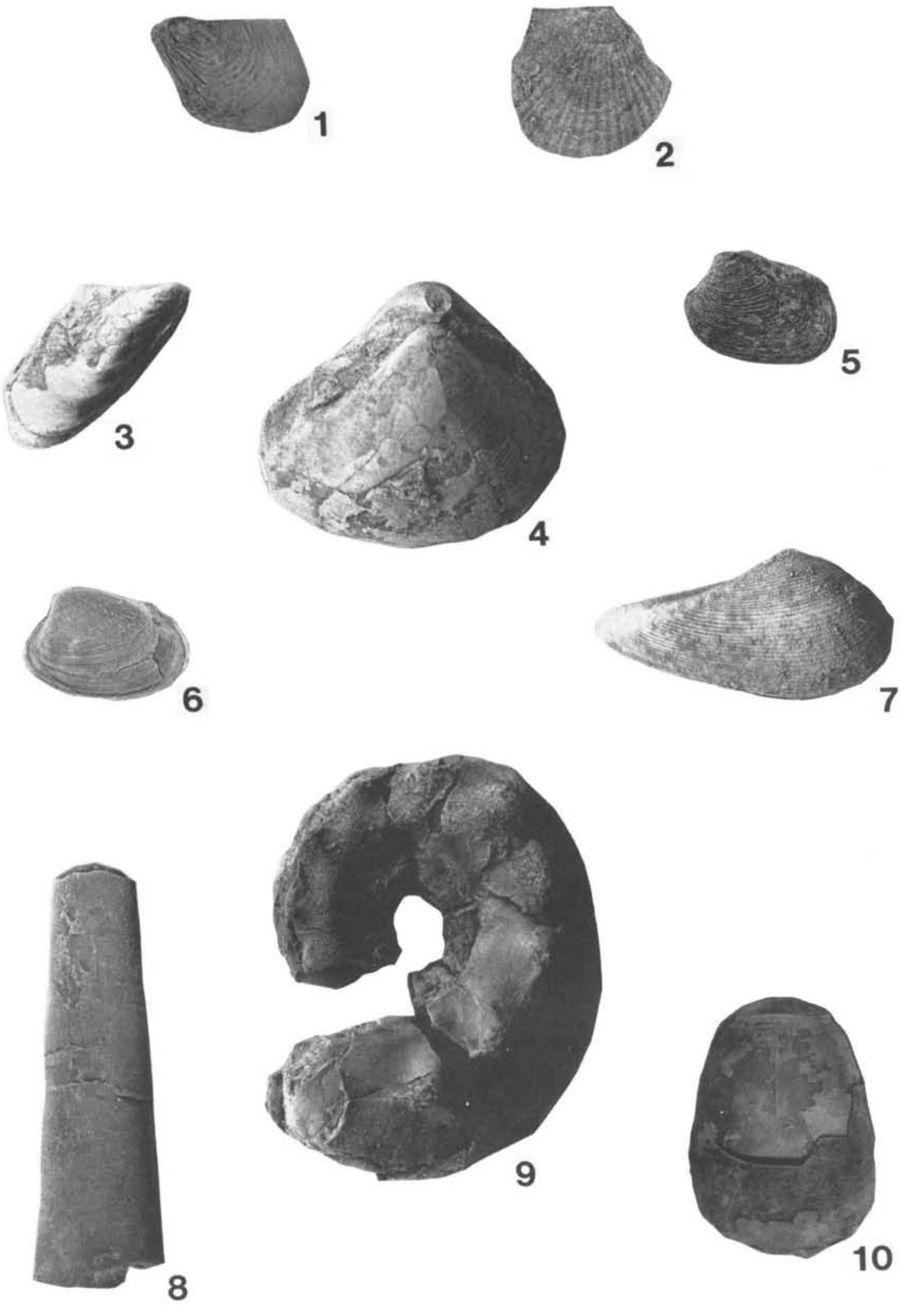


Plate 8. Common fossils from the Magoffin Member found along the field trip route. All specimens lightly coated with ammonium chloride.

Figure 1. *Posidonia vintonensis,* from black shales near the base of the Magoffin at Stop 9, Hindman Access Cut, Knott County. X2.3.

Figure 2. *Dunbarella striata,* from same bed as Figure 1. X2.3.

Figure 3. *Septimyalina perattenuata,* at Stop 5, Perry County, Kentucky. X1.7.

Figure 4. *Schizodus cuneatus,* at Stop 5, Perry County, Kentucky. X1.7.

Figure 5. *Astartella* cf. *A. newberryi,* at Stop 5, Perry County, Kentucky. X2.4.

Figure 6. *Nuculopsis girtyi,* perhaps the most common fossil in the Maggofin Member, from along Daniel Boone Parkway, near Hyden, Leslie County, Kentucky. X2.2.

Figure 7. *Phestia bellistriata,* very common, at Stop 5, Perry County, Kentucky. X2.5.

Figure 8. *Pseudorthoceras knoxense,* very common, from along Daniel Boone Parkway, near Hyden, Leslie County, Ken tucky. X1.7.

Figure 9. *Temnocheilus subrectangularis?,* common but usually crushed or fragmented, from along Daniel Boone Parkway, near Hyden, Leslie County, Kentucky. X0.9.

Figure 10. *Brachycycloceras* sp. *(Poterioceras),* Knott County, Kentucky. X1.

PLATE 9

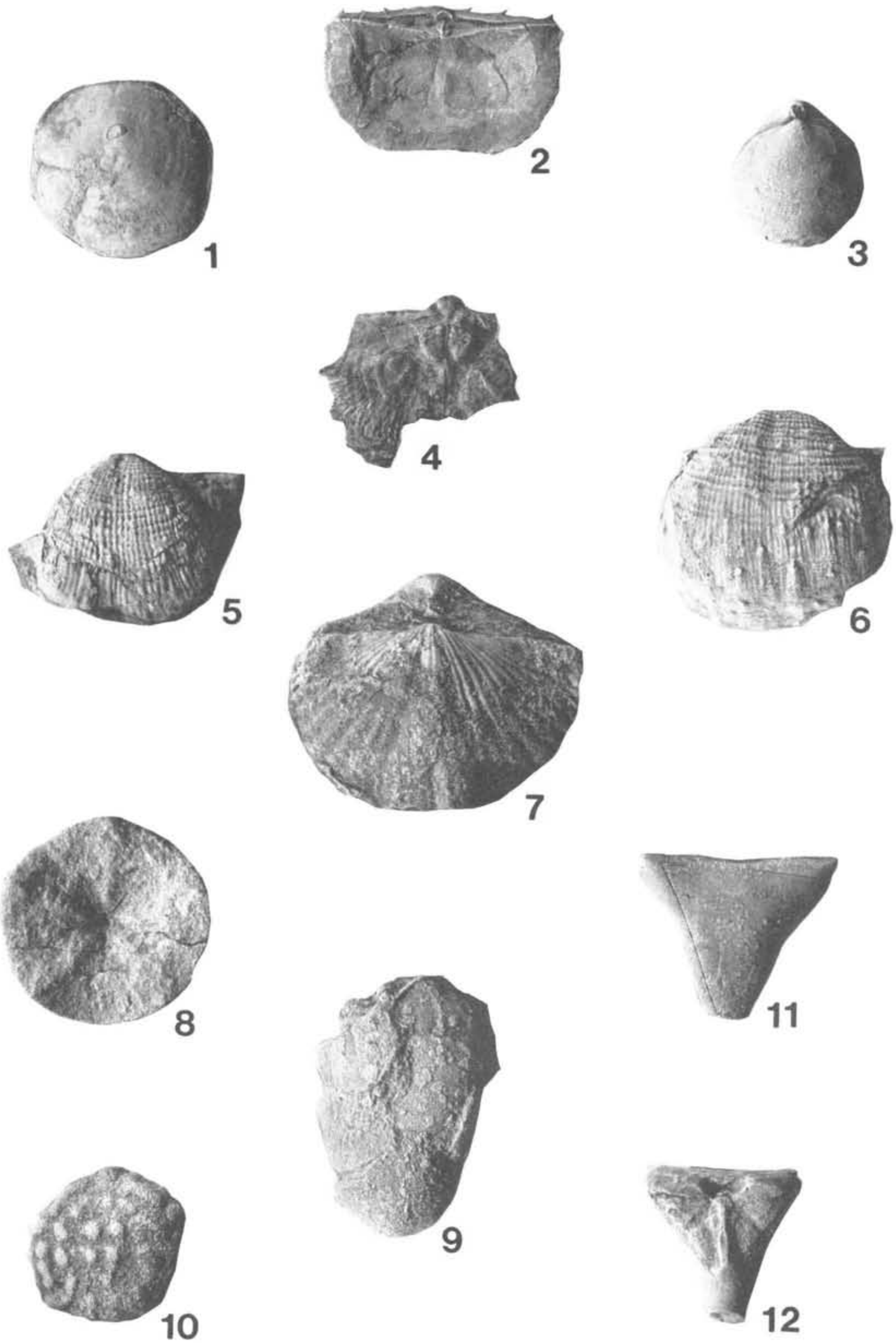


Plate 9. Common fossils from the Magoffin Member found along the field trip route. All specimens lightly coated with ammonium chloride.

Figure 1. *Orbiculoidea capuliformis,* an inarticulate brachiopod, at Stop 5, Perry County, Kentucky. X1.8.

Figure 2. *Rugosochonetes delicatus,* at Stop 5, Perry County, Kentucky. X1.1.

Figure 3. *Composita subtilita,* at Stop 5, Perry County, Kentucky. X2.5.

Figures 4-6. *Antiquatonia* cf. *A. portlockiana quadratia* (Fig. 4) internal view of brachial valve (Fig. 5) and external view of pedical valves (Fig. 6), along Daniel Boone Parkway, Perry County, Kentucky. X1.2.

Figure 7. *Anthracospirifer* cf. *A. matheri,* at Stop 5, Perry County, Kentucky. X1.7.

Figure 8. *Paragassizocrinus tarri* (low-cone ecopheno-type), infrabasal cone of a stemless crinoid that lived partially buried in mud, at Stop 5, Perry County, Kentucky. X2.5.

Figure 9. *Paragassizocrinus tarri* (medium-cone ecopheno-type), dorsal cup, at Stop 5, Perry County, Kentucky. X2.4.

Figure 10. Ornamental basal plate of a crinoid *(Metacromyocrinus?),* at Stop 5, Perry County, Kentucky. X2.3.

Figures 11-12. *Plaxocrinus mosresi,* spine-shaped primibrachial plate of a crinoid, dorsal and ventral views, at Stop 5, Perry County, Kentucky. X2.5.

able amount of post-depositional compaction occurred. This indicates that the remnant was enclosed in the sand still as a peat. The thick sandstone continues up to the level of the sixth bench.

Medium-dark-gray shale and thin coals overlie the thick sandstone at the top of the fining-upward sequence. The shale was deposited on an irregular surface having up to 10 feet of relief. Several thin sandstones, shales, and thin coals follow this shale. The coals are part of the Francis (Hazard No. 8) coal zone at the level of the seventh bench.

The Francis coal has five prominent benches of coal ranging from 2 inches thick up to 19 inches thick. These are separated by medium-dark-gray shales from 2 1/2 to 8 inches thick. The full thickness of the Francis coal zone at this location is 6.7 feet. About 4 miles east of here the Francis coal is mined where it occurs in two benches. There is about 48 feet of sandstone, siltstone, and shale in a fining-upward sequence (Plate 6 (in pocket) fining-upward sequence 4) above the Francis coal. These beds extend up to the ninth bench. A coal bed 6 to 7 inches thick at the ninth bench is informally named the Francis (or Hazard No. 8) rider.

A thin bed of silty shale and sandstone overlies the rider coal. This is laterally discontinuous due to the overlying sandstone. A medium to coarse sandstone directly overlies the rider coal in places. This thick sandstone contains trough cross-beds. It continues to the Hindman (Hazard No. 9) coal at about the tenth bench. The Hindman coal is 4.1 feet thick. It is overlain by thin-bedded sandstone and shale. These beds are overlain by black shale containing a thin limestone lens. Marine fossils are also found in the black shale. This unit is the Stoney Fork Member of the Breathitt Formation.

A thick sandstone with trough cross-beds in part continues to the top of this roadcut.

Interpretation

The typical marine fauna of the Magoffin Member indicates its deposition in the marine environment. The coarsening-upward nature of the Magoffin Member shows the increased influx of terrigenous clastics into a marine environment. The erosion surface that terminates the marine shales indicates the arrival of prograding distributary channels into the area of the marine bay.

As progradation continued, the distributary system persisted, depositing sands and silts in mouth bars, distal levees, and delta front environments. Sands, silts, and clays were also deposited in the interdistributary environments, environments which had marine- or brackish-water conditions. The succession of sandstone and shale facies separated by scoured surfaces shows that the distributary migrated while it built up.

A fining-upward sequence overlies the distributary-interdistributary facies sequences and indicates that channel, overbank, and crevasse splay deposits built into the distal deltaic environments. Vertical stumps, abundant plant fossils, and coals indicate frequent emergence, as would be expected on the natural levees and swamps of a major distributary system.

The sequence dominated by shale and siltstone with minor sandstones and coals, above the Hazard coal, shows episodic deposition of terrigenous sediments. Another rooted vertical stump in these deposits shows lengthy emergence interrupted by rapid sedimentation. Next, subsidence probably exceeded sediment input for a brief interval, causing a slight transgression which deposited calcareous burrowed shales.

The thick sandstone following the transgression represents the migration of a major distributary channel across this area. Erosion by this system was so extensive that the transition from marine back to fluvial was removed. The coal remnant enclosed by this sandstone suggests the accumulation of a thick peat deposit that was destroyed by the river. At the next stop (Stop 6) the Hazard No. 7 coal is 7 feet thick and has been the major producing coal in this area. A major focus of this trip is to observe the varied character of this coal. Here at Stop 5 it is reduced to an erosional remnant; at Stop 6 it is 7 feet thick; at Stop 7A it has a major shale parting; at Stop 7B it has a split 35 feet thick; and at Stop 10 it is split into many thinner coal beds.

This major sandstone fines upward into shales and thin coals capped by the Francis (Hazard No. 8) coal zone. Siltstones and shales of slack water and overbank origin continue up to a rider coal before the occurrence of another major fluvial sandstone. This sandstone is overlain by the Hindman (Hazard No. 9) coal bed. A minor transgression may have closely followed the deposition of the Hindman seam because marine fossils and thin carbonate beds overlie the Hindman coal. Another massive sandstone overlies the marine zone, indicating that distributary systems moved back into the area.

Paleontology

These fossils are usually common in the Magoffin Member and most are common in fossiliferous marine zones in the Breathitt Formation. The macrofossils listed here and in Plates 7, 8, and 9 were found along the Daniel Boone Parkway and new Kentucky Highway 80 (Day 1 and Day 2 of the field trip). Common fossils collected from the Magoffin Member but not included in the plates include the following taxa: *Derbyia crass, Antiquatonia* sp. A, *Linoproductus* cf. *L. planiventralis, L.* cf. *L. echinatus, Paleyoldia* sp., *Solemya* cf. *S. trapezoides, Astartella concentria, Microtychis* sp., *Mooreoceras* sp., unidentified coiled nautiloids, unidentified goniatite (awaiting identification), and unidentified crinoidal stems, dorsal cups, arms, and plates.

70.4 Cross over Kentucky Highway 451. Coal at road level is Fire Clay coal at milepost 56.

70.9 Milepost 57. Strip mining in Hazard No. 7, Francis, and Hindman coals.

71.2 Cross North Fork of the Kentucky River.

73.2 Stop 6: Hazard, Kentucky

Purpose

The purpose of this stop is to observe a significant section of the major producing coals of the Eastern Kentucky Coal Field. This stop will be organized in such a way that close inspection of many of the coals can be made and that coal samples, plant fossils, and marine fossils can be collected.

Location

This stop is located at the intersection of Kentucky Highway 80, Kentucky Highway 15, and the Daniel Boone Parkway about 2.7 miles northwest of Hazard, Kentucky, in Perry County. The stop is located at Carter coordinate section 14-J-76. The eastern side of this intersection begins a new section of Kentucky Highway 80. The intersection of these major highways opens a three-dimensional panorama in the Breathitt Formation. The maximum height reached by this roadcut is 350 feet. The location of this stop is shown on the field trip route map in Figure 3. **Caution:** This stop has exposures which alone are sufficient material for an entire field trip. This trip plans to spend more than the usual allotted time at this stop for trip participants to closely inspect the section exposed here, to collect samples, and to see the coals close at hand.

The dangers here are many. The danger from traffic is always present. All participants should be alert for the inherent dangers of the extreme heights, unstable highwalls, and unstable footings. People should always stand back from the highwalls. Be particularly aware of people below you and of injuries that could result from dislodged rocks falling down.

Do not enter adits or overhangs of adits! Blasting intended to collapse them has made them extremely unstable.

Field trip assistants will be stationed on the access trails to points of interest up the several highwalls. Each participant will receive instructions about the points of special interest. **Please follow only our suggested routes so that no one will be endangered by your climbing!** We have intentionally spread out the trails to points of interest to minimize the danger.

People are reminded that much of the geology is visible from the road and that climbing is not necessary and is UP TO YOUR OWN DISCRETION!

PLATE 11

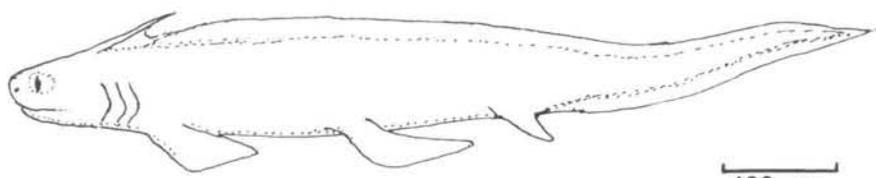
1

2a

2b

2c

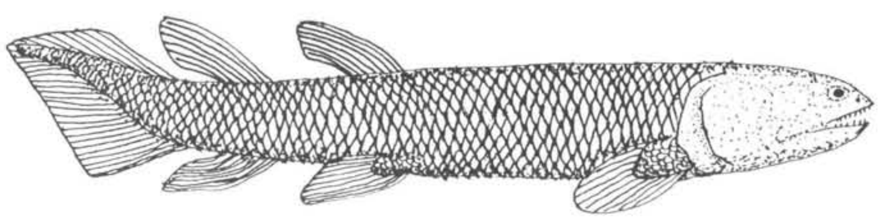
2d



100 mm.

3a

Xenacanthus sp. (after Moy-Thomas, 1971)



3b

10 mm.

Rhizodopsis sp. (after Moy-Thomas, 1971)

Plate 11. Fossil shark.

Figure 1. *Rhizodus* sp. (or *Rhizodopsis* sp.) scale, internal surface of scale. Photograph courtesy of Dr. Charles Helfrich. X1.7.

Figures 2a-b. *Diplodus* sp., two specimens. X2.

Figure 2c. *Polyrhizodus* sp.?. This small, poorly preserved tooth was found in the same bed as Figures 2a-b. X2.

Figure 2d. These small chitinous or phosphatic "y"-shaped fossils were found with the fish teeth in Figure 2a-c. X8.

Figure 3a. *Xenacantus* sp. (after Moy-Thomas, 1971), an eel-like fresh- or brackish-water shark possessing *Diplodus*-type teeth. Note the spine at the top of the head.

Figure 3b. *Rhizodopsis* sp. (after Moy-Thomas, 1971), a marine bony fish. *Rhizodus* was a larger bony fish than the related *Rhizodopsis* and lived in brackish or fresh water.

Stratigraphy

The named stratigraphic units at this stop from bottom to top are Magoffin Member, Haddix coal zone, Hazard (Hazard No. 5A) coal zone, Hazard No. 7 coal, Francis (Hazard No. 8) coal, and Hindman (Hazard No. 9) coal. The geologic setting and stratigraphy of this stop are shown in the inside front and outside back covers.

Description

A diagrammatic sketch showing all the coal beds, their stratigraphic nomenclature, and the structures and lithologies of enclosing strata is presented in Plate 10 (in pocket).

The Magoffin Member is only exposed in the lower cuts along Kentucky Highway 15 and in the exit ramp from Kentucky Highway 15 to the westbound Daniel Boone Parkway on the northwest corner of the intersection. The Magoffin Member is a medium-gray shale containing large calcareous concretions. The Haddix coal zone overlies the Magoffin and is seen in the northwest entrance ramp from Kentucky Highway 15 to the Daniel Boone Parkway. The Haddix consists of several thin coals separated by siltstone and black fissile shale. A black shale containing *Naiadites* and occasional shark teeth (Plates 11 and 12) (*see Paleontology,* this section) occurs between two of the Haddix coals. A sandstone containing log impressions, vertical stump, and cut-and-fill structures extends up to the Hazard coal zone.

The Hazard (Hazard No. 5A) coal zone consists of several coals separated by silty shale, siltstone, and fine sandstone. The two thickest coals in this zone are 1.1 and 4.3 feet thick. Above the upper coal, which is the thickest coal, is a fining-upward sequence (Plate 10 (in pocket) fining-upward sequence 1). Accretion-type beds occur at the top of the sandstone and interfinger with siltstone. This siltstone contains vertical stumps, *Calamites,* siderite nodules, and is intensively rooted. The fining-upward sequence culminates in three thin coals all less than 0.3 foot thick.

The thin coals are overlain by a marine sequence. Evidence for marine deposits is calcareous concretions, burrowed zones, and shell fragments. Gilbert Cumbee (in preparation) has traced this marine zone in several counties and has noted its occurrence at Stops 5, 6, and 7 of this field trip.

The Hazard No. 7 coal overlies an argillaceous sandstone with siderite nodules and flaser bedding. The full seam thickness of the Hazard No. 7 coal is 7.1 feet. Recognizing the Hazard No. 7 coal in this area is easy because it is extensively mined and the mine adits, now partially collapsed, are obvious. For those interested in coal mine engineering, these collapsed adits give an interesting perspective of roof falls.

Siltstone, fine sandstone, and shale overlie the Hazard No. 7 coal. Ripples, flaser bedding, lenticular bedding, siderite nodules, rooting, and plant fossils are common (*see* Jennings, this volume). Very thin coals also occur. Of very particular interest are the more than 20 vertical stumps and trunks found in the interval between the Hazard No. 7 coal and the Francis (Hazard No. 8) coal. The largest of these measures 3.0 feet in diameter and the average is more than 1.0 foot in diameter.

The Francis (Hazard No. 8) coal overlies the siltstone and shale above the Hazard No. 7 coal. The Francis coal in the southwest corner of this intersection is eroded, in the northwest corner eroded and slumped, and in the northeast corner contains a clay parting that disappears within the same roadcut. In the northeast corner this coal is a maximum of 8.6 feet thick with 0 to 3.0 feet of clay parting. The clay parting contains brackish or fresh-water fossils (*see Paleontology,* this section). The Francis coal is overlain by a thin and discontinuous claystone and a thick, coarse-grained sandstone. This sandstone begins a fining-upward sequence (Plate 10 (in pocket) fining-upward sequence 2) and is capped by a coal bed, informally known either as the Francis or Hazard No. 8 rider. This coal is 0.7 foot thick and is characterized by oddly shaped, grapefruit-size calcareous nodules. The nodules contain cone-in-cone structure and are enclosed in dark-

Plate 12. Pelecypods near Stop 6, "Four Corners," Perry County, Kentucky

Figure 1. *Anthraconaia (Naiadites)* sp., small form, from dark-brown shales associated with the Hazard No. 8 coal. Lightly coated with ammonium chloride. X2.

Figure 2. Unidentified pelecypod, incomplete. Occurs with specimen in Figure 1. X2.

gray claystone. The claystone is eroded at the top. A conglomerate sandstone that fines upward (fining-upward sequence 3) overlies the claystone. It contains coal spar, pebbles, log impressions, and convoluted bedding.

The Hindman (Hazard No. 9) coal is rooted into sandstone and is 3.1 feet thick. It is overlain by a dark-gray shale followed by a thick, dark-gray, silty shale; siltstone and sandstone interbeds; and a conglomeratic sandstone with log impressions. The shales and siltstones are known as the Stoney Fork Member, a marine unit. The shales at many locations contain abundant marine fossils (Stop 5); however, here, none have yet been found. The fossiliferous portion may have been eroded. At Stop 7, truncated lenses of the fossiliferous part of the Stoney Fork Member can be seen below the barren shales. Except for these two localities, the Stoney Fork Member is usually fossiliferous. It is a key stratigraphic marker bed in eastern Kentucky.

Interpretation

The Magoffin Member, as previously discussed, represents a marine environment which filled with terrigenous clastics. Upon these deposits the Haddix coal zone developed. The Haddix coal is mined in Breathitt County to the north but is often absent, as is the case at Stops 5, 8, and 9, where it was probably removed by erosion. Brackish- to fresh-water influences were still active during Haddix deposition, as seen by the fossiliferous black shale between coals of this zone.

Crevasse splay sediments were deposited over the Haddix peat deposits and built up to a level which supported tree growth. In-place stumps and transported logs can be seen in this zone. A reduction in sediment influx allowed sporadic peat accumulation. A sandstone with accretion beds directly overlying the thickest Hazard coal bed indicates fluvial processes, particularly point-bar deposition onto the peat swamp. This point-bar-type deposit marks the occurrence of a river channel in the area. The accretion beds are overlain by overbank deposits of siltstone containing abundant plant fossils and in-place stumps. Although peat accumulation continued, this sequence is dominated by thick overbank deposits. Subsidence developed faster than sediment influx and marine conditions developed above the overbank deposits. The fossil fragments, calcareous concretions, and burrowing indicate brackish to marine conditions for these deposits, but the grain size still shows a high terrigenous clastic input.

Following filling of the bay, the Hazard No. 7 peat accumulated. A succession of overbank deposits covered this extensive peat deposit. The burial of in-place stumps by these overbank deposits preserved a good example of a Pennsylvanian forest in eastern Kentucky. There are, in fact, at least two successive preserved forests separated by a dark claystone and several thin coals midway up the interval. The preserved trees probably represent a mature forest, because many reached a diameter of 3.0 feet (*see* Jennings, this volume).

A diversion in the major drainage system caused cessation of the overbank deposits. During this period of emergence, the Francis peat accumulated. At least once a period of more rapid subsidence caused brackish water to inundate the Francis coal swamp, depositing a fossiliferous claystone parting; however, peat accumulation resumed. The thick sandstone above the Francis coal represents the return of a major distributary. This distributary eroded Francis peat deposits in some places and caused major slumping in other places. A thick sandstone was deposited over the Francis peat by this system.

The Francis or Hazard No. 8 rider may have been deposited under marine influence, causing the unusual calcareous concretions in its immediate roof. These calcareous concretions can be traced at least for several miles eastward. These sediments are followed by fluvial channel and point-bar deposits.

The Hindman peat accumulated over the thick fluvial deposits during a period of emergence coupled with uniform subsidence. A marine zone sometimes present above this coal does not occur here, but marine conditions probably existed here after the peat was formed.

Coal Characterization

Hower and others (this volume) have analyzed the coals at this stop. For details about these coals see their text and Tables 8, 9, and 10.

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74.0 Hazard No. 8 rider through Hazard No. 10 coals exposed in this roadcut.

74.4 Upper part of Hazard coal zone through Hindman coal.

74.8 Hazard No. 7 through Hindman coals exposed. Kentucky Geological Survey core drilled near here (*see* Cobb and Smath, this volume).

75.2–75.7 **Stop 7: Darb Fork, Kentucky**

Purpose

The purpose of this stop is to see a major split in the Hazard No. 7 coal as it opens from a 26-inch parting to a split 35 feet thick.

Location

This stop is located on new Kentucky Highway 80 about 2 1/2 miles east of the intersection of the Daniel Boone Parkway and Kentucky Highway 15. The roadcuts of interest are on both sides of the Darb Fork stream cut, where Kentucky Highway 80 passes over the stream. Stop 7A is on the west side of the stream valley and Stop 7B is on the east side. These roadcuts are in the Hazard North Quadrangle in Perry County at Carter coordinate locations 9-J-76, 1,200 ft. FSL X 2,450 ft. FEL, and 1,200 ft. FSL X 1,600 ft. FEL. The roadcuts are about 0.2 mile in length and attain a maximum vertical height of 320 feet.

Stratigraphy

The named stratigraphic units exposed at this stop are the Hazard coal zone, the Hazard No. 7 coal, the Francis (Hazard No. 8) coal, the Hindman (Hazard No. 9) coal, and the Stoney Fork Member of the Breathitt Formation.

Approximately 0.26 mile to the west of Stop 7A, the Kentucky Geological Survey drilled a borehole 358 feet deep from road level. This borehole is described in Cobb and Smath (this volume) and shows the stratigraphy from the Hazard No. 7 coal down to the Upper Whitesburg coal.

Description

This roadcut is shown by a diagrammatic sketch in Plate 13 (in pocket).

The rider coals of the Hazard coal zone occur in the downhill parts of the roadcuts. These thin coals are persistent along the trip route and were seen at Stops 5 and 6. The coals are overlain by sandstones and siltstones which are calcareous and burrowed. The articulate brachiopod *Anthracospirifer* was found here.

The Hazard No. 7 coal is developed on siltstone above the calcareous beds. The Hazard No. 7 coal is 8.4 feet thick and contains a parting 1.6 feet thick at Stop 7A. The parting is shale and contains siderite nodules. The coal below the parting is 4.6 feet thick and the coal above the parting is 2.2 feet thick. Within only a few feet the parting increases to 6 feet.

At Stop 7B, approximately 0.2 mile east of Stop 7A, the parting becomes a split in the coal 34 feet thick. The lower coal is 4.5 feet thick, little changed from its thickness on the west side at 7A; but the upper coal is only 1.2 feet thick, about one-half of its thickness at 7A. Overlying the lower coal is only a few feet of dark-gray, fissile shale with abundant plant fossils (*see* Jennings, this volume). Above this is a gray, silty shale with some sandstone, abundant plant fossils, and siderite nodules. This interfingers to the east with a fine sandstone with interbedded shale.

The upper coal has relief and dips downward into a depression which is directly above a high in the lower coal. It is also above the interfingered contact between lobes of silty shale and fine sandstone with shale. Immediately below the depression the beds are disturbed (*see* Plate 13; in pocket). The remainder of this section is much the same as at Stop 6.

Interpretation

The depositional sequence for the upper part of the Hazard coal zone is nearly identical to that seen at Stops 5 and 6 (*see Discussion,* Stops 5 and 6).

The Hazard No. 7 coal is 7.0 feet thick at Stop 6 only 2 1/2 miles west of here. The thickness of the coal minus the parting at Stop 7A is 6.8 feet. Deposition of the thin parting apparently did not hinder the subsequent development of the seam. The combined coal thickness is only 5.7 feet at 7B, a loss of 1.1 feet from 7A. Since the lower seam thickness is nearly the same at 7A and B, and the upper coal is only half as thick at 7B, the split had considerable effect on the development of the upper coal but apparently none on the lower coal. The origin of the split was as a ponded environment accumulating only clay and organics which were blown or washed in. Then lobes of fine-grained clastics, probably from crevasse-splay-type processes, built into the ponded environment. The first lobe may have deformed the existing peat deposit, causing the high in the lower coal. A second lobe coalesced with the first, causing the interfingering between the lobes. Deposition was rapid and did not allow peat to accumulate while the sediments were being deposited. As a result, no coal stringers, thin coals, or heavily rooted zones are found in these deposits.

The depression in the upper coal of the Hazard No. 7 zone may be a swale that formed between the coalescing lobes, representing the original depositional relief. The disturbed beds below the depression in the upper coal are probably the result of minor slumping into the swale.

The thick sandstone above the upper coal of the Hazard No. 7 zone is the result of a river migrating across this area. This same river probably had earlier supplied the sediments which were deposited in the crevasse splays forming the split. Peat for the Francis (Hazard No. 8) coal accumulated on this sandstone after the river again migrated out of the area. The silty claystone with abundant plant debris above the Francis coal is an overbank deposit indicating the influence of the river on its flood plain. The river migrated back into this area as indicated by the scour surface on the overbank deposits above the Francis coal and the thick, fining-upward sequence of fluvial deposits which followed. The rider coal above the Francis coal developed as the culmination of fluvial processes once the river's drainage had again been diverted. An episode of brackish-water conditions invaded the coal swamp and terminated peat accumulation. Only nonfossiliferous clays with calcareous concretions formed in this restricted environment.

The river channel once again migrated into this area and scoured the deposits of the brackish-water environment. Its thick, fluvial, fining-upward deposits capped by the Hindman coal are a repetition of the previous coal-bearing sequence. Again, marine to brackish conditions developed, ending peat accumulation. This time a less restricted environment developed, with slightly coarser clastics being transported in and a diverse fauna being established. The sulfur bloom and pyrite masses found in this coal seem to agree well with the occurrence of marine deposits directly above it.

Deposition of fluvial sediments account for the remainder of the strata exposed by this roadcut.

Coal Characterization

The Francis (Hazard No. 8) and Hazard No. 7 coals and their rider coals at this stop were analyzed by the Institute for Mining and Minerals Research (*see* Hower and others, this volume). The Francis coal has a reflectance of 0.78 percent R_{max} and is high volatile A bituminous rank. It has 61 percent total vitrinite and

9.7 percent total liptinite. The megascopic petrography of the benches of the Francis coal can be followed for several miles along Kentucky Highway 80 from Stop 6 to a point between Stops 7 and 8. North of Hindman much of the bench structure is absent at Stop 6 and the remaining coal is thinner (Wayne Cross, 1981, work in progress). The total sulfur of the Francis coal at this stop is 0.54 percent (0.01 percent pyritic sulfur), significantly below the overall average for the Francis coal in this area.

The Hazard No. 7 (0.85 percent R_{max}, high volatile A bituminous rank) has 58.1 percent total vitrinite and 13.9 percent total liptinite, while the rider coal has 43.8 percent total vitrinite and 11.5 percent total liptinite, unusually low totals because of the high (26.8 percent) semifusinite content of the coal. The total sulfur of 0.55 percent (0.16 percent pyritic sulfur) is lower than the average. It is noted in Table 6 of Hower and others (this volume) that the Hazard No. 7 is generally a low-sulfur coal.

76.3 Upper split of Hazard No. 7 through Hindman coals. Stoney Fork Member. The Upper Hazard No. 7 coal is 8 inches thick. Odd limestone nodules above Francis rider coal.

76.6 Unmarked road intersection.

77.0 Hazard coal zone through the Francis (Hazard No. 8) rider coal. Hazard No. 7 is 24 inches thick for upper split, 15 inches thick for lower split, separated by 16 inches of parting. *Coal analysis.* Hazard coal, upper and lower splits, collected at this site have 81.7 percent and 78.5 percent total vitrinite and 4.6 percent and 11.4 percent liptinite, respectively. The coal rank is high volatile B bituminous (0.74 percent R_{max} and 0.73 percent R_{max}). The upper bench has 3.61 percent total sulfur (16.59 percent ash) compared to the 1.46 percent total sulfur (10.23 percent ash) of the lower bench.

77.3 Unmarked road intersection. Haddix(?) coal above the Magoffin Member.

77.9 Hazard No. 7 through Hindman coals. *Coal analysis.* The Hazard No. 7 coal at this site is of high volatile A bituminous rank (0.78 percent R_{max}) with 61.7 percent total vitrinite and 10 percent total liptinite. The coal has 8.48 percent ash and 0.62 percent total sulfur.

78.1 Unmarked road intersection.

78.4 Francis and Francis rider coals. James Jennings (this volume) collected plant fossils here from shale split in the Francis coal. Hazard No. 7 coal is below road level. *Coal analysis.* In contrast to the Hazard No. 7 coal described above, the Hazard No. 7 near this site is lower in total vitrinite (51.2 percent, with 11.6 percent total vitrinite) due to the concomitant increase in fusinite and semifusinite. The reflectance decrease to 0.73 percent R_{max} is a reflection of a regional decrease toward a low in central Knott County. The ash and sulfur percentages are 9.35 percent and 0.67 percent, respectively.

The Francis (Hazard No. 8) coal was sampled in three benches at this site. The coal is high volatile B bituminous rank (0.74 percent R_{max}). It exhibits a decrease in total vitrinite from the lower to the upper bench (85.7 percent to 72.3 percent to 68.2 percent); the liptinites are highest in the middle bench (11.2 percent versus 8.5 percent in the lower bench and 7.5 percent in the upper bench). The total sulfur decreases toward the top bench (1.33 percent to 0.60 percent to 0.57 percent), while the ash increases (8.47 percent to 10.59 percent to 27.93 percent).

78.7 Francis through Hindman coals. Limestone concretions above the Francis rider. *Coal analysis.* The Francis (Hazard No. 8) rider coal sampled at this site is of lower rank than the three Francis benches to the south (0.59 percent R_{max}) with 81.6 percent total vitrinite and 5.5 percent total liptinite. It is a relatively low-ash coal (5.70 percent) with 1.98 percent sulfur (0.89 percent pyritic sulfur).

79.3 Hazard coal (Hazard No. 5A) zone.

80.0 Unmarked road intersection.

80.2 Fire Clay coal through the Magoffin Member exposed here. Fire Clay coal occurs within a sandstone, but is mostly eroded.

81.07 Hazard coal zone through Francis coal. Hazard No. 7 coal eroded.

82.3 Unmarked road intersection.

82.5 Copland coals and the Magoffin Member. *Coal analysis.* The upper and lower splits of the Taylor (Copland) coal at this site are of high volatile B rank (average 0.66 percent R_{max}). The total vitrinite decreases from 79.8 percent in the lower bench (7.9 percent total liptinite) to 62.7 percent (8.3 percent total liptinite); this is due in part to the 20.7 percent fusinite in the upper bench. In the upper bench ash increases from 16.74 percent to 27.85 percent, and sulfur also increases, from 2.76 percent (1.71 percent pyritic sulfur) to 3.45 percent (1.94 percent pyritic sulfur). Perhaps this is due to the increasing marine influence which resulted in the deposition of the sediments of the Magoffin Zone.

82.6 Unmarked road intersection.

82.9 Copland coal through Hazard coal zone. Magoffin Member.

83.5 Copland coal zone through Hazard coal zone.

83.7 Unmarked road intersection.

84.0 Hamlin coal zone through Copland coal zone. Hamlin coal zone with bone.

85.0 Unmarked road intersection.

85.2 Copland coal zone through Hazard coal zone. *Coal analysis.* The Hazard coal at this site is high volatile B bituminous (9.67 percent R_{max}), with 59.9 percent total vitrinite and 8.3 percent total liptinite. Petrographically, the Hazard coal is among the more variable coals studied. Compare the vitrinite percentage here with the values previously reported at mileages 77.0, 89.7, and 92.5. Compared to many of the major eastern Kentucky coals, the Hazard is high in sulfur, having 1.91 percent total sulfur (half is pyritic) and 22.77 percent ash.

86.4 Copland coals and Magoffin Member.

87.1 Hazard coal zone through Hazard No. 7 coal. Magoffin Member. Hazard coals sporadically preserved in channel, but mostly absent.

87.5 Unmarked road intersection. Hamlin(?) coal zone through the Magoffin Member.

87.7 Unmarked road intersection. Limestone concretions above the Hamlin (Fire Clay) coal. *Coal analysis.* The Hamlin(?) coals (upper and lower benches) at this site are high volatile B bituminous (average 0.69 percent R_{max}), with an average of 73.5 percent total vitrinite (7.7 percent total liptinite for each). The coals are high ash (28.41 percent (upper bench) and 25.36 percent) and high sulfur (3.54 percent (upper bench) and 2.30 percent); both sets of values are high for the Fire Clay coal.

89.7 **Stop 8: Ogden Branch, Kentucky**

Purpose

The purpose for this stop is to show the sequence of Magoffin lithologies formed as deposition shifted from open marine, to distributary mouth bar, to river channel, and finally to peat swamp.

Location

Stop 8 is on new Kentucky Highway 80, approximately 500 feet west of the intersection of new Kentucky Highway 80 and the Hindman access road in Knott County, Kentucky. The intersection is located on Ogden Branch. The stop is in the Hindman Quadrangle and at Carter coordinate location 16-K-79, 1,750 ft. FSL X 3,100 ft. FEL. The location of this stop is shown on Figure 3, the field trip route map.

Stratigraphy

The stratigraphy exposed at this roadcut range from the top of the Magoffin Member of the Breathitt Formation through the Hazard coal zone. The geologic setting and stratigraphy of this stop are shown in the inside front and outside back covers.

Description

A diagrammatic sketch of this roadcut is shown in Plate 14. The lower part of the section consists of calcareous siltstone, which contains siderite layers and burrows. This grades upward into silty, fine-grained sandstones that alternate with layers of fine-grained sandstone. The silty sandstones contain calcareous concretions, while the fine-grained sandstone layers contain conspicuous deformed beds (convoluted bedding and flow rolls).

The next 15 to 30 feet of section consists of fine- to medium-grained, flaggy-bedded sandstone (flagstone). The bedding changes in attitude and thickness, becoming thinner and tangential to the west. The bedding planes are nearly parallel where they become horizontal, but they diverge updip, attaining maximum dips of 10 to 15 . The horizontal beds are about 6 inches thick, but thicken to 20 inches where steeply dipping. These beds are rippled, slightly calcareous, and have poorly defined graded bedding. They contain horizontal and vertical trace fossils. Vertical escape burrows are common and begin at the bottom and travel to the tops of individual graded beds. One escape burrow was seen to travel through two sets of graded beds. Other vertical and horizontal trace fossils are also common. One type, *Psammichnites* sp. (*see* Fig. 7), is a horizontal trace fossil of a semiburrowing, deposit-feeding gastropod.

An erosion surface across the entire outcrop separates the inclined beds from the overlying, medium-grained sandstone which appears more massive. The upper portion of this sandstone body is rooted and is capped by the Hazard coal.

Strata measured, but not studied, in detail overlying the coal include interbedded sandstone and shale, sandstone, coal, and shale (*see* Plate 14; in pocket.

Figure 7. *Psammichnites* sp., horizontal trace fossil of a deposit-feeding gastropod, found on top surfaces of sandstones at the top of the Magoffin Member (Saltlick Beds?), at Stop 2. X0.7.

Interpretation

The section below the lower coal represents an open marine bay which was progressively filled by increasingly coarser clastic material as deltaic sediments (or crevasse splay) prograded into the bay. The flaggy-bedded sands were deposited in distributary channels advancing into a marine- or brackish-water bay. Individual graded beds with escape burrows indicate that the beds were deposited in floods, with up to 20 inches of sediment deposited in a single event. Closely spaced flood events buried one unfortunate fellow beneath two graded beds, but his olympic burrowing heroics resulted in his escape. These beds were then truncated by the river as it eroded its previous deposits. Following abandonment of the distributary systems, vegetation was established and peat accumulated. Several sandstone sequence of probable fluvial origin and coals followed.

90.0 Intersection with Hindman access road. **Turn right.**

90.5 *Coal analysis*. The Fire Clay (Hazard No. 4) coal near this site is a low-sulfur (0.63 percent total; 0.04 percent pyritic), low-ash (8.47 percent) coal with 69.3 percent total vitrinite and 10.3 percent total liptinite. The rank of the coal is high volatile A/B bituminous (0.75 percent R_{max}). The rider is higher in both maceral categories being discussed (82.8 percent to 75.7 percent in total vitrinite; 9.4 percent to 7.5 percent in liptinite) as well as higher in total sulfur (3.30 percent (0.88 percent pyritic) to 1.07 percent (0.21 percent pyritic)). The main coal is higher in ash (24.17 percent to 9.44 percent).

90.7 **Stop 9: Hindman Access Roadcut**

Purpose

The purposes of this stop are to show: (1) an example of penecontemporaneous slumping related to channel development (this is the same channel system as exposed in Stop 8); (2) a fining-upward sequence of a fluvial point bar system; and (3) the Copland coal with overlying Magoffin Member.

Location

Stop 9 is located on the Hindman access road about 1/2 mile south of the intersection of new Kentucky Highway 80 and the Hindman access road. This stop is located in Hindman Quadrangle at Carter coordinate location 25-K-79, 4,850 ft. FSL X 1,600 ft. FEL. The location of this stop is shown on the map in Figure 3.

Stratigraphy

The strata exposed at this stop range from the Copland (Taylor) coal zone through the Hazard coal. This interval includes the Magoffin Member. The Haddix coal is absent. The geologic setting and stratigraphy of this stop is illustrated in the diagrams on the inside front and outside back covers.

Description

The strata exposed at this stop are illustrated in Plate 15 (in pocket). The lower part of the section exposed here consists of rooted claystones, shales, siltstones, and sandstones, with thin coals of the Copland (Taylor) coal zone. It is a fining-upward sequence (Plate 15, (in pocket), fining-upward sequence 1). Small vertical stumps were observed just above and below the lowest coal.

The next 60 feet is clayey, burrowed, fossiliferous, calcareous siltstone and silty shale which contain fossiliferous limestone concretions. This is a coarsening-upward sequence (Plate 15 (in pocket), coarsening-upward sequence 2). The fauna in this unit is Magoffin open-marine fauna (*see Paleontology,* this section).

The next 30 feet of section is disturbed. These beds may be a continuation of the previous coarsening-upward sequence, as was the case at Stop 8. The bedding is tilted, generally to the south, and offset in a normal fault displacement that is down to the north. The faults continue through the underlying marine siltstones for only a few feet, appearing to become tangential with the bedding of the underlying siltstone. Smaller-scale features observed in the disturbed beds include disharmonically folded beds, down-dip thickening of beds, boudinage of sideritic layers, and fracturing and mild deformation of calcareous concretions.

An erosional surface occurs at the top of this intensely disturbed section, which is followed by approximately 50 feet of sandstone in a fining-upward sequence (Plate 15 (in pocket) fining-upward sequence 3). This sandstone displays accretion bedding dipping to the north in the upper 15 feet. The primary sedimentary structures in this 15-foot section, in ascending order, are large-scale trough crossbeds followed by smaller scale, trough crossbeds, which are overlain by ripple-bedded, fine-grained sandstones capped by intensely rooted sandstone, claystone, and coal. This coal is the Hazard coal bed.

Sandstone, clayey siltstone, plant-rich claystone, and canneloid shale make up the rest of the section.

Interpretation

The in-place stumps, abundant plant fossils, rooting, and fining-upward nature support a fresh-water fluvial origin for the Copland coal zone and enclosing strata. Subsidence or eustatic change in sea level resulted in the development of a marine bay over the uppermost Copland coal bed. The next 60 feet represents the infilling of this bay with terrigenous clastics. Marine conditions persisted up to the upper portion of these finer grained beds, as evidenced by the marine fauna.

The disturbed zone resulted from slumping (*see* Hester and Brant, this volume) in response to channel erosion. This river channel was likely a part of the distributary system which deposited the flaggy-bedded sandstones at the previous stop (Stop 8), only 1 mile to the north.

The fluvial sandstone sequence above the paleoslumps represents the migration of a river across the slumped strata partially eroding them and then burying them. Peat-forming environments were again established in the area when the river system migrated out of the area.

Paleontology

Plant fossils from several beds within this Copland (Taylor) coal zone were collected and field identified by James Jennings. These include *Bothrodendron minutifolium, Calamites cistii, Calamites undulatus, Cordaites principalis, Lepidodendron aculeatum, Lepidophylloides* sp., *Lepidostrobophyllum lanceolata, Lepidostrobus* sp., *Mariopterus nervosa, Neuropteris* cf. *N. gigantea, Neuropteris* cf. *N. rarinervis, Neuropteris tenuifolia?,* *Sphenophyllum cuneifollium, Sphenophyllum* sp., *Sphenopteris footneri, Sphenopteris (= "Rhodea"), Sphenopteris souichi,* and *Sphenopteris straita.*

Fossils from the Magoffin shale were identified by Don Chesnut and found to be different from the typical Magoffin fauna and include *Posidonia vintonensis* and *Dunbarella straita,* as well as typical fauna such as *Trepospira* sp., *Plagioglypta* sp., *Pseudorthoceras knoxense, Phestia bellistriata,* and tiny chonetids, probably *Eolissochonetes fragilis.* Many specimens appear to be depauperate, and may indicate poor oxygenation of the water.

91.5 Copland coal and Magoffin Member.

91.9 Hazard(?) coal zone through Francis coal. Hazard No. 7 coal is split. *Coal analysis.* Collection of coal at this site was restricted to the thin middle bench of the Francis (Hazard No. 8) coal. This coal is high volatile B bituminous (0.72 percent R_{max}) and has 80.6 percent vitrinite, 9.7 percent liptinite, and 1.52 percent total sulfur (0.70 percent pyritic sulfur; 13.25 percent ash).

92.5 Hazard (?) coal zone through Hazard No. 7 coal zone. *Coal analysis.* The analysis of the Hazard coal (upper and lower splits) at this site shows the large variability of this seam. This is a high volatile B bituminous (0.64 percent R_{max}) coal. It varies from 85.5 percent vitrinite and 7.9 percent liptinite in the upper split to 62.7 percent vitrinite and 10.3 percent liptinite in the lower split. The sulfur content is the most significant aspect of the seam variability considered here: the upper bench has 3.56 percent total sulfur (2.14 percent pyritic sulfur and 17.72 percent ash) while the lower bench has 4.01 percent sulfur (2.31 percent pyritic sulfur and 10.06 percent ash).

92.9 Upper part of Magoffin Member. Hazard or Haddix coal.

93.4 Copland coal and Magoffin Member. *Coal analysis.* The Taylor (Copland) coal at this site, with a rank of high volatile C bituminous (0.58 percent R_{max}), has the lowest vitrinite percentage of any coal studied along the trip route, with the exception of a carbonaceous shale discussed below. The total vitrinite percentage of 28.3 percent (17.9 percent liptinite) is a consequence of the 39.2 percent fusinite and 12 percent micrinite. The coal has 37.91 percent ash and 2.58 percent sulfur (1.74 percent pyritic sulfur). The coal is overlain by the marine Magoffin Member.

94.9 Upper part of Magoffin Member at base of roadcut. Haddix(?) coal through Francis coal. A ganister occurs below the Haddix(?) coal. Slump structures are seen above the Haddix(?) coal.

95.3 Unmarked road intersection. Copland coal and Magoffin Member.

96.8 Hazard No. 7 coal zone through Hindman coal. *Coal analysis.* The Hindman (Hazard No. 9) coal (lower split) at this site is a low-sulfur (0.72 percent total; 0.06 percent pyritic), high-ash (30.11 percent), high volatile B bituminous (0.71 percent R_{max}) coal. The coal has 77.7 percent vitrinite and 7.4 percent liptinite.

98.5 Hazard through Hindman coals. Stoney Fork Member of the Breathitt Formation.

99.3 Copland coals and Magoffin Member. *Coal analysis.* The Copland (Taylor) coals are both high volatile B bituminous (average of 0.71 percent R_{max}). The upper split has 73.2 percent vitrinite, 8.8 percent liptinite, 26.62 percent ash, and 1.59 percent total sulfur (0.79 percent pyritic sulfur). The lower split should not be considered a coal because it contains 62.16 percent ash (0.53 percent total sulfur, 0.35 percent pyritic sulfur). The organic portion of the carbonaceous shale exhibits an unusual proportion of the maceral groups: 25.3 percent total vitrinite, 20.9 percent liptinite (includes alginite), 27 percent fusinite plus semifusinite, and 26.8 percent micrinite. The texture of the organic matter is detrital.

99.5 Whitesburg coal zone and Fire Clay coal. *Coal analysis.* The Fire Clay (Hazard No. 4) coal near here has the lowest vitrinite percentage (54.7 percent) of any Fire Clay sample studied to date, due largely to the 24.9 fusinite plus semifusinite (liptinite percentage of 8.2 percent). The high volatile A bituminous coal (0.76 percent R_{max}) is low in sulfur (0.69 percent), with a moderate ash content (14.85 percent). The upper Whitesburg split and the rider coal near here are both high vitrinite (80.7 percent and 86.1 percent, respectively, and 6.5 percent and 7.1 percent liptinite, respectively), high volatile B bituminous coals (0.67 percent R_{max}). The upper split is a high-ash (33.12 percent), low-sulfur (1.09 percent total, 0.58 percent pyritic) coal. The rider coal is low in ash (9.80 percent) and high in sulfur (4.22 percent total, 2.40 percent pyritic).

100.0 Kendrick Shale and Amburgy coal.

100.3 Kendrick Shale. Amburgy coal, Whitesburg coal zone.

101.7 Elkins Fork Shale, Kendrick Shale at top. Brachipods found in Elkins Fork Shale.

102.4 Unmarked road intersection.

102.7 Upper Elkhorn No. 3 coal and Elkins Fork Shale (marine zone).

103.1 Upper Elkhorn No. 2 and 3 coals.

103.4 Unmarked road intersection and Rock Fork Church.

103.5 Upper Elkhorn No. 2 coal.

103.9 Unmarked road intersection.

104.1 Upper Elkhorn No. 2 and 3 coals. Elkins Fork Shale. *Coal analysis.* The Upper Elkhorn No. 3 coal near here is a high volatile A bituminous (0.78 percent R_{max}) coal with 71.8 percent total vitrinite and 5.5 percent total liptinite. The coal is low in both ash (5.49 percent) and sulfur (0.64 percent total; 0.06 percent pyritic).

104.3 Upper Elkhorn No. 1 coal here is a canneloid coal, 71 inches thick. Collapse due to mining. *Coal analysis.* The Upper Elkhorn No. 1 coal from this site is a low-sulfur (0.74 percent total; 0.09 percent pyritic), low-ash (8.39 percent), high volatile A bituminous coal (0.78 percent R_{max}). The coal has 70.9 percent total vitrinite and 9.5 percent total liptinite.

105.2 Upper Elkhorn No. 2 coal.

106.4 Large roadcut. Kendrick Shale to Magoffin Member and the Whitesburg coal zone through the Taylor (Copland) coal zone. *Coal analysis.* Similar to the Fire Clay (Hazard No. 4) coal just encountered, the Fire Clay here has a relatively low percentage of vitrinite (55.2 percent, with 10.1 percent total liptinite). The high volatile B bituminous coal (0.70 percent R_{max}) has 17.14 percent ash and 1.14 percent total sulfur (0.39 percent pyritic sulfur). The upper and lower splits of the Whitesburg coal are both relatively high in vitrinite (80.1 percent and 77.1 percent, respectively); liptinite values are 8.0 percent and 6.4 percent, respectively. The upper split of the high volatile B bituminous coal (average of 0.73 percent R_{max}) has 9.38 percent ash and 1.04 percent total sulfur (0.28 percent pyritic sulfur), while the thicker lower bench has 34.32 percent ash and 1.92 percent total sulfur (0.98 percent pyritic sulfur).

107.0 Upper Elkhorn No. 2 and 3 coals. Elkins Fork Shale.

107.4 Upper Elkhorn No. 2 and 3 coals. Upper Elkhorn No. 1 coal covered by construction on the right just below road level.

109.7 Upper Elkhorn No. 2 coal split into upper and lower bed. *Coal analysis.* The Upper Elkhorn No. 2 coal at this site has a rank of high volatile B bituminous (0.68 percent R_{max}), with 78.2 percent total vitrinite and 7.1 percent total liptinite. The coal has 10.11 percent ash and 3.02 percent total sulfur, of which an unusually high proportion was reported to be pyritic (2.82 percent pyritic sulfur).

110.2 Unmarked road intersection.

110.3 Lower Elkhorn coal and three sandstones. Upper Elkhorn No. 1 coal missing. *Coal analysis.* The high volatile B bituminous (0.62 percent R_{max}) Lower Elkhorn coal sampled here has 75.8 percent total vitrinite and 8.7 percent total liptinite. The coal is not mined here, probably due to its high sulfur (4.77 percent total, 2.27 percent pyritic sulfur and 9.99 percent ash). It is an important mined coal to the southwest and east.

110.5 Upper Elkhorn No. 1 through No. 3 coals. Upper Elkhorn No. 1 coal is mostly eroded, but some remnants can be seen in the thick sandstone. There are two splits each of the Upper Elkhorn No. 2 and 3 coals. The Elkins Fork Shale is found over the Elkhorn No. 3 coal. *Coal analysis.* The upper and lower splits of the Upper Elkhorn No. 3 coal at this site have a rank of high volatile B bituminous (0.74 percent R_{max}). The splits have 68.8 percent vitrinite with 7.3 percent liptinite, and 79.2 percent vitrinite with 7.4 percent liptinite, respectively. The upper split is high in both ash (11.22 percent to 6.66 percent) and sulfur (1.39 percent (0.41 percent pyritic) to 0.97 percent (0.31 percent pyritic)).

111.6 Columbia Gas Beaver Creek Compression Station.

111.7 Upper Elkhorn No. 1 coal with sandstone above and below. *Coal analysis.* The high volatile A (0.76 percent R_{max}) Upper Elkhorn No. 1 coal at this site is a high-vitrinite (80.3 percent, with 5.7 percent liptinite) coal with 0.71 percent total sulfur (0.06 percent pyritic sulfur) and 13.13 percent ash.

112.2 Upper Elkhorn Nos. 1, 2, 3, and No. 3 rider coals. Elkins Fork Shale.

112.5 Upper Elkhorn No. 1 and 2 coals.

113.0 Exit, McDowell, Kentucky.

113.2 Large roadcut. Upper Elkhorn No. 3 coal, No. 3 rider coal, Elkins Fork Shale, Amburgy coal, Kendrick Shale, and Whitesburg coal zone. The Elkhorn No. 3 coal contains several splits.

113.6 Upper Elkhorn No. 2 coal, Upper Elkhorn No. 3, No. 3 rider coal, Elkins Fork Shale, Amburgy coal.

113.8 Unmarked road intersection. Upper Elkhorn No. 3, No. 3 rider coals, Elkins Fork Shale, Amburgy coal, and sandstone. The Upper Elkhorn No. 3 coal near here was mentioned in Hower and others (this volume; coal at Carter coordinate section 1-M-81 in Tables 8 and 9). The coal sampled is the only coal mentioned in the roadlog and stop descriptions that was not sampled from an extant roadcut. Instead, the coal was being mined for the construction of the road bed of Kentucky Highway 80. The characteristics of the Little Fire Clay, Whitesburg, and Upper Elkhorn No. 3 coals to the north of Stop 10 have been compiled in Tables 8 and 9 of Hower and others (this volume).

114.3 Upper Elkhorn No. 3 and No. 3 rider coals, Elkins Fork Shale, Amburgy coal(?), sandstone.

115.2 Stop 10: Martin, Kentucky

Purpose

Of particular interest at this stop are the cutout of the Fire Clay coal, the flint clay parting in the Fire Clay coal, the large clasts in the sandstone that replaces the Fire Clay coal, the channel-fill coal, vertical stumps, and the repetition of fining-upward sequences capped by coal zones. The strata exposed in this roadcut will illustrate the influence of fluvial processes on the deposition and destruction of coal.

Location

Stop 10 is approximately 1.2 miles north of Martin, Kentucky, in Floyd County. This stop is located on new Kentucky Highway 80 in the Martin Quadrangle at Carter coordinate location 21-N-81. The roadcut is approximately 1/3 mile in length and has a maximum vertical height of 475 feet. The Broas coal at an elevation of 1,450 feet is above the top of the roadcut and has been surface mined in this area. The location of this stop is shown in Figure 1.

Stratigraphy

The strata exposed in this roadcut, in stratigraphic order from road level upward, are Fire Clay coal (cutout), Fire Clay rider (channel-fill), Taylor (Copland) coal zone, Magoffin Member, Hazard coal zone, and the Peach Orchard coal zone. North along Kentucky Highway 80 from this roadcut for about 1.3 miles, the highway descends through several lower stratigraphic units. These units from the top down are the Little Fire Clay coal, Whitesburg coal, Kendrick Shale, Elkins Fork Shale, and the Upper Elkhorn No. 3 coal bed.

Description

A composite sketch of the roadcut is shown in Plate 16 (in pocket). This sketch shows geolhgy from both sides of the roadcut. As a help in spotting the units described in this text, the level of each bench is shown in the sketch as it occurs on the east side face.

The Little Fire Clay coal bed (1.0 foot thick) occurs below road level in the drainage ditch on the south end of the roadcut. A medium- to coarse-grained sandstone with large-scale crossbeds, coal spar, log impressions, and large angular clasts of siltstone overlie the coal. The Fire Clay coal bed (4.0 feet thick) with a 0.4-foot flint clay parting overlies the sandstone. The Fire Clay coal bed has been cut out and replaced by a medium- to coarse-grained sandstone. This sandstone begins a fining-upward sequence (Plate 16 (in pocket), fining-upward sequence 1). The ragged and splayed appearance of the coal bed and the convergence of structures in the sandstone illustrate differential compaction between the sandstone and the coal. A rough measurement of the compaction indicates a ratio of 4 to 1 for the coal. It seems likely that the stream erosion occurred before compaction of the peat had progressed very far.

Above the Fire Clay coal bed is the Fire Clay rider. The Fire Clay rider for most of the roadcut is flat lying, but near the north end it fills a channel scour. The channel, which cuts into the underlying sandstone, also truncates siltstone and shale beds. The rider coal progressively thickens into the channel. Where the rider coal is flat lying, some distance away from the channel, its thickness is 0.9 foot. The rider coal is 2.2 feet thick in the deepest part of the channel. The depth of the channel is 14 feet. Assuming that at least 14 feet of peat originally accumulated in the channel and that the equivalent peat for one foot of coal accumulated above this to provide the nearly one foot of coal outside the channel, then a compaction ratio of approximately 10 to 1 for peat to coal is estimated.

A vertical stump 5.2 feet high and 1.3 feet wide rests on the rider coal at the deepest part of the channel. Preservation of this stump is probably due to its location above the thickest deposit of peat. Compaction of peat in the channel most likely was more rapid than in the surrounding area; therefore, a topographic low formed, attracting sediment and rapid burial. A lens of fine sandstone splits the thin coals above the Fire Clay rider and fills in the depression of the channel fill. This lens fines upward and has thin coals overlying it.

Siltstone and sandstone that are burrowed and fossiliferous (including *Lingula*) occur above the thin coals. A fossiliferous limestone 1.0 foot thick persists across the roadcut. The fossiliferous limestone bed possibly correlates with marine beds associated with the Fire Clay rider. Abundant marine fossils collected in this roadcut include: an unidentified productoid brachiopod, *Derbyia crassa, Anthracospirifer,* and *Composita,* all brachiopods. *Derbyia* is so abundant in some layers that a *Derbyia* pavement was formed.

A coarse to very coarse sandstone that contains coal spar, large-scale trough crossbeds, and has an erosional base, overlies the Fire Clay rider and the marine beds. This sandstone begins a fining-upward sequence (Plate 16 (in pocket), fining-upward sequence 2) that is capped by claystones, black shales, and thin coals. These beds begin the Taylor (Copland) coal zone, which includes one coal bed 0.5 foot thick. A fossiliferous limestone above this coal marks the base of the Magoffin Member.

The Magoffin Member is 31 feet thick and consists of limestone, claystone, and silty shale in a coarsening-upward sequence (Plate 16 (in pocket), coarsening-upward sequence 3). It is thinner here due to greater truncation by a channel system, than at the previous stops. The Magoffin is extremely fossiliferous at this roadcut. A very coarse sandstone, erosional at its base, which contains trough crossbeds, coal spar, and log impressions, overlies the Magoffin Member. This sandstone contains small-scale trough crossbeds and ripple beds in its upper part and constitutes a fining-upward sequence (Plate 16 (in pocket), fining-upward sequence 4). Silty claystones, siltstones, and a thin coal above the sandstone mark the beginning of the Hazard coal zone. This coal zone includes one coal 2.5 feet thick. A conglomerate sandstone overlies the Hazard coal and contains crossbedding and log impressions.

The conglomerate sandstone marks the beginning of a fining-upward sequence (Plate 16 (in pocket), fining-upward sequence 5), 60 feet thick, capped by claystone and thin coals. Vertical stumps in fine sandstone occur above a thin coal bed. The coals and fine-grained beds begin the Peach Orchard coal zone. The Peach Orchard coal zone is correlated with the Hazard No. 7 and Francis coals. The Peach Orchard here contains coals 0.5 foot thick, 3.0 feet thick, and 1.0 foot thick. Sandstone with a thin claystone bed continues to the top of the roadcut.

The Broas coal, which occurs above the Peach Orchard coal zone in this area, has been extensively surface mined.

Interpretation

The depositon of rocks exposed in this roadcut is explained by at least five fining-upward sequences interrupted by two marine zones, one coarsening upward. The fining-upward sequences are characterized by the following physical features: erosional base, conglomeratic lag at base, large-scale crossbeds, and log impressions. In the upper part of the sequence are small-scale trough crossbeds, ripples, rooting, vertical stumps, plant fossils, thin and split coals, and carbonaceous shales. These features indicate deposition from fluvial processes. Each fining-upward sequence terminates at a coal zone, accounting for all the coals in this roadcut. The repetition of fining-upward sequences resulted from channel migration across a subsiding alluvial basin.

Coal Characterization

Hower and others have studied the coals at this stop (*see* text and Tables 8, 9, and 10, this volume).

115.3 Cement plant to left (west).

115.5 Whitesburg coal zone through Fire Clay rider coal.

115.8 Sandstone. Whitesburg coal between sandstones.

116.0 Amburgy coal, Kendrick Shale (note gas well), sandstone, Whitesburg coal. Sandstone below Kendrick Shale lenses out to the northeast.

116.6 Upper Elkhorn No. 3 and No. 3 rider coals, Elkins Fork Shale, Amburgy coal. No. 3 rider coal thickens in channel. No. 3 coal is 24 inches thick.

117.0 Upper Elkhorn No. 3 and No. 3 rider coals.

117.2 Upper Elkhorn No. 2 and 3 coals. No. 2 coal is two thin coals split by 3 feet of dark shale.

117.4 Upper Elkhorn Nos. 2, 3, and 3 rider coals.

117.8 Upper Elkhorn No. 1 coal to right (southeast); mine to left.

118.8 Upper Elkhorn Nos. 2 and 3. Elkins Fork Shale.

119.1 **Exit to the north (left) at intersection with Kentucky Highway 460.**

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121.4 Upper Elkhorn Nos. 2 and 3 coals?.

122.1 Turn left onto Kentucky Highway 114.

122.9 Historic marker.

124.2 Intersection with Kentucky Highway 404.

124.5 Clark School.

125.6 Upper Elkhorn No. 2 and 3 coals.

128.5 Stream capture (*see* Rice, this volume). Valley narrows to north.

129.0 Large roadcut. Whitesburg(?) coal zone.

133.8 Intersection with Kentucky Highway 1427.

134.1 Magoffin county line.

135.0 Pentecostal Church of God.

135.8 Upper Elkhorn coal zone.

139.4 Intersection with Kentucky Highway 460.

140.6 Burning Fork community.

141.0 Elkins Fork Shale.

141.5 Intersection with Kentucky Highway 460. Begin Mountain Parkway.

142.2 Milepost 75. Roadcut. Hamlin(?) through Prater (Hazard) coal zones, Magoffin Member.

142.5 Exit. *Coal analysis.* The Fire Clay (Hazard No. 4) coal near here is a high volatile C bituminous coal (0.53 percent R_{max}), with 81.8 percent vitrinite and 6.3 percent liptinite. This sample, as well as the next five samples, was obtained in pellet form from the study of Williams (1979).

142.7 Cross Licking River.

143.9 Magoffin through Prater(?) coal.

145.5 Exit, Kentucky Highway 30. Elkins Fork Shale, Kendrick Shale, Whitesburg coal zone, Fire Clay coal, Taylor coal, Magoffin Member.

147.0 Toll booth.

147.9 Fire Clay coal.

148.3 Haddix coal.

148.5 Milepost 69. Large roadcut. Prater (Hazard) and Peach Orchard coal zones.

149.3 Fire Clay and Fire Clay rider coals.

149.5 Milepost 68.

150.5 Fire Clay coal. *Coal analysis.* The Fire Clay (Hazard No.4) near here is high volatile C bituminous (0.48 percent R_{max}) but has a lower than usual amount of vitrinite (68.9 percent), and 12.5 percent liptinite.

151.0 Top of Kendrick Shale.
152.9 Fire Clay coal.
154.7 Morgan county line. Fire Clay and Hamlin coals.
155.6 Bridge over Kentucky Highway 134.
156.9 Peach Orchard coal zone.
157.3 Kentucky Highway 134 and Kentucky Highway 191.
157.7 Prater (Hazard) coal. *Coal analysis.* The high volatile B bituminous (0.62 percent R_{max}) Hazard coal here has 75.5 percent vitrinite with 10.0 percent liptinite.
157.9 Exit.
160.4 Wolfe county line.
160.6 Exit 57.
161.2 Red River.
161.5 Thin Magoffin Member over canneloid shale, overlying Fire Clay rider coal.
162.1 Milepost 56. Prater and Peach Orchard coal zones.
162.6 Fire Clay coal missing, but flint clay is present.
164.7 Exit 53, Hazel Green.
165.7 *Coal analysis.* The Whitesburg coal near here is high volatile C bituminous (0.55 percent R_{max}), and contains 81.7 percent vitrinite and 6.8 percent liptinite.
166.3 Large roadcut. Thin Magoffin Member.
167.1 Kendrick Shale(?) above Cannel City(?) coal (Cannel City = Amburgy).
167.5 Grassy(?) coal (= Upper Elkhorn No. 2 coal).
168.7 Broad Valley controlled by Corbin Sandstone.
169.2 Little Caney(?) and Cannel City(?) coals and Kendrick(?) Shale. These coals are equivalent to the Upper Elkhorn No. 3 and Amburgy coals.
169.8 Grassy(?) coal.
171.0 Little Caney(?) coal and Kendrick(?) Shale at top of roadcut.
172.2 Toll booth. Frozen Sandstone(?).
172.3 Bridge over Kentucky Highway 191.
173.0 Vires (= Blue Gem) coal(?).
173.7 Milepost 45. Grassy coal at top. *Coal analysis.* The high volatile C/B bituminous (0.58 percent R_{max}) Grassy (Upper Elkhorn No. 2) coal here has 78.9 percent vitrinite with 7.9 percent liptinite.
174.2 Marine zone (Cannelton Limestone equivalent). Flaggy beds, articulate brachiopods (*Leiorhynchoidea* sp.).
174.6 Milepost 44. Campton Lake. Corbin Sandstone and Cannelton Limestone equivalent, coarsening-upward sequence.
175.8 Milepost 43. Top of Corbin Sandstone, overlain by shale with marine fossils (Cannelton Limestone equivalent). Zachariah coal (= Lily coal).
178.0 Exit 40.
178.9 Glen Cairn Fault, downthrown side to the south. Zachariah coal and unnamed coal.
183.0 Milepost 36. Powell county line. Corbin Sandstone.
183.9 Mine Fork(?) (= Grayhawk) and Beattyville(?) (= Halsey Rough) coals below the Corbin Sandstone. *Coal analysis.* Beattyville coal exposed along the Parkway at this point has 71.7 percent vitrinite, 10.2 percent liptinite, and a rank of high volatile C bituminous (0.54 percent R_{max}). The coal sampled on the north side of the road is high volatile C bituminous (0.54 percent R_{max}) with 67.8 percent vitrinite and 8.6 percent liptinite. The low-ash (5.48 percent) coal has 2.30 percent total sulfur (0.94 percent pyritic sulfur).
184.3 Paleokarstic unconformity between Pennsylvanian sediments and the Newman Limestone (Mississippian).
184.7 Newman Limestone, Renfro Member (dolostone) and Nada Member (siltstone and shales) of the Borden Formation.
185.8 Milepost 34. Underpass, Kentucky Highway 15. Nancy Shale and Nada Member.
186.3 Toll booth. Exit 33. **Exit here. Turn left twice onto north Kentucky Highway 11 and Kentucky Highway 15.**
187.7 Borden Formation on left.
188.1 Turn east on Kentucky Highway 77. Cross river, pass Nada Member.
190.3 Nada Tunnel. Corbin Sandstone Member of Lee Formation.
192.2 Borden on right. Corbin Sandstone forms cliffs.
192.6 Menifee county line. Red River bridge. **Bear to the right after crossing bridge.**
193.4 **Turn left at junction with Kentuky Highway 715.** (For optional stop, proceed straight, instead of turning, for 4.1 miles. Bell Falls on the Pennsylvanian channel fill conglomerate in the Mississippian Borden Formation. Return to junction and turn right.)
194.0 Renfro Member (dolostone) of the Borden Formation.
194.4 Corbin Sandstone.

194.7 Unidirectional, large-scale sets of planar crossbeds in Corbin Sandstone.

203.0 Turn left (west) at junction with Kentucky Highway 460.

205.8 Base of Corbin Sandstone, bioturbated, silty; claystones; coarsening-upward sequence in the lower tongue of the Breathitt Formation.

206.2 Irregular surface on a much abbreviated Newman Limestone (20 feet) marks contact between Pennsylvanian and Mississippian rocks. The entire Pennington Formation and 50 feet of the Newman Limestone are missing.

207.0 Menifee County Courthouse in downtown Frenchburg, Kentucky. **Proceed straight (west) on Kentucky Highway 36 at caution light near courthouse.**

207.1 Bridge across Beaver Creek. We are crossing the projected trace of the concealed Kentucky River Fault System. The remaining part of the trip will be on the upthrown (north) side of the fault system.

207.8 A chert breccia concentrate rests on a 6-foot section of Newman Limestone (St. Louis) on hill east of the Menifee Medical Center. The breccia is overlain by terrigenous siltstone and sandstone of the lower tongue of the Breathitt.

208.7 **Turn left (northwest on Kentucky Highway 36) at junction with Kentucky Highway 1274.**

209.6 Cowbell siltstone on the right.

209.7 Cowbell siltstone on the left.

209.9 Nada shale overlying the Cowbell siltstone on the left.

210.1 Stop 11: Hill Top Church

Purpose

The purposes of this stop are to: (1) observe the Upper Mississippian-Lower Pennsylvanian stratigraphy; (2) examine a karstic unconformity between the Mississippian carbonate and the Pennsylvanian clastic sediments; and (3) discuss the possible effect of penecontemporaneous structural influence on deposition.

Location

Stop 11 is a roadcut on Kentucky Highway 36 at the Hill Top Church in Menifee County, Kentucky. The stop is in the Scranton Quadrangle and at Carter coordinate location 3-R-71, 800 ft. FSL X 600 ft. FEL (Fig. 3).

Stratigraphy

This roadcut exposes the upper Borden Formation (Nada and Renfro Members) and a truncated section of Newman Limestone overlain by approximately 20 feet of the Lower Tongue of the Breathitt Formation which is capped by an incomplete section of Corbin Sandstone (*see* front and back inside covers).

Description and Interpretation

Subaerial crust in the upper part of the St. Louis Limestone is well developed and suggests a period of subaerial exposure prior to deposition of the Ste. Genevieve oobiosparite. The pinnacled surface or paleokarst at the top of the Newman Limestone coupled with the absence of 20 to 30 feet of carbonate section (Haney and Glen Dean Members of the Newman Limestone) and the entire Pennington Formation suggest a considerable period of subaerial exposure prior to deposition of the nonmarine, coal-bearing, terrigenous clastics of the Lower Tongue of the Breathitt Formation.

The occurrence of dark-gray claystone and coal as sinkhole infilling gives the first indication of the flood of river-borne terrigenous clastics that will dominate the geologic scene in eastern Kentucky for the remainder of Pennsylvanian time. The coals are exposed at this cut. They are both thin (less than 10 inches) and discontinuous. Analyses or equivalent of coals from the Frenchburg area, where limited surface mining has taken place, show that sulfur contents run from less than 1 percent to greater than 2 percent. The coals with the higher percentage of sulfur are associated with overburden rocks of marine- or brackish-water origin.

Turn around and return to junction of Kentucky Highway 36 and Kentucky Highway 1274.

211.5 **Turn left at junction with Kentucky Highway 1274.**

215.8 Daniel Boone Forest.

216.6 Cowbell siltstone.

218.7 From 1819 to about 1830, iron was produced at the Beaver Furnace, which formerly stood along Beaver Creek near this location (Moore, 1878). The furnace used limonitic and sideritic ore mined from irregular, discontinuous deposits occurring on the upper surface of the Newman Limestone.

219.8 Long Bow boat ramp.

220.5–221 **Stop 12: Cold Cave Cut**

Purpose

The principal subjects of discussion at this stop are the sedimentary environments of the Newman Limestone, the Lower Tongue of the Breathitt Formation, and the Corbin Sandstone Member of the Lee Formation; the presence or absence of the Pennington Formation; the age of the coals; and the position and character of the Pennsylvanian-Mississippian boundary.

Location

Stop 12 is a roadcut on Kentucky Highway 1274 within sight of Cave Run Reservoir, Menifee County, Kentucky. It is in Ezel Quadrangle at Carter coordinate location 5-R-73, 2,600 ft. FSL X 1,750 ft. FEL.

Stratigraphy

At this stop three distinctly different stratigraphic units are well exposed. In general, this section consists of approximately 40 feet of carbonate rock (Newman Limestone) overlain by about 60 feet of siltstone, claystone, sandstone, and coal (Lower Tongue of the Breathitt Formation), followed by about 160 to 170 feet of sandstone with minor siltstone and claystone (Corbin Sandstone Member of the Lee Formation).

Description and Interpretation

The Newman Limestone at this locality is only 40 feet thick and has a very irregular surface on which several inches of iron oxide have developed. Of particular interest are the sedimentary breccias and subaerial crusts in the upper part of the St. Louis; rubbly bedding in the Paoli-Beaver Bend, which has caliche-like features; oobiosparite in the Reelsville-Beech Creek; and a dissolutional or ero sional surface on the Reelsville-Beech Creek (Fig. 8).

The features listed above suggest shallow-water deposition and subaerial exposure for undetermined periods of time. The absence of the uppermost carbonate of the Newman may be explained by dissolution resulting from subaerial exposure. There appears to be strong evidence for an unconformity between the Newman Limestone and the suprajacent terrigenous clastics of the Lower Tongue of the Breathitt.

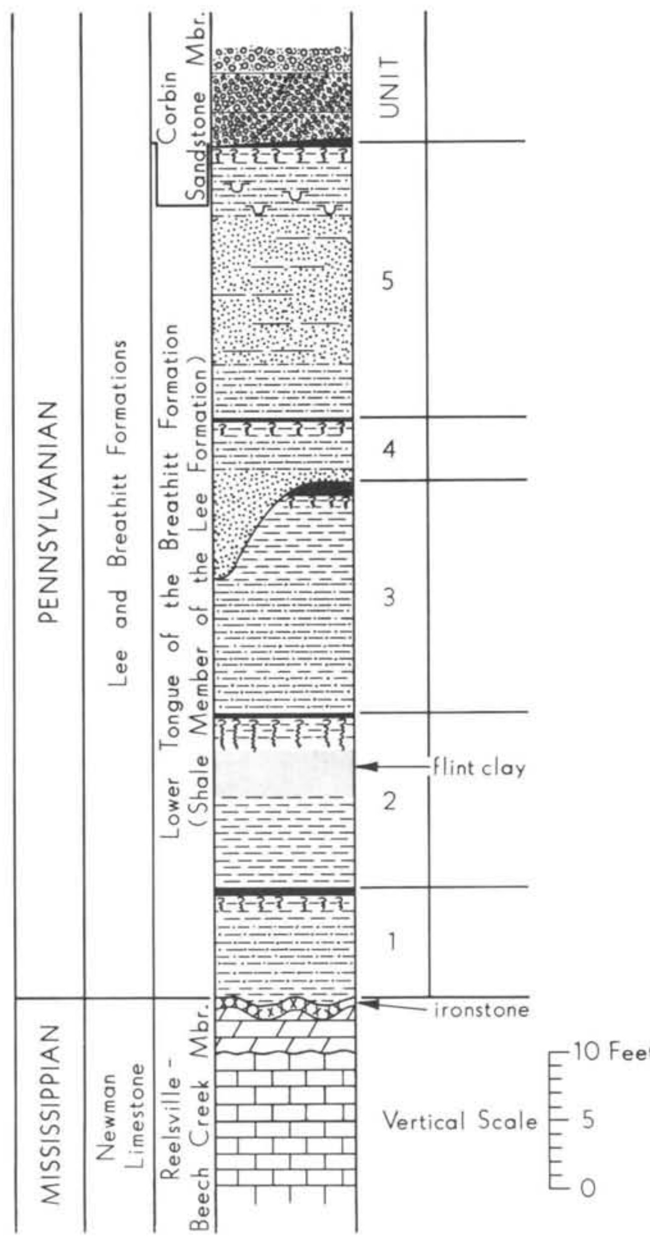

Figure 8. Erosion surface on Reelsville-Beech Creek at Stop 12.

Approximately 60 feet of rocks typical of the Lower Tongue of the Breathitt overlie the hummocky, iron oxide-encrusted Newman carbonate surface. This section is composed of five distinct units, all capped by thin coals (less than 1 foot thick) and associated underclays. The lower units are generally finer grained than the upper ones, indicating an overall coarsening-upward tendency.

Of particular interest in this part of the section are the kaolinitic claystones consisting of plastic, semi-flint, and flint clays. In Kentucky these clays are known as the Olive Hill clay beds and occur only in northeastern Kentucky.

James Jennings collected and field identified plant fossils from the silty, dark-gray claystones overlying the flint clay. The flora include *Cordaicarpon* sp., *Eremopteris* sp., *Lepidodendron aculeatum, Lepidophylloides* sp., *Lepidostrobophyllum* sp., *Lepidostrobus* sp., *Mariopteris* cf. *M. nervosa, Mariopteris pygmaea, Sphenopteris* cf. *S. neuropteroides, Sphenopteris* sp., and *Stigmaria ficoides.* According to Jennings (personal commun.) this flora indicates a lower Westphalian age, and he suggests that it might be middle or upper Westphalian A. Ettensohn and Peppers (1979) collected three samples at Cold Cave between the Corbin Sandstone and the Newman Limestone (sample numbers 2123, 2132, and 2131). Sample number 2132 appears to be from the same unit as Jennings' collection above; however, they date the spores as Namurian A. This suggests that the spores may have been reworked.

The presence of flint clay and other kaolinitic clays, abundant plant fragments, and oxidized (red) coloration, along with the absence of marine fossils, indicate that the lower part of the section was deposited in upland areas with freshwater affinities.

The siltstone and sandstone in the upper part of the section represent depositional pulses that resulted from frequent breaching of the levees and formation of crevasse-splay deposits in the flooded backbay areas. The siderite and burrowing in the upper part indicate that these interdistributary swamps eventually became influenced by brackish-water conditions.

At this outcrop the Corbin is 160 to 170 feet thick. The base is erosional and the top is gradational. The section consists of poorly sorted, terrigenous clastic rocks which range from conglomerates through coarse-grained, granular sandstones with large-scale crossbedding, to ripple-bedded, argillaceous, fine-grained, micaceous sandstones. Alternating claystones, siltstones, and fine-grained sandstones make up about 20 percent of the rock.

In Figure 9 the various lithologic types in the Corbin are indicated by number. Lithology 1 is a conglomeratic sandstone which in some places contains a rubbly zone consisting of clay pebbles and large wood fragments that have been replaced by iron oxide. In most places this work type is followed by pebbly or granular sandstone which has large-scale, generally steeply dipping crossbeds (Fig. 9, lithology 2). Lithology 3 is a fine-grained sandstone that has ripple crossbedding or small-scale, trough-type crossbedding; the conspicuous, larger scale bedding features are lens shaped. Alternating claystones and ripple-bedded siltstones make up a lithology 4; coal with an underclay is present at one of the intervals.

As can be seen on Plate 1 (in pocket), the lithologies may repeat several times in a particular sequence. In a rock core taken by the U. S. Army Corps of Engineers the lower 21.5 feet of this section consist of 11.5 feet of lithology 1, 2.5 feet of lithology 2, and 2.5 feet of lithology 3. This fining-upward sequence is truncated by a conglomerate which has a channel-shaped cross section in the outcrop. The cycle thus starts over. The only complete facies sequence of lithologies 1 through 4 occurs in the top 50 to 60 feet of the cut.

These deposits could be interpreted as tidal channel and barrier overwash in origin; however, based on the evidence presented in the discussion portion of this text such as fining-upward sequences, poor sorting, kaolinitic claystones, unimodal crossbedding, cycles of upward reduction in flow regime, and absence of body fossils and rare occurrence of trace fossils both in outcrop and core, we prefer a fluviatile interpretation for the depositional environment of these rocks. For more details on the origin of the Corbin Sandstone *see* the contributed paper by Hester and Taylor in this volume.

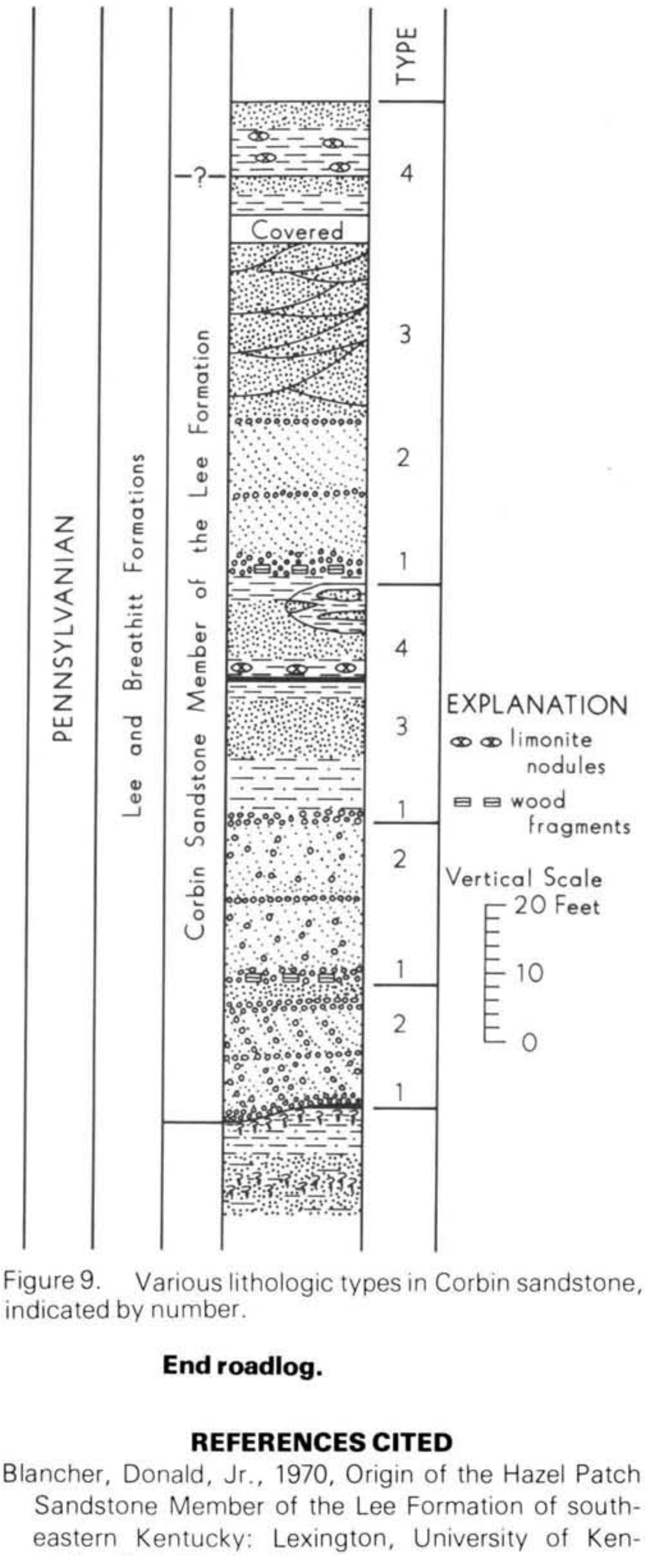

Figure 9. Various lithologic types in Corbin sandstone, indicated by number.

End roadlog.

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INVITED PAPERS

VOLCANIC ORIGIN OF THE FLINT CLAY PARTING IN THE HAZARD NO. 4 (FIRE CLAY) COAL BED OF THE BREATHITT FORMATION IN EASTERN KENTUCKY

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PREVIOUS WORK

Ashley (1928, p. 63) was the first to suggest a volcanic origin for the flint clay parting in the Fire Clay (Hazard No. 4) coal bed, but only on the basis of its widespread distribution and other nonmineralogical evidence. Hoehne (1957), who studied the Fire Clay (Hazard No. 4) parting petrographically, argued against a volcanic origin. Huddle and Patterson (1961, p. 1646-1647) concluded that its distribution and unique character indicate an unusual origin, though they did not specifically propose a volcanic origin.

Seiders (1965, p. D53) was the first to conclude that this parting had a volcanic origin, citing mineralogical as well as geological data. However, most of his mineralogical data were derived from thin-section petrography, a technique that we have found inadequate for completely characterizing partings. Stevens (1979) very thoroughly studied this parting over most of its areal extent in eastern Kentucky and concluded that it definitely had a volcanic origin (Stevens, 1979, p. 67-78). Again, in spite of the large amount of data presented, no clear graphical evidence ofthe presence of specific volcanic minerals was given in this study.

GEOLOGY

A flint clay parting occurs in the Fire Clay (Hazard No. 4) coal bed, in the Middle Pennsylvanian Breathitt Formation in eastern Kentucky. Coals that are believed to be correlative to the Fire Clay (Hazard No. 4) in adjacent states are the Windrock coal in Tennessee, the Phillips coal in Virginia, and the Chilton coal in West Virginia (Wanless, 1975).

We examined and sampled the flint clay parting in the Fire Clay (Hazard No. 4) coal bed at five locations in Pike and Perry Counties, eastern Kentucky. Several additional samples of the parting from the Breathitt Formation were submitted earlier by Norman Hester, formerly of Eastern Kentucky University, and these were examined by X-ray diffraction.

The 3- to 4-inch flint clay parting occurs near the bottom of the Hazard No. 4 coal bed. It is hard, fine grained, porcellaneous, and blocky, and breaks with a conchoidal fracture. It is dark brown to gray or black in color on fresh surfaces, and has extremely sharp contacts with the over- and underlying coal. It is widely distributed in eastern Kentucky; Stevens (1979) studied it throughout a 2,000-km^2 areal extent.

METHODS

Recent studies of certain partings in western United States coal beds have shown them to be volcanic in origin (Bohor and others, 1978; Ryer and others, 1980), based upon mineralogical evidence. These studies used grain separation techniques to prepare individual phenocrysts from the partings for study by high-powered binocular microscope, the SEM, and energy-dispersive X-ray analysis equipment. These instruments enabled us to pick out, photograph, and chemically analyze the phenocrysts from the Fire Clay (Hazard No. 4) parting. X-ray diffraction analysis was also used to characterize the clay mineral composition of this parting.

MINERALOGY

Kaolinite is the only clay mineral that shows up on X-ray diffraction traces of this parting. The basal peaks of the kaolinite are very sharp and intense; the prism reflections are sharp and well defined. These diffraction characteristics describe a well crystallized, authigenic kaolinite. This is confirmed by the presence of fragile, elongated stacks or vermicules of kaolinite platelets,

*(Editor's note – An investigation by Robl and Bland (1977) of the flint clay parting in the Fire Clay coal determined the existence of β-quartz and sanidine and their volcanic origin.)

which can be seen under the binocular microscope. This vermicular growth form of kaolinite also was noted in the flint clay parting by Hoehne (1957), Seiders (1965), and Stevens (1979).

The phenocrystic portion of the flint clay parting was examined in a scanning electron microscope (SEM). The elemental composition of individual crystals was determined by an energy-dispersive X-ray analyzer attached to the SEM, thereby providing positive identification of the minerals shown in the micrographs. The scale of each micrograph is indicated by the distance between the white markings along the base of the photograph; the actual distance between these markings is given in the legend below them in micrometers (μm).

Figures 10 and 11 show samples of sanidine, a high-temperature potassium feldspar. Figure 12 is rutile or anatase, and Figure 13 is a crystal of ilmenite, an iron-titanium mineral. Figure 14 shows a long, narrow, prismatic zircon crystal and a thicker, hexagonal apatite crystal; Figure 15 is a single idiomorphic zircon and Figure 16 shows zircon crystals of different shapes and sizes. Figure 17 shows a crystal of anatase with good faces and a negative crystal in the surface. Figures 18 and 19 are examples of idiomorphic β-quartz-form crystals (now α-quartz) in the form of dipyramids that display little prism development. Figure 20 is a rounded β-quartz crystal showing the effects of magmatic resorption on crystal edges and faces. Figure 21 shows a rounded, embayed, β-quartz crystal to the right of an angular igneous quartz grain.

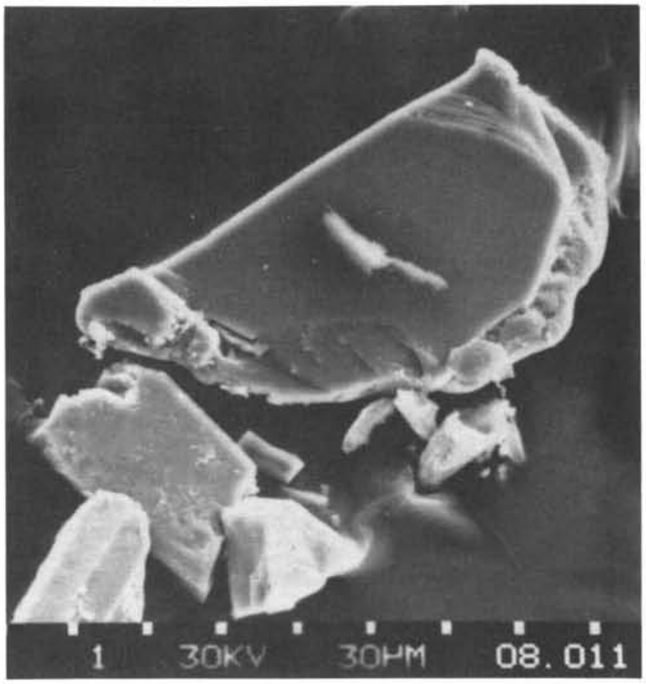

Figure 11. Photomicrograph of sanidine.

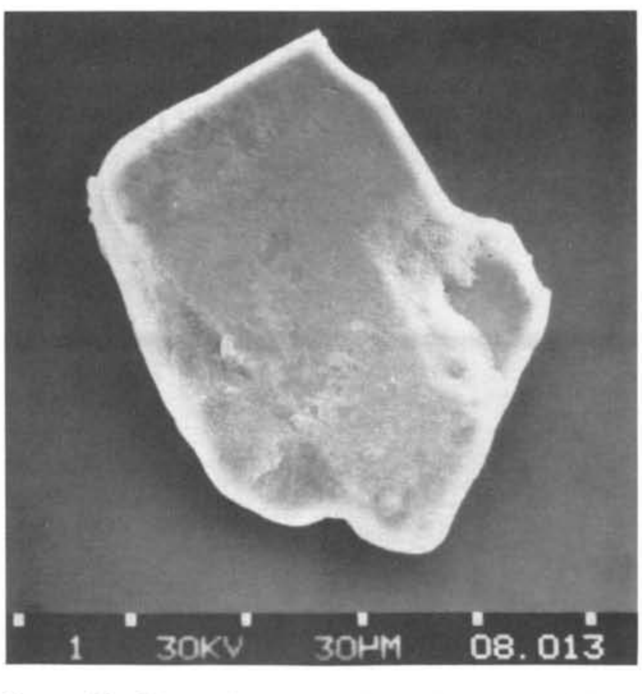

Figure 10. Photomicrograph of sanidine, a high-temperature potassium feldspar.

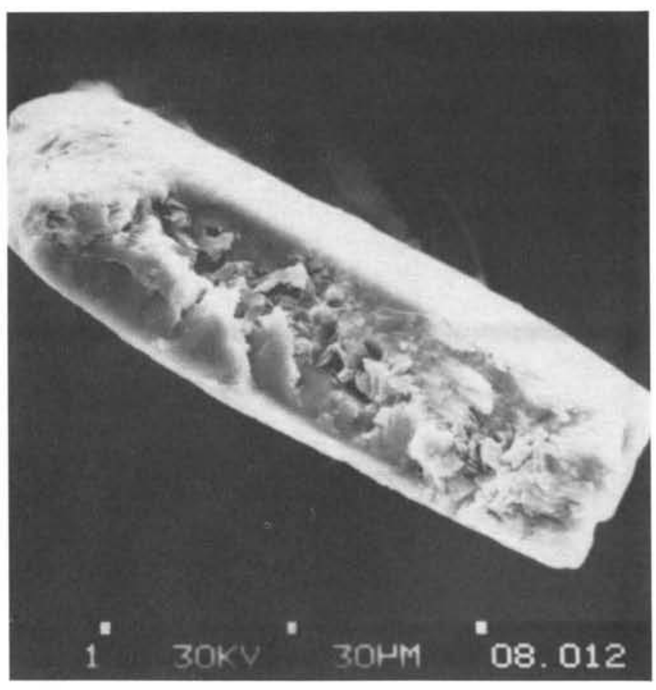

Figure 12. Photomicrograph of rutile or anatase.

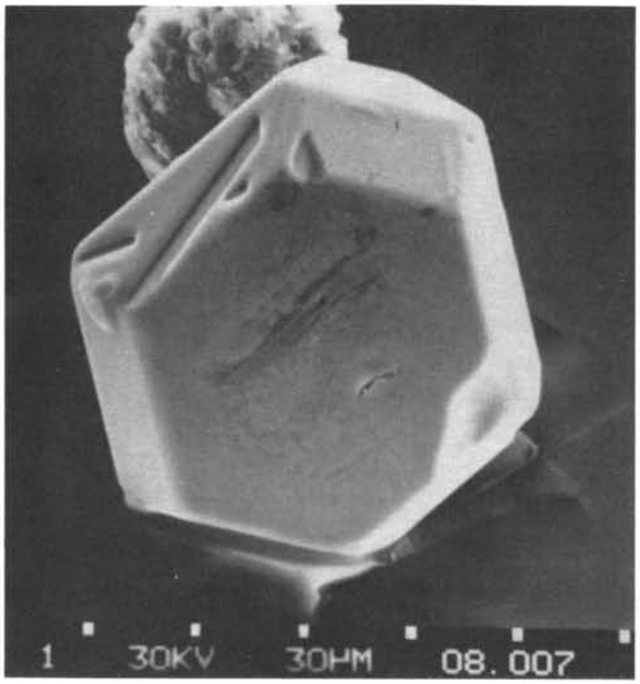

Figure 13. Photomicrograph of a crystal of ilmenite, an iron-titanium mineral.

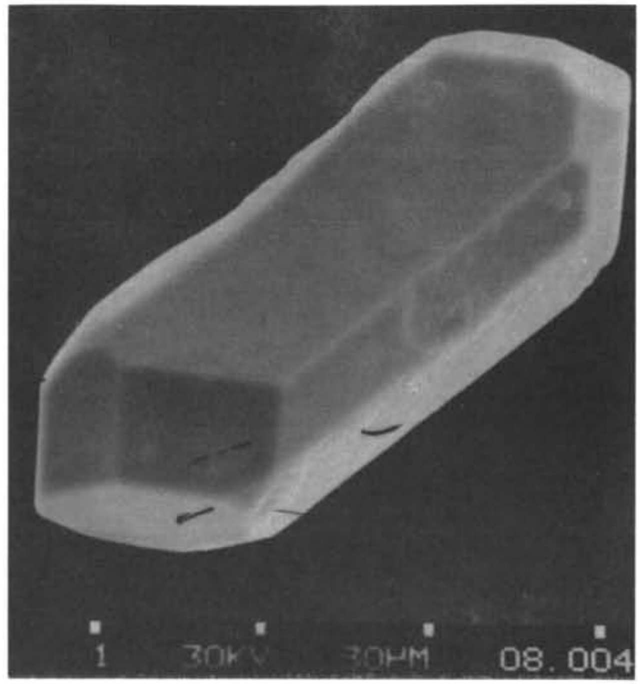

Figure 15. Photomicrograph of single, idiomorphic zircon crystal.

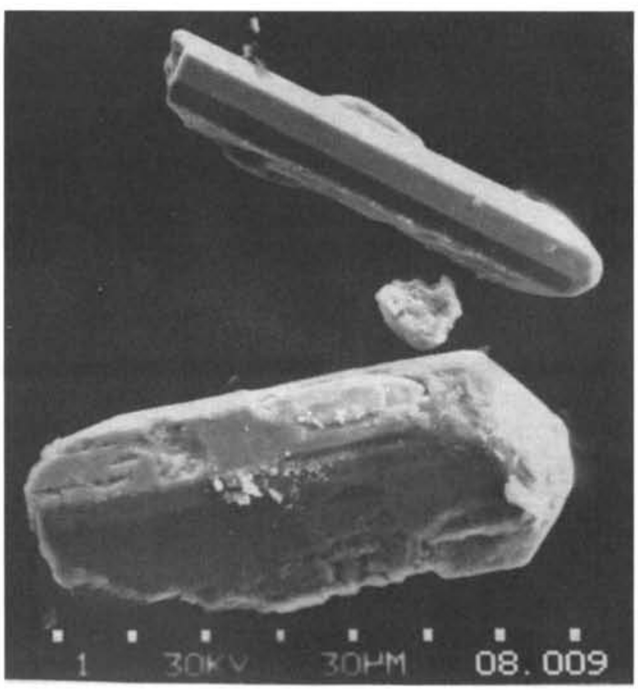

Figure 14. Photomicrograph of long, narrow, prismatic zircon crystal and thicker, hexagonal apatite crystal.

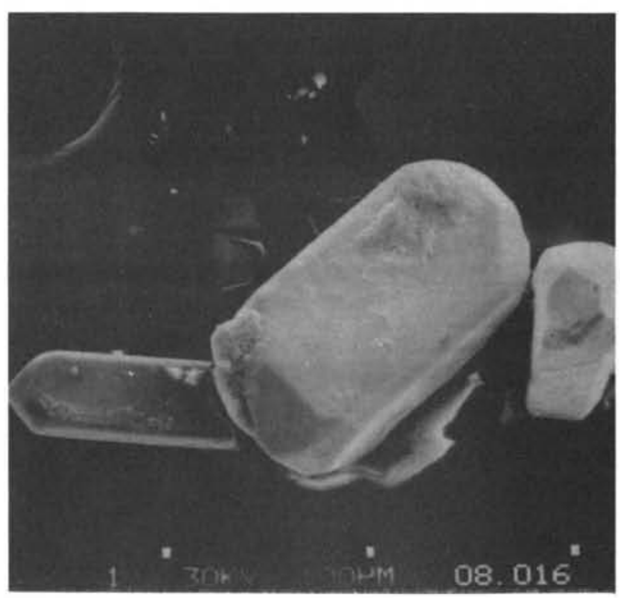

Figure 16. Photomicrograph of several zircon crystals. Note different shapes and sizes.

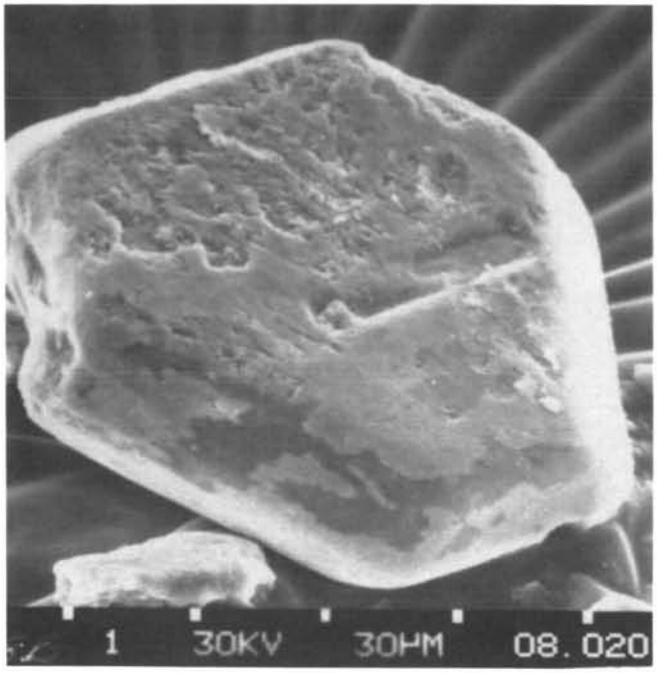

Figure 17. Photomicrograph of anatase crystal with good faces and a negative crystal in the surface.

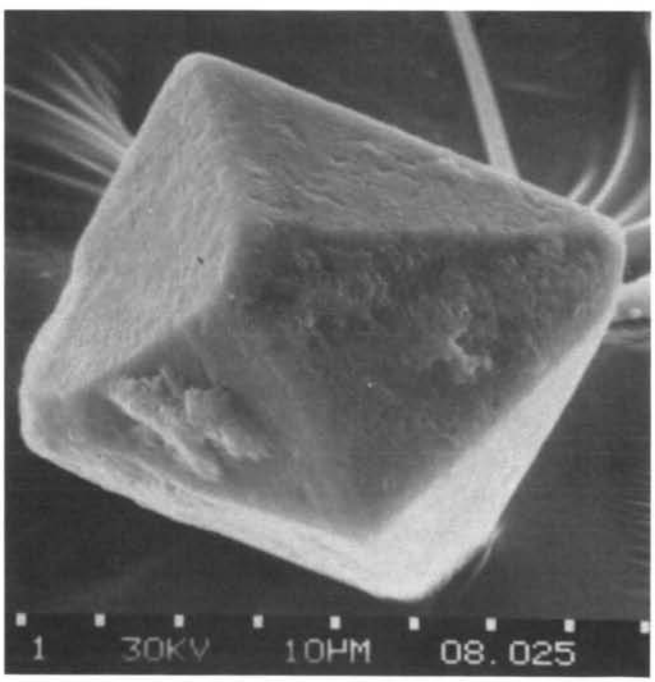

Figure 18. Photomicrograph of idiomorphic β-quartz-form crystal (now α-quartz) in dipyramid form displaying little prism development.

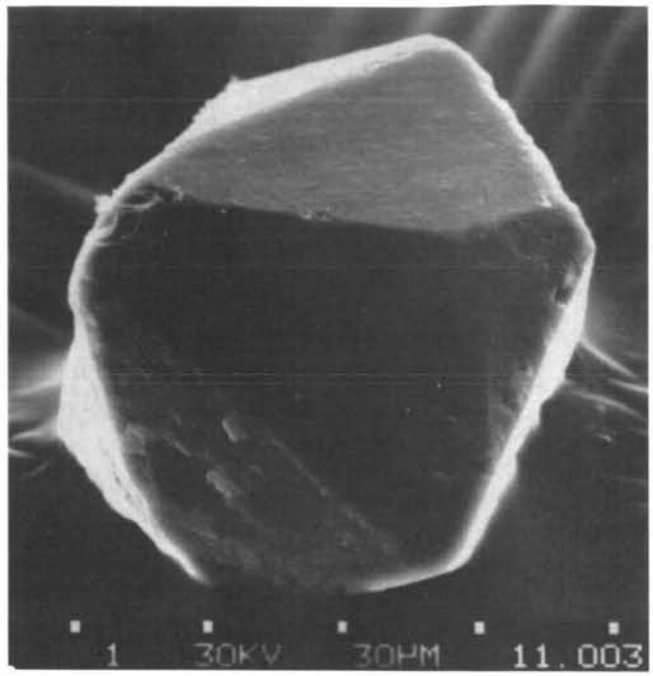

Figure 19. Photomicrograph of idiomorphic β-quartz-form crystal (now α-quartz) in dipyramid form displaying little prism development.

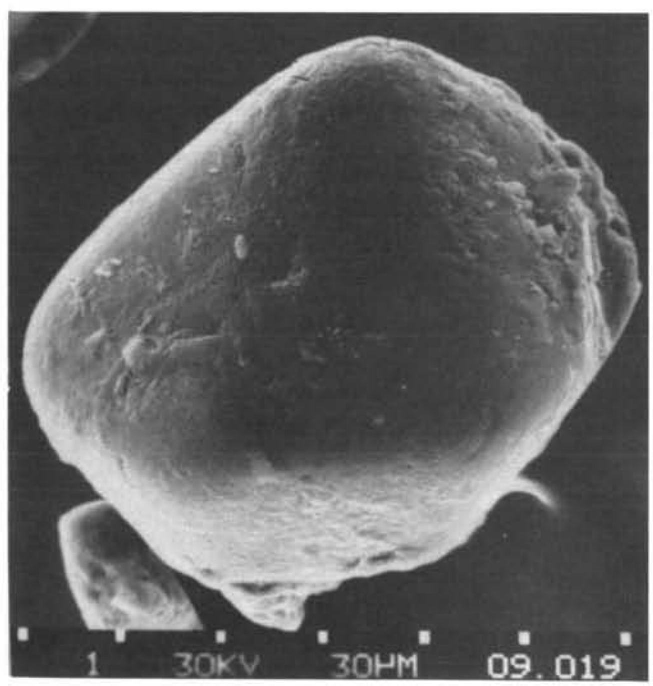

Figure 20. Photomicrograph of rounded β-quartz crystal showing the effects of magmatic resorption on crystal edges and faces.

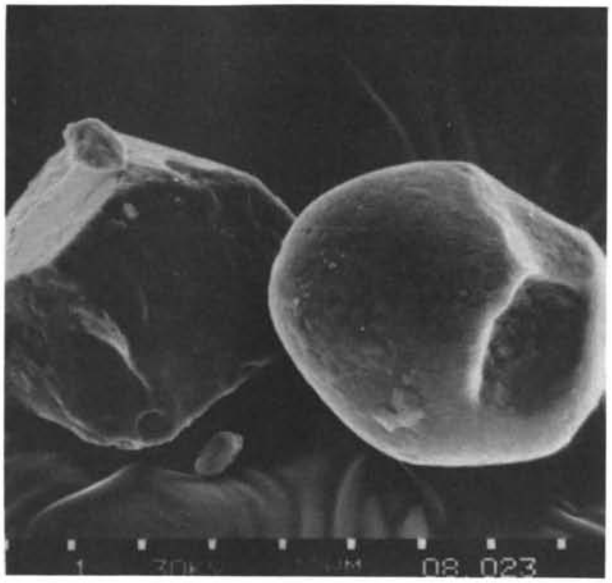

Figure 21. Photomicrograph of rounded, embayed β-quartz crystal to the right of an angular igneous quartz grain.

ORIGIN

All of the mineralogical data obtained on this parting indicates a volcanic origin. The only clay mineral present is extremely well crystallized kaolinite. It is almost impossible to conceive of a method of emplacing a thin, widespread layer of pure kaolinite throughout a coal swamp, except by in-situ alteration of a glassy, air-fall volcanic ash. The presence of delicate and fragile vermicules of well crystallized kaolinite in this layer can only be explained by in-situ alteration of a homogenous parent material such as a rhyolitic glass.

The phenocryst mineral assemblage displayed in the SEM photographs from this parting also indicates a volcanic origin. The idiomorphic β-quartz-form crystals are especially indicative, as these are found only in effusive rocks. Among previous workers, only Stevens (1976) had found these high-temperature crystal forms of quartz in this parting, and his graphic evidence was not convincing. Sanidine, a high-temperature form of potassium-rich feldspar, is a clear indicator of volcanic origin. Idiomorphic zircons and apatite, along with unrounded anatase, rutile, and ilmenite, complete the suite of exclusively volcanic minerals; no nonvolcanic or detrital minerals were found. All these phenocrysts are found floating in a matrix of kaolinite clay—a situation which cannot have resulted from detrital sedimentation.

The widespread distribution of this thin parting and its sharp contacts with the enclosing coal are additional arguments for a volcanic air-fall origin. These data, along with the mineralogical data presented here, effectively remove any doubts about the origin of this parting—all evidence indicates that this flint clay parting is the product of in- situ alteration of a rhyolitic vitric tuff in a peat swamp environment.

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KENTUCKY COAL RESOURCES PROGRAM

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In 1974 the Kentucky Geological Survey, under funding from the Institute for Mining and Minerals Research, started an extensive program to describe the coal in Kentucky quantitatively and stratigraphically. This quantification effort followed closely the Kentucky Geological Survey-U.S. Geological Survey Cooperative Geologic Mapping Program, which at that time had not been completed. However, that work progressed to a point where lead time provided mapped outcrops of the principal coal beds and benches.

The object of our present effort is not so much to emulate Marius Campbell, as valid as his efforts and goals were at his time, as it is to describe the nature of each coal bed or its mineable bench and to provide a permanent, accurate set of point-specific data that will be readily available for public and private agencies. The data include measurements of thickness, partings, and benches (splits), and a description of roof and floor at the point of measurement. The plan of work includes field examination of each quadrangle for coal in outcrops, roadcuts, or mine exposures. Additional data are sought from mine operators and the project has drilled some 55 diamond drill test holes. Extending beyond these efforts, the Survey maintains and operates a geophysical logger which has been used to wireline log its own test holes as well as a fair number offered by private companies. Core data from other sources such as the Tennessee Valley Authority, the U.S. Army Corps of Engineers, and that volunteered by industry are also utilized. The field staff has ranged from 8 to 6 since 1976, and three geologists work in the central office directing, coordinating field and office data handling, computerizing point-specific data, and estimating and cataloging resources. When field crews consider data for a quadrangle complete, a summary report is written describing the general conditions. This report, together with field notes, coal data cards, and a location map are checked for consistency and completeness.

The quadrangle data set including the coal cards is then processed for computer entry and rechecking. This phase provides printouts that serve as work sheets for transferring data to quadrangle outline maps on which county boundaries and coal outcrop lines have been traced. When the isopaching is completed for a quadrangle and the reliability arcs are cast, the coal resources map is ready for measuring the several categories by planimeter. The measurement data are summarized on forms, entered into the computer, calculated, and reported in tables showing distribution of the original resources by bed, thickness, and reliability and by geographic area—quadrangle, county, and coal resources district.

As may be appreciated, eastern Kentucky's geologic settings provide the gamut of challenges in describing the coal beds and estimating the tonnages. Examples to be seen on this trip range from splitting, thinning with or without feathering, the occurrence of benches at mineable thickness, isolated pods with no identifiable entity, and abrupt cutouts by subsequent or penecontemporaneous channel development. Some beds or benches are thin but persistent; others are erratic and vary from 0 to several feet within short distances. Beds assigned to zones present a complex that is not always accurately interpreted. Where benches of a coal bed are separated by considerable thicknesses of parting, mapping and estimating are made on a separate basis. The risk of stratigraphically misidentifying the bed or bench is offset in the accounting for the coal, even though it is assigned to the wrong bench.

The sedimentary complexes that are viewed in this region have been described, analyzed, and explained with delta models. Models are excellent. However, in examining the detail and narrow scope of just how far a bed extends, the location of the bed margin remains a stochastic element in the absence of drill hole data. Variation by thickness is shown by isopachus maps. The accuracy of this information is dependent on variability of the coal bed and frequency of data points. The attempt is made to gather an optimum number of points and to avoid 'clustering.'

As one looks at the outcrop maps the 'lacework' pattern is striking. We attempt to take advantage of the greatly undulating structure and conceive the outcrops as providing elements of fence diagrams. Where this condition occurs arbitrary limits are applied on bed extent, in the absence of drill data.

*Marius Campbell was a pioneer coal resources geologist of the U. S. Geological Survey who produced estimates for regions and states early in this century (*see* reference below).

The structure and sedimentology of the region also play a complicating role because of the thickening section from north to south. However, most of the problems have been previously solved by the field mappers. One apparent consequence is the increasing occurrence of partings reflected in the mapping of coal occurrences in zones.

Our project is scheduled for completion in 1983. At this time 16 quadrangles have yet to be examined in the field. Coal beds in the Princess and Southwest 'Reserve' Districts have been isopached and measured. The Licking River District resources maps are in preparation. Hazard and Upperland Cumberland Districts are completed with respect to field work and Big Sandy District is 65 percent completed in the field. All of the data assembly and analysis activities follow closely thereafter.

This project represents one of the most intensive efforts of its kind ever undertaken. We feel that with the geologic quadrangle maps, the data bank, and coal resources tabulations, by bed and small area, the information is provided in its most useful form. This bank of data, particularly the coal resources maps, has immediate application in the search for mineable coal and will provide a base for plotting mined-out areas and for overburden studies as applied to particular coal beds.

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MARINE ZONES OF THE UPPER CARBONIFEROUS OF EASTERN KENTUCKY

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This is a preliminary report on ocurrences of marine zones in the Pennsylvanian of eastern Kentucky. The recognition and interpretation of marine zones within the coal-bearing sequence are important for basic understanding of the depositional history of Pennsylvanian rocks. Marine zones have proved to be of great importance for stratigraphic analyses in the Pennsylvanian of eastern Kentucky. As key beds, the marine zones provide a stratigraphic framework and aid in the identification and correlation of coal beds across the coal field. The relationship between coal quality and depositional history is important in coal exploration, as higher sulfur content of coal is sometimes associated with marine rocks overlying the coal (Horne and Ferm, 1976; Hester and Leung, 1978). Acid mine drainage in surface coal mining operations is associated with the higher sulfur content of overburden rocks of marine or brackish origin (Despard, 1974; Caruccio and others, 1976; Hester and Leung, 1978). In a similar manner the occurrence of carbonate rocks can help in the neutralization of acid water, creating a beneficial environmental effect. The fossil fauna can be used to determine these depositional environments (e.g., marine, brackish, freshwater). Deposition of Pennsylvanian strata, particularly the Breathitt Formation, has been characterized as upper and lower delta plain by Ferm and others (1971), but little attention has been given to the marine contribution to the depositional record. A perusal of geologic quadrangle maps for eastern Kentucky shows that marine rocks are at least locally associated with almost every named coal. Most of these marine zones are thin and discontinuous, and are difficult to identify. Some, like the Magoffin, Kendrick, and Stoney Fork Members of the Breathitt Formation, are quite extensive. Forty-nine stratigraphically distinct zones that contain invertebrate fossil forms, animal bioturbation, limestone concretions, or calcareous lithologies have been identified in the lithologic descriptions of the geologic quadrangle maps of eastern Kentucky. All of these features are thought to be associated with marine conditions. Freshwater limestones have not been identified in the Breathitt Formation in eastern Kentucky, though better paleontological studies may show that some freshwater fauna have been misidentified as marine.

Many marine zones have been long recognized in the Pennsylvanian of eastern Kentucky. Morse (1931) reported seven: the Dwale Shales, Elkins Fork Shales, Kendrick Shales (Jillson, 1919), Magoffin Beds, Saltlick Beds, Lost Creek Limestone, and the Flint Ridge Flint. Later, MacFarlan (1943) added four more that had appeared in other geological investigations: the Campbells Creek Limestone (White, 1885), Vanport Limestone (Phalen, 1912), "Lower Cambridge" Limestone (Brush Creek) (Phalen, 1912), and the Ames Limestone (Phalen, 1912). McFarlan and some other earlier workers generally considered the marine contribution to the Pennsylvanian sedimentary record to be very minor (5 percent when computed from Morse's total section, 1931, p. 296). After studying a limited part of the Pennsylvanian section in the Cumberland Overthrust Sheet in southeastern Kentucky, Eagar (1970, 1973) suggested that marine contribution might be much greater, perhaps as much as 25 percent of the total section. The area in which Eagar worked may have received more marine sediment than the rest of eastern Kentucky due to its proximity to the axis of the Appalachian geosyncline, where rapid subsidence took place (Rice and others, 1979, p. F19). The average percentage of rocks of marine origin for the Pennsylvanian section of eastern Kentucky is most likely between these two figures. In any case, only three of the above named marine zones are well enough known to be formally named; most of the others are known only informally by the name of the geologist who first recognized them, or are referred to only as "the marine zone" above a particular coal bed (Rice, personal commun.).

Three studies involve the fauna of the Lower Pennsylvanian of the Cumberland Overthrust Sheet (Scott and Summerson, 1943; Eagar, 1970, 1973). Since 1958, several invertebrate studies have been made of the Kendrick Shale in Kentucky. These include studies on ammonoids (Furnish and Knapp, 1966), crinoids (Strimple

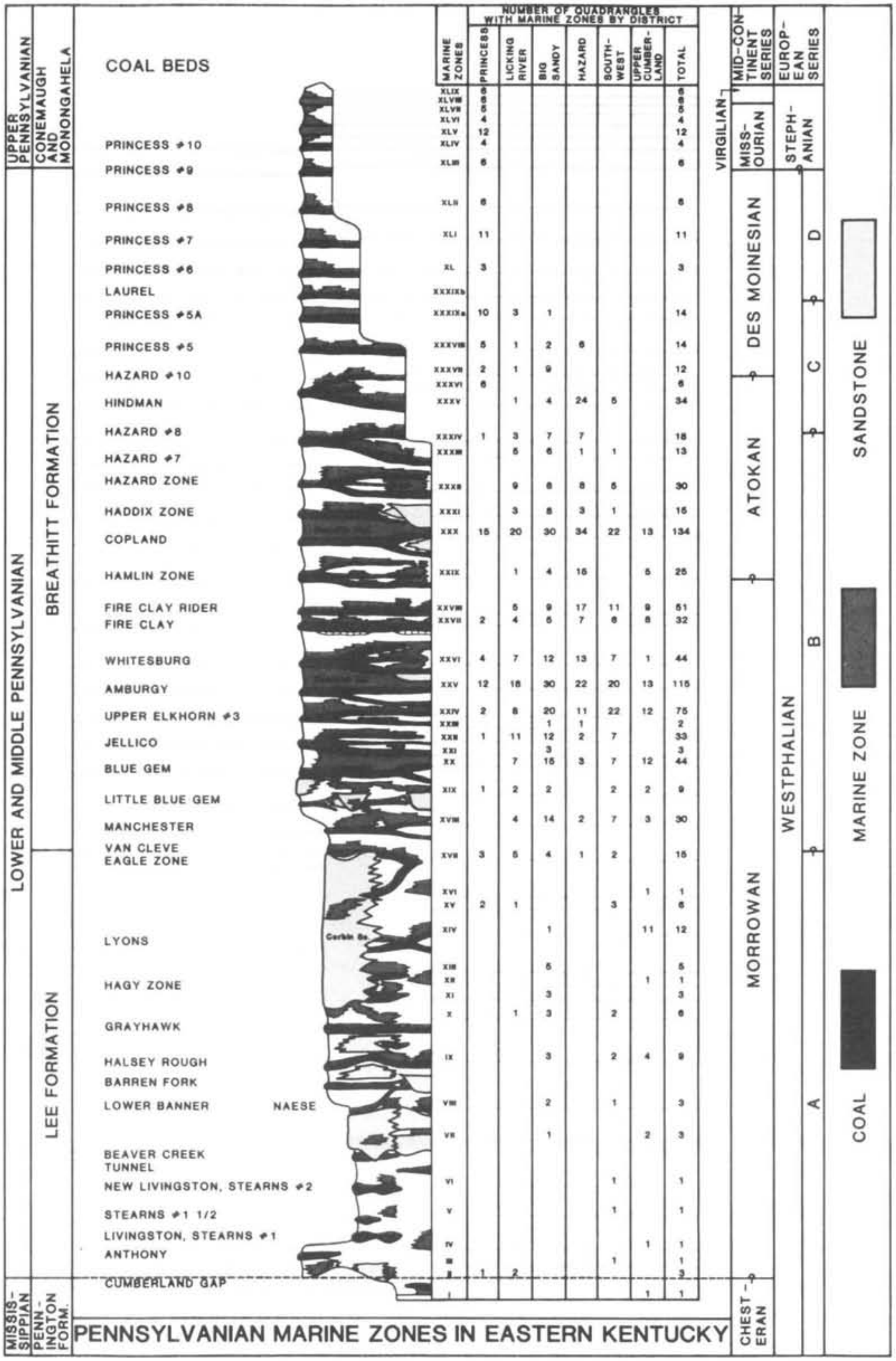

Figure 22. Pennsylvanian marine zones in eastern Kentucky. *See* facing page for explanation of marine zones.

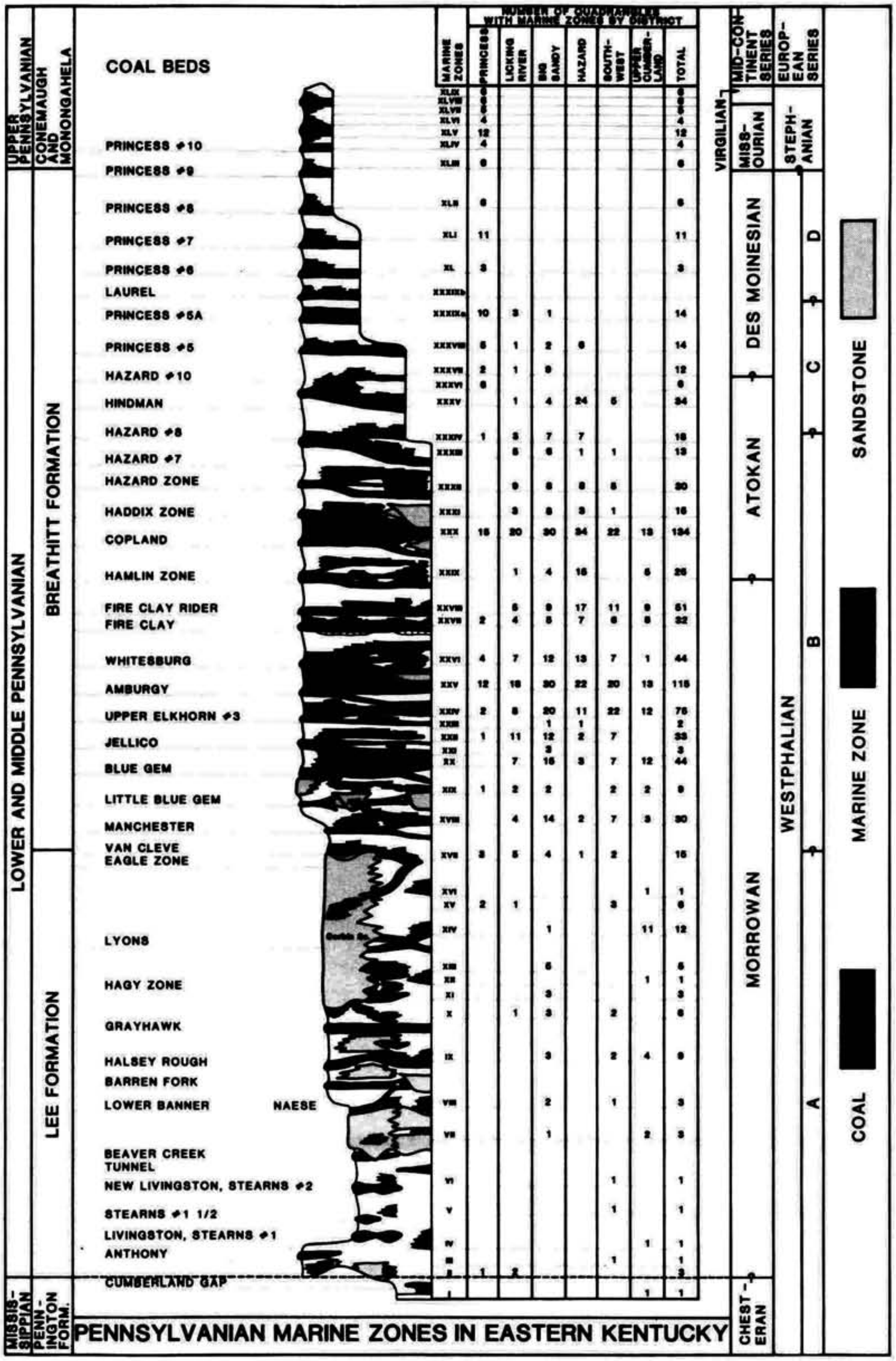

Figure 22. Pennsylvanian marine zones in eastern Kentucky. *See* facing page for explanation of marine zones.

XLIX
Marine beds above the Ames Limestone
XLVIII
Ames Limestone Member of the Conemaugh and Monongahela Formation
XLVII
Marine beds immediately below Ames Limestone
XLVI
Marine beds above Brush Creek Limestone
XLV
Brush Creek Limestone Member of the Conemaugh and Monongahela Formation
XLIV
Marine beds between Brush Creek Limestone and Princess No. 10 coal
XLIII
Marine beds above and within the Princess No. 9 coal zone
XLII
Marine beds above the Princess No. 8 coal
XLI
Marine beds above the Princess No. 7 coal
XL
Marine beds above the Princess No. 6 coal
XXXIXb
LimeKiln (Johnston, 1962)
XXXIXa
Vanport Limestone of Kentucky (Phalen, 1912)
XXXVIII
Flint Ridge Flint of Morse (1931)
XXXVII
Marine beds above the Broas coal zone
XXXVI
"Main Black Ore"
XXXV
Stoney Fork Member
XXXIV
Marine beds above and within the Hazard No. 8 coal zone
XXXIII
Marine beds above and within the Hazard No. 7 coal zone
XXXII
Marine beds above and within the Hazard coal zone
XXXI
Marine beds above and within the Haddix coal zone
XXX
Magoffin Member
XXIX
Marine beds above and within the Hamlin coal zone
XXVIII
Marine beds above the Fire Clay rider coal
XXVII
Marine beds above and within the Fire Clay zone
XXVI
Marine beds above and within the Whitesburg coal zone
XXV
Kendrick Shale Member
XXIV
Elkins Fork Shale and Dwale Shale of Morse (1931)
XXIII
Marine beds within the Upper Elkhorn No. 3 coal zone
XXII
Marine beds above the Jellico coal
XXI
Marine beds above the Upper Elkhorn No. 1 coal
XX
Campbells Creek Limestone of White (1885)
XIX
Marine beds above the Little Blue Gem coal
XVIII
Cannelton Limstone of White (1885)
XVII
Marine beds above the Van Cleve coal
XVI
Marine beds below the Hance coal
XV
Marine beds within the Corbin Sandstone
XIV
Marine beds above the Lyons coal
XIII
Eagle Limestone of White (1891)
XII
Marine beds below the Mason coal
XI
Marine beds above the Hagy coal bed
X
Marine beds above the Grayhawk coal
IX
Marine beds above the Halsey Rough coal
VIII
Marine beds above the Naese sandstone
VII
Marine beds above the Bee Rock Sandstone
VI
Marine beds above the Stearns No. 2 coal
V
Marine beds between Hazel Patch Sandstone and Livingston Conglomerate
IV
Marine beds in the Middlesboro Member
III
Marine beds associated with the Livingston Conglomerate
II
Marine beds associated with or above the Olive Hill Clay bed
I
Marine beds below the Cumberland Gap coal
The term "marine beds," as used in this index actually refers to marine and brackish beds.

Figure 22. Continued. Explanation of marine zones. The term "marine beds" as used in this index actually refers to marine and brackish beds.

and Knapp, 1966), and holothurian sclerites (Summerson and Campbell, 1958). Cavoroc and Ferm (1968) investigated the sponge spiculite of the Kilgore Flint (Flint Ridge Flint of Morse, 1931). Since 1975, 12 reports have investigated marine zones in some detail. These studies involve the Magoffin Member (Dennis, 1975; Ketani, 1980; and Ketani, this volume), an unnamed zone above the Hazard No. 5 coal (Cumbee, in preparation), the Stoney Fork Member (Lost Creek Limestone) (Garrison, 1977; Ping, 1978), the Flint Ridge Flint (Wetmore, 1978), the Brush Creek and Ames Limestones (Walter, 1979), and the Kendrick Shale Member (Rice, 1980; Brand, 1981a, 1981b).

Present data (Fig. 22) indicate that the marine contribution to the sedimentary record is greater than previously thought. Most of the marine beds identified in this study have not been recognized as such in the lithologic descriptions of geologic quadrangles. A preliminary examination of available literature suggests that the extent of marine-dominated depositional environments can be determined in a general way in the coal-bearing rocks of eastern Kentucky by plotting their occurrences on base maps (Chesnut, in preparation). Closer attention in the future to the lithologies from core holes and careful investigation in the field might further extend our knowledge of the occurrence and distribution of marine zones, too often overlooked in eastern Kentucky.

The typical marine zone (Fig. 23) is usually recognized as being a coarsening-upward, bayfill sequence that may be from a few feet to as much as 120 feet thick. They commonly overlie coal beds and are typically clay shale at the base and siltstone, sandy siltstone, or siltstone with thin beds of sandstone at the top. Sediment representing the maximum extent of transgression is usually directly overlying the coal bed or within a few feet over the coal bed. Brackish to marine fossils are commonly found at the base of the bayfill deposits. Pennsylvanian transgressions probably came from the southwest and south prior to and in Magoffin time, and from the west and north after Magoffin time (Rice and others, 1979, p. F19). The Magoffin and the Kendrick Shale were deposited in seas that covered most of eastern Kentucky. Many marine sediments, however, were deposited in small marine embayments separated laterally by distributary and other terrestrial clastic sediments; these units are commonly difficult to trace laterally. Rice and others (1979, p. F19) suggest that some discontinuous marine sequences were probably deposited in tidal channels or small bays perhaps tens of kilometers from large open bays (such as those represented by the Magoffin). Limestone beds associated with marine zones tend to be thin and discontinuous. They commonly occur at the base of the bayfill sequence.

The transgressive sequence above a coal, which is sparsely to abundantly fossiliferous, is usually overlain by a barren to sparsely fossiliferous progradational-regressive sequence of upward-coarsening sediments representing a variety of local deltaic environments (e.g., bayfill). Some investigations (Eagar, 1970; Bless, 1970; Williams, 1960) suggested that bays formed by widespread transgressions tend to become progressively less marine with time and the enclosed fauna tend to reflect these changes. Many bayfill sequences do not contain macrofossils; some, however, may contain only trace fossils. In the absence of macrofossils, the use of microfossils to identify depositional environments should be attempted in future work.

LARGE CALCAREOUS CONCRETIONS

Large limestone concretions are frequently found in the Pennsylvanian section above the Lee Formation in eastern Kentucky. These concretions can be observed at Stops 2, 3, 4, 5, 8, 9, and 10 of this field trip, though they are best exposed at Stops 3, 5, 8, and 9. The calcareous concretions, sometimes up to 15 feet long and 6 feet high, are thought to have been formed by very early diagenetic concentration of calcite from the water column or the calcareous sediment. Laminations from the host rock can be seen to go through the concretions, though the laminations are more compacted in the host rock. Although the concretions often occur along definite horizons within a coarsening upward sequence, many can be found throughout the sequence. There is a tendency for concretions to become more spherical-shaped as the grain size of the rock increases. Some concretions tend to be lens-shaped in shales, and almost spherical-shaped in sandstones. The lens shape could be controlled by the amount of compaction of the sediment; shales compact more than sandstones, therefore concretions in shales are lens shaped. More likely, however, is that migration of calcium ions was isometric in sandstones (i.e., equal in all directions), but in shales most of the migration was from a lateral direction controlled by the orientation of clay minerals (bedding). Migration would be slower in a direction normal to bedding. The concretions almost invariably show calcite-filled cracks due to de-watering and shrinkage. The concretions are fossiliferous when they occur in fossiliferous strata. Calcite is often in great enough proportion to classify the rock a limestone, although varying amounts of calcite and siderite are found. The mineralogical content of the concretions is variable, but the clastic content always matches the host rock. These calcareous concretions were formed by early diagenetic

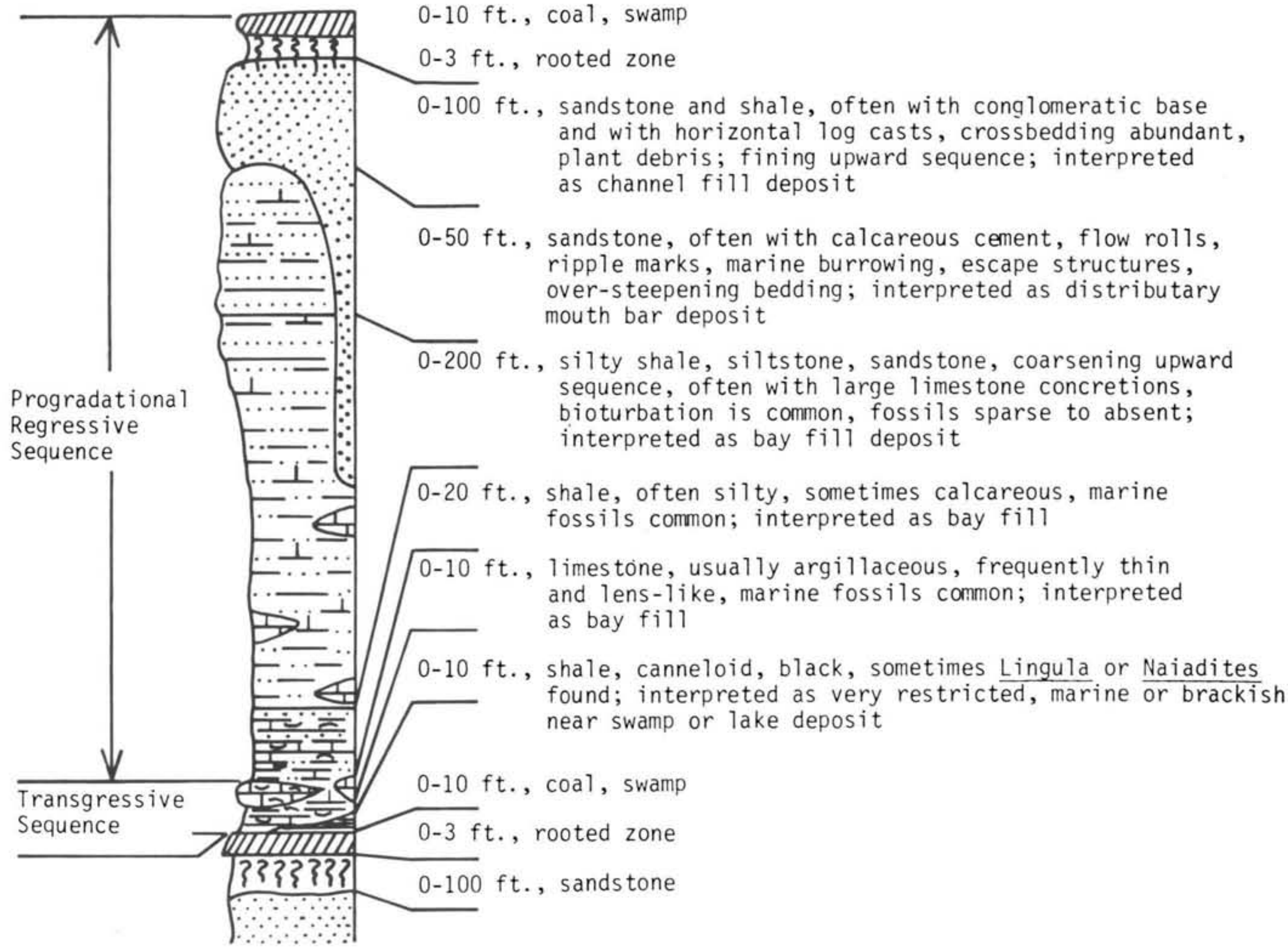

Figure 23. Generalized stratigraphic column of a marine zone.

concentration of calcite. Their presence is used to identify marine to brackish water conditions.

NOTES ON SOME COMMON TAXA

While there are commonly a large number of species represented in the population of abundantly fossiliferous marine zones, most of the Pennsylvanian section contains only rare examples of a few taxa. Figure 24 shows the environmental range of common taxa from the freshwater environment to marine environments. The following are notes on some common non-open marine and brackish taxa which are sometimes found in large numbers.

Naiadites-Anthraconaia

The pelecypod *Naiadites* has been used as an indicator for freshwater sediments by some (Rogers, 1965; Henry and Gordon, 1979, p. 101). Eagar (1973), however, said that some of these are probably a naiaditiform *Anthraconaia* (probably *A. ohioense* for the southeastern Kentucky forms). He suggested that the southeastern Kentucky *Anthraconaia* faunas lived in brackish waters, whereas the European forms lived in fresh water. Both viewpoints admit that they existed in waters of less-than-marine salinity. The pelecypod, when flattened, looks like and is frequently misidentified as *Lingula* (Figure 2 of Plate 17). Each valve of *Lingula* has bi-

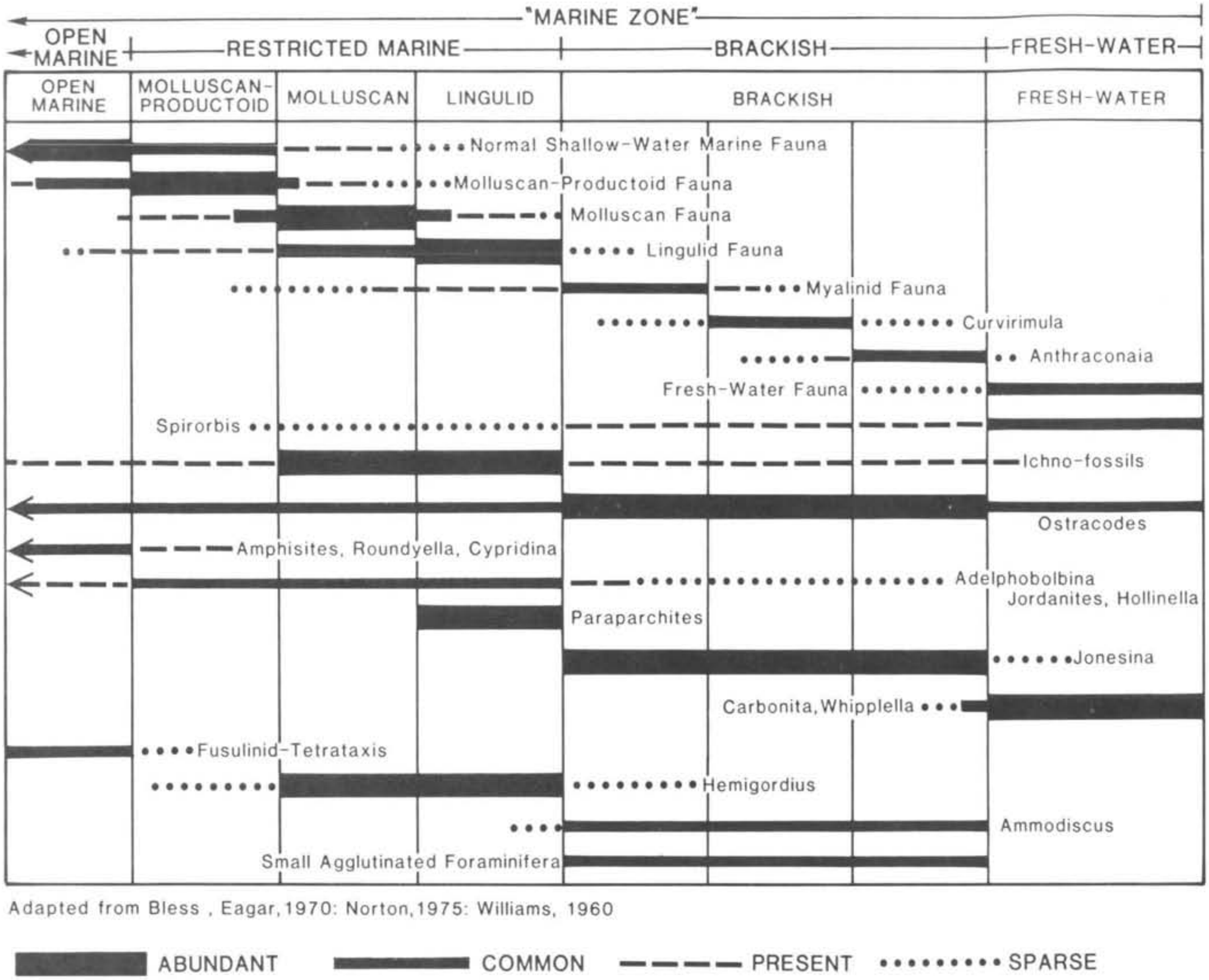

Figure 24. Preliminary environmental range chart of common taxa.

lateral symmetry, and is smooth, while a valve *Anthraconaia* is not symmetrical and has rougher concentric growth ridges. These pelecypods are frequently found in large numbers pyritized in brittle, black, fissile shale, often in association with *Calamites* stems. Perhaps the *Anthraconaia* grew on stems or floating algae overlying environments having anaerobic reducing conditions. They were preserved and pyritized when they settled to the sediment surface. Some forms of the pelecypod *Dunbarella*, which lived in more saline conditions, are found in similar black shales and may also have lived in a similar manner.

Lingula

The inarticulate brachiopod, *Lingula* (Figure 1 of Plate 17), is often used in upper Carboniferous work as an indicator of brackish conditions, but according to Rudwick (1965, p. 211-212) in the "Treatise on Invertebrate Paleontology"

> . . . The lingulids can survive occasional brief periods of immersion in brackish or fresh water (e.g., a tropical storm while exposed at low tide); but they do so by closing their shells tightly and by retreating into their burrows, i.e., by temporarily suspending all normal metabolic activities. No other living

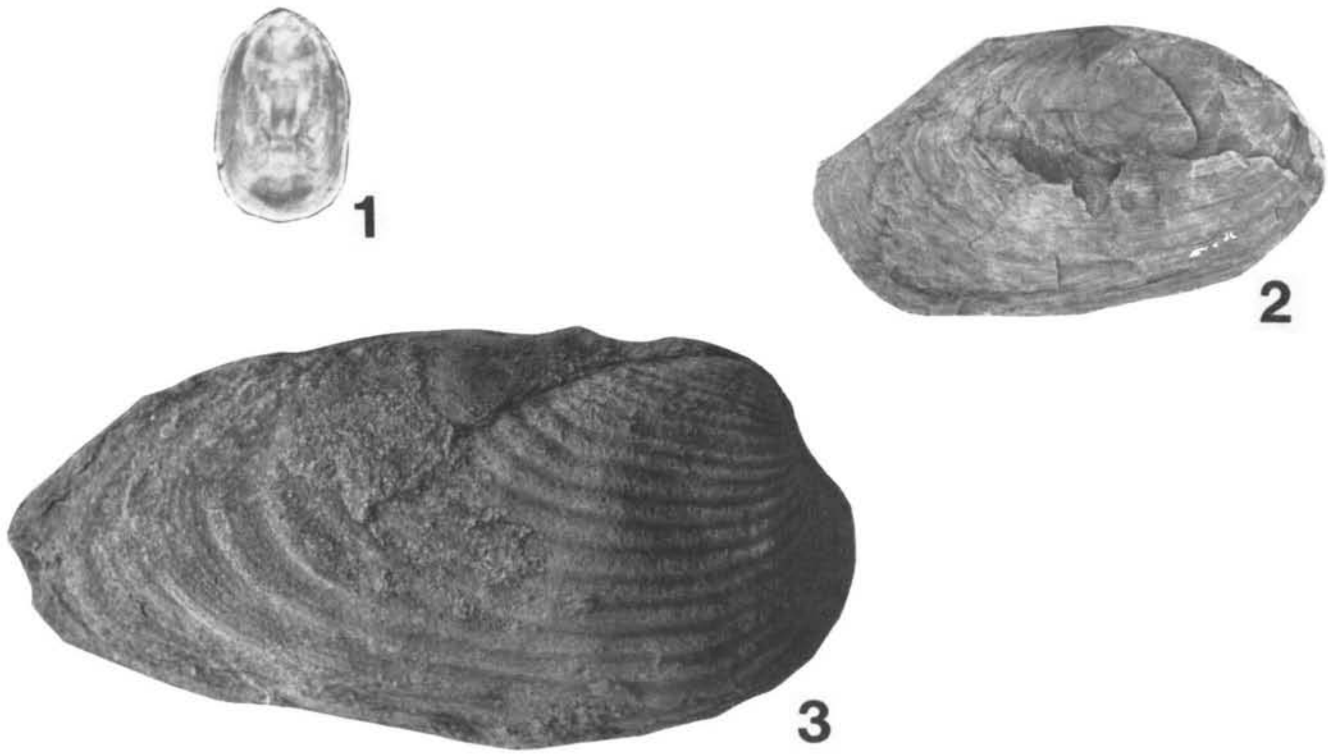

Plate 17. Upper Carboniferous fossils of Kentucky.

Figure 1. *Lingula carbonaria,* pyritized, from the Pennsylvanian of western Kentucky. X1.4.

Figure 2. *Anthraconaia (Naiadites)* sp. from a population of large forms in McCreary County, Kentucky. Pyritized in canneloid shales, overlying the River Gem (Lily) coal. X2, lightly coated with ammonium chloride.

Figure 3. *Wilkingia terminale,* sideritized cast, in heavily burrowed sandstone, near the Fire Clay coal in Knott County, Kentucky. X1.3, lightly coated with ammonium chloride.

brachiopods possess even this limited tolerance of non-marine conditions . . . The presence of fossil lingulids unaccompanied by other brachiopods is not a reliable indicator of brackish conditions of deposition. Such assemblages may indicate conditions that were normally marine but liable to occasional brief periods of brackish water. But lingulids are ecologically abnormal in several other aspects, and other explanations are therefore possible . . . the inarticulate Lingula . . . (is) well adapted to living in water that is generally turbid.

Wilkingia terminale

Frequently, burrowed sandstones and siltstones are the only indication of marine or near-marine conditions. The burrowing pelecypod, *Wilkingia terminale* (Figure 3 of Plate 17) is usually the only body fossil found in these sandstones. Both pelecypod and burrows are often replaced by siderite.

CONCLUSIONS

Further study of the fauna and distribution of marine zones is needed in eastern Kentucky. The Kentucky Geological Survey is conducting a coal resource study of eastern Kentucky. In the course of this work, many new exposures of marine zones have been found and collected, adding to our knowledge of both the paleontology of the Pennsylvanian and its depositional framework. Studies have shown that the quality of coal can be related to environments of deposition. Currens (this volume), among others (Hester and Leung, 1978; Williams and Keith, 1963), shows in his work on coal quality that the sulfur content of coal beds may be related to the distribution of marine strata in the roof rocks of the coal beds. Comprehensive studies of coal quality and its relationship to the enclosing rocks will be possible as our knowledge of the marine zones grows.

Additional information about marine zones will assist in a better understanding of the depositional models for the Pennsylvanian. The resolution of such controversies as the back barrier-lower delta plain-upper delta plain model versus the cyclothemic model or other models may hinge on our knowledge of marine transgressions. The lateral extent and number of marine zones should decrease as progradation from lower delta plain to upper delta plain occurs. There is no apparent decrease in marine transgressions in the Breathitt Formation of eastern Kentucky to suggest a shift from lower delta plain to upper delta plain.

Further work is necessary to determine the areal distribution of these marine zones (this study examined only surface data). Closer examination of the fossil distribution and the environments they indicate may help in determining proximity to shore (Stevens, 1971; Cavaroc and Ferm, 1968) and thus a better understanding of the lateral extent of the marine zones.

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THE MISSISSIPPIAN-PENNSYLVANIAN CONTACT IN EASTERN KENTUCKY

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The contact between the basal Pennsylvanian rocks and underlying rocks at Stops 1, 11, and 12 and in most localities along the western belt of outcrop in eastern Kentucky is unconformable. At first glance, the contact at the southernmost roadcut at Stop 1 appears to be conformable, but if one follows the difference in lithologies (red and green shales, coals, gray to black shales, and sandstones) across all three sections of this large roadcut, the erosional nature of the contact can be seen (Fig. 25, Stop 1). At no point higher in the section (in the Breathitt Formation) are Pennington-type lithologies found at any of the stops. The interruption of sedimentation and erosion was caused by regional uplift or eustatic sea level change near the Mississippian-Pennsylvanian time boundary, and this affected sedimentation on the craton (especially on high areas, e.g., along the Cincinnati Arch and the Waverly Arch). The Pennington is variably eroded and at some places is completely missing (Fig. 25). At Mt. Vernon (near milepost 61, Interstate Highway 75), a few miles north of Stop 1 (*see* Fig. 25), the Pennington is virtually absent, and paleoslumps of Pennsylvanian terrigenous clastics rest on the uppermost surface of the Newman Limestone (Dever and others, 1979; Hester and Brant, this volume). The slumping is very likely related to the very large and deep Livingston Channel, an ancient model of the Amazon or Brahmaputra Rivers, which cut scores of feet below sea level (Norman Hester, personal commun., 1981). In Rockcastle and Madison Counties, the large paleochannel cuts deeply into the Newman Limestone (Brown and Wixted, 1979a, 1979b). Evidence of deep erosion also occurs southwest of the stop near Somerset, Kentucky, at the old Colyer Quarry (Somerset Quadrangle, Carter coordinate location 20-H-59, 800 ft. FSL x 4,500 ft. FEL), where slumped Pennsylvanian rocks rest on limestone within the Newman Limestone equivalent (Hiram Smith, personal commun., 1980). An extensive channel-related paleoslump occurs at the Mississippian-Pennsylvanian contact in the Barthell Quadrangle, McCreary County, Kentucky (*see* Hester and Brant, this volume).

Further to the northeast in Carter County on the Wavery Arch of Ettensohn (1974) Pennsylvanian sediments rest unconformably on sediments as old as the Borden Formation, which occurs below the Newman Limestone (Sheppard, 1964). Pennsylvanian sediments also fill paleokarst in the Newman Limestone between milepost 35 and 36 on the Mountain Parkway near Slade, Kentucky (Weir, 1974), and at Stop 11 in the north half of eastern Kentucky.

Other than paleochannels such as these, the Pennington-Breathitt unconformity along the western belt of outcrop in eastern Kentucky is undulating. The unconformity is paraconformable in some places. However, only by tracing strata laterally does the nongradational and noninterfingering character of the two lithologies become apparent. Hematitic crust developed on the upper surface of the rocks overlain by Pennsylvanian strata, and the known missing section of the Pennington often indicate an unconformable contact. Along the western belt of Pennington outcrop, the preserved wedge of Pennington sediments increases in thickness to the south into Tennessee. Conformable contacts may be preserved in Tennessee (Milici, 1974). Conformable contacts are more likely to occur in a basin because subsidence is greater. Further basinward to the southeast, the Pennington Formation increases in thickness, and in extreme southeastern Kentucky Englund (1964) reported intertonguing of Pennington lithologies with Lee Formation (Pennsylvanian) sandstones.

The overall model of deposition of the Upper Mississippian and Lower Pennsylvanian in Kentucky still needs further study. McFarlan (1943) and other early workers characterized the Pennington Formation as uppermost Mississippian separated by a regional unconformity from the overlying Pennsylvanian Beattyville Shales (Lower Tongue of the Breathitt Formation) and Lee Formation. Englund (1964), in work done in extreme southeastern Kentucky, determined that there was lateral intertonguing between the Pennington Formation and Lee Formation. Horne and others (1971) developed a "Lee-Newman Barrier

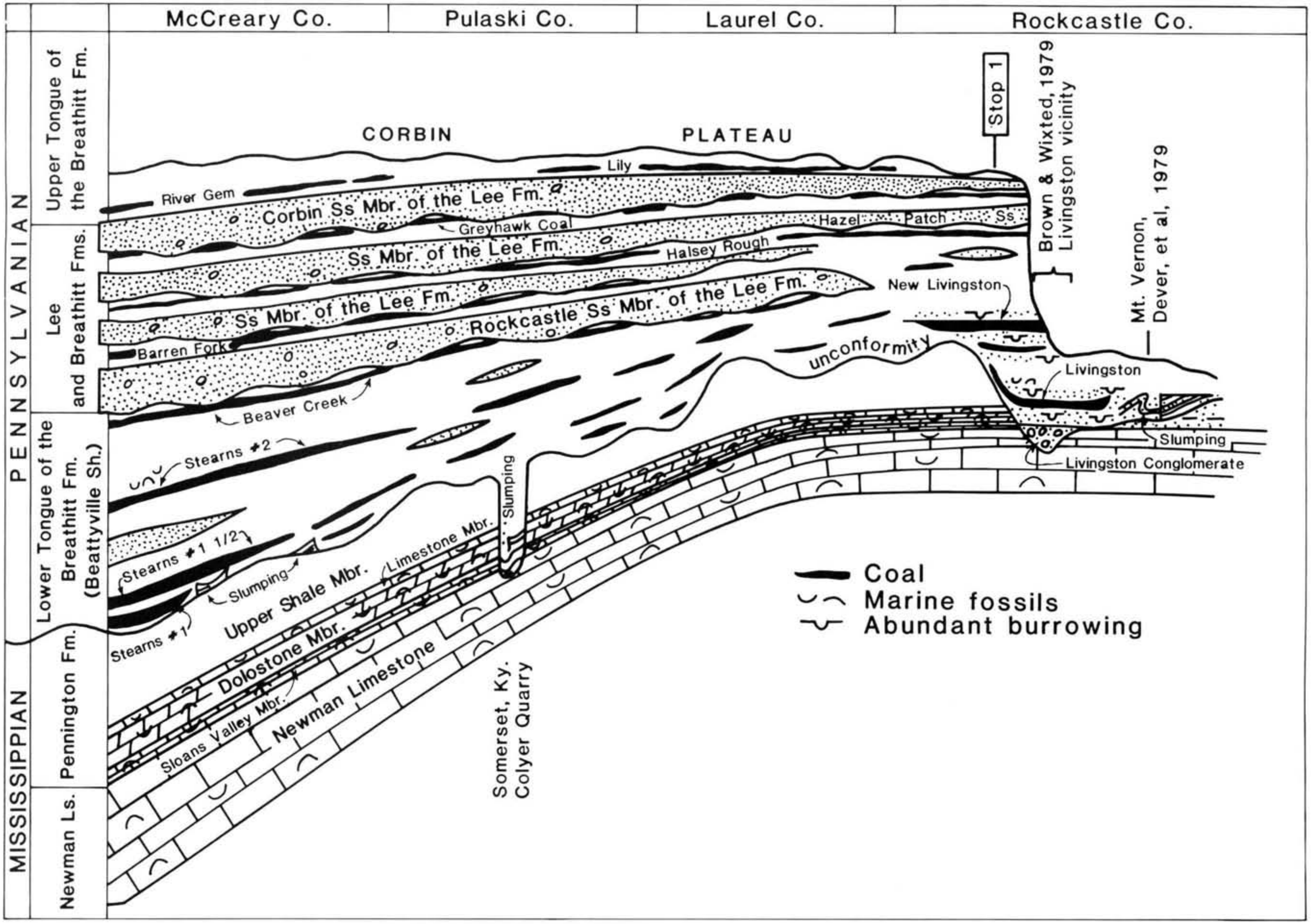

Figure 25. Generalized cross section from Stop 1 to Tennessee state line.

Shoreline Model" using an area in northeastern Kentucky as an example. They suggested that the Newman Limestone, the Pennington Formation, the Lee Formation, and the lower Breathitt Formation (the portion just above the Lee Formation in their study area) represented, respectively, carbonate barriers and carbonate-mud islands, off-shore clays, orthoquartzitic barrier sands, and tidal-flat clays and lagoonal sediments. They interpreted all of these formations to be lateral facies deposited at the same time. However, the assignment of different ages to these formations by biostratigraphic means and the occurrence of several widespread disconformities in the Upper Mississippian in north-central Kentucky and the regional unconformity near the Mississippian-Pennsylvanian boundary suggest that the "Lee-Newman Barrier Shoreline Model" may be incorrect (Ettensohn, 1980a, 1980b). Ettensohn characterized the Borden through the Breathitt Formation as being a series of tabular units representing several easterly and westerly transgressions and westerly clastic progradations. The last westerly progradation in latest Mississippian time began with deposition in east-central Kentucky of shallow distal prodelta clays of the Upper Shale Member of the Pennington Formation. In the cratonic area of eastern Kentucky a regional uplift (or eustatic sea level lowering) interrupted the westerly progradation near the Mississippian-Pennsylvanian boundary. (Further basinward in extreme southeastern Kentucky the unconformity may not be present, hence the intertonguing relationship between the upper Pennington and the Lee Formation reported by Englund, 1964.) Subsequent deposition following the tectonic uplift (or sea level lowering), resuming the westerly progradation, deposited the sediments represented by the Lower Tongue of the Breathitt and Lee Formations in east-central and south-central Kentucky. These sediments represent shallow-water deltaic environments including bays, mouth bars, channels, swamps, and marshes.

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INSECT WING FROM ROAD GAP

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Eastern Kentucky University

In the course of collecting fossil plants within the lower part of the Whitesburg coal zone at Road Gap, Kentucky, a fossil insect wing was found. Insect wings are quite rare and few are known from the Lower Pennsylvanian. This is the first Pennsylvanian insect wing reported from Kentucky.

The lower part of the Whitesburg coal zone (Breathitt Formation, Morrowan, Westphalian B) at this stop is composed of several thin coal beds within a series of channel-fill shales, siltstones, and sandstones (*see* Plate 4; in pocket). The two lowermost coals were cut-out by subsequent channel erosion at the eastern end of the roadcut. A third coal occurs within the channel-fill sediments and dips down into the channel. A coarsening-upward (in part) sequence overlying the third coal consists of silty shale and siltstone, grading (in part) into sandstone. There are minor scour features within this interval. Overlying the interval are several similar intervals ending, finally, with an overlying thick sandstone sequence. The insect wing was found in medium-gray, argillaceous siltstone overlying the third coal. The strata above all three coals contain plant fossils, though they are best collected above the third at the eastern end of the roadcut. Each of these intervals contain roughly the same forms of plant fossils (*see* floral list in Stop 3 *Description*).

Insect bodies decompose rather quickly, but the cuticle of the wings contains very little body fluid and is somewhat more resistant to decomposition. This is the reason that most ancient insects are known only from wings. The insect and plant fossils were probably carried into the channel-fill area by gentle currents.

The venation of this wing (Figures 2 and 3 of Plate 18) indicates that it belonged to the family Spilapteridae of the extinct order Palaeodictyoptera.* Insects of this order are probably ancestral to all the modern winged insects and had two pairs of wings which could not be folded back across the abdomen when resting.

Some of the generically diagnostic features are not discernible on our specimen, but the venation that is preserved is different from any of the three species of the family described from North America (Carpenter and Richardson, 1971). These species are *Homaloneura dabasinskasi, Mcluckiepteron luciae,* and *Spilaptera americana,* all from the Francis Creek Shale (Middle Pennsylvanian) in Illinois. This specimen is thus the oldest known representative of the family in North America and may belong to an undescribed genus (a more detailed report is planned).

Of the three described species of the family, Carpenter and Richardson (1971) report only one, *Homaloneura dabasinskasi,* which has preserved mouth parts. This species had a beak, which was probably used for sucking as shown on the reconstruction (Figure 1 of Plate 18).

*We wish to thank Dr. Paul H. Freytag of the Entymology Department at the University of Kentucky and Dr. Frank M. Carpenter, Museum of Comparative Zoology, Harvard University, for their confirmation of the identification of the wing.

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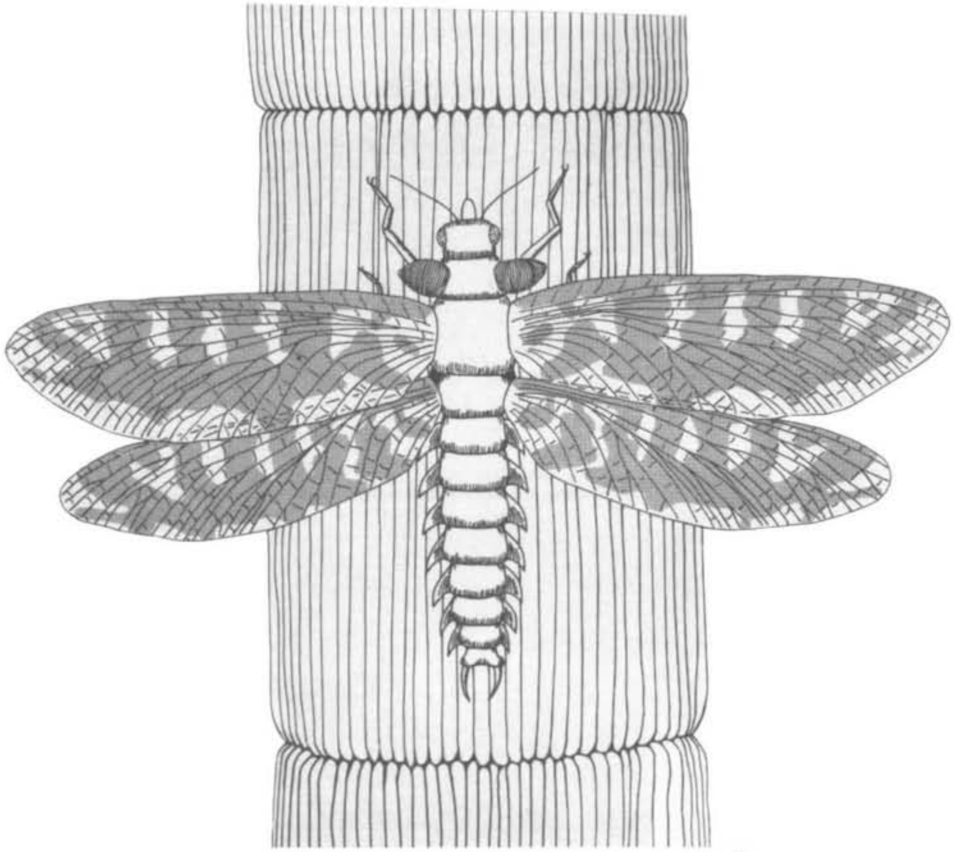
PLATE 18



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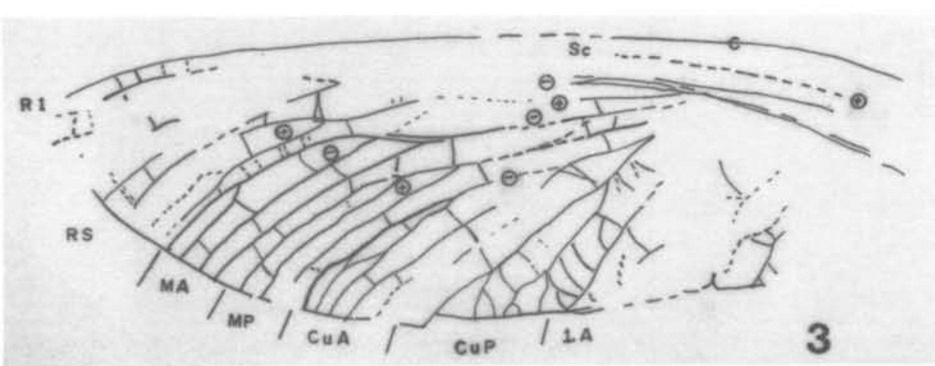

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Plate 18. Extinct insect of the family Spilapteridae, order Palaeodictyoptera.

Figure 1. Artistic conjecture of generalized spilapterid insect on *Calamites* stem. Wing coloration is that of the spilapterid, *Homaloneura dabasinskasi* (Carpenter, 1964). X1.

Figure 2. New genus and species. Ventral surface of right forewing. X2.

Figure 3. Wing venation pattern of same specimen as Figure 2. C = costa; Sc = subcosta; Rl = radius; Rs = radial sector; MA = anterior media; MP = posterior media; CuA = anterior cubitus; CuP = posterior cubitus; 1A = first anal; ¡ = convex vein on this surface; - = concave vein on this surface. X2.

GEOPHYSICAL WELL LOGGING FOR COAL EXPLORATION IN THE EASTERN KENTUCKY COAL FIELD

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INTRODUCTION

Geophysical well logging is an important tool used in coal research and exploration. Geophysical logs provide valuable data about coal thickness, thickness of mineral partings, roof lithology, coal correlation, and depositional sequences. The technology of geophysical logging has traditionally focused on oil and gas exploration; therefore, the specific logs and logging scales used in many boreholes have not been well suited to the needs of the coal geologist. The increased interest in coal geology over the past several years has resulted in logging technology tailored to coal research.

The purpose of this paper is to demonstrate some aspects of geophysical log analysis in the Eastern Kentucky Coal Field. This paper illustrates several of the principal coals and stratigraphic units in eastern Kentucky as recognized on geophysical logs. Also described are some geophysical methods such as recognition of lithologies, construction of composite logs, geological interpretations, coal quality, coal thickness, and stratigraphic correlations.

Several boreholes with geophysical logs were selected for use in this paper. Cores were available from these boreholes with which to verify the geophysical interpretations. These boreholes were also selected because they are in the vicinity of the route of the field trip between Hazard and Martin, Kentucky (Stops 6 and 10). They are from Noble, Hazard North, Vest, and Broad Bottom Quadrangles. (For an index to quadrangles, *see* Hower and others, this volume.) Two boreholes on Kentucky Highway 80 near Hazard, Kentucky, were drilled especially for the field trip. The core and geophysical logs from these boreholes will be available for study during the field trip. Their geophysical logs are also presented here.

GEOPHYSICAL LOGGING FOR COAL EXPLORATION AND ITS RESPONSES TO LITHOLOGY

The suite of geophysical logs used by the Kentucky Geological Survey for coal research includes: caliper (C), spontaneous potential (S.P.), resistivity (R), gamma ray (G), density (D), and expanded density (ED). The logging equipment used is a Well Reconnaissance Model 8036. A brief description of these logs follows:

1. *Caliper (C).* The caliper log measures the borehole diameter as a function of depth and is particularly valuable for correcting the density log where excess borehole caving has affected the density log responses. The caliper log also provides an indication of potentially incompetent strata that may be important when considering underground mining. One must be aware that problems encountered during drilling or certain procedures used during drilling can be responsible for borehole irregularity and that geological differences are not always the only explanation.
2. *Spontaneous Potential (S.P.).* The S.P. log measures the naturally occurring electrical potential (in millivolts) in a borehole as a function of depth. A common use of the S.P. log is for formation water quality and permeability determinations, but lithology, bed thickness, stratigraphic correlations, and depositional sequences are also indicated.
3. *Resistivity (R).* This log measures electrical resistivity between electrodes at the top and bottom of the probe when a current is passed through the adjacent wall of the borehole as a function of depth. The resistivity log indicates permeability, water quality, bed thickness, lithology, correlations, and depositional sequence.
4. *Gamma Ray (G).* The gamma ray log records the naturally occurring radiation in a borehole as a function of depth. The gamma ray response is particularly valuable for distinguishing shales and shaly units from sandstones. The gamma ray response from coal beds is usually minimal and is not considered particularly good for coal bed determinations. Shaly partings in coal beds often give recognizable responses, however.
5. *Density (D).* The density log records gamma radiation that is scattered back to a receiver in the density probe from a radiation source in the probe. The amount of radiation received is a function of the electron density in the rocks in the borehole and, there-

fore, an indirect measure of their bulk density. The extreme low density of coal compared to other rocks makes the density log especially valuable in coal geology. Coal thickness as well as the thickness of mineral partings in the coal can be determined from density logging. Coal quality, especially ash content, can be determined from some applications of the density log.

6. *Expanded-Scale logs (ED).* The density log is run past each coal bed encountered in a borehole at an expanded scale which allows improved coal quality determinations, coal bed thickness measurements, and measurements of mineral partings in the coal. Density logs are an important source of information for coal correlation studies because of the recognition of identifying features such as partings.

In coal research, geophysical logs are routinely run at a scale of 1 inch on the chart equals 10 feet in the borehole. The expanded-scale density log is run on a scale of 1 inch on the chart equals 1 foot in the borehole. Other logs can be run on expanded scales to emphasize various details of interest.

Recognizing lithologies is an important function of geophysical logs in coal exploration. Figure 26 shows a suite of geophysical logs from a borehole in the northern part of Knott County. The basic lithologic interpretations from the density, spontaneous potential, resistivity, and gamma ray logs are shown. The following discussions about coal, shale, siltstone, limestone, and sandstone refer to Figure 26.

Coal

The density log gives an excellent response to coal because of the large density differences between coal (1.2 to 1.5 density) and clastic rocks such as sandstone (2.65 density). The spontaneous potential responds to coal with a deflection left, which is to the negative potential. The resistivity log deflects to the right, toward lower resistivity, for coal. The gamma ray log responds to coal with a deflection to the left, toward lower radiation, but often deflections are so slight as to be difficult to identify or are overly influenced by thin, shaly partings in the coal.

Shale

The bulk density differences between shales (2.2 to 2.7 bulk density) and sandstones (2.5 to 2.9 bulk density) are not always large enough to cause definitive responses on the density log. The rocks in eastern Kentucky are commonly gradational between the general rock types and occur as silty shale, silty sandstone, etc. Another factor compounding the difficulty in interpreting the density log for lithologies other than coal is the amount and kind of cementation (i.e., calcareous, siliceous, and sideritic). Therefore, identifying shale from the density log is only done in conjunction with other data.

The spontaneous potential responds to shale with a deflection right toward positive potential. This deflection is an indirect measure of the lower permeability of shale compared to enclosing coarser grained beds. The resistivity log responds to shale with a deflection to the left to higher resistivity, which is also an indication of lower permeability.

Gamma ray provides an excellent indication of shale with a deflection to the right, indicating higher radiation. The higher radiation levels are due to the large amount of radioactivity isotopes contained in clay minerals composing the shale.

Sandstone

Sandstone is generally not definitively identified from a density log, and recognition of it depends upon the other logs. Spontaneous potential gives an excellent indication of sandstone with a deflection to the left, toward negative potential. This deflection indicates the higher permeability of the sandstone compared to the other strata in the sequence. The resistivity log also responds well to sandstone, deflecting to the right, toward lower resistivity, which is likewise an indication of its higher permeability. Just as the larger amounts of clay minerals cause higher radiation in shales, the absence of this radiation source in sandstone results in a good response on the gamma ray log. In most cases, spontaneous potential, resistivity, and gamma ray used in conjunction with one another identify sandstone.

Siltstone

Differentiating siltstone from other clastic rocks using geophysical logs is difficult. Siltstones contain varying amounts of siderite and calcite as cement and concretions, are frequently burrowed or rooted and contain interbeds of shale and sandstone. These features complicate the geophysical responses and create problems in unequivically identifying siltstone by geophysical logs alone.

Limestone

Well developed limestones are rare in the Pennsylvanian section of eastern Kentucky. Marine zones usually occur as calcareous shales with limestone concretions. Occasional beds of limestone occur but are difficult to identify on geophysical logs. The higher density of limestone provides one way of recognition on density logs and their biogenic origin usually means higher natural-gamma radiation levels.

COMPOSITE GEOPHYSICAL LOGS

One of the best ways to fully utilize the geophysical

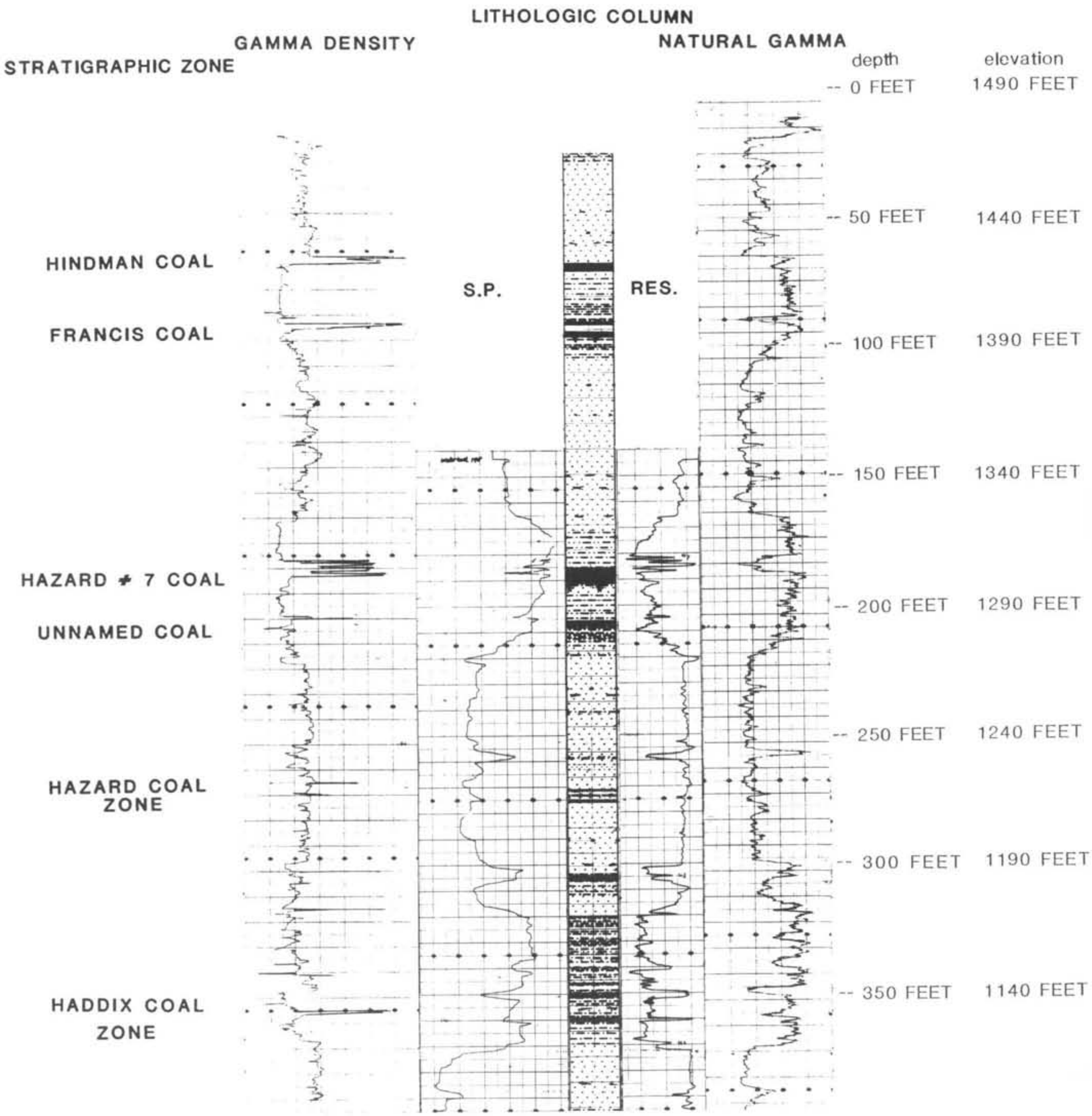

Figure 26. Geophysical responses to various lithologies in a composite geophysical log from Vest Quadrangle.

logs in exploration, particularly in new areas of exploration, is the construction of composite geophysical logs. A composite geophysical log is constructed by first measuring and describing the core in detail. Then a strip log using lithologic symbols at the same scale as the geophysical logs is made. The strip log and geophysical logs can then be aligned and a comparison made to better interpret and verify each source of information. Problems such as core losses, depth inaccuracies, and nondefinitive geophysical responses can thus be identified and corrected. Much firmer geological interpretations can be made using a composite geophysical log. These include lithologic identification, bed thickness measurement, depth, depositional sequence, and stratigraphy.

Figure 27 is a composite geophysical log from two boreholes drilled on new Kentucky Highway 80 north of Hazard between Stops 6 and 7 of the field trip. The holes were located such that a small amount of vertical overlap would occur. Figure 27 shows the density, S.P., resistivity, gamma ray logs, and lithologies indicated from core descriptions and geophysics. The depths, elevation, and stratigraphic nomenclature are also shown.

By utilizing information from the core descriptions to supplement the geophysical data, intermediate rock types such as silty, shaly, and sandy beds can be recognized. Other details valuable for geological analysis such as fossils, burrowing, rooting, bedding, siderite, pyrite, cementation, coal spar, and conglomerate must also be included in the composite geophysical log. From the combined information, depositional sequences are inferred, leading to a better knowledge about the geology

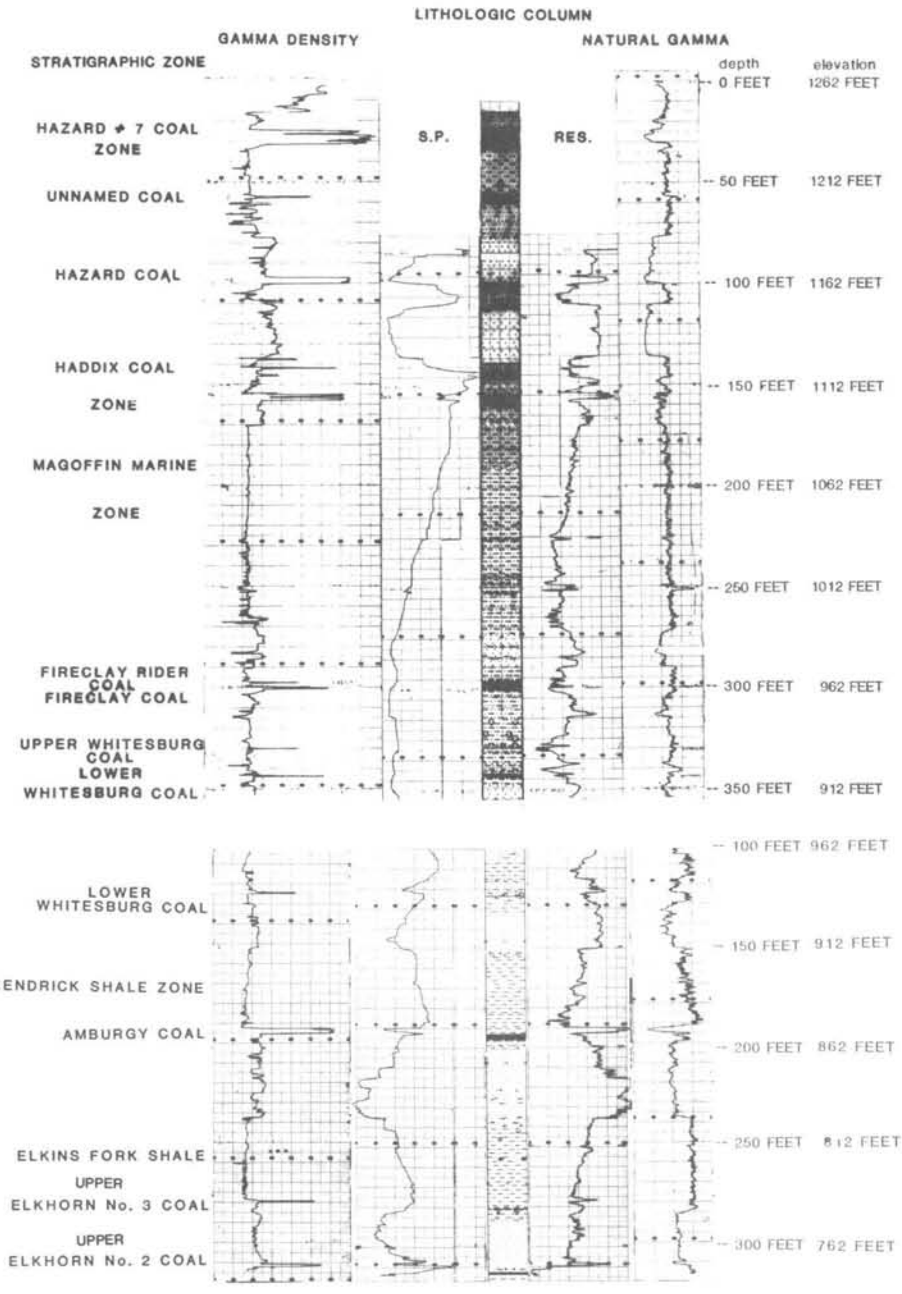

Figure 27. Composite geophysical logs from two boreholes drilled on new Kentucky Highway 80 in Hazard North Quadrangle, near Stop 7 of the field trip.

of the coal beds of interest.

For example, several depositional episodes are recognized in the composite geophysical log shown in Figure 27. The Elkins Fork Shale, which is the sequence from the Upper Elkhorn No. 3 coal to the Amburgy coal, is a coarsening-upward sequence. Characteristics of its coarsening-upward nature are evident on each of the geophysical logs. The S.P. and resistivity logs are the most diagnostic because of their divergence upward through coarsening-upward sequence. This divergence is due to the upward increase in permeability caused by the upward-coarsening grain size. Of similar importance are the smoother, more regular curves in the lower part of the sequence. These characteristics indicate uniform lithology and thinly bedded units of the shale part of the sequence. On the other hand, the curves in the upper part of the sequence show more fluctuations in lithology and thicker bedded units, as might be expected from interbedded sandstones and siltstones.

The density log shows denser and more uniform lithology in the lower part of the coarsening-upward sequences. In this identical part of the sequence, the gamma ray log shows higher clay content. This part of the sequence is the marine shales of the Elkins Fork Shale. Then, in the upper part, the density log indicates less dense lithologies and thicker bedded units, while the gamma ray log shows a decreased clay content in this same interval. This lithology is the sandstone overlying the marine shales.

The next depositional episode shown in Figure 27 is another coarsening-upward sequence. This sequence, which is between the Amburgy coal and the Lower Whitesburg coal, is the Kendrick Shale. This coarsening-upward sequence is again recognizable on all geophysical logs. The discussion of geophysical responses given for the Elkins Fork Shale likewise adequately describes them in this sequence.

The third depositional episode shown in Figure 27 is the Magoffin Member, another marine shale and another coarsening-upward sequence. This marine shale is much thicker than the two previously described marine shales. This is most evident by the length of the flat-line segment on the density log, showing very uniform and dense shale lithology. The coarsening-upward nature of this sequence is best seen in the divergence of the resistivity log and in the increase in bed thickness at the top of the sequence. The gamma ray log shows a slight decrease in clay content upward and a corresponding increase in bed thickness at the top of the sequence.

An example of a fining-upward sequence is shown in Figure 27. The thick sandstone above the Haddix coal fines upward into shale with coal. The S.P. and resistivity logs abruptly converge at the top of the sequence, showing decreased permeability caused by decreasing grain size. The density log shows progressively more dense lithologies upward. The gamma ray log shows higher clay content in the upper part of the sequence and much lower clay content in the sandstone in the lower part of the sequence.

Nearly every change in lithology is indeed a small-scale coarsening- or fining-upward sequence, and attempting to define them all is pointless. It is also the case that many sequences overlap one another or are interrupted, having no well defined ending or beginning such as a coal bed or marine shale. Therefore, one needs an idea about the depositional history and regional stratigraphy of the coals of interest in an area of exploration or production.

The analysis of geophysical logs adds greatly to the predictability of the stratigraphic column. The absence of a coal bed, for example, may be explained by penecontemporaneous erosion where a fluvial sequence has been identified from the geophysical logs. The appearance of an unexpected coal may likewise be explained from geophysical logs by relating it to partings or splits in coals of nearby boreholes. Indication of coal quality may also be gained by the inferred depositional environments associated with the coal bed. The use of composite geophysical logs can certainly benefit these kinds of geological analyses.

COAL BED CORRELATIONS

It is essential to correctly correlate coal beds when determining coal reserves in an exploration target area. Regional coal resources studies likewise rely upon assumptions about coal bed continuity over several miles. Therefore, the ability to correlate coal beds is of paramount importance. The correlation of coal beds can be enhanced by the use of geophysical logs. Characteristics on geophysical logs can be traced to different boreholes by these logs which give something of a "fingerprint" for stratigraphic identification.

Figure 28 shows coal bed correlations between four boreholes located along a line paralleling the field trip from Hazard to Martin, Kentucky (Stops 6 to 10). About 13 coal beds are correlated. The coal peaks on the density logs give the succession of coal beds, while the S.P. and resistivity logs provide characteristics for correlation. For example, the flat density, S.P., and resistivity curves in the Hazard North and Broad Bottom sections aid in recognition of the Magoffin Member. Consequently, the coals immediately above and below the Magoffin Member are the Haddix and Copland (or Taylor) coals, respectively. The Kendrick Shale and Elkins Fork Shale are equally recognizable, identifying the Upper Elkhorn No. 3, Amburgy (Williams), and Lower Whitesburg coals. The correlations agree well

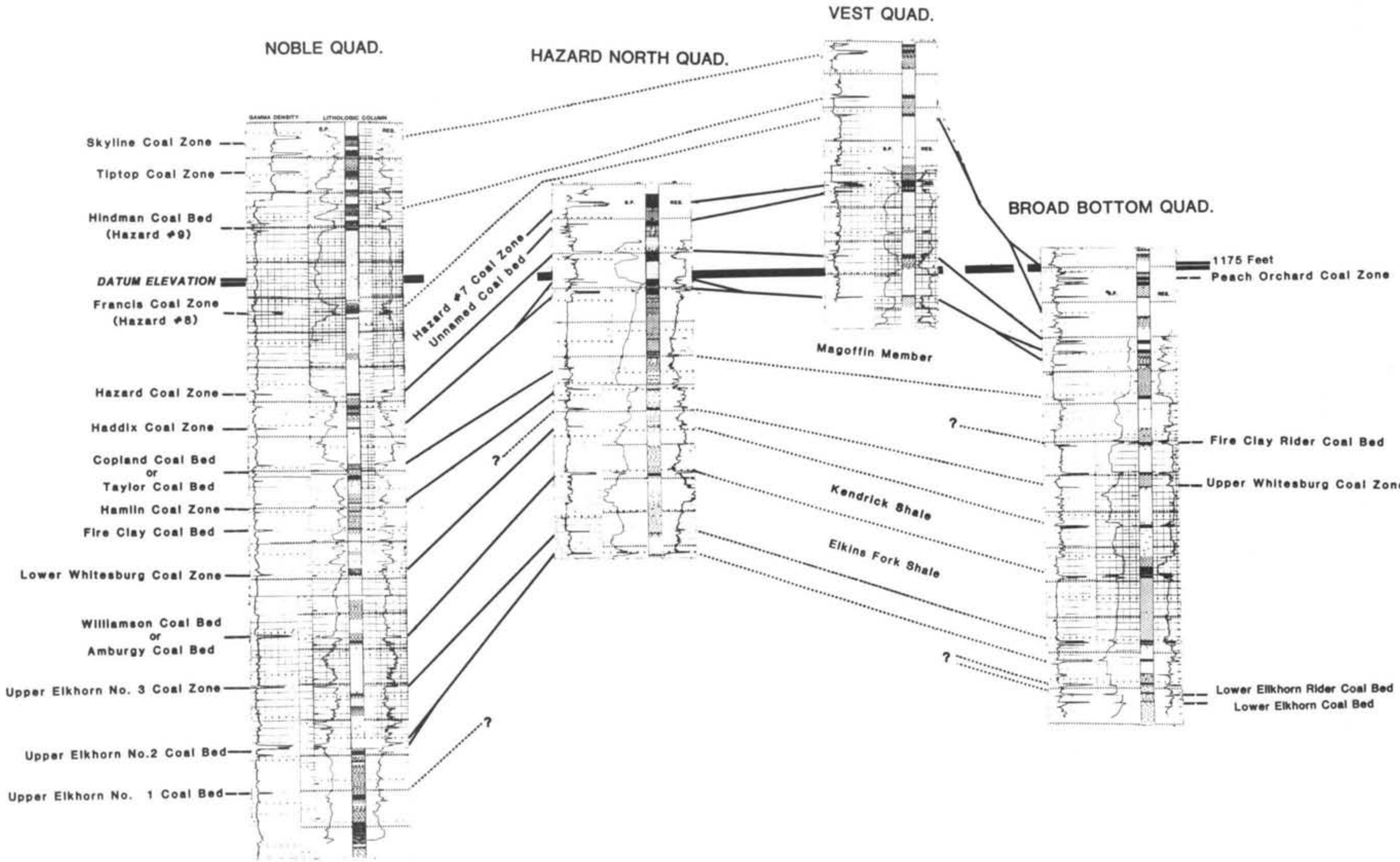

Figure 28. Coal-bed correlations from composite geophysical logs from the route of the field trip, Hazard to Martin, Kentucky.

with Rice and Smith (1980).

The sharp dip of the beds to the northwest between Noble and Hazard North sections is due to a structure known as the Eastern Kentucky Syncline (McFarlan, 1943). The northwesterly dip is a reversal in the normal regional dip. The easterly dips of the beds from Hazard North to Broad Bottom is because the beds dip toward the axis of the Appalachian Basin.

DETERMINATIONS OF COAL THICKNESS AND QUALITY

The density log is used to determine coal thickness and to give indications of coal quality. Some commercial operations offer quantitative coal-quality estimations of sulfur and ash content, but this method of analysis will not be discussed here. The abrupt density-log responses betweeen coal and its enclosing rocks give a rather flat curve from which to pick bed tops and bottoms. This is in contrast to the more gradual responses given by the other logs. The use of expanded-scale density logs enhances the ability to accurately measure coal thickness and to determine coal bed compositions.

Figure 29 shows an expanded-scale density log of the Amburgy coal from a log from Hazard North Quadrangle (Fig. 27). This log was selected to illustrate determinations of thickness and composition because the core of this Amburgy coal was described and measured by James Currens (personal commun., 1981), and the core itself was analyzed by the Kentucky Institute for Mining and Minerals Research.

The determination of coal thickness and composition from the density log cannot be attempted until an inspection of the caliper log is made to insure a constant borehole diameter. The caliper log for this segment of the borehole showed no variations in the diameter. The determination of coal thickness is done by first choosing the appropriate baseline and reference line, as shown in Figure 29. These lines were chosen at the points of maximum change in slope. Next, the midpoint between these lines is determined and a vertical line which represents the coal bed thickness is drawn from the bottom to the top of the density curve. In Figure 29, the coal bed thickness measured from the density log is 2.70 feet. This measurement compares with the core measurement, which is 2.62 feet, a difference of only .08 foot.

Certain compositional differences in the banding of the Amburgy coal bed are recognized on the density log. Descriptions and measurements of macrolithotypes of the coal core are also shown in Figure 29. The core description is for comparison to the density log.

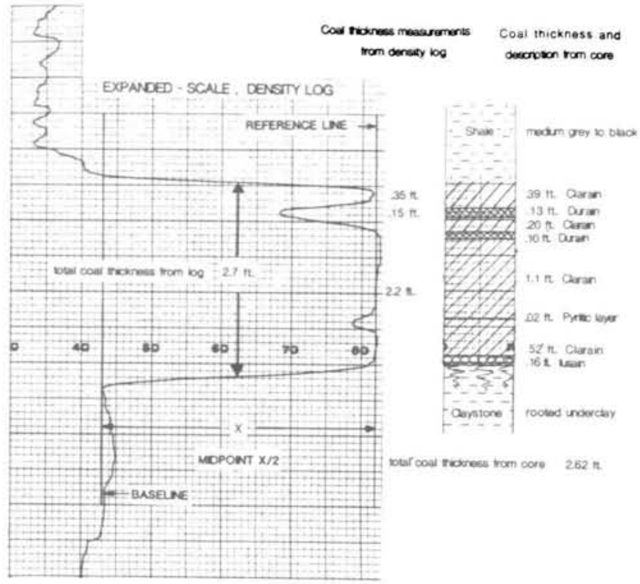

Figure 29. Expanded-scale density log of the Amburgy coal and macrolithotype description of the coal core.

The expanded-scale density log shows five distinct layers in the coal bed. The top layer measures 0.35 foot on the log and compares well to the core which has 0.39 foot of clarain at the top. The next layer measures 0.15 foot on the log, and has a higher density than the clarain above. It compares well to the 0.13 foot of durain in the core. The remaining 2.2 feet of coal on the density log compares well to the remaining 2.10 feet of core.

The 0.02-foot pyritic layer measured in the core shows up as the small, higher density peak near the bottom of the density log. A durain layer 0.10 foot thick in the core is not readily seen on the density log, possibly because it is not dense enough, not thick enough, or is present on the density log but is hidden in the lower portion of the peak already correlated with the 0.13-foot durain layer. It appears that clarain can be distinguished from durain by the density log.

The density log of the Amburgy coal shows no mineral partings and a small durain composition, suggesting a low-ash coal. The chemical analysis of the coal core shows 7.3 percent ash. The minor sulfur layer described in the core is indicative of the low-sulfur content of this coal. The low-sulfur content of this Amburgy coal is also indicated by the large proportion of the density log at or near the reference line, which is the low density side of the curve. The sulfur content as chemically analyzed is 0.82 percent total sulfur. The coal analysis also showed 2.88 percent moisture, 37.7 percent volatile matter, 52.1 percent fixed carbon, and 13,340 B.T.U.

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THE MANCHESTER COAL OF SOUTHEASTERN KENTUCKY

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ACKNOWLEDGMENTS

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INTRODUCTION

The Manchester coal bed of the Eastern Kentucky Coal Field was studied to determine variations in its chemical and physical character. The study area was limited to the southwestern part of the Eastern Kentucky Coal Field in McCreary, Whitley, Laurel, Clay, and Jackson Counties.

The purpose was to determine the quality of the Manchester coal and its suitability for industrial uses, and to determine some aspects of the environment of deposition for the Manchester coal based on chemical character and the components of low-temperature ash. A complete model of the depositional history of the Manchester coal bed is not presented; rather, the proximity to marine environment, based on chemistry and mineralogy is determined.

DESCRIPTION

The Manchester coal bed (also known as the Lily, Horse Creek, River Gem, Swamp Angel, and Tightwad coals) is located in southeastern Kentucky (Fig. 30). The coal is above drainage in most of Laurel, Clay, and Whitley Counties; in the southern part of Jackson County; and in the southeastern part of McCreary County. West of these counties the coal is absent because of erosion. East of these counties the coal occurs below drainage, except near the Bell-Knox county line, where it has been uplifted on the Flatlick Anticline.

STRATIGRAPHIC LOCATION

The Manchester coal (Middle Pennsylvanian) is the first coal above the massive sandstones of the Lee Formation (Rice and others, 1979; Huddle and others, 1968) (*see* stratigraphic column, inside front cover.) The coal is usually single bedded with an underclay immediately below it and a carbonaceous shale above, but is split by clay and carbonaceous shales in the northern part of Laurel County and the southern part of Jackson County. Near the Tennessee border a rider bed is present an average of 20 feet above the principal bed and is separated from it by clays and shales.

ANALYSES

Twenty-four representative samples of the Manchester coal were collected (Fig. 30). Analytical tests were performed by the West Virginia Geological and Economic Survey, Analytical Section and Coal Section.

COAL QUALITY

Analytical results (Figs. 31-36; Tables 1 and 2) indicate that it is high-volatile A bituminous coal suitable for steam generation. Rank was determined by the American Standards for Testing Materials classification on the basis of heating value by using the Parr formula

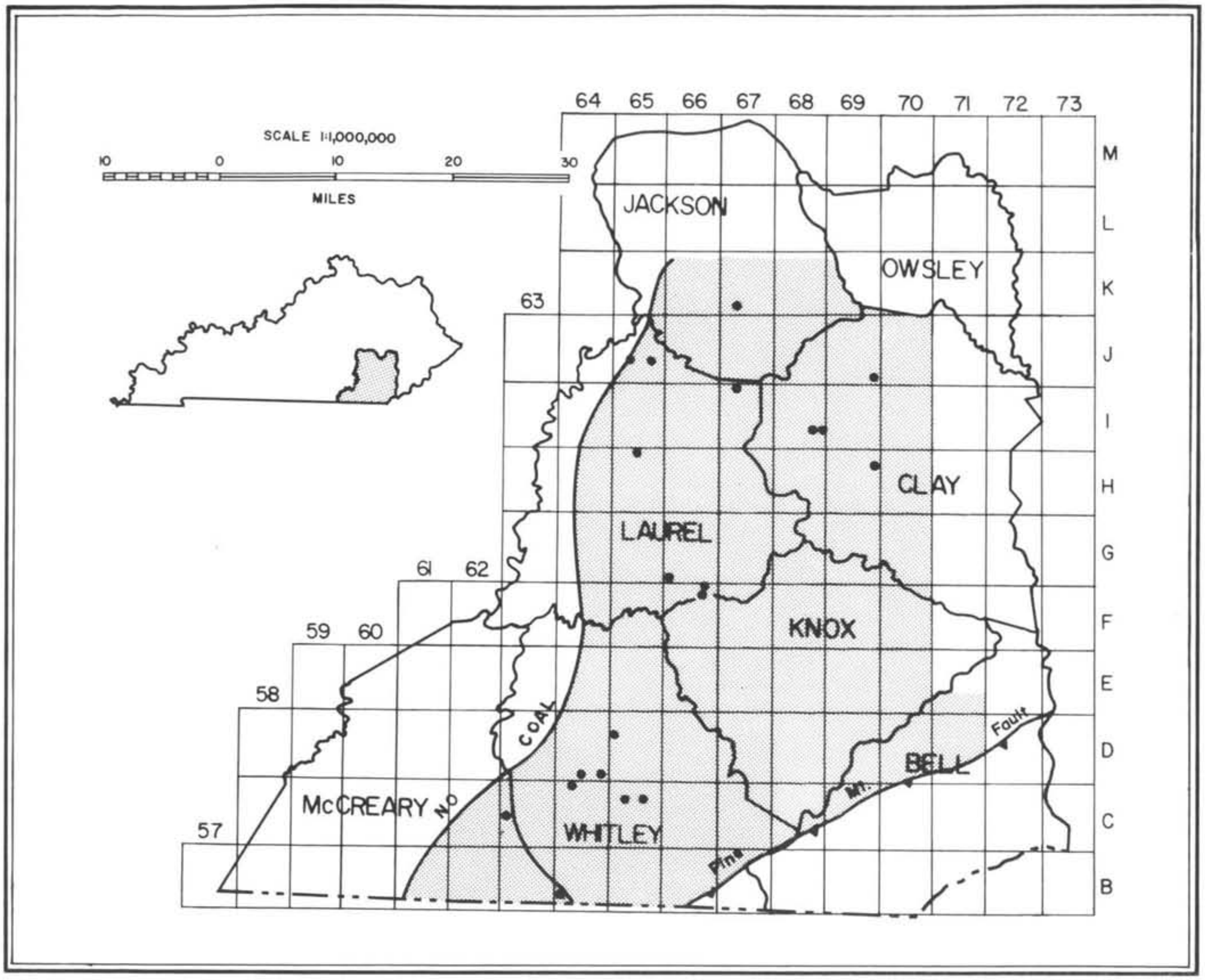

Figure 30. Index map of study area showing locations of samples.

for the dry-mineral-matter free BTU's. The range of heating values calculated from Table 1 is 14,160 BTU to 15,449 BTU, with an average of 14,856 BTU for the samples. Average fixed carbon is 60 to 65 percent; sulfur, 0.6 to 7.0 percent; and ash, 3.14 to 31.88 percent. Coal quality increases to the east, where fixed carbon and heating value increases as sulfur and ash decrease.

The results of the plasticity tests range from 120 Dial Divisions per minute (DDPM) to 28,000 DDPM. Only three samples were more than 1,100 DDPM. The temperature of fluidity ranges varied from 60 to 94 C (Fig. 36).

CONDITIONS OF DEPOSITION

The Manchester coal appears to have been formed from peat which was deposited under brackish-water conditions in the western margin of the study area and under more fresh-water conditions in the eastern margin. High sulfur and pyrite concentrations (determined by sulfur and X-ray analysis), high ash values, and a high illite/kaolinite ratio are characteristic of modern marginal marine swamps (Spackman and others, 1976). Studies in the Florida Everglades (Spackman and others, 1976) show that sulfur and ash values in the brackish areas and marginal to marine environments are twice the values documented in fresh-water areas.

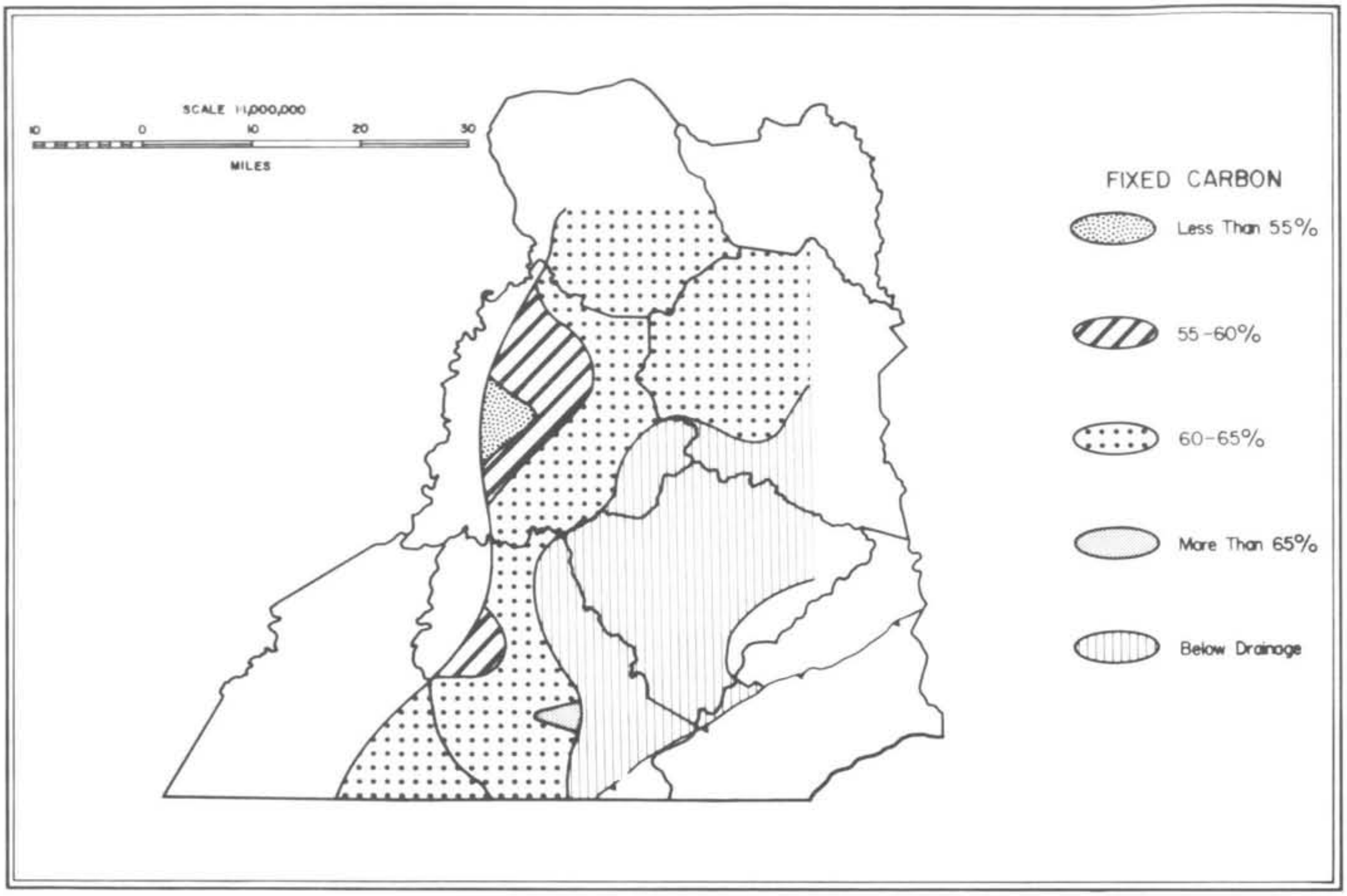

Figure 31. Distribution of fixed carbon values for the Manchester coal in study area determined on dry, ash-free basis (5 percent interval). *See* Table 1 for detailed proximate analysis.

Other studies (White and Thiessen, 1933; Williams and Keith, 1963) indicate that coals formed under a marine influence or coals with marine roofs have high sulfur and pyrite values.

In the Manchester coal bed, the sulfur and pyrite concentrations are areally zoned, decreasing to the east. Ash and illite concentrations (Figs. 33 and 34) are also areally zoned and decrease to the east. The ash and sulfur values of the Manchester coal are similar to the Everglades studies of Spackman and others (1976) in that the highest values in the Manchester coal are to the west, toward what is considered to be the distal margin of the coal swamp (Wanless, 1975). Values for Manchester coal samples in the western part of the study were more than double values for samples in the eastern part of the study.

The mineral composition of the low-temperature ash is also an indicator of depositional environments. A high illite concentration relative to kaolinite, a high percentage of expandable clays, and the lack of siderite in the ash indicate marine influence following deposition of coal (Degens, 1965; Gluskoter, 1967; Grim, 1968; Kemezys and Taylor, 1964; Keller, 1956; Folk, 1965; Rao and Gluskoter, 1973; Ward, 1977).

The Manchester coal is similar to marine-influenced coals of the Illinois Basin in that the low-temperature ash is relatively high in illite and low in kaolinite and contains only trace amounts of siderite. The illite/kaolinite ratio of the Manchester coal is greater than 50 percent illite in most cases. The presence of expandable clays and the lack of siderite in the Manchester coal indicate that marine waters had access to the Manchester coal swamp and that the swamp waters were of a brackish nature.

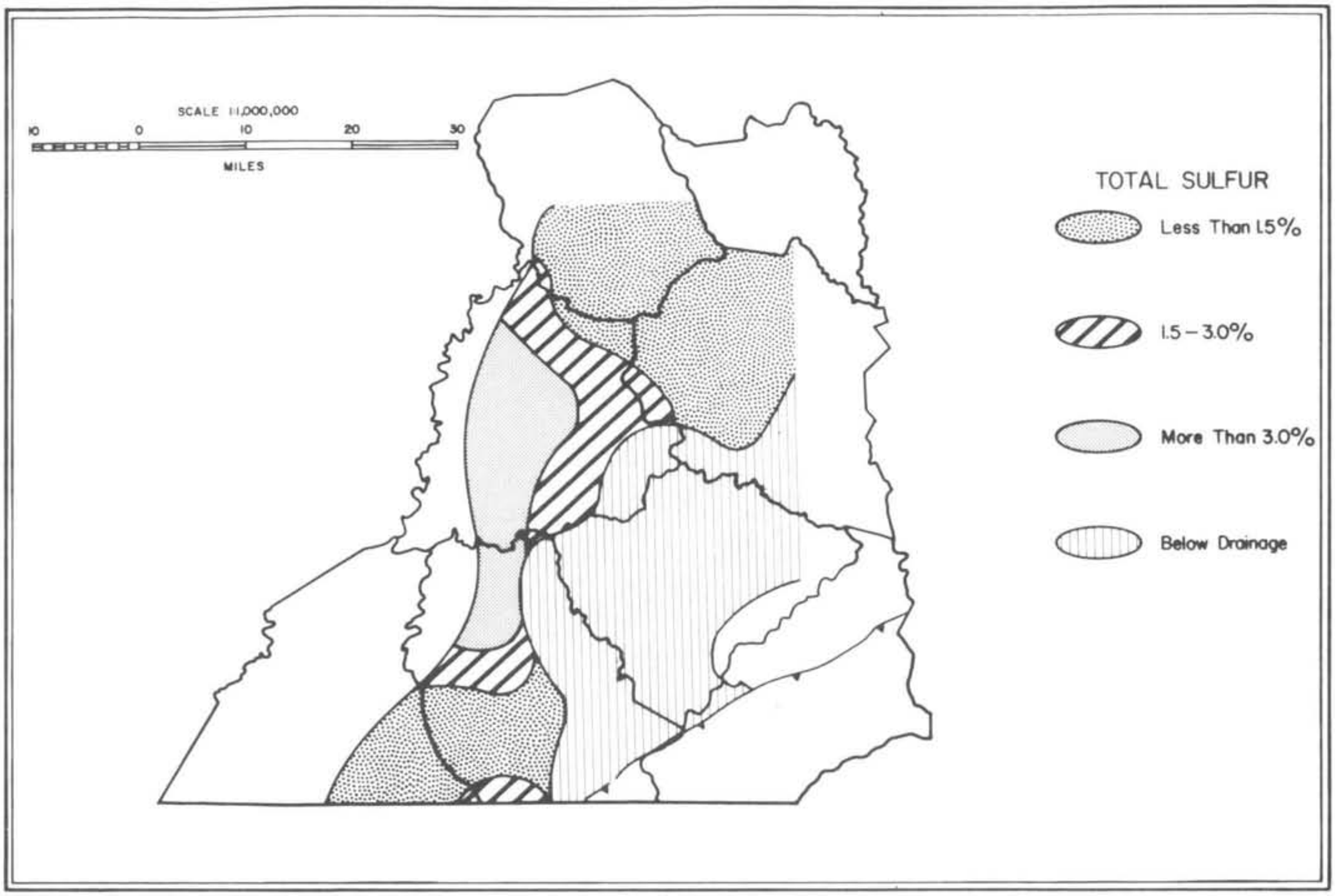

Figure 32. Distribution of total sulfur values for the Manchester coal in study area determined on as-received basis (1.5 percent interval). Range was 0.6 to 7.0 percent; higher values occurred near western limits. *See* Table 2 for detailed analysis.

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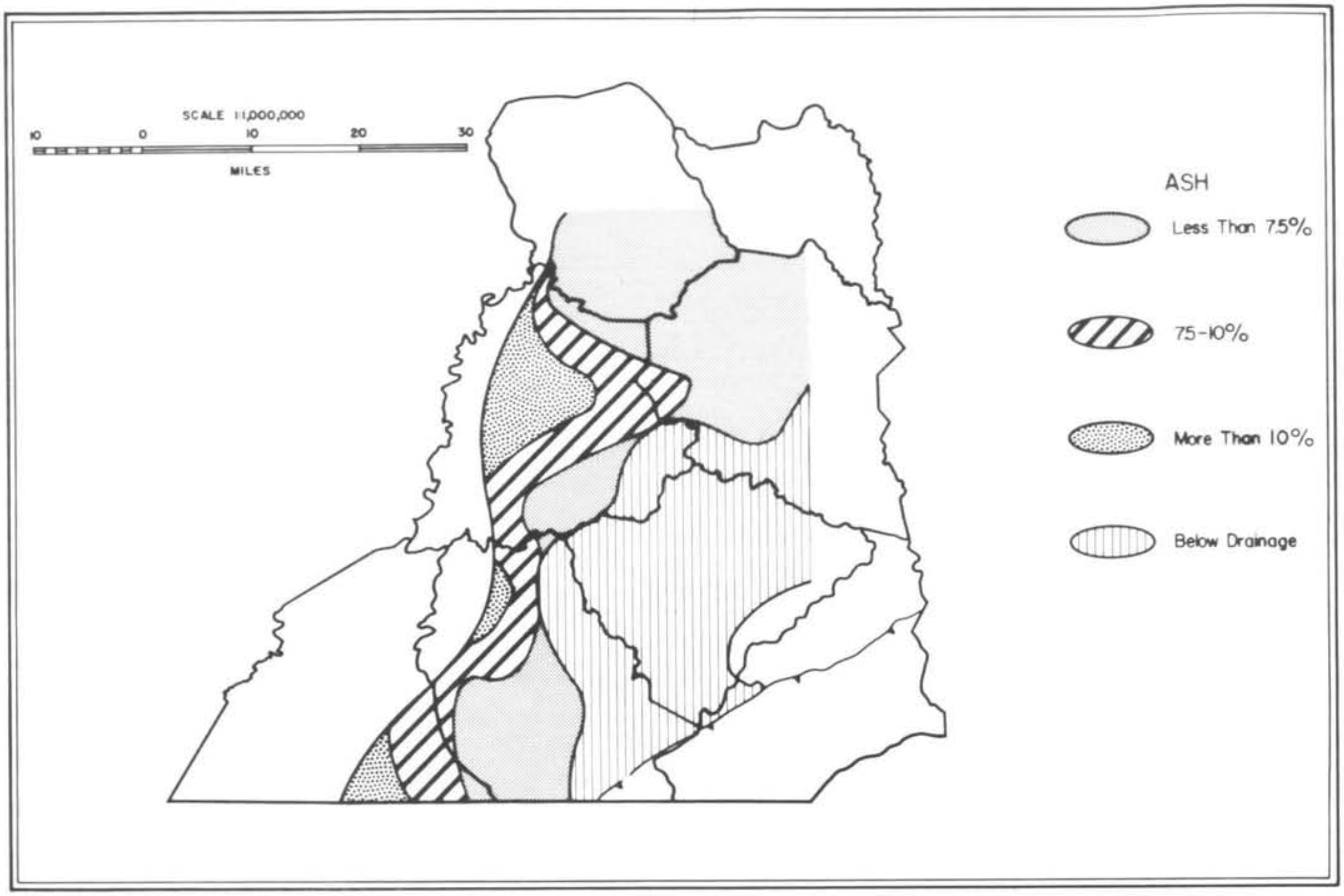

Figure 33. Distribution of ash values for the Manchester coal in study area determined on as-received basis. Range was 3 to 33 percent; higher values occurred near western limits.

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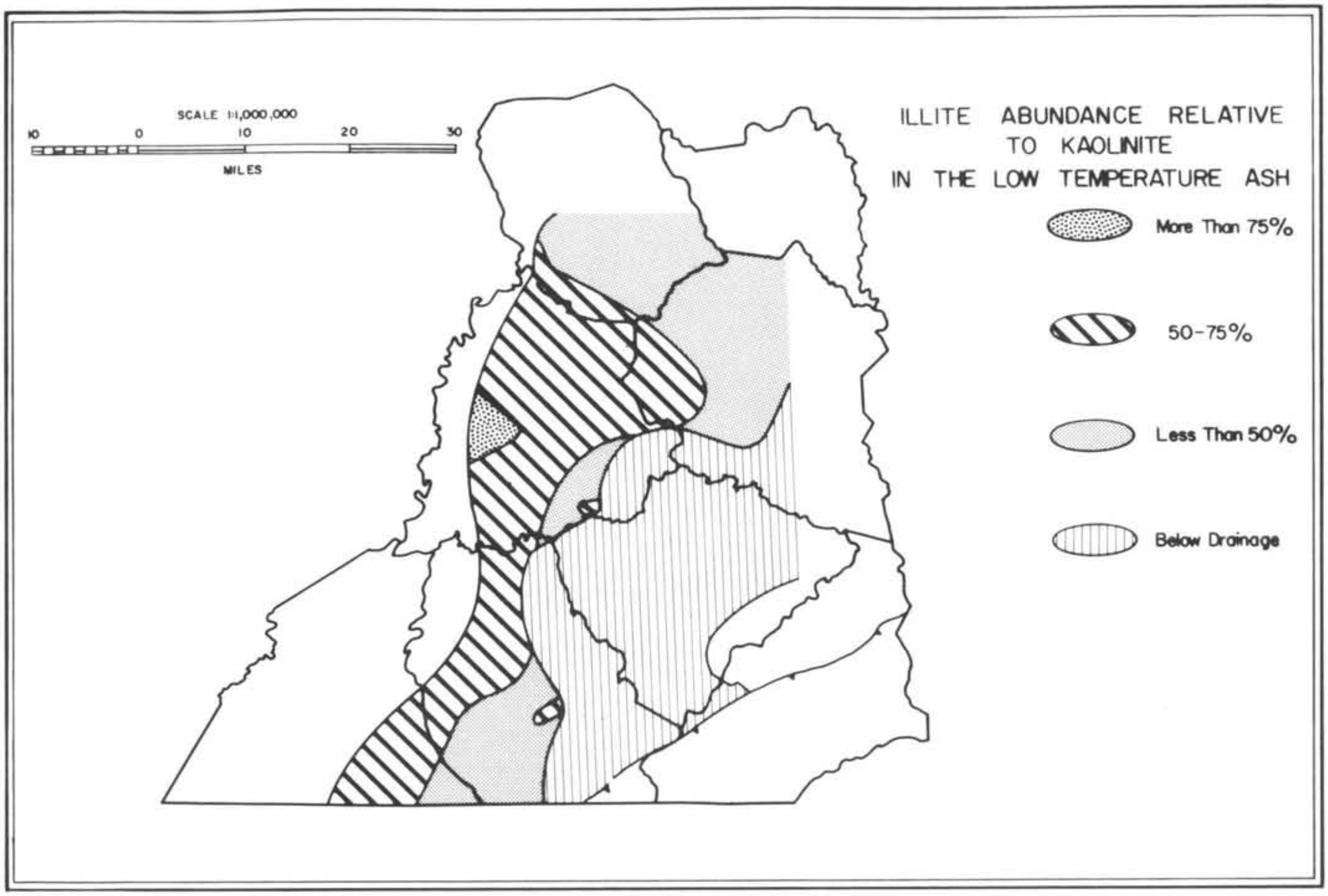

Figure 34. Distribution of illite abundance relative to kaolinite in the low-temperature ash for the Manchester coal in study area.

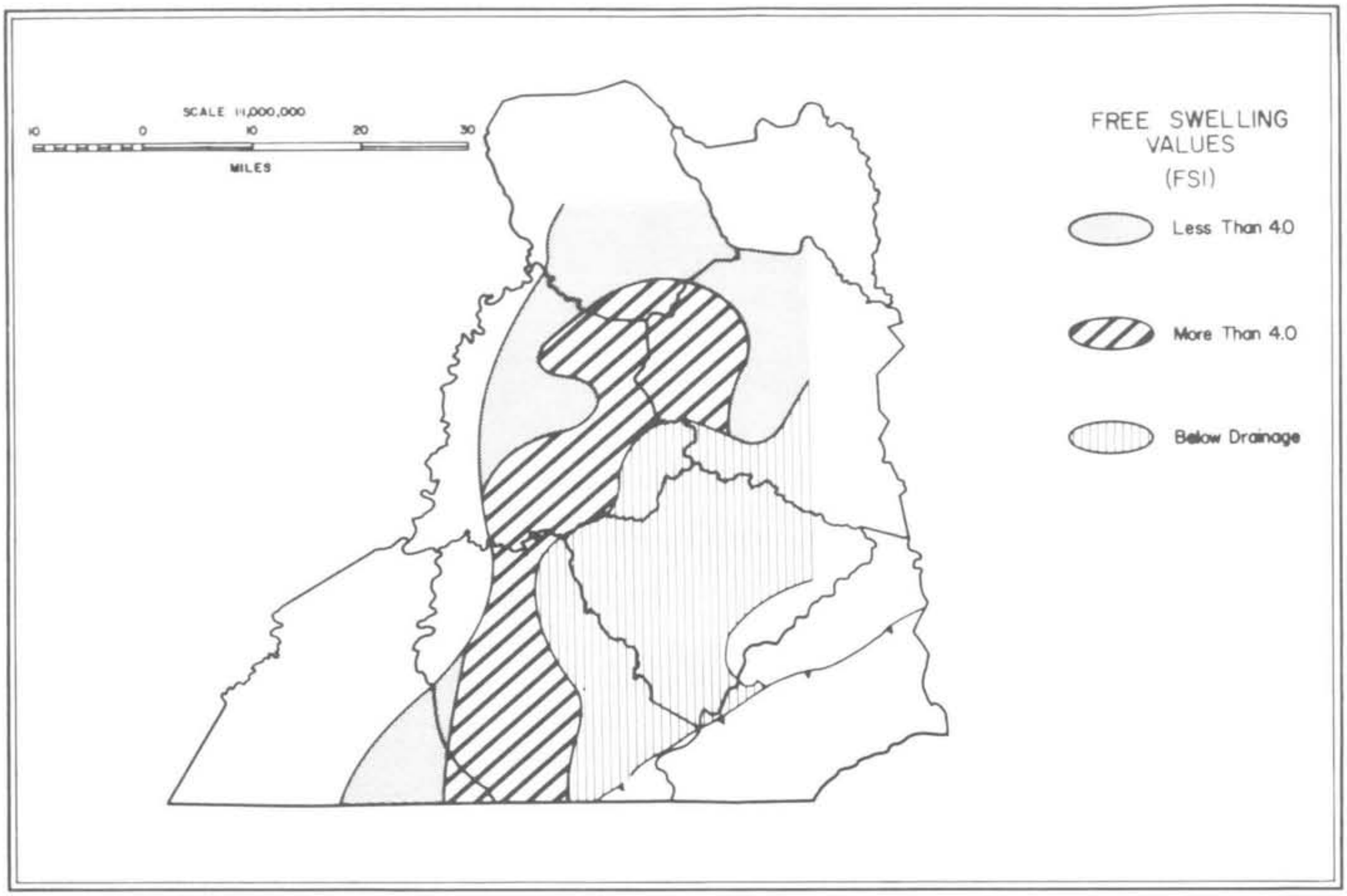

Figure 35. Distribution of free-swelling values (FSI) for the Manchester coal in study area. Range was 2.5 to 5.5.

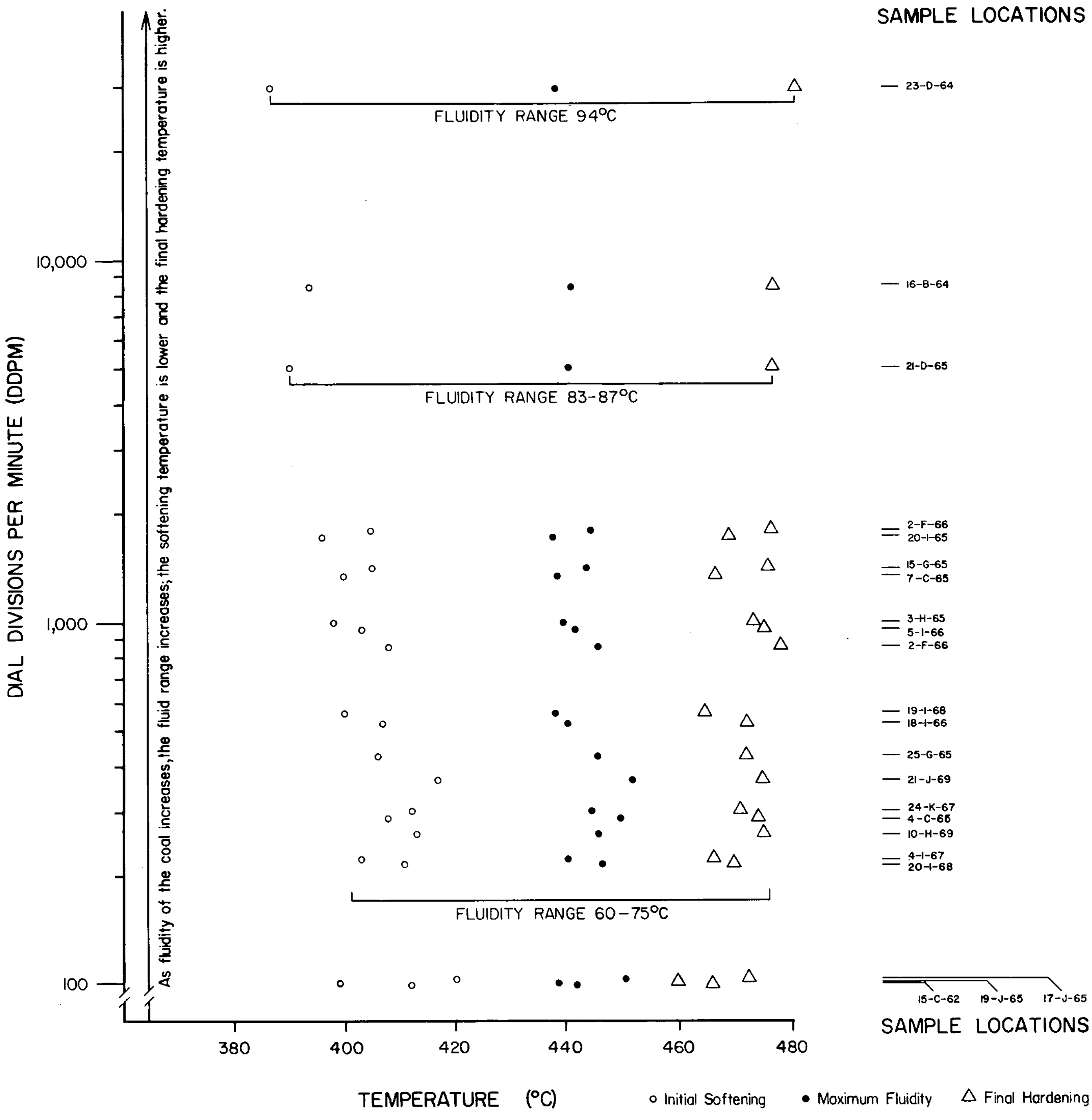

Figure 36. Plasticity of the Manchester coal.

Table 1.—Proximate Analysis, Varieties of Sulfur, and B.T.U. Values for the Manchester Coal in the Study Area.

Sample No.	As Received				Proximate Analysis moisture-free			moist.-ash free		Varieties of Sulfur				BTU (mmmf)
	moist.	ash	vol. mat.	f. carbon	ash	vol. mat.	f. carbon	vol. mat.	f. carbon	pyritic	organic	sulfate	total	
24-K-67	2.65	3.94	35.02	58.39	4.05	35.97	59.98	37.49	62.51	0.060	0.805	0.031	0.896	14,623
21-J-69	3.65	6.03	33.96	56.36	6.26	35.25	58.49	37.60	62.40	0	0.577	0.026	0.601	14,662
20-I-68	2.20	5.46	35.67	56.67	5.58	36.47	57.95	38.63	61.37	0.037	0.689	0.003	0.729	14,765
19-I-68	2.61	7.50	31.81	58.08	7.70	32.66	59.64	35.39	64.61	0.071	0.752	0.088	0.911	14,784
10-H-69	2.46	6.80	35.68	55.06	6.97	36.58	56.45	39.32	60.68	0.354	0.841	0.108	1.303	15,049
4-I-67	2.51	5.55	36.10	55.84	5.49	37.03	57.28	39.27	60.73	0.094	0.818	0.050	0.962	14,504
19-J-65	3.85	4.62	34.84	56.69	4.80	36.24	58.96	38.06	61.94	0.250	0.909	0.126	1.285	14,399
17-J-65	5.45	6.54	35.90	52.11	6.92	37.97	55.11	40.79	59.21	1.209	0.800	0.250	2.259	14,160
17-J-65	3.13	23.07	30.76	43.04	23.82	31.75	44.43	41.68	58.32	0.803	1.793	0.204	2.800	14,972
3-H-65	2.16	31.88	31.04	34.92	32.58	31.73	35.69	47.06	52.94	5.606	0.983	0.411	7.0	15,449
25-G-66	3.40	6.65	34.54	55.41	6.88	35.76	57.36	38.40	61.60	1.570	1.037	0.389	2.996	14,615
2-F-66	2.78	5.88	35.39	55.95	6.05	36.40	57.55	38.75	61.25	1.054	0.656	0.158	1.868	14,893
2-F-66	3.01	4.72	34.87	57.40	4.87	35.95	59.18	37.79	62.21	0.457	1.041	0.180	1.678	14,865
21-D-64	1.71	8.16	36.82	53.31	8.30	37.46	54.24	40.85	59.15	1.825	1.306	0.257	3.388	15,157
23-D-64	1.13	8.01	39.13	51.73	8.10	39.58	52.32	43.07	56.93	0.580	2.077	0.200	2.857	15,100
4-C-64	1.96	5.10	35.30	57.64	5.20	36.01	58.79	37.98	62.02	0.092	0.837	0.011	0.940	14,875
7-C-65	1.88	6.61	32.44	59.07	6.74	33.06	60.20	35.45	64.55	0.547	0.844	0.129	1.520	15,234
9-C-65	2.88	3.14	32.61	61.37	3.23	33.58	63.19	34.70	65.30	0.012	0.782	0.048	0.842	14,618
16-B-64	1.60	6.77	35.03	56.60	6.88	35.60	57.52	38.23	61.77	0.803	1.182	0.084	2.069	15,002
15-C-63	2.84	7.85	31.65	57.66	8.08	32.58	59.34	35.44	64.56	0.338	0.790	0.088	1.216	14,702
6-D-65TOP	0.75	7.27	37.68	54.30	7.32	37.97	54.71	40.97	59.03	-----	-----	-----	3.50	14,926
6-D-65MID.	0.34	14.39	37.19	48.08	14.44	37.32	48.24	43.61	56.39	-----	-----	-----	6.00	15,356
6-D-65BOT.	0.09	20.45	34.44	45.02	20.47	34.47	45.06	43.34	56.66	-----	-----	-----	5.13	15,249
17-J-65*	4.40	14.14	34.65	46.81	14.79	36.25	48.96	42.54	57.46	1.089	1.159	0.209	2.457	14,589

*composite sample

Table 2. —X-Ray Analysis of Low-Temperature Ash for the Manchester Coal. Based on Raw Integrated Intensities; Illite, Pyrite, and Quartz Calculated with a Weighting Factor. Method Described by Renton and Hidalgo (1975).

Sample #	Expandables	Kaolinite	Quartz	Plagioclase	Illite	Pyrite	Siderite	$Fe(SO_4)_3 \cdot 9H_2O$	Calcite	$FeSO_4 \cdot H_2O$	Orthoclase	Dolomite	1/K+1
24-K-67	2	38	24	1	27	6	-	-	-	1	-	-	42
21-J-69	3	38	25	-	34	-	-	-	6	-	-	-	47
20-1-68	+	32	28	10	37	1	-	-	-	+	-	-	54
19-1-68	2	33	27	-	36	2	-	-	-	+	-	+	52
10-H-69	4	38	19	1	26	9	-	-	1	-	1	1	41
4-I-67	1	35	23	-	39	1	-	-	+	-	-	-	53
19-J-65	2	28	23	1	45	1	-	-	+	-	-	-	62
17-J-65	2	29	26	+	23	16	+	2	-	-	+	-	44
17-J-65	1	22	19	1	52	4	-	-	+	+	-	-	70
3-H-65	1	9	33	+	27	26	-	1	+	2	+	-	75
25-G-66	-	31	8	-	20	36	-	2	1	-	2	-	39
2-F-66	2	27	19	-	42	9	1	-	+	-	-	-	61
2-F-66	2	31	29	1	29	8	-	-	-	-	-	-	48
6-D-65T	-	19	29	-	17	28	-	5	3	-	-	-	47
6-D-65M	5	17	28	+	34	15	+	-	+	-	-	+	67
6-D-65B	-	19	37	-	26	16	-	-	2	-	-	-	58
21-D-64	2	24	19	1	27	24	-	1	1	-	-	-	53
23-D-64	2	33	41	+	14	5	-	1	1	1	2	-	28
4-C-64	2	29	28	1	35	3	-	+	-	+	1	+	55
7-C-65	1	39	31	-	17	11	-	-	+	-	-	-	30
9-C-65	4	6	43	2	35	5	1	-	3	-	1	-	85
16-B-64	-	41	25	-	4	26	-	2	1	1	-	-	9
15-C-63	2	31	17	-	44	6	-	1	-	-	-	-	59
17-J-65	1	24	20	+	48	5	-	1	+	+	+	-	67

HYDROGEOLOGY OF THE EASTERN KENTUCKY COAL FIELD

Steven Cordiviola, James Dinger, John Kiefer, James Kipp, and Fred Lawrence
Kentucky Geological Survey

The Surface Mining Control and Reclamation Act of 1977 (PL95-87) requires the assessment of potential impacts to the surface- and ground-water resources of mineable lands prior to issuing mining permits. Regulations, promulgated by the Office of Surface Mine Reclamation, require mine permit applications to outline the hydrologic conditions existing in the area and beneath the property to be mined, expected changes (impacts) to the hydrologic conditions during and after mining, and programs to monitor any hydrologic changes.

Mining companies and regulatory agencies in Kentucky trying to formulate pre-mine plans and permit applications are severely handicapped by the lack of baseline ground-water quantity and quality information. There are some data from the Kentucky coal fields on surface water, but little, if any, reliable ground-water data in areas where coal mining is occurring or will probably occur in the future.

Previous ground-water investigations and reports were primarily regional and of a reconnaissance nature and had to rely mainly on relatively shallow, privately owned wells. These reports indicate that some aquifers have relatively limited areal extent, and therefore predicting yields from one aquifer to the next is very difficult, if not impossible. There is not enough baseline information available to form a conceptual model of ground-water conditions for specific watersheds within Kentucky's coal fields. Water quality is also variable. For example, ground water containing brine can exist at relatively shallow depths (in some areas within 100 feet of the valley bottom).

Plans to monitor the hydrologic elements during mining are currently submitted with permit applications, but they are little more than "hit or miss" propositions, which vary greatly from one permit application to the next. Such haphazard monitoring will not insure proper protection of ground-water system. Even if the plans are carefully formulated, the lack of baseline information makes it impossible to accurately measure the extent of the changes which take place. Since the growing energy crisis virtually insures an increase in deep mining activity in the future, it will also be imperative to have an understanding of the regional ground-water system.

Objectives of the current research program are to provide baseline geologic and hydrogeologic information about ground water in the Eastern Kentucky Coal Field and to assess the effects of surface mining on ground-water quality and quantity. Information gained from this project will add to the understanding of the ground-water system throughout the coal field and aid regulatory agencies and the mining industry in developing reliable ground-water monitoring programs to insure adequate aquifer protection. The study is funded by the Water Resources Division of the U. S. Geological Survey. The project began in January 1980 and is scheduled for completion in January 1985.

A network of approximately 10 permanent ground-water observation sites will be established in the 1,000-square-mile drainage basin of the North Fork of the Kentucky River, upstream of Jackson, Kentucky. Rather than individual wells, each site will consist of a series of observation wells drilled to various depths. These observation wells will provide long-term information necessary to assess the existence of a regional aquifer system and define its hydrologic response.

Within the larger watershed, several first- or second-order watersheds will be selected for detailed study. Criteria for selection of these smaller drainages include a pristine watershed in which no mining will occur during the term of the project, a watershed in which some portion will be mined and reclaimed during the project, a watershed on which mining and reclamation has occurred, and a watershed on which mining has occurred but on which there has been no reclamation. Approximately 40 borings will be drilled for the detailed studies. Hydrogeologic, stratigraphic, and water-quality information will be collected and compiled.

A conceptual model of the hydrogeology of the coal field will be developed. Products of this project will include reports and maps which will be useful in preparing pre-mining, mining, and post-mining plans and will be helpful in assessing environmental impacts to both surface and deep mining of coal.

Observation borings have been drilled at Jackson and at two sites in the vicinity of Hazard. The cores were utilized for hydrogeologic and stratigraphic information. In addition, the borings were geophysically logged. Several ground water monitoring wells have also been drilled at these sites. Selection of the pristine and the pre-mined watersheds should be concluded in fall 1981 and drilling for stratigraphic and hydrologic information will begin shortly thereafter in conjunction with the completion of the regional well sites.

QUALITY CHARACTERISTICS OF THE UPPER ELKHORN NO. 3 AND FIRE CLAY COAL BEDS

James C. Currens
Kentucky Geological Survey

The areal distribution of total sulfur, ash, and B.T.U. content of specific coal beds has been studied by many authors for several Appalachian, midwestern, and western states, with most work concentrated in Pennsylvania and Illinois (Williams and Keith, 1963; Gluskoter and Simon, 1968; Gluskoter and Hopkins, 1970; Gomez and Hazen, 1970; Eddy, 1971). Although considerable work has been completed on depositional environments of the Pennsylvanian coals of eastern Kentucky (Ferm and Horne, 1979; Currens, 1978), little work has been done on the areal distribution of sulfur, ash, and B.T.U. Maps of these coal characteristics have been prepared for the Upper Elkhorn No. 3 and Fire Clay coal beds, and the preparation of maps for several other beds is in progress. For a discussion of the petrographic characteristics of these coals *see* Hower and others, this volume.

METHOD OF STUDY

The development of maps showing coal characteristics in eastern Kentucky has been hampered by the complexities of correlating coal beds in the Appalachian Basin and by the paucity of analytical data in public files. The recently completed Kentucky Geological Survey-U. S. Geological Survey geologic mapping program made it possible to correlate coal beds with reasonable certainty over the region; coal beds from which old and new samples were taken were, as a result, identified with greater certainty than ever before possible. The coal beds and coal zones mapped on the geologic quadrangle maps have been correlated by Rice and Smith (1979). The geologic quadrangle maps and the correlation chart of Rice and Smith are the best references currently available for correlation and were exclusively used to determine the stratigraphic equivalence of sample sites in the present study.

Eddy (1971) demonstrated the feasibility of using proximate coal analyses (conforming to American Society for Testing and Materials standards) for his study of the relationship between paleotopography and coal thickness, ash, and sulfur content. The vast majority of older data for eastern Kentucky conforms to these standards. Most early analytical work on eastern Kentucky coal was performed by the U. S. Bureau of Mines, but was concentrated in the principal producing areas. Prior to 1978, the Kentucky Geological Survey had not actively collected coal samples for 25 years, and the older sample sites were descriptively located, making it difficult to accurately relocate them. While the U. S. Geological Survey has collected samples more continuously over the years, the number and distribution was somewhat limited. All of these data were scattered in a multitude of reports, bulletins, and computer files, making it difficult to incorporate them into a regional study.

In 1979 an extensive coal sampling program by the Kentucky Geological Survey was funded through the U. S. Geological Survey, requiring site locations for older sample sites for which usable data are available. Substantial effort has gone into relocating the sample sites of most of the older analytical data to confirm bed identification. Using mine names, coordinates, or a descriptive location, each site was plotted on 7 1/2-minute geologic quadrangle maps. If the sample site could not be satisfactorily relocated and the bed identification verified, the analytical data were not used. Insofar as could be determined, all analytical data used for these maps are from core samples or channel samples. Most were collected following ASTM guidelines (Holmes, 1918), but some were collected using guidelines by Swanson and Huffman (1976). To make the data compatible to the present study and relevant to a freshly mined product, only analyses of fresh samples were used. However, not all coals are mined everywhere they occur, and fresh exposures are not always available. Analysis of slightly weathered samples may be of value in these areas. Table 3 lists analyses for some of the coal samples collected for the current program.

Most of the older analytical data were prepared in the laboratories of the U. S. Bureau of Mines. Some analytical work was performed by the University of Kentucky

Table 3.—Selected Analyses, Upper Elkhorn No. 3 and Fire Clay Coals.

KGS ID No.		Carter Coordinate Section	As Received Moisture	Volatile Matter	Fixed Carbon	Moisture Free Ash	Total Sulfur	Moisture and Ash Free B.T.U.
006	Van Lear	16-R-79	3.7	43.1	52.0	4.9	3.3	14,799
007	Van Lear	2-Q-79	6.6	38.7	60.4	0.9	0.7	14,430
008	Van Lear	15-R-79	6.8	37.9	61.1	1.0	0.6	14,404
009	Van Lear	10-R-79	7.4	36.6	61.6	1.8	0.7	14,216
012	Van Lear	9-Q-80	5.8	39.1	51.0	9.9	3.2	14,491
075	Upper Elkhorn No. 3	21-0-81	3.6	39.9	50.7	9.4	2.2	14,293
110	Upper Elkhorn No. 3	21-0-81	3.8	38.2	46.0	15.8	2.9	14,613
115	Upper Elkhorn No. 3	23-I-81	2.6	39.9	54.6	5.5	1.9	15,046
287	Upper Elkhorn No. 3	9-L-80	4.2	38.6	56.5	4.9	0.7	14,901
Mean (Van Lear and Upper Elkhorn No. 3 samples)						6.01	1.8	14,577
095	Fire Clay	2-I-76	3.1	34.3	51.5	14.2	0.6	14,784
116	Fire Clay	5-L-81	3.1	34.3	46.4	19.3	1.0	14,448
135	Fire Clay	25-K-79	2.0	40.2	52.0	7.8	0.7	15,039
168	Fire Clay	4-H-80	2.2	36.1	54.2	9.7	0.7	14,927
238	Fire Clay	11-M-82	3.6	34.8	50.4	14.8	0.8	14,652
Mean (Fire Clay Samples						13.16	0.76	14,770

Analytical work by U. S. Department of Energy, Bureau of Mines

Mining Laboratory and by private laboratories. Samples were collected by the U. S. Bureau of Mines, U. S. Geological Survey, and the Kentucky Geological Survey. The samples collected under the current program were analyzed by the U. S. Department of Energy's Bureau of Mines Laboratory and by the Institute for Mining and Minerals Research.

Because very few coal samples have been analyzed for trace elements to date, there are insufficient data points for the preparation of contour maps of elemental species. The preparation of trace element maps is planned for a future study.

RESULTS

Compilation of data is complete for two major coal beds (zones). Contour maps of the Upper Elkhorn No. 3 coal (Figs. 37-39) and the Fire Clay coal (Figs. 40-42) delineating total sulfur and ash on a moisture-free basis and caloric content in B.T.U.'s on a moisture and ash-free basis were prepared. The maps were constructed for utilization in coal resource exploration and do not indicate rank.

Contouring reveals a high degree of correspondence in the patterns of ash and sulfur distribution. Low-sulfur regions tend to form elongated, sinuous patterns that branch to the northwest (Figs. 37 and 40). The high-sulfur regions flank the low-sulfur areas in broad lobate patterns. The low-ash regions generally parallel the low-sulfur trends (Figs. 38 and 41). The high-ash regions frequently coincide with high-sulfur regions. Exceptions occur where relatively small, isolated high-ash areas closely flank the low-sulfur regions. The B.T.U. maps revealed an overall increase in the caloric content to the southeast (Figs. 39 and 41).

DISCUSSION

The association of high-sulfur coal with marine-influenced depositional environments is well established (White and Thiessen, 1913; Jillson, 1919; Ashley, 1920; Williams and Keith, 1963; Gluskoter and Hopkins, 1970; Gomez and Hazen, 1970; Eddy, 1971; Guber, 1972; Hester and Leung, 1978). Cecil and others (1979) have shown that coals associated with marine environments are also high in ash. This is due to "increasing pH resulting from buffering by dissolved $CaCO_3$ species," which could reduce leaching of mineral matter and increase concentration of mineral matter by increased bacterial degradation of the peat and reduction of sulfate. However, the ash content of coals deposited in fresh-water environments may also be high because of sediment influx during peat deposition (Frazier and Osanik, 1969). Boctor and others (1976) and Casagrande and others (1977) have demonstrated that most nonorganic sulfide minerals in peat form from ions

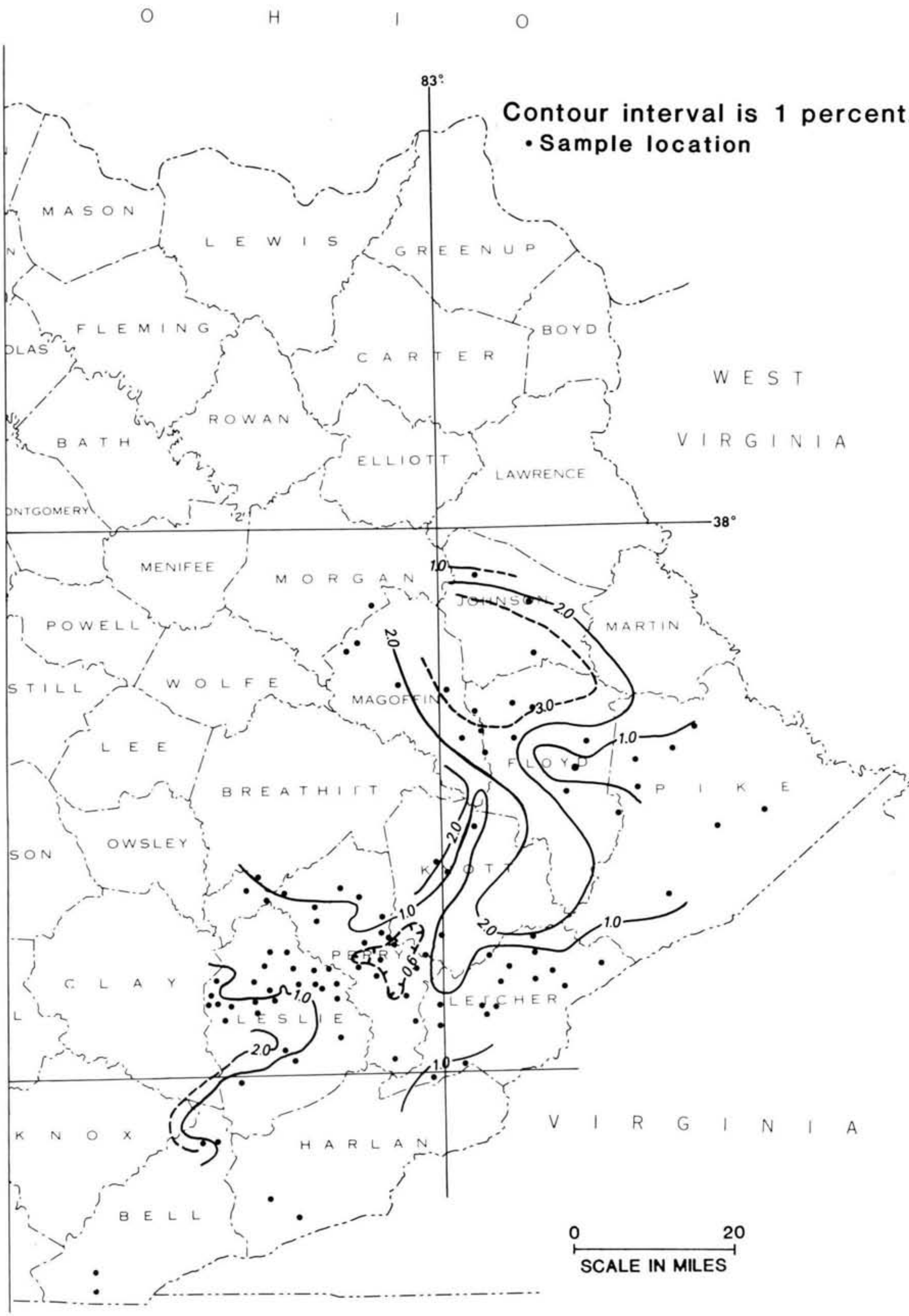

Figure 37. Sulfur distribution of Upper Elkhorn No. 3 coal bed determined on moisture-free (dry) basis.

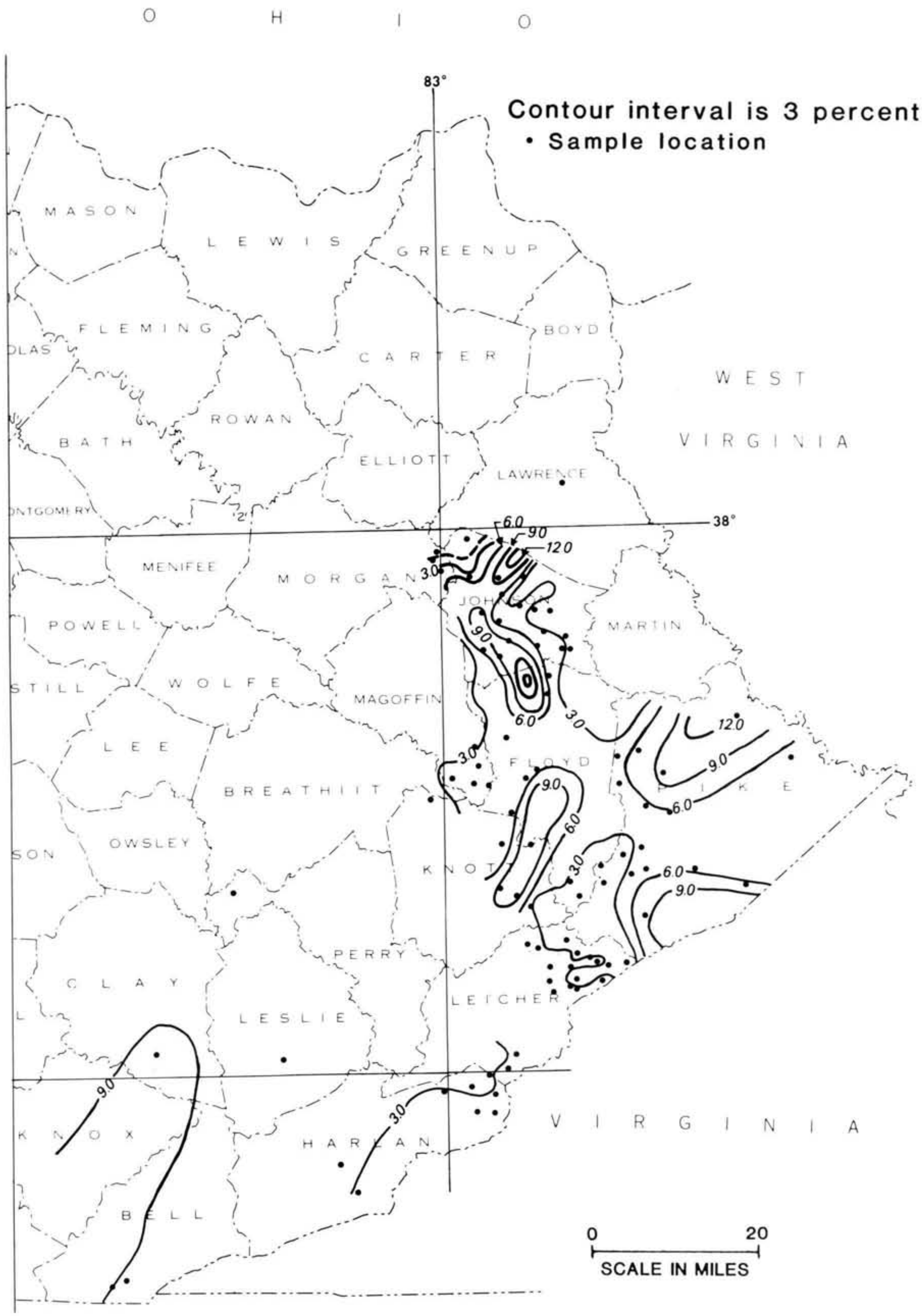

Figure 38. Ash distribution of Upper Elkhorn No. 3 coal bed determined on moisture-free (dry) basis.

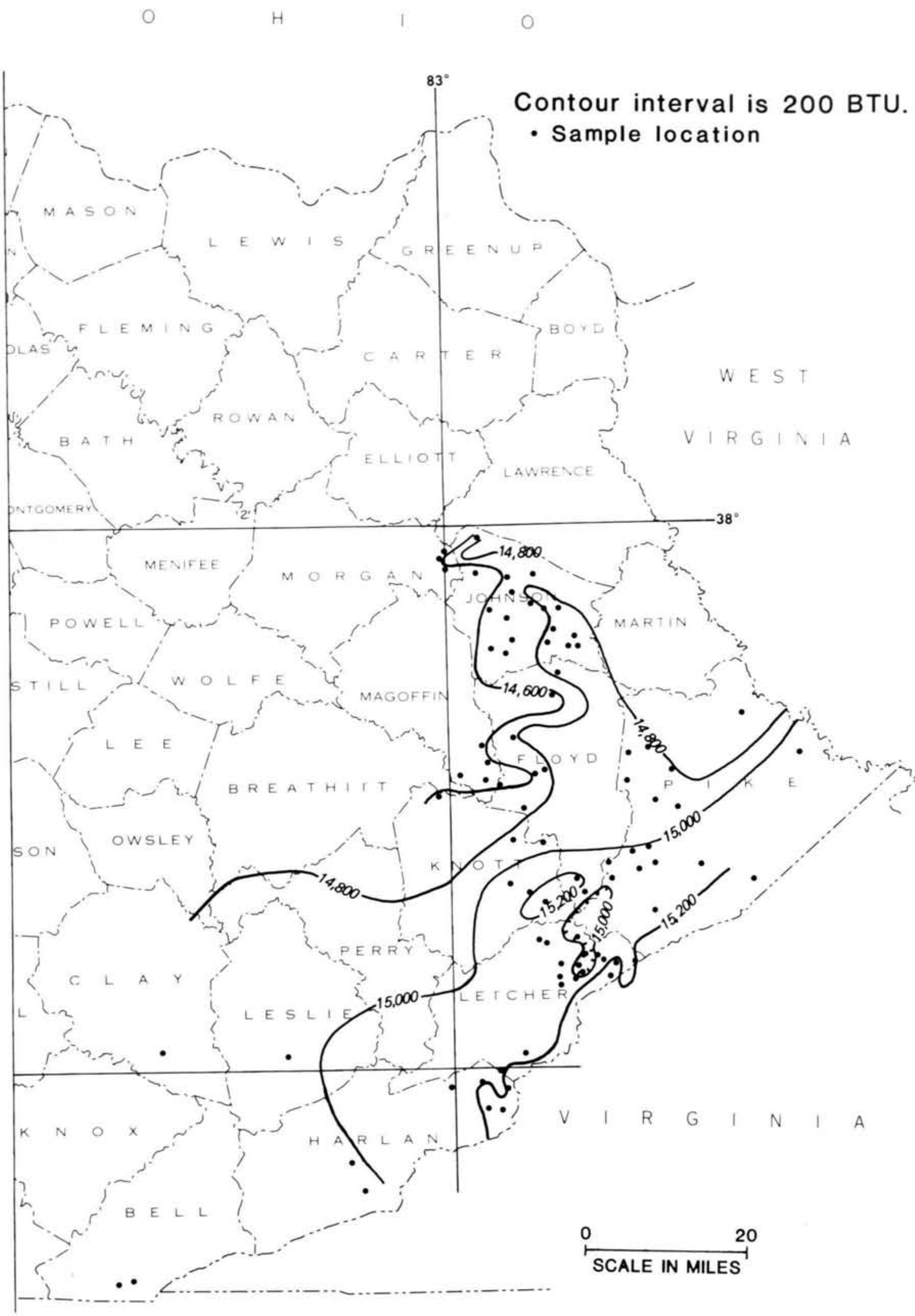

Figure 39. B.T.U. distribution of Upper Elkhorn No. 3 coal bed determined on moisture- and ash-free basis.

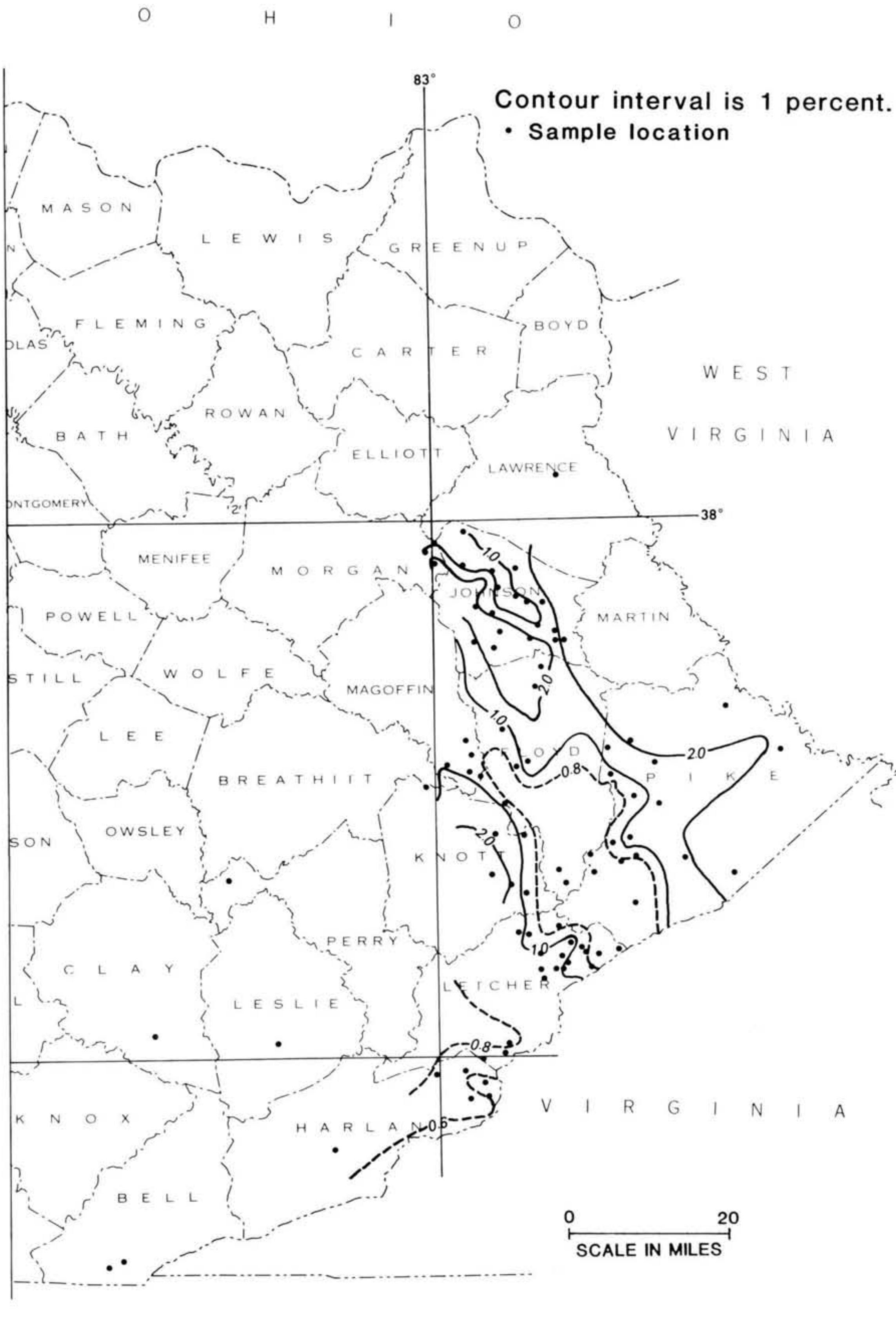

Figure 40. Sulfur distribution of Fire Clay coal bed determined on moisture-free (dry) basis.

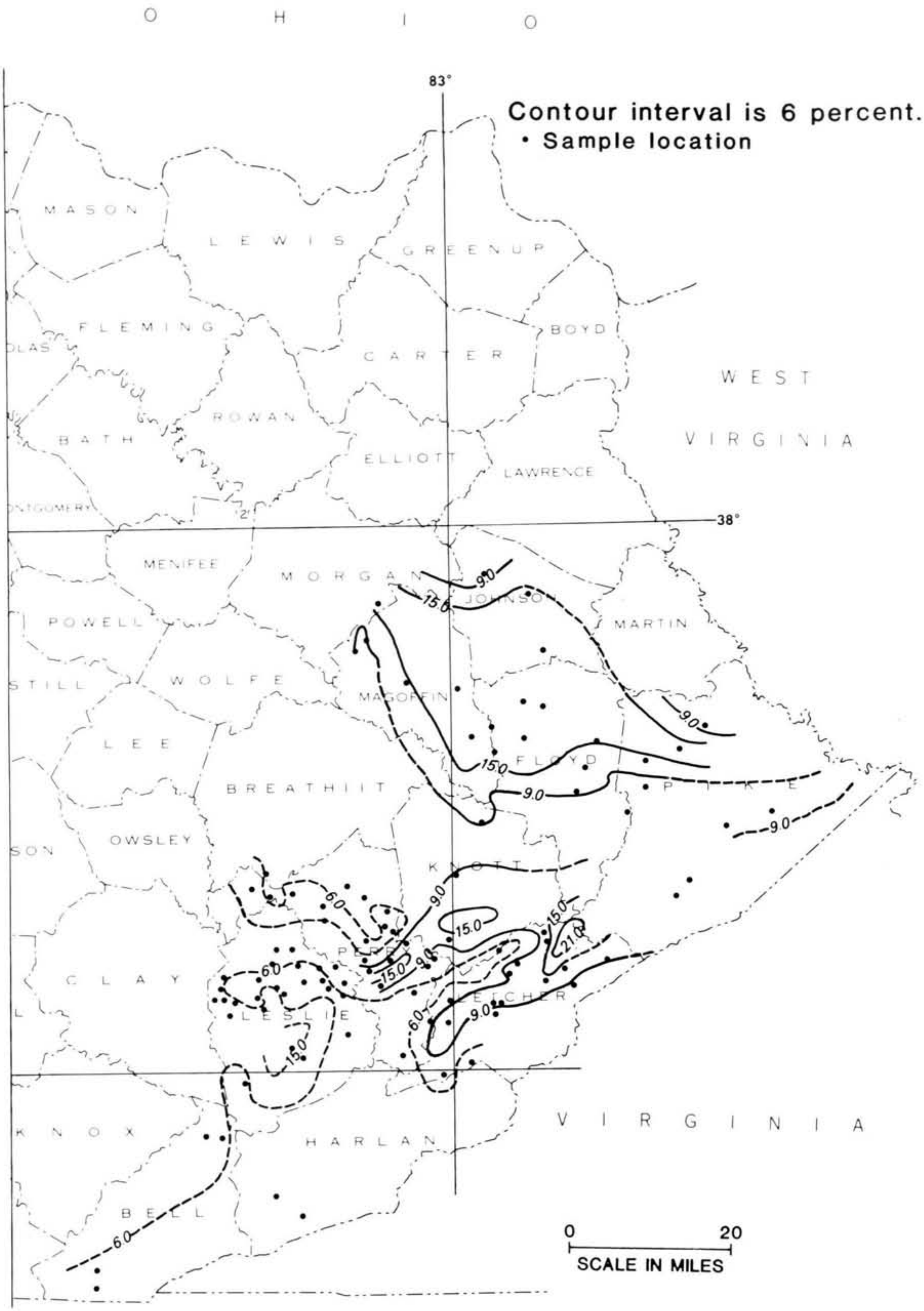

Figure 41. Ash distribution of Fire Clay coal bed determined on moisture-free (dry) basis.

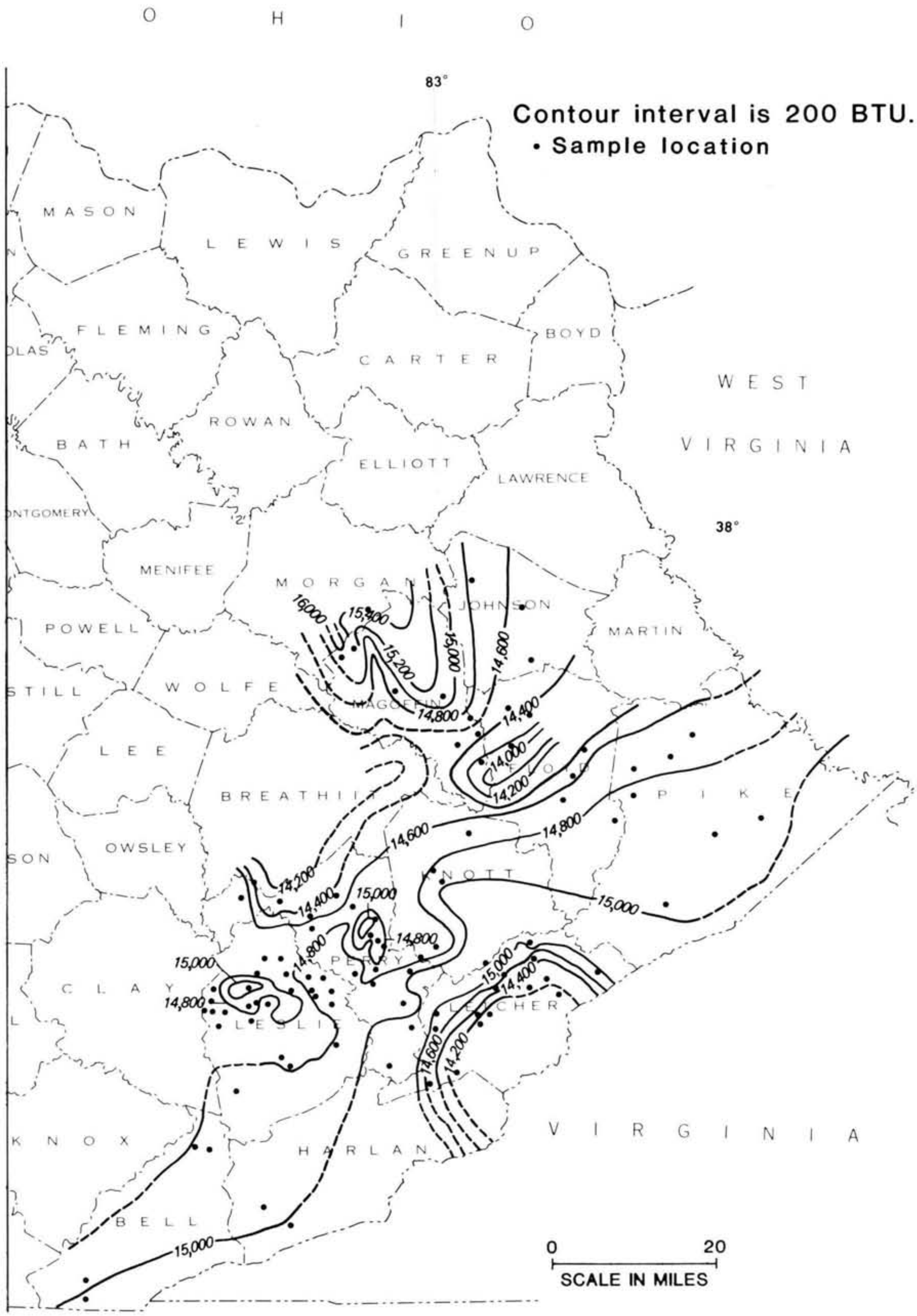

Figure 42. B.T.U. distribution of Fire Clay coal bed determined on moisture- and ash-free basis.

and compounds precipitated during peat accumulation. Price and Shieh (1979) have shown that about 87 percent of the organic sulfur in low-sulfur coals (less than 0.8 percent organic sulfur) is plant-assimilated sulfur, which can only be deposited during peat accumulation. The remainder of the organic sulfur is probably contributed by bacterially reduced sulfate. This contribution increases dramatically in high-sulfur coals, which suggests the introduction of sulfur into the peat from the surrounding environment. However, the timing of the later introduction of sulfur is not discussed. Casagrande (1977, p. 166) concluded that "(1) the total amount of sulfur found in coal can be incorporated during the peat forming stage' and '(2) all forms of sulfur found in coal are found in peat."

The sulfur and ash patterns of Figures 37, 38, 40, and 41 are suggestive of deltaic depositional regimes. Figure 43 shows the relationship between the sulfur and ash distribution and their speculative relationship with a distributary system contemporaneous with peat accumulation. Because the bulk of the ash content of coal must be deposited during the peat accumulation stage, either through the process discussed by Cecil and others (1979) or through sediment influx from contemporaneous adjacent distributory channels, the ash content largely reflects the environmental conditions prevailing in the peat swamp. The sulfur distribution of both the Upper Elkhorn No. 3 and Fire Clay coal can be logically explained by a deltaic system where brackish water produces high-sulfur and high-ash peat and fresh water produces low-ash and low-sulfur peats. Exceptions occur along the distributary flanks where splay events might locally increase ash content dramatically. Because of this relationship and since the ash content reflects conditions prevailing during peat deposition, it is proposed that, for these two coals, the sulfur content also reflects depositional conditions during peat accumulation.

Although sparse evidence exists to prove the existence of plants tolerant of saline water in Pennsylvanian time, there is no evidence disproving their existence (James Jennings, personal commun., 1981). Modern peat swamps contain many salt-tolerant species and develop peat deposits under marine to brackish conditions (Scholl, 1969; Frazier and Osanik, 1969; Spackman and others, 1976). Phillips (1979) indicated that swamp *Cordaites* of early Desmoinesian age may have occupied some habitats in brackish to strongly saline-influenced environments. The Lexington Coal of Missouri is separated by a few inches of clay from the underlying Higginsville Limestone and is overlain by marine shales (Anna Shale), and the Jamestown coal of southwestern Illinois immediately overlies a rooted, fossiliferous marine limestone (Wanless and others, 1969). The peat forming these coals was certainly developed in a near-marine environment.

Williams and Keith (1963) were the first to demonstrate the relationship between the regional distribution of sulfur in coal and the depositional environment of the roof rock. However, their map of the Lower Kittanning coal indicates areas of low-sulfur coal (less than 2 percent sulfur) in regions where the roof rocks are mapped as marine and areas of high-sulfur coal (greater than 2 percent sulfur) in regions overlain by terrigenous rocks. This observation leads to the question of how these low-sulfur and high-sulfur regions persist in areas where they are overlain by rocks of dissimilar depositional environment. Either the mapping of the depositional environment was not sufficiently detailed or, in certain cases, roof rock fails to infallibly indicate sulfur content. This question becomes important if one is "attempting to predict the occurrence and mode of distribution of sulfur in coal by identifying the environments of deposition of their enclosing strata" (Caruccio and Ferm, 1977) instead of using marine beds as an indication of a potential sulfur problem. Mapping the roof rocks of the Upper Elkhorn No. 3 and Fire Clay coals in eastern Kentucky has just recently begun, and only scattered and preliminary data are available. Although no definitive conclusions can be drawn, there seem to be exceptions to a one-to-one relationship between roof rock depositional environment and sulfur content of the coal.

CONCLUSIONS

The distribution of ash and sulfur in the Upper Elkhorn No. 3 and Fire Clay coals reflects the depositional environments prevailing during peat accumulation rather than during its burial. The regions of high-ash and high-sulfur coal are tentatively interpreted as having formed in brackish to marine peat swamps. The regions of low-ash, low-sulfur coal are provisionally interpreted as forming in fresh-water peat swamps. Finally, the areas of the coal with high-ash and low-sulfur content are interpreted as forming in fresh-water peat swamps with a locally high sediment influx, possibly from splay events.

Because the maps of ash and sulfur distribution in the Upper Elkhorn No. 3 and Fire Clay coals relate to each other so well, and because there are areas where roof rock does not infallibly indicate sulfur content, the extent to which the depositional environment of roof rocks controls sulfur content of these two coals is questioned. It is suspected that the strong correlation between marine roof rocks and high-sulfur coals is due to the coincidental relationship between coals deposited in a marine-influenced environment and roof rocks deposited in similar environments. Because the depositional environment must change slightly between depo-

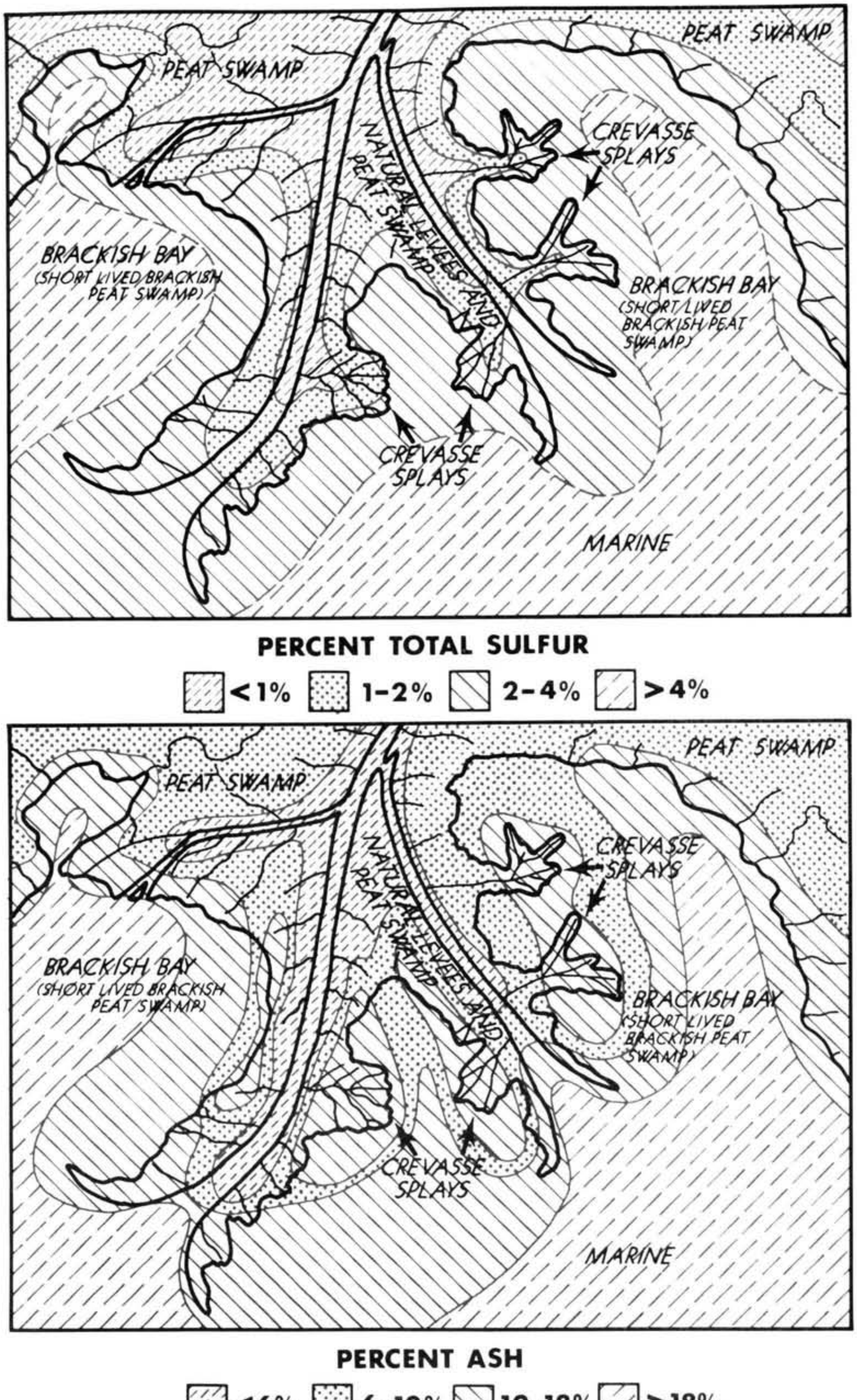

Figure 43. Speculative relationship between sulfur and ash distribution of Upper Elkhorn No. 3 and Fire Clay coal beds and distributary system contemporaneous with peat accumulation.

sition of the peat and burial of the peat, there cannot be an exact one-to-one relationship between marine roof rocks and high-sulfur coals. Rather, the sulfur distribution in the coal and the depositional environment of the roof rock mimic one another.

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PRELIMINARY CORRELATIONS OF COALS OF THE PRINCESS RESERVE DISTRICT IN EASTERN KENTUCKY

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INTRODUCTION

The miospore content of the coals of the Princess Reserve District in eastern Kentucky is being studied in cooperation with the Kentucky Geological Survey. The many local names for eastern Kentucky coals have been correlated by Rice and Smith (1980), following completion of the Kentucky Geological Survey-U. S. Geological Survey geologic mapping program. Their chart lists the most important coals and their equivalents in each district. These correlations are based in large part on the position of the coals with reference to key marine horizons, or on other available physical markers such as partings, flint clays, or other lithic sequences.

In retrospect, marine horizons have been observed over nearly every major coal in the Eastern Kentucky Coal Field. Donald Chesnut (this volume) of the Kentucky Geological Survey has documented approximately 50 local marine horizons. Several marine zones have been and are still used as marker horizons over large areas of eastern Kentucky. However, the existence of so many relatively local marine zones raises questions about the continuity or reliability of the several mapped marine zones as reference markers. The discontinuous, repetitious nature of the clastics and significant differences in rates of subsidence in some areas of eastern Kentucky further complicate the problems facing the physical stratigrapher in correlation of eastern Kentucky coals.

The spore succession observed in coals from cores in the Princess Reserve District has shown that correlations can be established with the use of spores. Cursory examinations of these coals make it apparent that similar studies will be necessary in each district in order to fully understand the complicated nature of the Pennsylvanian System and the varied depositional conditions in this area during Pennsylvanian time.

PREVIOUS WORK

Kosanke's (1973) publication on the Princess Reserve District is the only publication based on extensive palynological studies in eastern Kentucky. Peppers and Ettensohn (1979) have included palynological data in their paper but were not primarily documenting the spore succession. Significant work on spore zonation or succession in the Middle and Upper Pennsylvanian of North America has been done by Peppers (in press). The Carboniferous miospore zonation for western Europe by Clayton and others (1977) has been of significant help in interpreting the changes observed in eastern Kentucky coals and is mentioned subsequently under the floral succession. The synthesis of the palynology of British coals and summarization of palynological nomenclature for the Carboniferous, by Smith and Butterworth (1967), serves as the groundwork for the taxonomic approach taken in identifying the various spore taxa mentioned in this paper.

CARBONIFEROUS MIOSPORE SUCCESSION

Smith and Butterworth (1967) updated and summarized work on the Carboniferous miospores and documented a succession of 11 miospore zones for the coals of Great Britain. Clayton and others (1977) have presented a more comprehensive zonation scheme based on published data for all of western Europe. Their zonation scheme documents the floral succession from the latest Devonian through the earliest Permian of Europe. It is comprehensive in that it includes miospore data from all lithotypes rather than just the coal horizons and has been loosely correlated with the zonation scheme of Smith and Butterworth (Fig. 44).

Stage	Substage	Clayton and others 1977	Smith and Butterworth 1967
STEPHANIAN	D, C	NM Potonieisporites novicus - bhardwajii Cheiledonites major	
STEPHANIAN	B, A	ST Angulisporites splendidus Latensina trileta	
WESTPHALIAN	D	OT Thymospora obscura Thymospora thiessenii	Thymospora obscura XI
WESTPHALIAN	C	SL Torispora securis Torispora laevigata	Torispora securis X
WESTPHALIAN	C / B		Vestispora magna IX
WESTPHALIAN	B	NJ Microreticulatisporites nobilis Florinites junior	Dictyotriletes bireticulatus VIII
WESTPHALIAN	A	RA Radiizonates aligerens	Schulzospora rara VII Radiizonates aligerens VI
WESTPHALIAN	A	SS Cirratriradites saturni Triquitrites sinani	Densosporites anulatus V
NAMURIAN	C	FR Raistrickia fulva Reticulatisporites reticulatus	
NAMURIAN	B	KV Crassispora kosankei Grumosisporites varioreticulatus	Crassispora kosankei IV
NAMURIAN	A	SO Lycospora subtriquetra Kraeuselisporites ornatus	Rotaspora knoxi III
NAMURIAN	A	TK Stenozonotriletes triangularis Rotaspora knoxi	

Figure 44. Upper Mississippian and Pennsylvanian spore zonation for European strata and coals. After Smith and Butterworth (1967) and Clayton and others (1977).

MIOSPORE SUCCESSION IN THE PRINCESS RESERVE DISTRICT

This report is based on the study of coals from four of the cores made available through the Kentucky Geological Survey and the Institute for Mining and Minerals Research. The code designations and locations of the cores are shown on Figure 45. All coals from cores R 1 and R 2 have been examined and spores identified at the generic level. In addition, all coals 1 foot or greater in thickness have been examined from all four cores and spores identified to the specific level (Table 4). Top of hole elevations and depths of these cores are shown in Figure 46 and sample numbers given for the thickest coals. Miospores common to the Princess Reserve District are shown in Plates 19-21.

One spore horizon, the *Radiizonates difformis* horizon, has been identified in all four cores. This spore horizon is of particular significance in that several spore changes are noted below, within, and above this horizon that might prove useful in wider correlations within eastern Kentucky. The distinguishing feature of this horizon is the occurrence of *Radiizonates difformis.* This horizon is also marked by a diversity of forms of the genus, *Dictyotriletes.* The diversity of *Dictyotriletes* decreased markedly above this horizon. These relationships have also been observed in samples from the Hazard North Quadrangle in eastern Kentucky (*see* Kosanke, this volume). Kosanke (1973 and this volume) reported the occurrence of *R. difformis,* and his floral lists also document similar occurrences for *Dictyotriletes.* The form *Triquitrites bransonii* is common above the *R. difformis* horizon. This occurrence was similarly observed in coals from the Hazard area. The form *Cristatisporites indignabundus,* although rare in the samples from the cores, does occur below the *R. difformis* horizon and is found below this horizon in the Hazard area.

Using occurrences from R 7 and published occurrences, a second spore horizon which contains the spores *Thymospora obscura, Thymospora pseudothiessenii,* and *Mooreisporites inusitatus* was recognized. Only one sample, from R 2, a thin coal approximately 157 feet (47.8 m) from the top of the core, can be tentatively correlated with this horizon. It contains *Thymospora* sp. and *Cadiospora magna.* The *Thymospora obscura-Thymospora pseudothiessenii* horizon is widely documented in Europe (Clayton and others, 1977) and the Illinois Basin (Peppers, in press). Although both horizons have similarities to floral zones used by Smith and Butterworth (1967) and Clayton and others (1977), these terms are being used informally and will be until more is known about the vertical succession and the lateral continuity of the spore flora in eastern Kentucky coals.

DISCUSSION

The continuity of the *Radiizonates difformis* horizon across the four cores, if it is assumed that they represent the same coal bed, can be used to estimate the amount of subsequent subsidence across the Kentucky River Fault Zone. In R 9, the *R. difformis* horizon stands approximately 900 feet (274 m) above present sea level. It is lowest in R 2 at approximately 30 feet (9 m) above sea level. This would indicate a relative displacement of about 870 feet (265 m) across this fault zone following deposition of these beds. It is even possible to suggest that the subsidence across the fault zone was renewed shortly after the deposition of the coals in the *R. difformis* horizon. This suggestion is based on the lack of continuity of coals above the *R. difformis* horizon between R 7 and R 1, and R 2, which has undergone relatively more subsidence. The timing of this subsidence could account for the increased thickness of coarse clastics in R 2 and the thin, discontinuous nature of the coals across the fault basin.

The microfloras reported in the paper are documented from four cores from the Princess Reserve District; however, it is possible to suggest some correlations regarding the Hazard area roadcuts described in the roadlog in this guidebook. The flora of the *Radiizonates difformis* horizon has been documented by Kosanke (1973) in the Richardson coal at its type section in the Milo Quadrangle, and in the Skyline seam at its type section in the Tiptop Quadrangle. In the roadcuts on the Hazard North Quadrangle, the *R. difformis* flora occurs in the Hazard No. 7 and No. 8 coals. The forms *Densosporites anulatus* and *Cristatisporites indignabundus* are also present in the subjacent Hazard (No. 5) coal and lower coals.

Applying physical stratigraphic principles for identification, the coals containing the *R. difformis* flora from the four cores are:

- R 1. Three thin coals, 83 feet (25 m) to 135 feet (41 m) below the Princess No. 3.
- R 2. Two coals, 75 feet (23 m) and 110 feet (33.5 m) below the Princess No. 3. The lower coal was questionably identified as the Fire Clay coal.
- R 7. Two coals, the lower coal identified as the Princess No. 3.
- R 9. Coal identified as Fire Clay coal.

Kosanke (1973) correlated the Princess No. 5 with the Richardson and Skyline seams to the south of the Princess Reserve District. On the Hazard North Quadrangle, the *R. difformis* flora is present in the Hazard No. 7 and No. 8 coals. These coals are approximately 300 feet (91

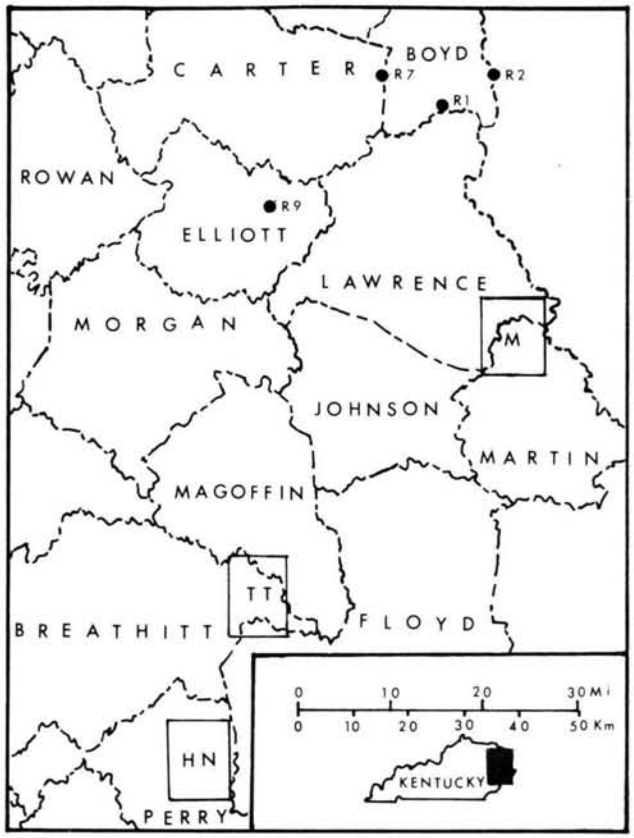

Figure 45. Index map of study area showing general locations of cores and Milo (M), Tip Top (TT), and Hazard North (HN) Quadrangles.

m) above the Fire Clay coal in the Hazard North Quadrangle area. Comparison with an adjacent quadrangle, where both Hazard No. 7 and No. 8, and Skyline seams are identified, indicates that the Skyline seam would be approximately 200 feet (61 m) above the Hazard No. 7 and No. 8 seams. Spore data in the eastern Kentucky districts are far from complete. The present data, however, indicate that coal correlations between the Princess and Hazard Reserve Districts could be off by as much as several hundred feet (61 to 91 m), depending on which name is used for the coals from the Princess cores. Similarly, the correlations of the Skyline in its type area with adjacent areas could be misplaced by at least 200 feet (61 m) in comparison with data from coals in the Hazard North Quadrangle. These discrepancies could be accounted for by slight changes in structural dip combined with misidentification of key marker beds. These indications, however, are preliminary.

The *Thymospora obscura-Thymospora pseudothiessenii* horizon contains spores which are generally accepted by Clayton and others (1977) and Smith and Butterworth (1967) as spanning Westphalian D time in Europe and Great Britain. The *Radiizonates difformis* horizon could range from upper Westphalian A to as high as Westphalian C. Smith and Butterworth (1967) record the range of this form as upper Westphalian A in Great Britain. Peppers (in press) records this form as occurring above the Westphalian A form *Radiizonates aligerens* and indicates a Westphalian C age for *Radiizonates difformis*.

CONCLUSIONS

Present work shows that spore zonation in eastern Kentucky will prove valuable in coal correlation. The development of a useful correlation scheme, however, will depend on documentation of the spore succession in coals from cores in each of the districts in eastern Kentucky. This must be followed by the analysis of the microfloral content of major named coals in their type sections. With this base, constructive evaluation of the correlations of Rice and Smith (1980) can be attempted.

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Table 4. – Frequency of Occurrence of Spores in Coals from the Princess Reserve District.

	R1				R2						R7						R9		
	1005	1004	1003	1001	1011	1010	1009	1008	1007	1006	1031	1030	1029	1028	1027	1026	1034	1033	1032
Acanthotriletes castanea														I		I		+	
A. echinatus																		F	I
A. triquetrus											F	F		+		+		F	
Ahrensisporites guerickei															+				+
Alatisporites hexalatus												+							
A. hoffmeisterii							+					+							
A. trialatus		+								+									
Anaplanisporites cf. A. globulus																+			
Anapiculatisporites minor						+													
A. spinosus										+					+				
Apiculatisporis abditus		+		I							+	+	+		+		+	+	
A. aculeatus												+				+			
A. cf. latigranifer					I														
A. spinososaetosus						+	+			I					+				
Apiculatasporites spinulistratus		+		F								+			I		+	+	+
Calamospora breviradiata											+					+			+
C. cf. breviradiata													C	A	F				
C. cf. laevigata						+			+										
C. microrugosa			+	+	I		+					I			+			+	+
C. mutabilis						+					+	+						+	+
C. pallida	F	C		V	F	F		C		I	F	+					+	F	I
C. parva	C	C		F	V	V	I	F	C		F	F	+	F	I	F	+	C	I
C. pedata						+		F					+						+
Camptotriletes bucculentus																		+	
Cirratriradites annuliformis			+					+		+			F	+	+	F		+	+
C. saturni	+	+			+	+					I	+		+			+	+	
Converrucosisporites armatus												+							
Convolutispora florida																	+		
Crassispora kosankei	I	F	F		F		I	F	F		+	+	F	F	+	I		C	+
Cristatisporites connexus																			+
C. indignabundus	+				I														
C. solaris	+																		
Cyclogranisporites aureus	+				+	I			+	+	F	+	F	+	+	+		+	I
C. minutus							I	F					+					I	
C. cf. C. minutus	F			+		F				+			F	+	+	F	+	F	
C. multigranus			F													+			
C. orbicularis											+								
Densosporites anulatus	+				F												A	C	+
D. gracilis																			I
D. pseudoannulatus				F		+	C									+		F	
D. sphaerotriangularis							F			A	A	F						+	+
Dictyotriletes bireticulatus	I					F					+	+						+	+
D. castaneaeformis												+	+						+
D. falsus	+										+								+
D. muricatus											+	+						I	+
D. reticulocingulum	I										+	+					+		

R1

1005	Unnamed
1004	Princess No.3
1003	Princess No.7
1001	Pittsburgh(?)

R2

1011	Unnamed
1010	Fire Clay?
1009	Unnamed
1008	Princess No.3
1007	Unnamed
1006	Princess No.4

R7

1031	Princess No.3
1030	Unnamed
1029	Unnamed
1028	Princess No.6
1027	Princess No.7
1026	Princess No.8

R9

1034	Unnamed
1033	Whitesburg
1032	Fire Clay

I	Infrequent	$<0.5\%$
F	Frequent	0.5–2.0%
C	Common	2.1–5.0%
V	Very common	5.1–10.0%
A	Abundant	$>10.0\%$

Abundance data are based on population counts of 250 miospores for each sample. Taxa encountered during scanning of slides following completion of the population counts are represented by "+".

Table 4. — Continued.

	R1				R2						R7						R9		
	1005	1004	1003	1001	1011	1C10	1009	1008	1007	1006	1031	1030	1029	1028	1027	1026	1034	1033	1032
Endosporites globiformis	C	+	+	C		+		+		I	+	+	C	C		+		I	
E. rarus																			+
E. zonalis											+	+	+				+	+	+
Florinites cf. F. florini	C						+					+				I	+	+	
F. mediapudens		V	F	F	C	C	C		C	C	C	+	I	+		+			+
F. millotti		F		V					+					F	+				
F. pumicosus	+			+								+	+	+			+	+	+
F. similis																	+		
Granisporites micrognanifer																I			
G. pannosites															+				
Granulatisporites adnatoides					F					I	F	+	+	+		+	+		+
G. granulatus	F	C	I	I			F	V	C	I		C	F	F	F		C	+	C
Grumosisporites papillosus											+								
G. varioreticulatus																	+		
Kewaneesporites?						+					+								
Knoxisporites?																	+		+
Laevigatosporites minimus	I			V						F		F		F					F
L. minor	V	C	V	A	A	V	C	A	C	V	C	F	+	F	F	C	F	V	V
L. vulgaris	+						+	I			F							+	
Latosporites globosus														F					
L. minutus											F								
Leiotriletes inermis															I	+			
L. parvus							F	F				F		F		I			
L. cf. L. priddyi	I	I		I	F	F				F	F	F	F		+		+	F	
L. sphaerotriangularis	+								F	+	I		+				+		+
Lophotriletes commissuralis										+		+			+	I			I
L. cf. L. gibbosus									+							+			
L. microsaetosus	+	I					I	C	F				+			+	I		I
Lycospora granulata									I	F	I	+							
L. noctuita																			+
L. pellucida			I					I		F			I			+	F	C	
L. pusilla	A	V	A		A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Microreticulatisporites nobilis		F		+	I			+	I	+	I	+	+						
M. sulcatus									I					+	+	+			
Mooreisporites fustis											+								
M. inusitatus													+	+	+	+			
Pityosporites westphalensis				F															
Planisporites granifer?	+										+						I	+	
Punctatisporites aerarius	+									+					+				
P. edgarensis													+						
P. minutus	I		F	A		F		F	I				F	+	I	+		+	I
P. cf. P. minutus	F								I										I
P. obliquus			F	C					+							+			
P. punctatus																+			
Punctatosporites granifer														F	F				
P. minutus	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	I	A	A

R1

1005	Unnamed
1004	Princess No.3
1003	Princess No.7
1001	Pittsburgh(?)

R2

1011	Unnamed
1010	Fire Clay?
1009	Unnamed
1008	Princess No.3
1007	Unnamed
1006	Princess No.4

R7

1031	Princess No.3
1030	Unnamed
1029	Unnamed
1028	Princess No.6
1027	Princess No.7
1026	Princess No.8

R9

1034	Unnamed
1033	Whitesburg
1032	Fire Clay

I	Infrequent	<0.5%
F	Frequent	0.5-2.0%
C	Common	2.1-5.0%
V	Very common	5.1-10.0%
A	Abundant	>10.0%

Abundance data are based on population counts of 250 miospores for each sample. Taxa encountered during scanning of slides following completion of the population counts are represented by "+".

Table 4. – Continued.

	R1				R2						R7						R9		
	1005	1004	1003	1001	1011	1010	1009	1008	1007	1006	1031	1030	1029	1028	1027	1026	1034	1033	1032
P. cf. P. minutus																C			
Pustulatisporites papillosus	+	+											+				+		
Radiizonates difformis						C	F				V	F							+
Raistrickia aculeata	+			+					+					+	+	+			
R. crinita												+	F	F					+
R. crocea											+								+
R. fulva					+				+		+		+				+	+	+
R. protensa											+								
R. saetosa		+					+				+		+			+		I	A
Reinschospora speciosa											+						I		
R. triangularis											+	+							
Reticulatisporites carnosus									+										+
R. reticulatus						+	I										+		
Savitrisporites nux					+												+	I	+
Schopfites dimorphus														I	+				+
Schulzospora rara				+			+						+						
Spackmanites facierugosus													+	+					
Spencerisporites radiatus											I	+						+	
Thymospora obscura													+	F	A				
T. pseudothiessenii														F	A	+			
Torispora securis				+				I	I	F					+	+			
Triquitrites additus															+				
T. bransonii	C							F	F	+			C	F	F	+			I
T. crassus													I	+	I				
T. minutus															+				
T. sculptilis	+										+	+	+			+			
T. tribullatus	+										+					+			
T. trigonappendix															+				
Verrucosisporites donarii										+						+			
V. microtuberosus									+			+			+				
V. microverrucosus					I			+					I				+	+	
V. morulatus	+																+	+	
V. sifati						F	+			+						I		+	+
V. verrucosus					+	+	+					I				+			
Vestispora costata								+											
V. fenestrata						I		C	F	+			C	+	+	+			+
V. laevigata								+				+							
V. pseudoreticulata		+			+	+	+		+		+	+						I	
Wilsonites delicatus		+					I				+		+		+				

R1

1005	Unnamed
1004	Princess No.3
1003	Princess No.7
1001	Pittsburgh(?)

R2

1011	Unnamed
1010	Fire Clay?
1009	Unnamed
1008	Princess No.3
1007	Unnamed
1006	Princess No.4

R7

1031	Princess No.3
1030	Unnamed
1029	Unnamed
1028	Princess No.6
1027	Princess No.7
1026	Princess No.8

R9

1034	Unnamed
1033	Whitesburg
1032	Fire Clay

I	Infrequent	<0.5%
F	Frequent	0.5-2.0%
C	Common	2.1-5.0%
V	Very common	5.1-10.0%
A	Abundant	>10.0%

Abundance data are based on population counts of 250 miospores for each sample. Taxa encountered during scanning of slides following completion of the population counts are represented by "+".

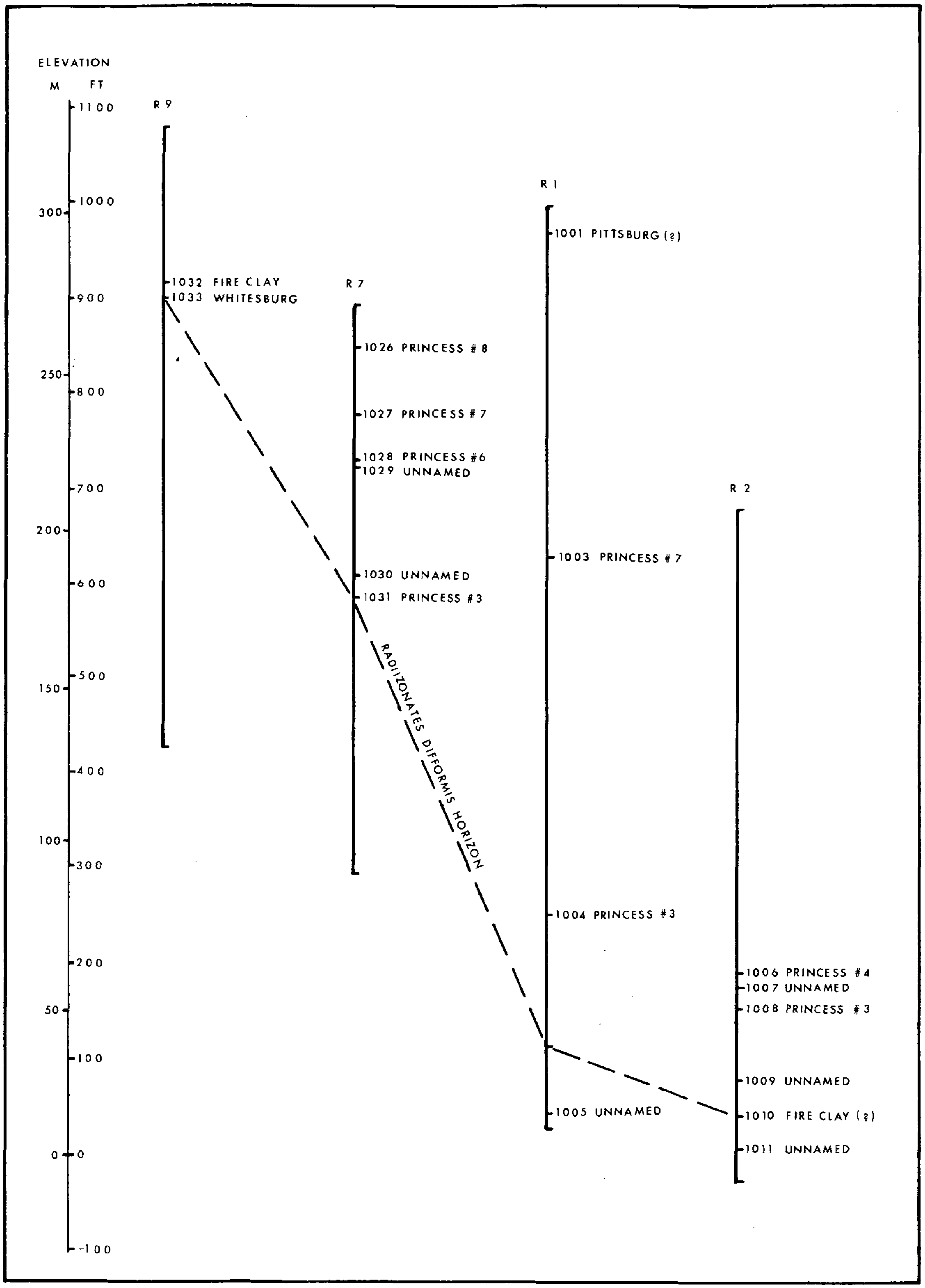

Figure 46. Core sample data and correlation based on the *Radiizonates difformis* horizon in the Princess Reserve District.

PLATE 19

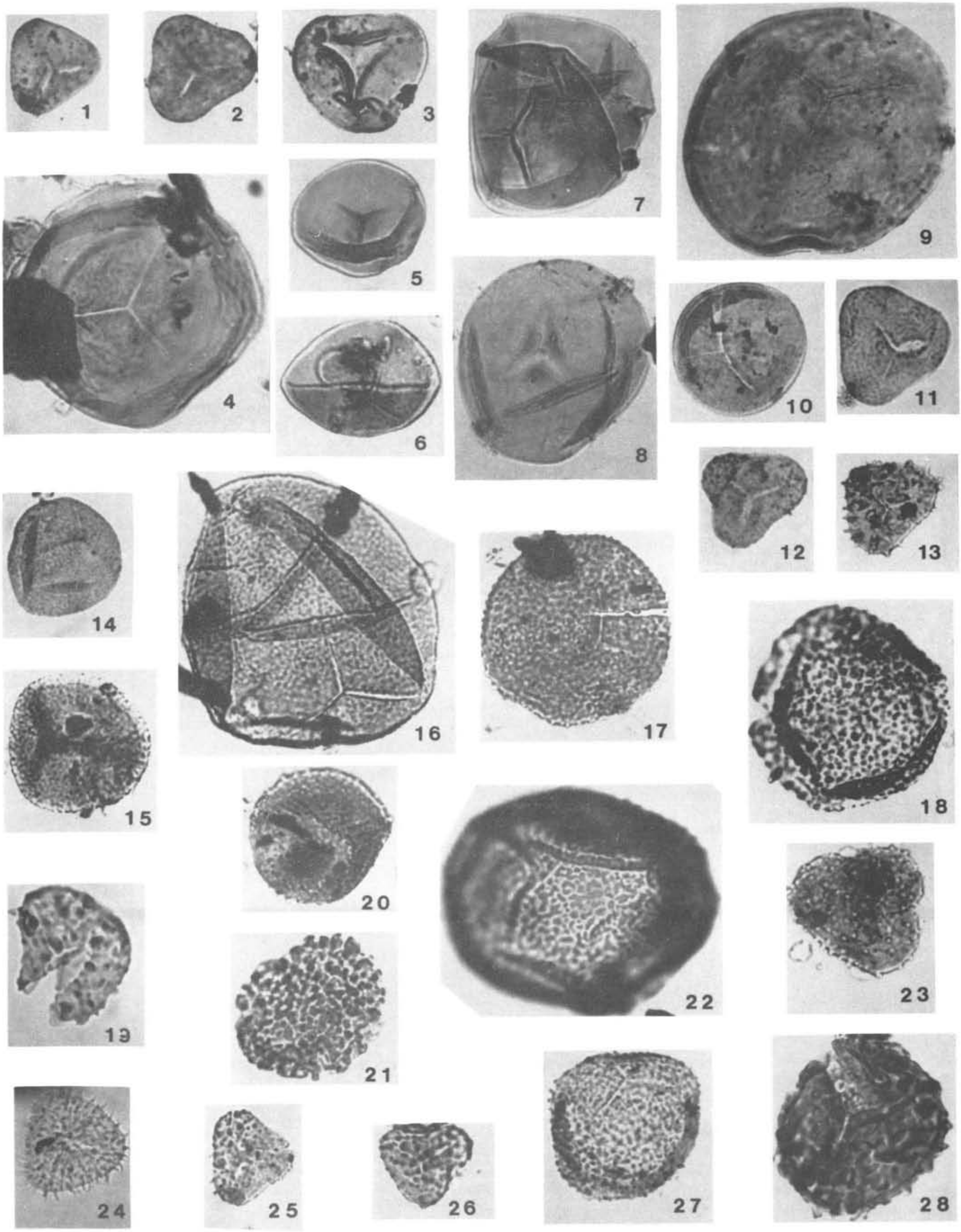

Plate 19. Miospores from Princess Reserve District. All figures X600.

Figure 1. *Leiotriletes parvus.* Guennel, 1958 (1028).

Figure 2. *L.* cf. *priddyi.* (Berry) Potonie and Kremp, 1955 (1034).

Figure 3. *L. sphaerotriangularis.* (Loose) Potonie and Kremp, 1954 (1029).

Figure 4. *Calamospora mutabilis.* (Loose) Schopf, Wilson, and Bentall, 1944 (1032).

Figure 5. *C. parva.* Guennel, 1958 (1033).

Figure 6. *C. pedata.* Kosanke, 1950 (1029).

Figure 7. *C. pallida.* (Loose) Schopf, Wilson, and Bentall, 1944 (1033).

Figure 8. *C.* cf. *breviradiata.* Kosanke, 1950 (1028).

Figure 9. *Punctatisporites edgarensis.* Peppers, 1970 (1029).

Figure 10. *P. obliquus.* Kosanke, 1950 (1026).

Figure 11. *Granulatisporites adnatoides.* (Potonie and Kremp) Smith and Butterworth, 1967 (1031).

Figure 12. *G. granulatus.* Ibrahim, 1933 (1033).

Figure 13. *Lophotriletes microsaetosus.* (Loose) Potonie and Kremp, 1955 (1032).

Figure 14. *Cyclogranisporites* cf. *minutus.* Bharadwaj, 1957 (1033).

Figure 15. *C. orbicularis.* (Kosanke) Potonie and Kremp, 1955 (1031).

Figure 16. *C. aureus.* (Loose) Potonie and Kremp, 1955 (1030).

Figure 17. *Verrucosisporites donarii.* Potonie and Kremp, 1955 (1026).

Figure 18. *V. verrucosus.* (Ibrahim) Ibrahim, 1933 (1026).

Figure 19. *Pustulatisporites papillosus.* (Knox) Potonie and Kremp, 1955 (1001).

Figure 20. *Apiculatisporis aculeatus.* (Ibrahim) Smith and Butterworth, 1967 (1026).

Figure 21. *Verrucosisporites morulatus.* (Knox) Smith and Butterworth, 1967 (1033).

Figure 22. *V. sifati.* (Ibrahim) Smith and Butterworth, 1967 (1033).

Figure 23. *Lophotriletes* cf. *gibbosus.* (Ibrahim) Potonie and Kremp, 1954 (1026).

Figure 24. *Acanthotriletes echinatus.* (Knox) Potonie and Kremp, 1955. R2—Thin coal 5 feet (1.5 m) below Princess No. 3 coal (1008).

Figure 25. *A. triquetrus.* Smith and Butterworth, 1967 (1031).

Figure 26. *Lophotriletes commissuralis.* (Kosanke) Potonie and Kremp, 1955 (1026).

Figure 27. *Apiculatasporites spinulistratus.* (Loose) Ibrahim, 1933 (1001).

Figure 28. *Apiculatisporis abditus.* (Loose) Potonie and Kremp, 1955 (1034).

PLATE 20

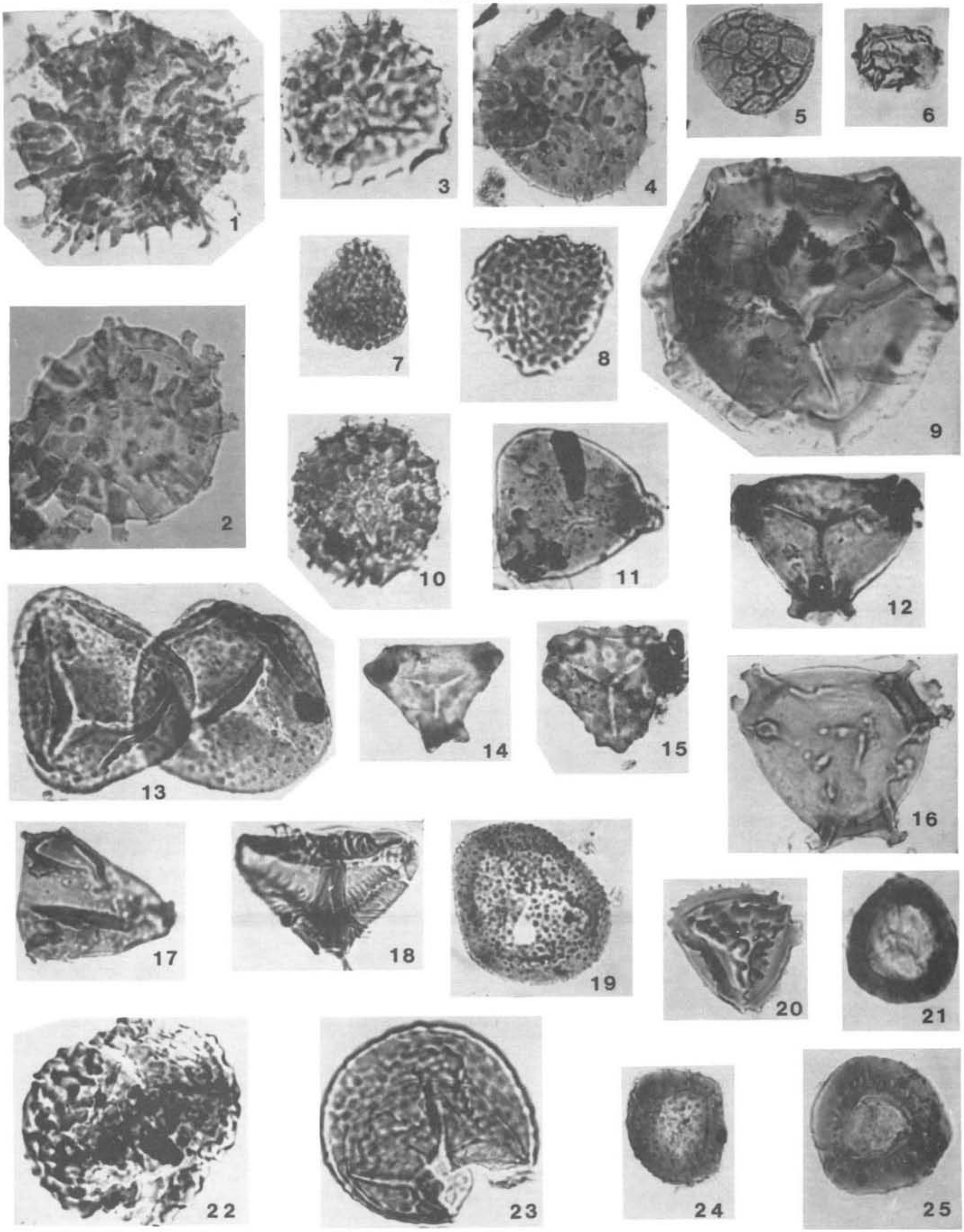

Plate 20. Miospores from Princess Reserve District. All figures X600.

Figure 1. *Raistrickia aculeata.* Kosanke, 1950 (1001).

Figure 2. *R. lacerata.* Peppers, 1970. R2—Thin coal 30 feet (9.1 m) below Princess No. 3 coal (1008).

Figure 3. *R. fulva.* Artuz, 1957 (1029).

Figure 4. *R. saetosa.* (Loose) Schopf, Wilson, and Bentall, 1944 (1031).

Figure 5. *Dictyotriletes bireticulatus.* (Ibrahim) Smith and Butterworth, 1967 (1031).

Figure 6. *D. castaneaeformis.* (Horst) Sullivan, 1964 (1032).

Figure 7. *Microreticulatisporites nobilis.* (Wicher) Knox, 1950 (1030).

Figure 8. *M. sulcatus.* (Wilson) and Kosanke) Smith and Butterworth, 1967 (1028).

Figure 9. *Dictyotriletes muricatus.* (Kosanke) Smith and Butterworth, 1967 (1030).

Figure 10. *D. reticulocingulum.* (Loose) Smith and Butterworth, 1967 (1031).

Figure 11. *Triquitrites crassus.* Kosanke, 1950 (1029).

Figure 12. *T. tribullatus.* (Ibrahim) Schopf, Wilson, and Bentall, 1944 (1031).

Figure 13. *Planisporites granifer.* (Ibrahim) Knox, 1950 (1031).

Figure 14. *Triquitrites bransonii.* Wilson and Hoffmeister, 1956 (1028).

Figure 19. *Crassispora Kosankei.* (Potonie and Kremp) Bharadwaj, 1957 (1031).

Figure 15. *T. sculptilis.* (Balme) Smith and Butterworth, 1967 (1031).

Figure 16. *Mooreisporites fustis.* Neves, 1958 (1031).

Figure 17. *M. inusitatus.* (Kosanke) Neves, 1958 (1029).

Figure 18. *Reinschospora triangularis.* Kosanke, 1950 (1031).

Figure 20. *Savitrisporites nux.* (Butterworth and Williams) Smith and Butterworth, 1967 (1032).

Figure 21. *Densosporites anulatus.* (Loose) Smith and Butterworth, 1967 (1034).

Figure 22. *Grumosisporites papillosus.* (Ibrahim) Smith and Butterworth, 1967 (1031).

Figure 23. *G. varioreticulatus.* (Neves) Smith and Butterworth, 1967 (1034).

Figure 24. *Densosporites pseudoannulatus.* Butterworth and Williams, 1958 (1033).

Figure 25. *D. sphaerotriangularis.* Kosanke, 1950 (1031).

PLATE 21

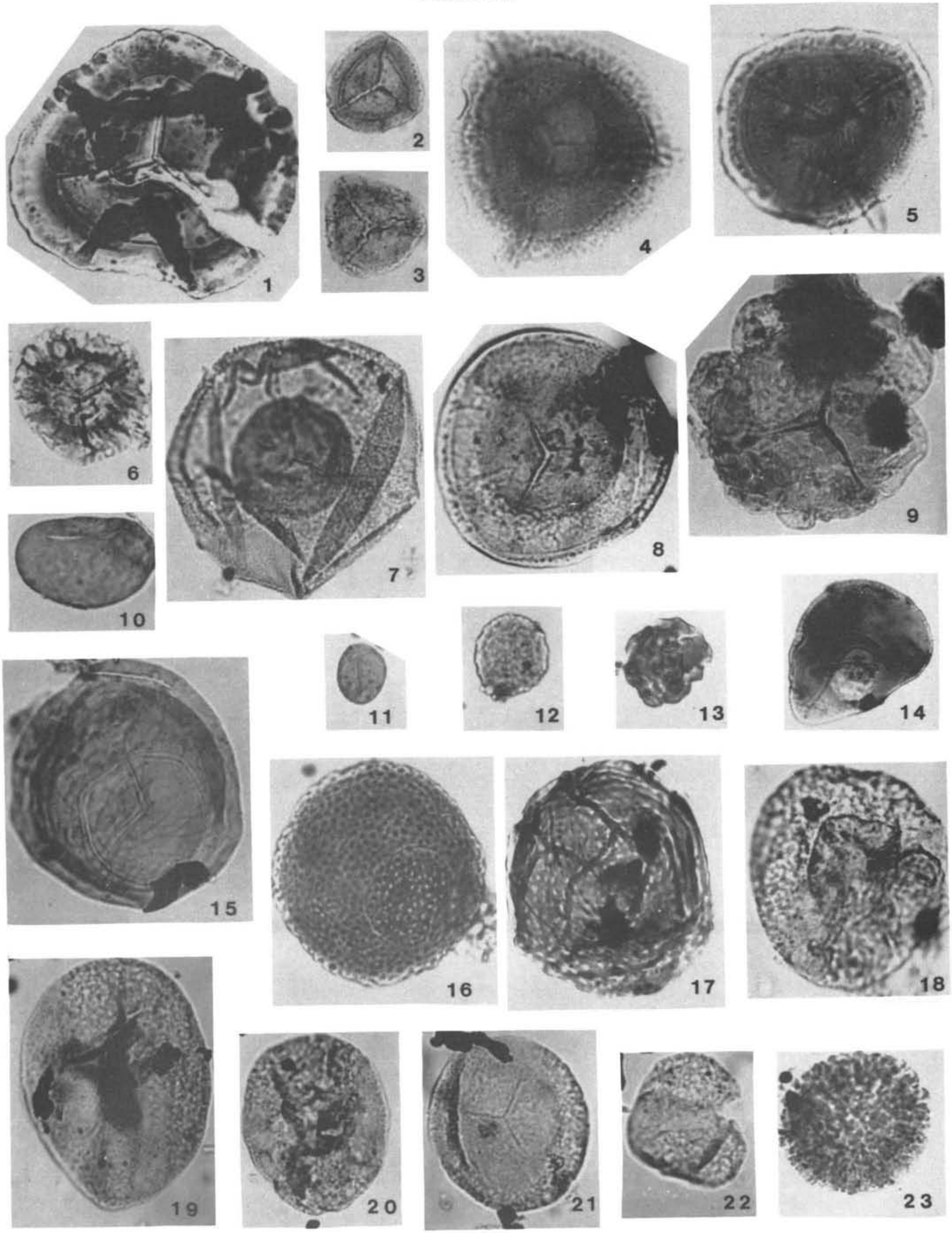

Plate 21. Miospores from Princess Reserve District. All figures X600.

Figure 1. *Reticulatisporites carnosus.* (Knox) Neves, 1964 (1032).

Figure 2. *Lycospora pellucida.* (Wicher) Schopf, Wilson, and Bentall, 1944 (1026).

Figure 3. *L. pusilla.* (Ibrahim) Schopf, Wilson, and Bentall, 1944 (1029).

Figure 4. *Cirratriradites saturni.* (Ibrahim) Schopf, Wilson, and Bentall, 1944 (1033).

Figure 5. *C. annuliformis.* Kosanke and Brokaw *in* Kosanke, 1950 (1026).

Figure 6. *Radiizonites difformis.* (Kosanke) Staplin and Jansonius, 1964 (1031).

Figure 7. *Endosporites globiformis.* (Ibrahim) Schopf, Wilson, and Bentall, 1944 (1026).

Figure 8. *E. zonalis.* (Loose) Knox, 1950 (1031).

Figure 9. *Alatisporites hoffmeisterii.* Morgan, 1955. R2—Thin coal 5 feet (1.5 m) below Princess No. 3 coal (1008).

Figure 10. *Laevigatosporites minor.* Loose, 1934 (1030).

Figure 11. *Punctatosporites minutus.* Ibrahim, 1933 (1032).

Figure 12. *Thymospora obscura.* (Kosanke) Wilson and Venkatachala, 1963 (1028).

Figure 13. *T. pseudothiessenii.* (Kosanke) Wilson and Venkatachala, 1963 (1028).

Figure 14. *Torispora securis.* Balme, 1952 (1026).

Figure 15. *Vestispora laevigata.* Wilson and Venkatachala, 1963 (1008).

Figure 16. *V. fenestrata.* (Kosanke and Brokaw) Spode *in* Smith and Butterworth, 1967 (1026).

Figure 17. *V. pseudoreticulata.* Spode *in* Smith and Butterworth, 1967 (1030).

Figure 18. *Florinites mediapudens.* (Loose) Potonie and Kremp, 1956 (1029).

Figure 19. *F. pumicosus.* (Ibrahim) Schopf, Wilson, and Bentall, 1944 (1033).

Figure 20. *F.* cf. *florini.* Imgrund, 1960 (1030).

Figure 21. *Wilsonites delicatus.* Kosanke, 1950 (1031).

Figure 22. *Pityosporites westphalensis.* Williams, 1955 (1001).

Figure 23. *Spackmanites facierugosus.* (Loose) Habib, 1966 (1028).

PALEOSLUMPS: A COAL MINE ROOF HAZARD

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Russell A. Brant
Kentucky Geological Survey

INTRODUCTION

Unstable or hazardous roof conditions are responsible for more deaths, injury-accidents, and temporary or even permanent mine shut-downs than any other single condition associated with subsurface coal mining in the Appalachian Basin. Therefore, the prediction of roof conditions is the ultimate desire of any geologist, engineer, or mining operator responsible for pre-mine planning.

There are a number of geologic parameters that affect roof conditions. Although the causes of roof falls are not so easily understood that they can be explained in terms of a singular geologic or engineering condition, among the several factors, rock fabric appears to be the most important factor to consider in room and pillar mining. Rock fabric is also an element that provides a common bond for the geologist and mining engineer by requiring their combined skills and disciplines to alleviate a mining hazard.

Laminated rocks offer the ideal conditions for engineers to perform rock mechanics tests and develop roof bolting procedures for holding the roof. However, where the original depositional fabric is disrupted or destroyed by some post-depositional or noncontemporary process or mechanism such as faulting, fracturing, slumping, rooting, burrowing, etc., standard roof bolting practices are no longer adequate for maintaining a stable roof. Often the changes in the roof conditions are so subtle and unrecognized that the roof falls with no advance warning. With the proper geologic interpretation, particularly during pre-mine planning, these situations could be avoided in many places.

It may be said that the singular weakness most responsible for hampering the prediction of hazardous roof conditions is inadequate knowledge of the environments of deposition of the sediments which now occur as the roof rock. This paper will concentrate on one geologic process which destroys original sediment fabric: the paleoslump, its origin and recognition.

DESCRIPTION

Although the rock disturbances observed include everything from rotational block in which the original bedding is well preserved, to those with chaotic bedding, the term "paleoslump" is used for convenience to cover all gravity-related failures.

Paleoslumps have been recognized in most of the states in the Appalachian and Eastern Interior Basins, for example in Ohio (Gray and Arnold, 1952), in Pennsylvania (Ferm, 1957; Williams and others, 1965), in Illinois (Bristol and Howard, 1974), and in Kentucky (Wayne Newell, 1972, personal commun.; Hester and Brant, 1978; Charles Rice, 1978, personal commun.; Horne and others, 1979).

Paleoslumps we have observed in Kentucky and Ohio (Fig. 47) demonstrate stratigraphic offset as great as 35 feet (Fig. 48) and disruption of sediments for a linear distance as much as 450 feet (Fig. 49). In Tuscarawas and Stark Counties, Ohio, stratigraphic throw is on the order of 100 feet or more, and the disturbance affects the rocks for a lateral distance of approximately 2,000 feet.

Paleoslumps commonly include one or more of the following features: (1) rotated bedding, (2) oversteepened bedding, (3) deformed bedding, (4) arcuate shear planes with striated surfaces, (5) dislocated or detached blocks, (6) coal cut out or abnormally thickened. Although this list is not necessarily complete, it includes the features that we have recognized in the Pennsylvanian rocks of eastern Kentucky.

Paleoslumps are difficult to recognize in the subsurface cores and in mines, and, if recognized at all, they are usually after a roof fall. The realization that the fall was slump related should serve to warn of the possibility of other similar conditions in the area. The occurrence of channels should be a warning that paleoslumps may have occurred over a rather wider area than has previously been considered.

In man-made exposures such as highway cuts,

1.	Interstate Highway 75, mile 60	17-K-63	Mt. Vernon
2.	U. S. Highway 25, 3/4 mile east of Mt. Vernon	19-K-63	Mt. Vernon
3.	U. S. Highway 25, south of Livingston	17-J-64	Livingston
4.	U. S. Highway 25, north of Livingston	7-J-64	Livingston
5.	Just north of U. S. Highway 80 northeast of Somerset	20-H-59	Somerset
6.	South of Sloan's Valley	22-F-60	Burnside
7.	South Fork of Cumberland	8-C-60	Barthell
8.	Kentucky Highways 15 and 80	14-J-76	Hazard North
9.	Hindman Access and Kentucky Highway 80	25-K-79	Hindman
10.	West of Interstate 75, Corbin exit	9-F-65	Corbin
11.	North of Corbin	10-F-65	Corbin
12.	Tiptop along railroad cut	22-N-77	Tiptop
13.	Kentucky Highway 15, southeast of Jackson	12-M-74	Quicksand
14.	Kentucky Highway 1264, Cold Cave	5-R-73	Bangor
15.	Interstate 64, 3 miles west of Catlettsburg	11-W-82	Boltsfork
16.	Catlettsburg, north of H-cool plant	9-W-83	Catlettsburg
17.	Ashland, back of Heck's department store	1-X-82	Ashland
18.	Kentucky Highway 23, south of Zelda	19-U-83	Prichard

Figure 47. Map showing locations of slump structures.

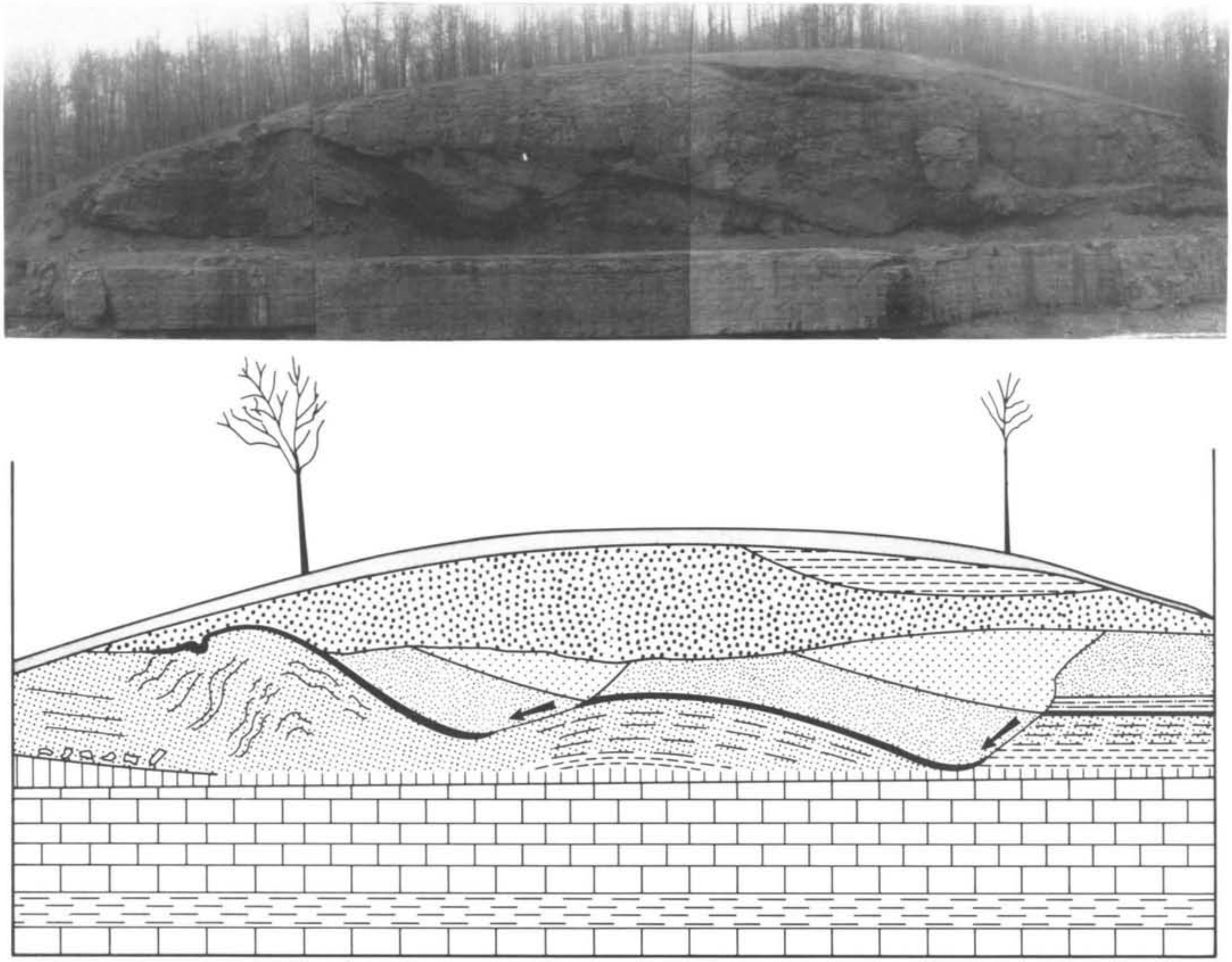

Figure 48. Slump structure on Interstate Highway 75, north of Mt. Vernon.

surface mine highwalls, haul roadcuts, etc., paleoslumps are most easily recognized. When sandstone slumps against shale, the offset, rotation, deformation, etc., are conspicuous (Fig. 48). However, when fine-grained rocks such as argillaceous siltstones slump against claystones (shales), recognition is difficult (Fig. 50).

Some slump features are difficult to assess because bedding is often obliterated. Figure 49 shows a sequence of three sections of a single slump structure from the undisturbed strata to highly contorted strata. Figure 49a shows undisturbed strata adjacent to the slump structure. Figure 49b is of the oversteepened, mostly competent, but laterally displaced rocks. Figure 49c is of the highly disturbed shale which has convoluted and overturned bedding. The bedding for the most part has been destroyed by the slumping.

Oversteepened bedding (Fig. 51) is the best indicator of a slump both in the surface exposure and rock cores. We assume, of course, that there is adequate knowledge of the local geology to exclude the presence of tectonically related faults in the area. As a rule, the presence of slumping should be considered when the bedding angles in the following rock types are exceeded:

(1) Coarse Sandstone	35°
(2) Fine Sandstone	20°
(3) Siltstone	10°
(4) Claystone (Shale)	5°
(5) Limestone	5°

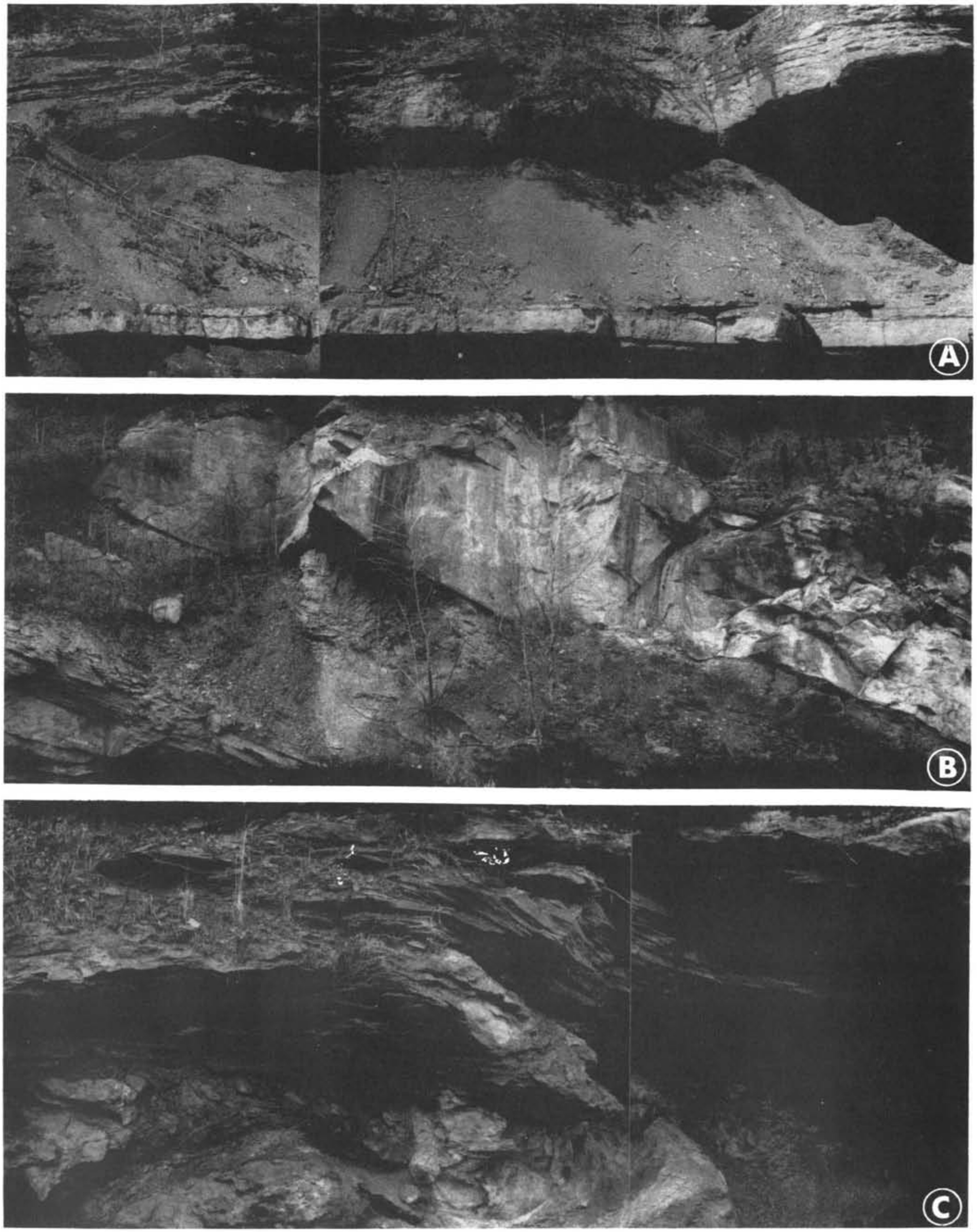

Figure 49. Details showing different portions of slump block at location 7 (Fig. 47). (A) Section of rocks from which slump separated. (B) Oversteepened competent beds. (C) Convoluted phase of bedding displacement.

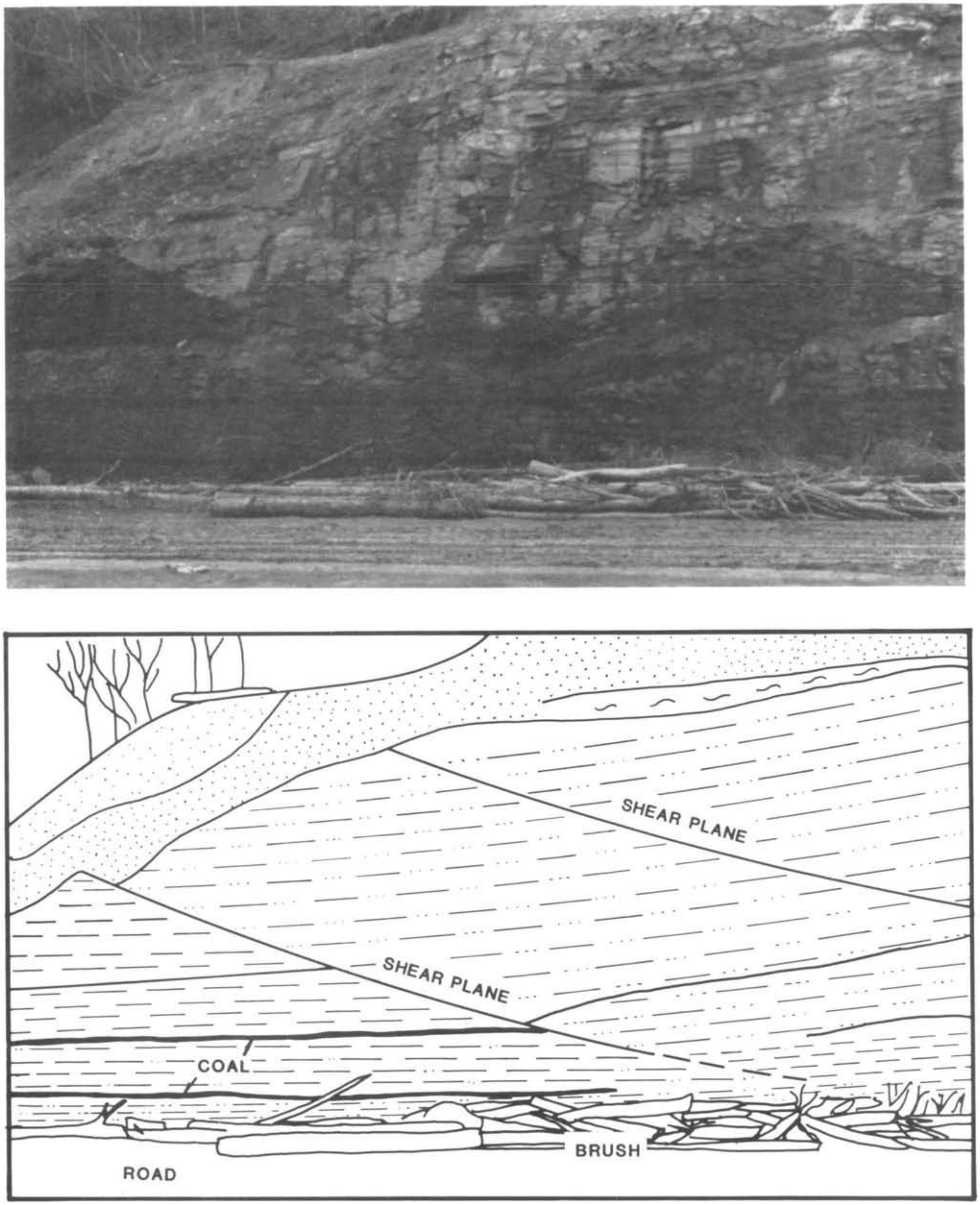

Figure 50. Slump structures near Jackson, Kentucky, showing subtle expression.

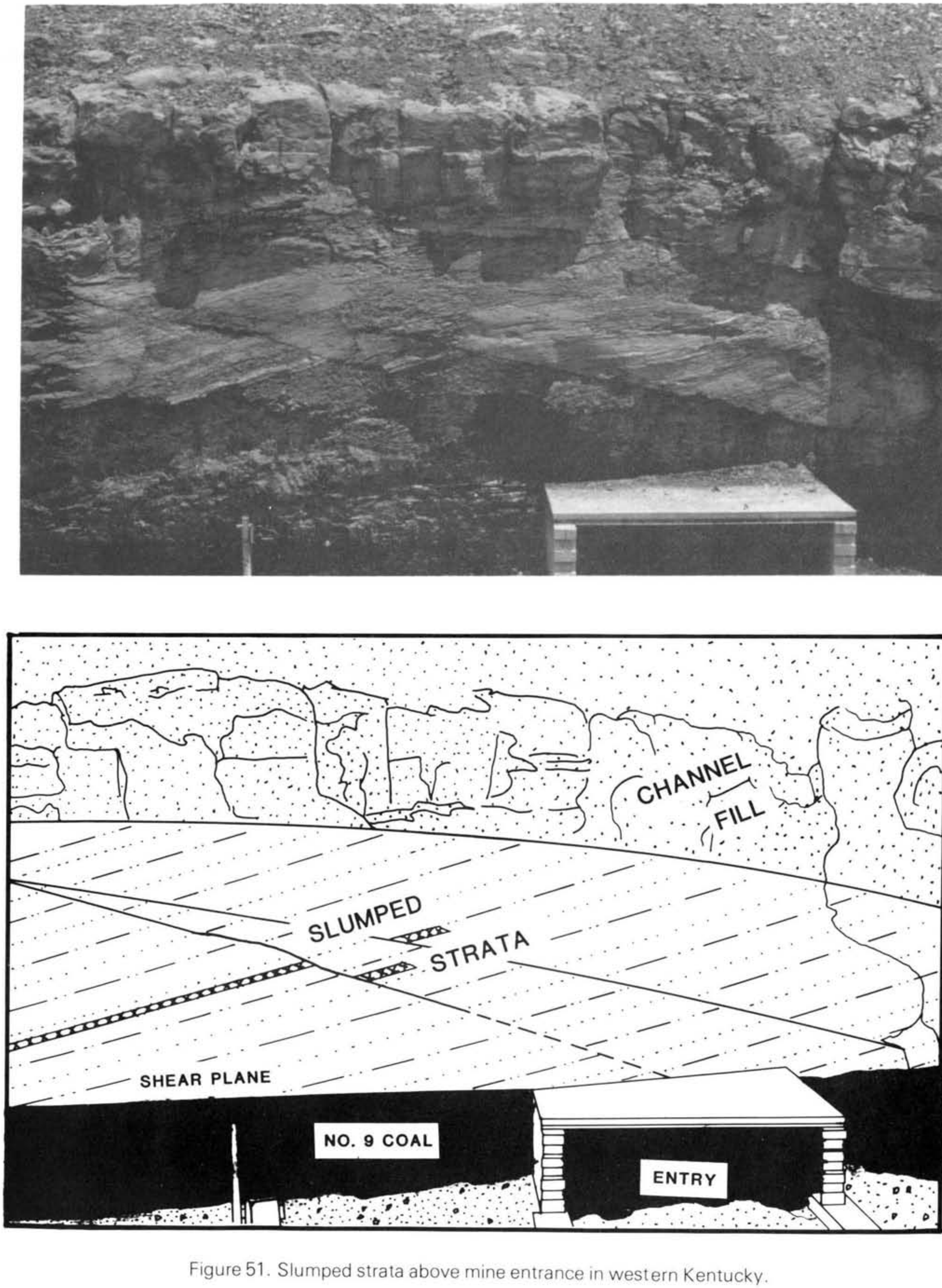

Figure 51. Slumped strata above mine entrance in western Kentucky.

ORIGIN

The cause of paleoslumps and related rock deformation can be related to channeling which oversteepened the banks and allowed the non- or weakly lithified sediments to fail and slide.

Slumps in the rock record were preserved as a result of sliding into exceptionally deep channels below the normal erosional base level of the river. We believe that these deep channels were associated with intense storms such as hurricanes or monsoons. However, large, relatively short-lived eustatic changes of base level cannot be eliminated from consideration. Thus, a subaqueous origin may be argued for their structures, but a subaerial event origin may be defended as well. Extensive instability (on the order of thousands of feet as in Tuscarawas County, Ohio) presents the possibility that a slightly steepened paleoslump may have enhanced a displacement that was triggered by the development of a deep channel.

SUMMARY

Slumped sections of coal-bearing rocks have local but profound effects on coal resources, mining, and safety. In the past, slumped sections have generally not been recognized in either subsurface cores or in the mining until an attributable rock fall has occurred. Criteria of critical angles for recognition of paleoslumps will aid in their pre-mining recognition; however, because of their areally restricted nature, mining environment criteria must be developed. It is hoped that this discussion and description will assist those in mine planning to recognize and delineate areas of potential hazard from this source. Criteria for identification of paleoslumps in underground mining near the working face can be developed, but such a body of knowledge is not yet integrated into a working mode.

Early recognition of paleoslumps associated with subsurface mining is important for several reasons, but mainly for the prevention of slump-block-related roof falls, roof falls being the primary hazard and number one killer in coal mines. Roof falls are costly. A single roof fall may cost more than $100,000 in direct remedy. Search for these structures in advance of mining is justifiable (Fig. 51). Research into even this single element of roof instability promises a considerable return in human welfare and safety and economically in terms of prevention or anticipated remedy.

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ORIGIN OF THE CORBIN SANDSTONE MEMBER OF THE PENNSYLVANIAN LEE FORMATION

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The Corbin Sandstone Member of the Lee Formation is a terrigenous clastic unit which has an unconformable contact with underlying units ranging from the Borden Formation (Lower Mississippian) to the lower tongue of the Breathitt Formation (Fig. 52). According to Gordon Weir (personal commun., 1976), this sandstone body has a maximum width of about 30 miles and a maximum thickness of 280 feet. In the southwestern part of the Scranton Quadrangle the Corbin Sandstone has a maximum thickness of 220 feet. The lithology consists predominantly of crossbedded sandstone with scattered quartz pebbles. The pebbles are generally no coarser than 2 inches in mean diameter; however, a sandstone cobble 12 by 10 by 6 inches was found in the unit. In the field trip area the crossbedding directions fall mainly in the range of southwest to northwest. To the south, however, the dominant crossbedding direction changes from west to south (Gordon Weir, personal commun., 1976). The sandstone generally is poorly sorted. No body fossils and few trace fossils have been reported from the Corbin. In both outcrop and cores, rooted coals are commonly found below the sandstone.

The origin of the Corbin Sandstone is controversial. Based principally on field observations, two diametric interpretations have been proposed for the origin; both involve the vertical and horizontal stratigraphic relation of the Corbin to underlying units.

One interpretation describes the Corbin as a body of sediment deposited by a fluvial system which eroded its way across the Early Pennsylvanian landscape, truncating pre-existing Pennsylvanian or Mississippian units. The Corbin in this case would everywhere have an unconformable relationship with underlying units, representing a considerable break in geologic time.

The other interpretation is that the Corbin Sandstone is representative of a barrier-bar system, either occurring as tidal-channel deposits, overwash deposits, or as the barrier bar proper. This explanation considers the Corbin as being a facies equivalent in facies with underlying units; therefore, the relationship with those units is generally conformable, with little or no break in geologic time.

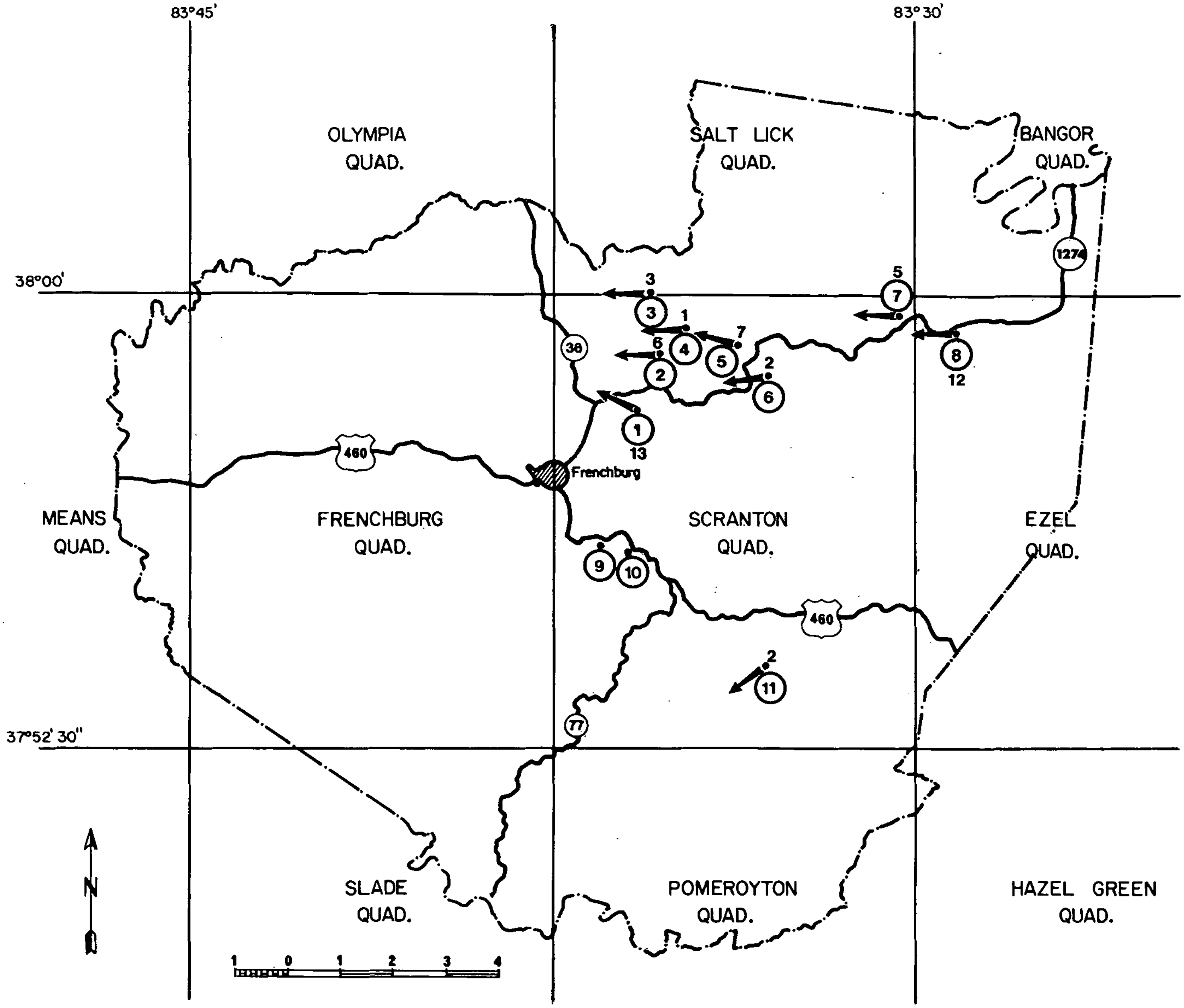
The purpose of this paper is to evaluate these two interpretations in light of field observations and laboratory analyses and offer an interpretation for the environment of deposition of the sandstone for eastern Kentucky.

STRATIGRAPHIC RELATIONSHIPS

At locality 1 on Figure 53, the Corbin Sandstone is approximately 120 feet thick. The base consists of a 10-foot bed of poorly sorted, conglomeratic, coarse-grained sandstone with pebbles up to 2 inches in diameter. Sandstone above the conglomerate consists of thick crossbedded sets; the thickest set is about 4 feet. Small-scale sets ranging from 3 to 6 inches in thickness directly overlie the 4-foot crossbedded set. Based on 13 crossbedding measurements, the direction of transport is N 72° W. The crossbedding is strongly unimodal, and the vertical change in bedforms and grain size shows an upward reduction in energy level for the basal 30 feet of this section.

At locality 2 (Fig. 53), approximately 18 feet of the basal portion of the Corbin is exposed. Here the Corbin is a pebbly sandstone. Its lowermost crossbedding set is greater than 4 feet in thickness. The overlying sandstones have smaller scale cross-sets and the grain size fines upward, suggesting an upward reduction in energy. Based on six crossbedding measurements, the direction of transport is S 80° W, and the crossbedding is strongly unimodal.

At locality 9 (Fig. 53), the base of the Corbin Sandstone consists of thick crossbed sets with scattered pebbles. This grades upward into fine- to medium-grained sandstone with small-scale crossbed sets, which in turn grades into clayey, ripple-bedded, fine-grained sandstone and siltstone. The sandstone is



EXPLANATION

Average crossbedding direction

Locality number inside circle; number of crossbedding measurements shown outside

Figure 52. Generalized section in vicinity of Stop 12.

approximately 60 feet thick. These lithologies illustrate an upward reduction in energy.

The base of the Corbin at locality 10 (Fig. 53) consists of 3 to 5 feet of sandstone containing quartz pebbles, iron oxide-replaced clay pebbles, and large wood fragments, overlain by large-scale crossbedded sandstone that is poorly sorted and coarse grained.

The Corbin Sandstone at locality 8 (Fig. 53) (Stop 12 for this field trip) is approximately 175 feet thick. It has an unconformable contact with the underlying lower tongue of the Breathitt and a gradational boundary with the upper member of the Breathitt (*see* Stop 12 of roadlog). Although the Corbin consists predominantly of sandstone, there is also a significant amount of con-

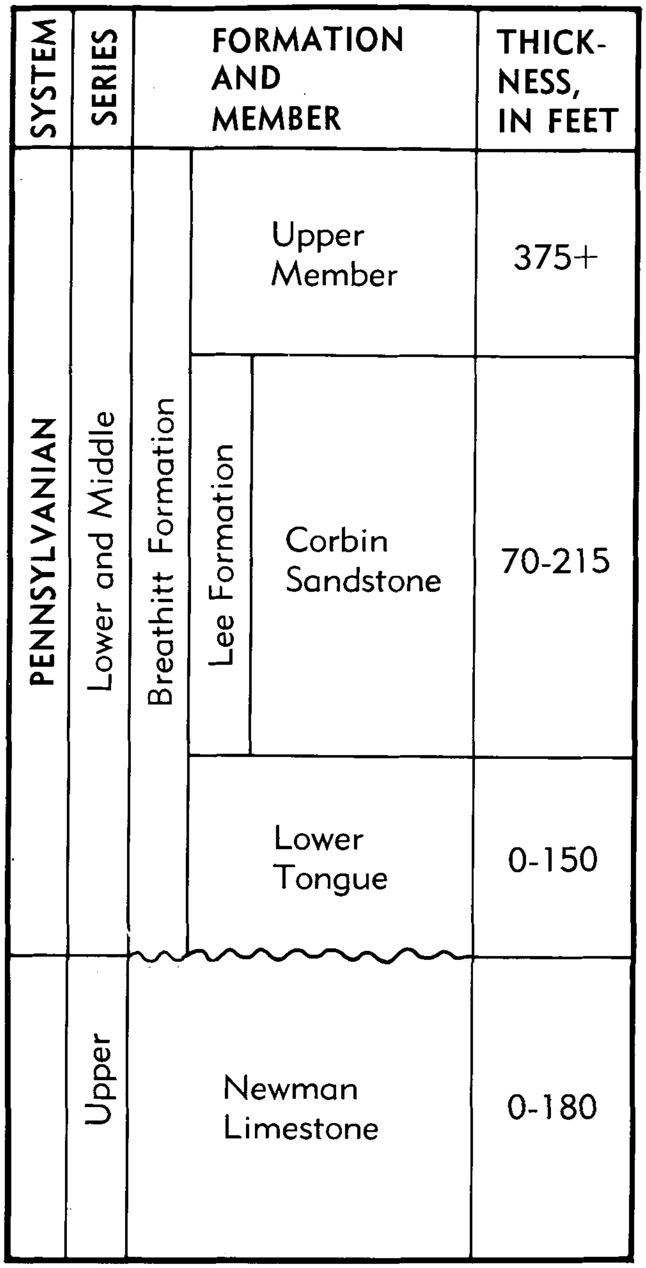


Figure 53. Generalized stratigraphic column at Stop 12.

glomerate, siltstone, and claystone. One coal mapped by Pipiringos and others (1968) as the Mine Fork coal crops out approximately 70 feet above the base.

Cycles of sedimentation which display fining-upward sequences occur in this section. Although only one complete cycle exists, we believe that portions of at least three others are present. The one complete cycle appears in the upper 60 to 70 feet of the section. The vertical sequence starts with a lag concentrate of rubble consisting of quartz pebbles, ironstone-replaced clay pebbles, and limbs and logs which have been replaced by silica or iron oxide. This is followed by medium- to coarse-grained sandstone with quartz pebbles which has large-scale unidirectional, trough-type crossbed sets. This unit grades upward into fine- to medium-grained sandstone which is also cross stratified, but on a much smaller scale than the sandstone below. Ripple crossbedding is common, and the sandstone bodies occur as lenses. The overlying unit consists of silty clay or clayey silt. This same type of vertical sequence starts at the base of the Corbin Sandstone but is truncated by another cycle in the form of a lag concentrate (channel deposit) cutting through the large-scale, crossbedded, medium- to coarse-grained sandstone about 20 feet above the base of the Corbin.

The Corbin Sandstone consists of quartz, muscovite, and less than 1 percent other heavy minerals. No feldspars have been identified. However, because potassium feldspar is present in Upper Mississippian fossiliferous sandstones approximately 7 miles to the northeast along Kentucky Highway 1274, it is likely that feldspars were also present in this sand at the time of deposition. Perhaps post-depositional alteration in the form of subaerial weathering or intrastratal solution in these open-framework sandstones has altered the feldspars to kaolinite. Therefore, much of the kaolinite occurring as clay matrix may have been feldspar originally (Hester, 1974).

The heavy minerals consist for the most part of a mature to super-mature assemblage. The minerals are muscovite, zircon, rutile, tourmaline, leucoxene, and ilmenite. Small quantities of staurolite and garnet have been identified from the Upper Mississippian sandstone 7 miles to the northeast, and it is likely that these minerals were also present in the Corbin Sandstone but were removed by post-depositional alteration. Based on its mineralogy, using the classification of Folk (1974), the sandstone can be described as an orthoquartzite.

Visual examination and a limited number of textural analyses indicate that the sandstone is poorly sorted. Shape studies indicate that the majority of the grains are elongate and subrounded to subangular. Crossbedding measurements indicate a westerly direction of transport ranging from S 30° W to N 60° W. No crossbeds were found having an easterly component.

Two modes of cross-stratification are present. One ranges from S 30° W to S 50° W and characterizes large trough-type crossbed sets as thick as 4 feet. This form of crossbedding occurs immediately above the rubble deposits which are lag concentrates. The other mode ranges from N 50° W to N 60° W and characterizes trough crossbeds that are generally less than 1 foot thick. The sandstone is much finer grained than that found in the first mode, and crossbeds are contained within lens-shaped bodies which have low-angle (less than 10 degrees) accretionary bedding.

ENVIRONMENT OF DEPOSITION

Based on the generally poor sorting characteristics throughout the Corbin Sandstone, the absence of body fossils, the infrequent occurrence of trace fossils, the absence of heavy mineral concentrates, the presence of fining-upward sequences, the common occurrence of autochthonous coals below the sandstone body, it is highly doubtful that the Corbin Sandstone originated as a barrier bar or barrier-bar overwash.

The disconformable base with the lag concentrate may support a tidal-channel origin. However, the presence of strong unimodal crossbedding direction, the truncation of units (in some places as low as the Borden Formation), the absence of any easterly crossbedding components or herringbone structures, no reports of body fossils, and the infrequent occurrence of trace fossils in all lithologies indicate that a tidal-channel origin is unlikely.

The presence of nonmarine rocks below and above the Corbin Sandstone lends strong support to a nonmarine origin for this sandstone. The occurrence of coal-bearing measures between the Newman shallow water carbonates and the Corbin Sandstone makes a barrier origin for this sand body in a progradational sequence implausible.

The generally poor sorting characteristics; the presence of thick conglomerates, in some places associated with cobbles and large wood fragments (logs up to 14 inches in diameter); the presence of fining-upward sequences along with the vertical change in primary sedimentary structures from large-scale crossbed sets through small-scale crossbeds to ripple-bedded, fine-grained sandstone and siltstone; and the unconformable nature of the base lend strong support to a fluviatile origin. The strongly unimodal crossbedding direction to the west or slightly southwest also supports a fluviatile, especially braided-river, interpretation such as that described by Coleman and others (1969). The section described at Cold Cave (Stop 12 for this trip) may better fit the braided-river interpretation, especially in the lower portion. The upper portion of the section which displays a complete cycle from channel deposits to slackwater sediments may indicate that the river system settled into a meandering pattern before abandoning this particular area of eastern Kentucky.

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PETROLOGY, MINERALOGY, AND GEOCHEMISTRY OF COALS IN THE CENTRAL PORTION OF THE EASTERN KENTUCKY COAL FIELD

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INTRODUCTION

Any assessment of the nature of the coals in eastern Kentucky cannot be considered complete without discussion of coal quality. Currens (this volume) discusses ash and sulfur trends for the Fire Clay (Hazard No. 4) and Upper Elkhorn No. 3 coals, and Cole and Williams (this volume) discuss chemical, mineralogical, and thermal properties of the Manchester coal. This study represents a preliminary compilation of the petrographic, mineralogic, and geochemical properties of the coals in the central portion of the Eastern Kentucky Coal Field (as traversed on this field trip; *see* Fig. 54). Future studies from our Institute will include more coals and more extensive analyses for many of the coals represented in the present study.

DISCUSSION

No coal has been sampled over the area in the necessary detail to produce a single seam reflectance map. Williams (1979) presented a composite reflectance map based on all of the eastern Kentucky seams in his study. Some of the rank trends he discussed were exaggerated by variations in stratigraphic position across the coal field. Similar trends can be seen on Figure 55, where coal rank is mapped in restricted areas. Three north-south rank highs are apparent on the map. In general, the coal rank (reflectance) increases to the east (Pike County) and to the southeast (Letcher and Harlan Counties), and decreases to the north (Princess Reserve District (Hower and Wild, 1980a, 1981a). The possible significance of the rank trends in relation to maceral trends is discussed below. The coal rank in most of eastern Kentucky is high-volatile B and A bituminous. High volatile C bituminous rank is common in the Princess Reserve District to the north of the study area (Hower and Wild, 1980a, 1981a), and medium-volatile bituminous rank is found in eastern Pike County (Williams, 1979).

Vertical rank trends can be constructed from superposed seams in cores (as determined from two Institute for Mining and Minerals Research-Kentucky Geological Survey drilling projects) and from roadcuts. The reflectance gradients for core C-7 in the Salyersville South Quadrangle (near the third day route on the Mountain Parkway); for the roadcuts at the intersection of the Daniel Boone Parkway, Kentucky Highway 15, and Kentucky Highway 80 (Stop 6, Hazard North Quadrangle); and along Kentucky Highway 80 north of Martin (Stop 10, Martin Quadrangle; Fig. 56) do not all show the increase in rank normally expected with an increase in depth. Core C-7 shows the best developed reflectance gradients of any core analyzed in the series. The two reflectance gradients from roadcut profiles do not show the expected trends. However, vitrinite reflectance is not necessarily the best rank indicator in the high-volatile bituminous range, and this may be the reason for the lack of expected vertical rank trends.

Maceral analyses of all of the coals studied to date from the central part of the Eastern Kentucky Coal Field are summarized in Table 5, geochemistry in Table 6, and mineralogy in Table 7. The listing of the coals in the table, as well as in the following discussion, is in descending stratigraphic order. Younger coals (*see* discussion of palynology by Helfrich, this volume),

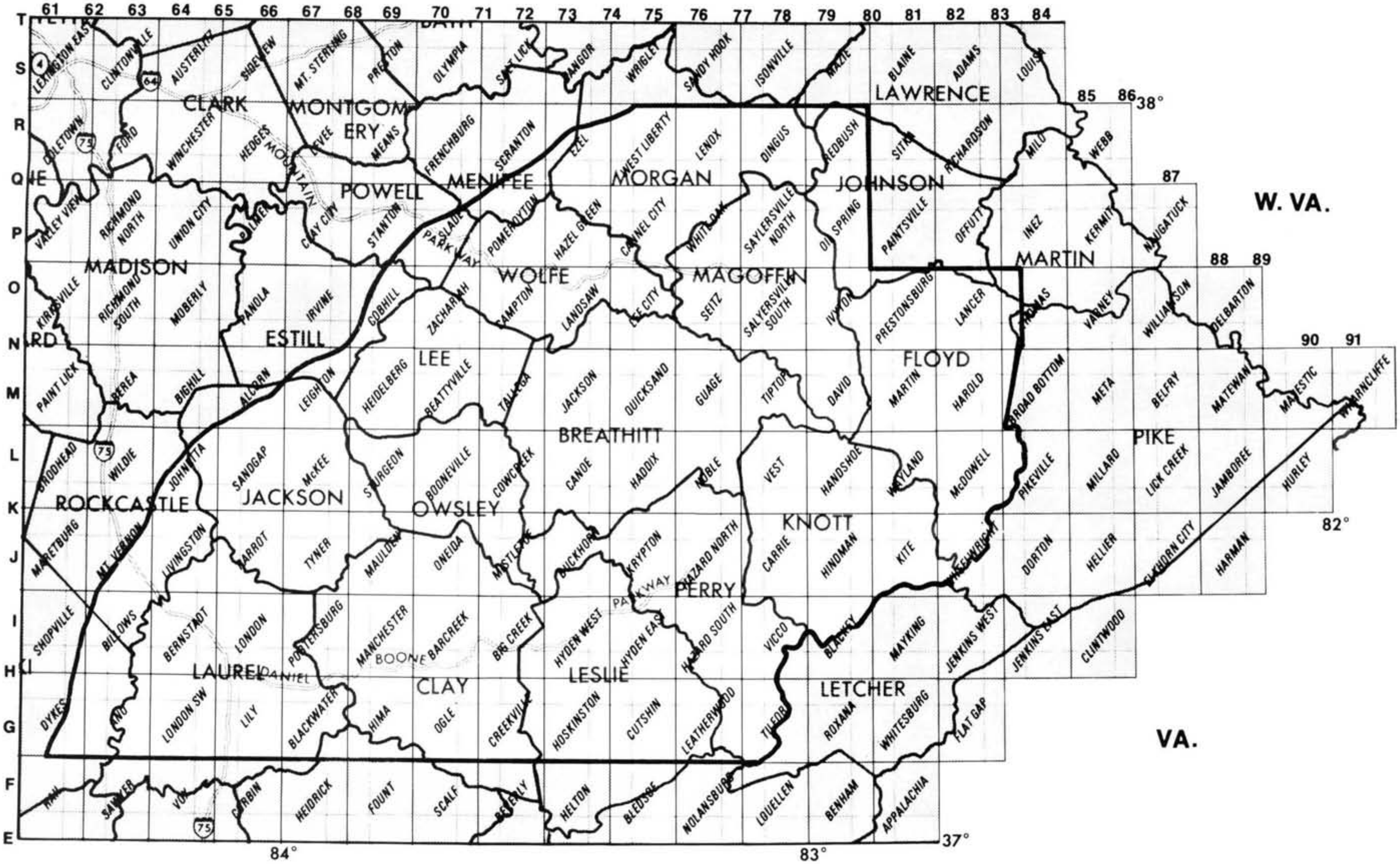

Figure 54. Study area.

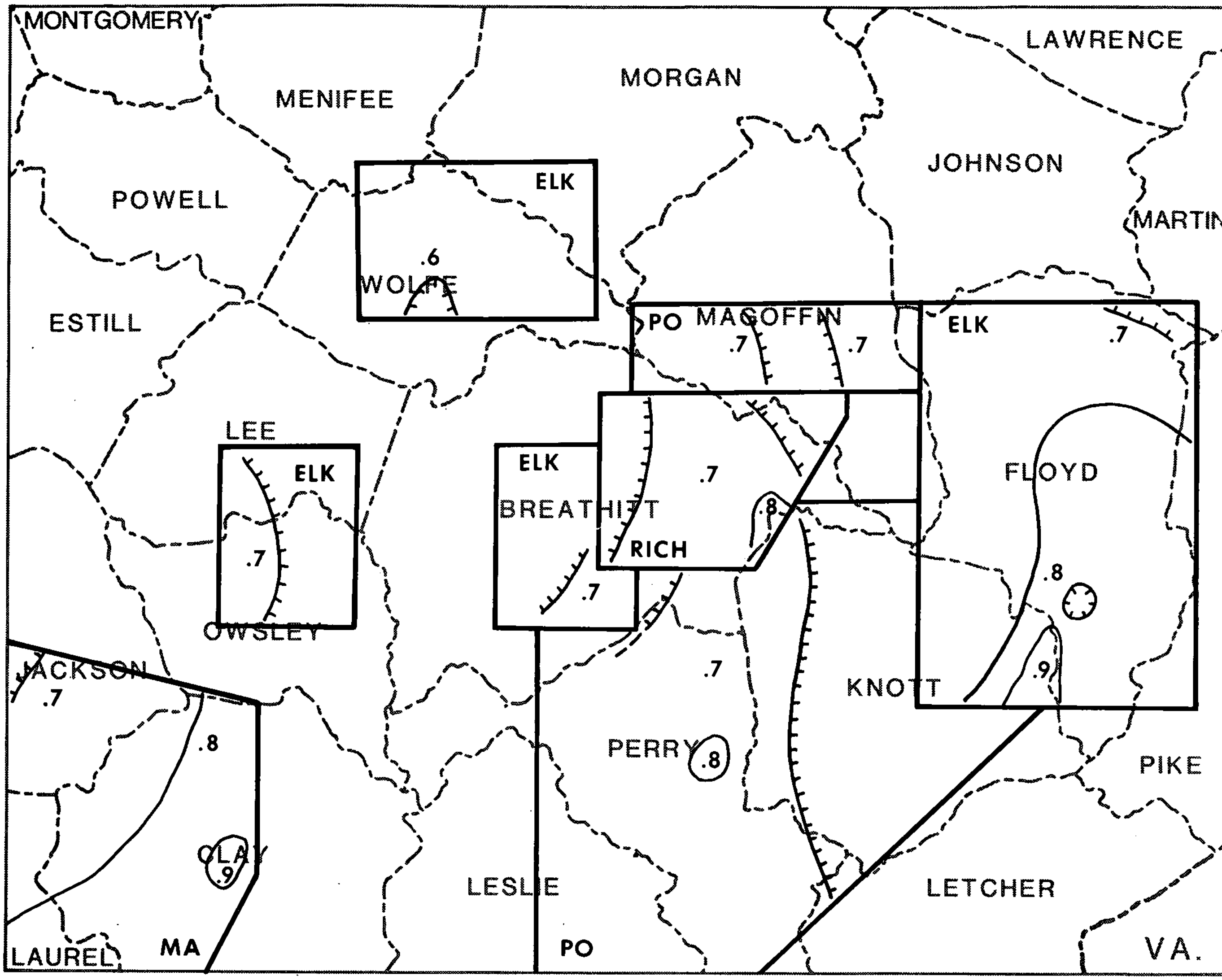

Figure 55. Composite vitrinite reflectance (R_{max}) in study area. ELK = Upper Elkhorn No. 1, 2, 3 coals; PO = Peach Orchard, Hazard No. 7, 8 coals; RICH = Richardson coal; MA = Manchester coal.

which are correlatives of the Conemaugh and Allegheny coals of Ohio, West Virginia, and Pennsylvania, are found in the Princess Reserve District of northeastern Kentucky (Hower and Wild, 1980a, 1981a). The coals included in this study range from the New Livingston coal just above the Mississippian-Pennsylvanian boundary to the Laurel coal above the Vanport Limestone (equivalent to lower Allegheny of the Northern Appalachian Coal Field).

The Richardson (Skyline) coal frequently occurs in several splits. The map of percent total vitrinite (Fig. 57a), based on averaging of split seam sections (a method not recommended except for reconnaissance analysis), shows a consistently higher total vitrinite through eastern Breathitt County.

Splits of the Broas coal correlate with the Tip Top (Hazard No. 10) and Hindman (Hazard No. 9) coals (Rice and Smith, 1980). The unsplit Broas coal was sampled at one locality (Lancer Quadrangle, Floyd County). The relatively high and low total vitrinite percentages from the upper and lower benches of the Broas coal continue to the Tip Top and Hindman coals. The Hindman coal is the highest coal in the roadcut (Stop 6) in the Hazard North Quadrangle at the intersection of the Daniel Boone Parkway, Kentucky Highway 15, and Kentucky Highway 80 (northeast corner of intersection). At this location the Hindman coal is lower than average for Hindman coal in total vitrinite (61.6 percent) and in total liptinite (7.1 percent), concomitant with a high semi-fusinite percentage (15.8

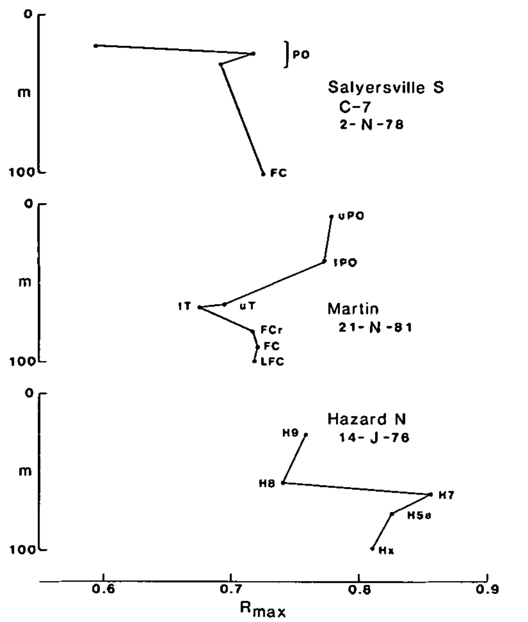

Figure 56. Vertical vitrinite reflectance (R_{max}) gradients for borehole C-7 and Stops 6 and 10. Locations by quadrangle and Carter coordinate section. PO = Peach Orchard coal; FC = Fire Clay coal; LFC = Little Fire Clay coal; T = Taylor coal; H9 = Hazard No. 9 coal; H8 = Hazard No. 8 coal; H7 = Hazard No. 7 coal; H5a = Hazard No. 5a coal; Hx = Haddix coal; u = upper; l = lower; r = rider.

percent). The low temperature ash percentage (LTA) in the Hindman appears to increase to the northeast (Fig. 58a) while sulfur exhibits an east-west low. The pyrite content of the coal ash is highly variable but decreases in the high ash samples. Marcasite is also present in the samples which are higher in pyrite. The petrographic, geochemical, and mineralogical properties of the coals in the Hazard North and Martin Quadrangles (Stops 6 and 10) are given in Tables 8-10.

Splits of the Peach Orchard coal correlate with the Francis (Hazard No. 8, Sebastin, Fugate) and the Hazard No. 7 coals (Rice and Smith, 1980). The vitrinite trends for the upper and lower benches continue to the Francis and Hazard No. 7 coals, the upper bench being slightly higher in total vitrinite. Both benches of the Peach Orchard were sampled at the roadcut along Kentucky Highway 80 in the Martin Quadrangle, where the stratigraphic position between the benches is such that the coals could be considered the Francis and Hazard No. 7 coals. At the Hazard North roadcut (Stop 6), the Francis (Hazard No. 8) coal was sampled in two benches and as a whole seam where the parting was thinner. The megascopic structure of the seam visible at the Hazard North stop (Stop 6) (roughly durain-clarain-durain) persists to the northeast along Kentucky Highway 80. The LTA of the Upper Peach Orchard-Francis coal generally increases to the southwest (Fig. 58b), with a few low ash (about 10 percent) samples in the Hazard North area. Analysis of the ash mineralogy indicates that quartz is present in all samples with little variability. Pyrite is not present in all of the Francis samples but is found in all of the Upper Peach Orchard samples. Sulfates forming from the oxidation of this pyrite are very distinctive on outcrops. The yellow sulfate masses seen are coquimbite ($Fe_2(SO)_3 \cdot 9H_2O$ and the fibrous white acicular crystals are usually melanterite ($FeSO_4 \cdot 7H_2O$, although other minerals may also be present. The illite detected in the Francis is more crystalline, possibly due to the presence of detrital mica, than in other coals. Kaolinite is abundant in the Upper Peach Orchard samples but appears to be diluted by other minerals in the higher ash Francis coal. The Hazard No. 7 coal was sampled at the Hazard North stop, where it had been deep mined (for discussion of the flora, *see* Jennings, this volume). The trends in total vitrinite on the Lower Peach Orchard-Hazard No. 7 map (Fig. 57b) are not clear. A low in total vitrinite in eastern Perry-western Knott Counties passes into a high with broad areas of poor representation. It is possible that the low of 44.8 percent may not be from a Hazard No. 7 correlative (but it cannot be discarded at the present time). The Hazard No. 7 samples with the lowest ash content contain quartz and clays to the virtual exclusion of other minerals. The clay fraction appears to be largely kaolinitic, with illite almost absent in the Lower Peach Orchard and neglible in the Hazard No. 7. Similar to the Upper Peach Orchard-Francis trends, the Lower Peach Orchard coals all contain pyrite, although it is not always present in the Hazard No. 7 coals. Siderite is present in the Hazard No. 7 samples from eastern Perry-western Knott Counties but not in the Lower Peach Orchard samples. The siderite-pyrite-marcasite zoning correlates with the vitrinite low and reflectance low to indicate a possible oxidized zone that may be related to penecontemporaneous tectonic activity (Fiene and Hower, 1981).

The Hazard No. 5a (Hazard, Prather) coal is lower in total vitrinite than most of the other major coals. The upper and lower benches were sampled at road level on the northeast corner of the Hazard North stop. There is a large petrographic variability in the composition of the benches within the Hazard North Quadrangle. The mineralogy of the ash further reflects the variability of the Hazard No. 5a coal.

The Taylor (Copland) coal was sampled in two benches at Martin (Stop 10). From the limited amount

Table 5.—Maceral Percentages (Mean (Standard Deviation)) for Coal Seams and Partial Seam Sections in Study Area.

			VITRINITE	PSEUDO VITRINITE	FUSINITE	SEMI-FUSINITE	MICRINITE	MACRINITE	EXINITE	RESINITE
Laurel		1	78.6 (---)	3.6 (---)	6.5 (---)	5.8 (---)	2.4 (---)	0.2 (---)	2.8 (---)	0.2 (---)
Richardson	unsplit	5	58.4 (6.7)	7.2 (6.1)	9.7 (1.7)	8.0 (4.4)	5.4 (1.1)	0.4 (0.3)	9.8 (2.7)	1.0 (0.9)
	upper	6	62.1 (8.3)	6.9 (4.5)	9.1 (6.3)	6.8 (4.7)	4.2 (1.6)	0.5 (0.6)	9.1 (2.1)	1.1 (1.4)
	middle	7	61.7 (6.6)	6.1 (1.7)	8.6 (3.8)	8.1 (2.9)	4.9 (1.8)	0.5 (0.3)	9.4 (2.3)	0.7 (0.7)
	lower	10	65.5 (4.4)	6.1 (2.2)	8.0 (2.8)	6.7 (2.8)	4.8 (2.1)	0.4 (0.3)	8.0 (2.0)	0.9 (0.7)
Broas	unsplit	5	58.8 (7.8)	5.3 (1.6)	12.1 (4.3)	5.9 (3.2)	7.1 (2.1)	0.2 (0.3)	10.3 (0.8)	0.1 (0.2)
	upper	1	66.7 (---)	9.7 (---)	5.2 (---)	6.1 (---)	5.1 (---)	0.2 (---)	6.5 (---)	0.5 (---)
	lower	2	63.8 (4.0)	6.1 (2.8)	8.3 (3.1)	4.8 (4.8)	4.4 (1.3)	0.5 (0.1)	12.0 (2.3)	0.3 (0.4)
Clarion		1	49.8 (---)	12.4 (---)	10.8 (---)	10.4 (---)	7.4 (---)	0.3 (---)	6.0 (---)	2.9 (---)
Hazard 10	unsplit	2	64.1 (4.0)	4.5 (1.1)	7.4 (1.6)	9.6 (2.1)	4.6 (0.6)	0.5 (0.1)	8.4 (4.3)	1.1 (0.4)
	upper	1	61.1 (---)	4.2 (---)	12.5 (---)	8.3 (---)	4.3 (---)	0.6 (---)	8.0 (---)	1.0 (---)
	lower	1	61.4 (---)	5.4 (---)	7.4 (---)	7.9 (---)	7.8 (---)	1.2 (---)	8.2 (---)	0.7 (---)
Hazard 9		8	59.7 (6.0)	5.0 (1.5)	8.4 (2.2)	9.3 (4.7)	6.8 (2.4)	0.6 (1.0)	9.0 (2.8)	1.0 (1.4)
Peach Orchard	unsplit	4	63.2 (8.4)	4.7 (1.1)	8.1 (1.3)	8.1 (6.6)	3.7 (1.3)	0.2 (0.1)	11.6 (1.3)	0.3 (0.3)
	upper	8	62.6 (9.7)	5.4 (1.9)	9.3 (4.6)	6.8 (3.9)	5.3 (1.8)	0.5 (0.6)	9.3 (3.1)	0.9 (0.9)
	middle	1	71.7 (---)	3.0 (---)	9.7 (---)	2.1 (---)	1.9 (---)	0 (---)	11.6 (---)	0 (---)
	lower	6	60.7 (10.9)	4.8 (3.9)	8.5 (4.6)	9.6 (9.6)	5.1 (2.5)	0.2 (0.2)	10.2 (5.0)	1.3 (1.1)
	rider	1	45.0 (---)	12.8 (---)	6.3 (---)	11.6 (---)	10.3 (---)	0.7 (---)	10.0 (---)	3.3 (---)
Hazard 8	unsplit	10	59.3 (6.6)	9.8 (3.2)	8.8 (4.0)	7.3 (3.4)	4.6 (1.9)	0.6 (0.4)	8.9 (2.2)	0.7 (0.5)
	upper	2	60.5 (2.3)	6.2 (1.1)	4.9 (0.1)	12.8 (4.7)	5.1 (0.8)	0.5 (0.1)	9.5 (0)	0.6 (0.1)
	middle	2	66.9 (10.9)	5.2 (1.1)	5.3 (2.6)	4.8 (5.5)	5.0 (4.7)	0.4 (0.5)	12.2 (3.5)	0.4 (0.5)
	lower	2	61.0 (3.3)	8.0 (0.3)	5.8 (0.5)	8.6 (3.4)	5.1 (1.8)	0.3 (0.4)	11.1 (4.6)	0.3 (0.1)
	rider	4	67.2 (12.4)	8.2 (6.1)	6.0 (1.6)	6.2 (9.8)	4.8 (4.2)	0.3 (0.4)	6.9 (1.4)	0.5 (0.8)
Hazard 7	unsplit	14	55.6 (5.9)	6.4 (4.1)	8.5 (3.3)	9.7 (4.0)	8.1 (1.8)	0.3 (0.2)	10.3 (1.9)	1.1 (1.5)
	rider	2	55.4 (22.3)	4.5 (1.0)	5.0 (2.2)	16.3 (14.9)	7.9 (4.8)	0.3 (0.4)	8.8 (1.3)	2.0 (2.3)
Hazard 5A	unsplit	8	55.1 (7.5)	7.5 (4.2)	8.5 (2.5)	11.3 (6.2)	7.5 (2.9)	0.4 (0.2)	8.7 (1.6)	1.1 (1.0)
	upper	5	57.8 (8.4)	11.8 (9.5)	7.4 (4.7)	6.3 (5.9)	6.5 (2.4)	0.4 (0.8)	9.4 (4.1)	0.4 (0.2)
	middle	1	49.8 (---)	3.8 (---)	11.8 (---)	15.6 (---)	7.3 (---)	0.4 (---)	10.5 (---)	0.9 (---)
	lower	5	63.8 (3.4)	6.9 (4.1)	8.8 (6.9)	4.7 (3.1)	4.7 (1.9)	0.3 (0.1)	10.8 (2.4)	0.2 (0.2)
	rider	3	60.8 (3.7)	8.6 (1.9)	5.9 (2.5)	9.1 (3.0)	6.5 (1.7)	0.7 (0.1)	7.6 (1.3)	0.9 (0.6)

of samples studied to date, no coal in the area appears to have greater variability than the Taylor, which lies at the base of the Magoffin marine zone. Of two samples from the Handshoe Quadrangle, which are of uncertain correlation and may be from the Amburgy coal (base of Kendrick Marine Shale), a lower bench sample contains 25.3 percent total vitrinite and a sample of the whole seam contains 28.3 percent total vitrinite. The whole coal sample has 39 percent fusinite. The lower bench sample has about 19 percent fusinite, 27 percent micrinite, and 21 percent total liptinite (also 62 percent ash, making its status as a coal questionable). Much of the lower bench sample from the Handshoe Quadrangle has a detrital texture (Fig. 59). The ash mineralogy has great variability; quartz, pyrite, siderite, kaolinite, and illite are present in varying extremes.

Samples of the whole coal, upper and lower benches, and the rider (two samples) were collected from the Fire Clay (Hazard No. 4) coal at Martin (Stop 10). The rider seam, thin at Martin, is mineable to the southeast (Dorton Quadrangle, Pike County) where the Fire Clay coal and rider together constitute up to 5 meters of combined coal thickness. The total vitrinite map (Fig. 57c) for the Fire Clay coal shows a low percentage of vitrinite in eastern Knott-western Floyd Counties, which may connect to a similar low on the Morgan-Magoffin county line. The southern area of low percent vitrinite coincides with a reflectance low on a composite Fire Clay-Whitesburg rank map (used in the compilation of, but not shown on, Figure 55). The relationship is complex (and not demonstrated statistically) and does not follow as clearly elsewhere. The high aluminum and low potassium percentages in the ash and the strong kaolinite X-ray intensity peaks in most samples supports a possible volcanic origin for much of the ash in the coal as well as the major parting. The sanidine- and β-quartz-

Table. 5. — Continued.

Haddix	unsplit	2	60.9 (14.6)	9.0 (4.1)	4.2 (2.8)	8.8 (7.4)	7.1 (1.6)	0.5 (0.4)	8.4 (1.2)	1.4 (0.6)
	upper	1	65.3 (---)	13.2 (---)	2.1 (---)	3.7 (---)	4.1 (---)	0 (---)	10.4 (---)	1.2 (---)
	lower	1	58.8 (---)	13.5 (---)	7.4 (---)	7.7 (---)	5.0 (---)	0.4 (---)	7.2 (---)	0 (---)
Taylor	unsplit	3	43.8 (16.4)	7.2 (7.8)	19.5 (17.1)	7.5 (6.9)	9.3 (4.1)	0.2 (0.2)	12.1 (5.0)	0.5 (0.6)
	upper	2	66.4 (7.8)	6.5 (6.6)	10.5 (14.4)	1.3 (1.3)	7.6 (2.6)	0.1 (0.1)	6.3 (3.1)	1.5 (1.8)
	lower	3	57.1 (27.7)	4.5 (4.0)	9.9 (8.2)	4.0 (3.8)	11.7 (13.3)	0.1 (0.1)	12.5 (7.2)	0.3 (0.4)
Hazard 4	unsplit	18	62.4 (7.2)	6.9 (2.8)	8.4 (4.5)	6.7 (3.7)	6.8 (2.6)	0.3 (0.3)	7.6 (2.0)	1.9 (3.9)
	upper	1	70.9 (---)	14.6 (---)	5.7 (---)	0.4 (---)	2.6 (---)	0.1 (---)	5.6 (---)	0.1 (---)
	lower	1	47.4 (---)	5.8 (---)	15.0 (---)	14.4 (---)	2.2 (---)	2.3 (---)	12.1 (---)	0.8 (---)
	rider	3	66.4 (10.0)	6.1 (3.9)	6.7 (0.8)	4.9 (2.7)	7.5 (2.5)	0.1 (0.1)	7.0 (1.1)	1.3 (0.8)
Little Fire Clay		1	66.2 (---)	8.6 (---)	4.7 (---)	4.0 (---)	6.5 (---)	0.3 (---)	6.4 (---)	3.3 (---)
Whitesburg	unsplit	6	67.8 (8.4)	9.1 (3.8)	5.0 (2.9)	5.4 (3.8)	5.0 (1.8)	0.4 (0.4)	6.8 (1.5)	0.6 (0.6)
	upper	1	64.0 (---)	16.7 (---)	6.9 (---)	2.3 (---)	3.4 (---)	0.2 (---)	6.3 (---)	0.2 (---)
	rider	2	76.7 (2.9)	7.8 (0.6)	2.0 (0.3)	1.2 (1.1)	3.9 (0.1)	0.3 (0.1)	6.9 (1.4)	1.4 (0.2)
Amburgy		6	66.0 (10.9)	11.8 (2.8)	5.0 (1.6)	5.1 (2.4)	6.8 (2.1)	0.5 (0.5)	7.8 (2.5)	0.6 (0.4)
Upper Elkhorn #3	unsplit	17	63.6 (9.0)	11.9 (6.4)	6.5 (3.2)	4.0 (3.1)	5.9 (1.8)	0.3 (0.4)	7.3 (1.8)	0.4 (0.5)
	upper	1	58.1 (--)	10.7 (---)	9.6 (---)	5.3 (---)	8.7 (---)	0.3 (---)	6.7 (---)	0.6 (---)
	lower	1	70.3 (---)	8.9 (---)	4.3 (---)	2.7 (---)	6.4 (---)	0 (---)	6.5 (---)	0.9 (---)
Upper Elkhorn #2	unsplit	10	62.9 (7.2)	11.4 (5.2)	4.0 (2.2)	5.4 (2.7)	6.2 (2.7)	1.9 (2.6)	7.8 (1.6)	0.6 (0.5)
	upper	1	74.0 (---)	4.1 (---)	7.7 (---)	1.2 (---)	3.8 (---)	0 (---)	9.2 (---)	0 (---)
	lower	1	61.5 (---)	20.1 (---)	4.0 (---)	0.9 (---)	7.5 (---)	0.1 (---)	5.7 (---)	0.2 (---)
Upper Elkhorn #1		11	69.1 (6.8)	10.5 (3.3)	4.7 (2.0)	3.1 (3.0)	4.6 (2.2)	0.1 (0.1)	7.4 (2.8)	0.4 (0.5)
Lower Elkhorn		1	62.3 (---)	13.5 (---)	6.2 (---)	1.9 (---)	7.4 (---)	0 (---)	7.5 (---)	1.2 (---)
Manchester	unsplit	20	71.4 (6.7)	6.7 (3.6)	3.7 (1.9)	4.0 (2.7)	6.5 (2.1)	0.2 (0.1)	6.7 (2.1)	0.5 (0.4)
	upper	1	64.1 (---)	9.0 (---)	4.6 (---)	8.2 (---)	5.6 (---)	0.3 (---)	7.5 (---)	1.3 (---)
	lower	1	80.7 (---)	6.0 (---)	4.5 (---)	2.2 (---)	1.3 (---)	0.1 (---)	5.2 (---)	0 (---)
Gray Hawk		6	66.9 (3.5)	9.6 (2.2)	3.9 (2.2)	5.0 (1.8)	5.6 (0.6)	0.4 (0.3)	7.9 (2.0)	0.9 (0.5)
Beattyville		2	66.8 (1.3)	7.8 (2.8)	4.9 (1.3)	6.4 (2.4)	5.1 (1.8)	0.4 (0.2)	8.3 (2.1)	0.5 (0.1)
Barren Fork		1	73.1 (---)	11.6 (---)	4.0 (---)	2.3 (---)	3.6 (---)	0.1 (---)	5.0 (---)	0.3 (---)
New Livingston	unsplit	1	68.3 (---)	14.6 (---)	4.7 (---)	4.4 (---)	4.0 (---)	0 (---)	2.7 (---)	1.3 (---)
	rider	2	73.3 (8.9)	5.5 (0.8)	4.5 (1.7)	5.1 (0.4)	2.8 (2.5)	0.1 (0.1)	7.2 (1.6)	1.6 (1.8)
Unknown	Breathitt	7	71.9 (12.1)	5.2 (2.7)	5.1 (3.5)	3.8 (5.3)	3.9 (2.2)	0.2 (0.2)	8.7 (1.7)	1.3 (1.6)
	Lee	4	71.1 (5.9)	5.9 (2.9)	6.1 (4.6)	5.7 (2.4)	4.7 (4.3)	0.1 (0.1)	6.3 (2.6)	0.5 (0.3)

bearing tonstein after which the coal is named is likely to have originated as an ash-fall deposit (Robl and Bland, 1977; Bohor and Triplehorn, this volume). In the coal ash, plagioclase and sanidine are important accessory minerals. Pyrite is present in over half of the samples and marcasite occurs in a third of the samples.

The Little Fire Clay coal, sampled to the northeast of Stop 10, is considered to be the Upper Whitesburg coal in some places. The Whitesburg coal was sampled to the northeast of the Little Fire Clay outcrop.

The Upper Elkhorn No. 3 (Little Caney, Van Lear) coal was sampled to the northeast of the Martin cut (Stop 10) and at the town of Martin in an excavation for the roadbed of Kentucky Highway 80. The coal near Martin is above average in total vitrinite (82.3 percent) and is notable in having distinctive "pseudovitrinite" (Fig. 60), a variety of vitrinite which is common in many eastern Kentucky coals. The total vitrinite map (Fig. 57d) shows a low in eastern Floyd County which corresponds with the combined Elkhorn reflectance high. The ash-sulfur map (Fig. 61a) shows an ash low in central Floyd County. There appears to be a southeast-northwest-trending low-sulfur area (0.5-1.0 percent) surrounded by a 2 to 3 percent area. As with other coals in the region, the correlation between ash and sulfur is obscure. The Upper Elkhorn No. 2 (Grassy) coal total vitrinite map (Fig. 57e) shows a possible east-west low in eastern Knott-southern Floyd Counties. Vitrinite trends for other coals are roughly north-south, but the Upper Elkhorn No. 2 trend (or any other) may be biased by insufficient data points. The ash-sulfur map (Fig. 61b) has similar trends to the Upper Elkhorn No. 3 map.

Table 6. – Geochemistry of Central-Eastern Kentucky Coals. (Standard Deviation is on Second Line.)

	Mois	Ash	VM	FC	S_t	S_{py}	S_{sulf}	S_{org}	BTU	BTU (mmmf)	SiO_2	Al_2O_3	TiO_2	Fe_2O_3T[1]	CaO	MgO	K_2O	Na_2O	P_2O_5
				(As-Received)										(Moisture-free whole coal)					
Laurel	5.13[3]	13.78	36.7	44.4	2.66	1.55	.16	.95	11630	13447	7.06	3.28	.15	3.01	.08	.11	.34	.04	.03
(1)[2]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Broas	3.52	12.50	34.63	49.33	1.19	.41	.01	.77	12070	14013	7.47	3.62	.26	.79	.07	.05	.16	.01	.01
(3)	.32[4]	3.75	2.58	1.19	.41	.31	.01	.09	599	695	2.67	1.36	.12	.40	.01	.02	.10	.01	-
Upper	2.68	6.02	37.9	53.4	.80	.34	.01	.45	13400	14363	3.26	2.06	.08	.41	.07	.06	.18	.01	.01
(1)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lower	2.13	9.32	39.3	49.2	.69	.19	.01	.49	13020	14518	5.30	3.05	.14	.26	.07	.07	.26	.02	.01
(1)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Clarion	3.74	4.26	39.1	52.9	.68	ND	ND	ND	13490	14163	2.28	1.64	.08	.09	.07	.02	.02	.01	<.01
(1)	-	-	-	-	-	ND	ND	ND	-	-	-	-	-	-	-	-	-	-	-
Tip Top	4.28	8.87	35.3	51.55	.93	.33	.03	.57	12495	13860	4.88	3.03	.18	.44	.43	.06	.18	.02	.01
(2)	1.09	4.00	.42	4.74	.28	.25	.04	.01	813	902	2.09	1.44	.03	.30	.49	.03	.11	.01	-
Hindman	3.92	14.69	35.83	45.8	1.89	.81	.05	1.03	11771	14071	8.09	4.25	.27	1.63	.16	.10	.31	.03	.04
(7)	1.04	7.48	2.48	5.19	1.12	.59	.05	.62	1206	1442	5.21	2.33	.15	1.12	.03	.05	.30	.02	.03
Peach Orchard																			
Unsplit	4.54	12.25	34.57	48.67	1.04	.38	.02	.66	11943	13820	6.94	3.92	.23	.77	.10	.09	.28	.03	.05
(3)	1.42	3.37	1.97	.45	.37	.47	.01	.01	326	377	1.90	.69	.12	.60	.05	.01	.06	.02	.06
						(2)	(2)	(2)											
Upper	3.67	11.91	36.78	47.64	1.35	.41	.02	.43	12200	14061	6.57	3.63	.19	1.04	.11	.10	.29	.03	.03
(5)	1.24	2.82	1.72	3.40	1.11	.14	.01	.07	676	779	1.38	.63	.07	1.25	.03	.03	.09	.01	.02
						(3)	(3)	(3)											
Lower	3.56	11.31	36.35	48.80	1.35	.39	.02	.68	12320	14092	6.23	3.10	.24	1.54	.12	.06	.17	.02	.01
(4)	.74	4.03	1.61	2.50	.65	.42	.02	.08	610	698	3.35	1.17	.18	.76	.10	.02	.07	.01	-
						(2)	(2)	(2)											
Francis	3.35	18.50	34.91	43.26	1.34	.46	.10	.77	11574	14556	11.06	5.37	.29	1.15	.12	.17	.57	.04	.03
(9)	1.42	9.06	4.68	5.67	1.17	.56	.21	.44	1363	1714	5.73	2.63	.15	1.28	.05	.10	.30	.02	.02
									(8)										
Hazard 7	3.05	10.59	37.03	49.28	.84	.25	.02	.60	12686	14372	6.00	3.16	.19	.67	.17	.08	.21	.02	.04
(12)	.76	4.80	2.63	3.00	.30	.40	.04	.11	789	894	3.19	1.22	.11	.45	.19	.04	.14	.01	.03
Hazard 5A	2.46	10.29	36.04	51.18	1.19	.50	.02	.67	12891	14556	5.52	2.84	.18	1.14	.11	.07	.21	.03	.03
(5)	.56	2.64	1.96	2.60	.46	.28	.01	.37	406	458	1.60	.81	.06	.58	.01	.03	.13	.02	.02
Haddix	1.66	14.25	33.8	50.2	.76	<.33	.01	.42	12430	14754	8.02	4.28	.21	.50	.12	.14	.48	.04	.01
(1)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

A total vitrinite low (Fig 53f), in the same place as the Upper Elkhorn No. 3 lc v, corresponds to the reflectance high. The ash-sulfur map (Fig. 61c), although based on a small number of data points, shows similar trends to the other Upper Elkhorn maps. The only exposure of the Lower Elkhorn coal sampled to date is on Kentucky Highway 80 near Maytown in southern Floyd County.

The Manchester (Lily, Zachariah, Colony) coal, the only coal well represented in the southwestern portion of the study area, was the subject of a chemical and mineralogical study by Cole and Williams (this volume). The rank (reflectance) decreases to the west (edge of coal field) from a high in the Bar Creek Quadrangle, the highest rank observed in the western portion of the study area. The rank trends are roughly north-south as in the eastern part of the field. The coal is generally a high vitrinite coal with vitrinite decreasing toward the area of high rank (Fig. 57g). The inverse (although not necessarily causal) relationship between the total vitrinite percentage and the vitrinite reflectance is similar to the trend observed in the Upper Elkhorn No. 3 and Upper Elkhorn No. 1 coals.

A coal tentatively identified as the New Livingston coal (and two riders) was sampled at the roadcut on Interstate Highway 75 south of the Mt. Vernon exit. The vitrinite reflectance for the three coals averages 0.71 percent R_{max}.

The last two entries in Tables 5 and 6 represent uncorrelated Breathitt and Lee Formation coals. In most

Table 6. — Continued.

Taylor	1.98	20.76	34.75	42.55	2.03	1.06	.02	.96	11270	14644	10.87	5.47	.28	2.99	.16	.30	.75	.07	.09
(2)	.47	8.29	3.32	5.44	.62	.37	.01	.23	1344	1746	5.97	2.49	.11	.66	.01	.20	.56	.04	.06
Hazard 4	2.91	15.65	35.41	46.05	1.17	.52	.05	.64	11857	14343	8.15	4.86	.29	3.97	.17	.12	.27	.04	.02
(14)	1.31	9.67	3.68	6.57	.92	.67 (13)	.08 (13)	.26 (13)	1389	1680	4.81	3.12	.21	9.18	.17	.10	.25	.04	.01
Little Fire Clay	4.74	9.74	38.6	47.0	1.44	1.15	.08	.21	12440	13955	5.09	3.08	.12	.89	.16	.09	.27	.04	.01
(1)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Whitesburg	2.88	16.25	36.64	44.20	1.56	.70	.02	.96	11553	14094	9.22	5.04	.25	.91	.13	.15	.53	.05	.02
(5)	2.10	12.53	5.76	6.30	.73	.55 (4)	.02 (4)	.24 (4)	1859	2268	7.35	3.95	.19	.44	.09	.13	.47	.03	.03
Amburgy	2.74	10.63	38.56	48.06	2.23	1.09	.02	.73	12616	14323	4.91	2.79	.12	2.26	.12	.09	.20	.05	.03
(5)	.81	5.70	1.66	5.78	1.37	.77 (4)	.02 (4)	.51 (4)	960	1090	2.70	1.22	.07	1.86	.04	.06	.15	.02	.03
Upper Elkhorn #3	2.81	7.96	39.48	49.75	2.01	1.10	.05	.94	13107	14396	3.51	1.82	.10	1.93	.18	.08	.16	.05	.03
(13)	.54	3.14	1.85	3.83	.92	.58 (11)	.05 (11)	.39 (11)	584	641	1.64	.90	.05	1.03	.09	.03	.06	.02	.02
Upper Elkhorn #2	3.06	8.11	38.0	50.9	1.90	1.08	.03	.93	13071	14381	3.83	1.77	.10	2.55	.16	.07	.13	.02	.01
(5)	2.13	3.29	2.7	2.3	1.21	.97	.03	.55	758	834	3.48	1.06	.09	2.37	.07	.02	.03	.01	.01
Upper Elkhorn #1	3.05	7.75	38.13	51.08	2.05	1.04	.04	.97	13144	14401	3.37	2.06	.08	1.96	.12	.08	.20	.04	.02
(9)	.71	2.63	2.81	2.15	1.37	.85	.05	.54	596	653	2.03	1.00	.06	1.41	.03	.04	.15	.01	.02
Lower Elkhorn	4.08	9.99	39.5	46.4	4.77	2.27	.17	2.33	12490	14108	2.97	1.63	.08	4.32	.28	.10	.19	.05	.02
(1)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Manchester	3.96	5.25	37.41	53.36	1.50	.69	.03	.76	13349	14169	2.35	1.25	.06	1.28	.08	.05	.10	.03	.01
(7)	1.41	2.27	2.13	2.47	1.08	.73	.03	.43	721	765	.87	.39	.02	1.42	.02	.02	.05	.02	-
Gray Hawk	5.21	2.99	37.98	53.82	1.24	.56	<.01	.68	13487	13963	1.27	.75	.04	.66	.11	.02	.05	.03	.01
(6)	.72	1.51	.85	1.72	1.36	.75	<.01	.63	197	204	.44	.31	.01	.78	.05	.01	.02	.01	.03
Beattyville	2.93	6.56	40.4	50.1	2.60	1.55	.01	1.04	13310	14385	2.14	1.41	.05	2.40	.16	.05	.08	.03	.08
(1)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Barren Fork	3.84	20.29	35.3	40.6	3.27	ND	ND	ND	10740	13884	9.64	5.46	.19	4.28	.11	.18	.51	.06	.03
(1)	-	-	-	-	-				-	-	-	-	-	-	-	-	-	-	-
New Livingston	5.40	13.33	31.3	49.0	.57	ND	ND	ND	11430	13403	6.08	4.21	.11	.64	.09	.11	.25	.04	.02
(1)	-	-	-	-	-				-	-	-	-	-	-	-	-	-	-	-
Lee	4.94	8.15	38.18	48.75	2.71	.86	.11	1.74	12668	13957	3.17	1.81	.06	2.76	.10	.06	.12	.03	.02
(4)	3.56	2.23	3.14	.44	1.92	.58	.17	1.40	466	513	1.80	1.38	.03	2.15	.02	.02	.07	.02	.01
Breathitt	4.31	12.31	38.5	44.9	2.23	.92	.09	1.22	11903	13803	6.34	2.84	.17	2.42	.15	.12	.33	.04	.02
(7)	2.01	3.61	4.26	3.70	1.65	.89	.07	.72	1197	1388	2.87	1.50	.15	1.55	.07	.07	.21	.02	.02

1. Total iron calculated as Fe_2O_3
2. Number of Samples
3. Mean of Analyses
4. Standard Deviation

ND means Not Determined

cases, the individual coals are not likely to be correlated with each other.

SUMMARY

In general the major coals of eastern Kentucky do not exhibit as great a lateral consistency in rank or in maceral composition as do the major western Kentucky (Illinois Basin) coals, namely, the Western Kentucky No. 9 (Hower and Wild, 1980b), the Western Kentucky No. 11 (Hower and Wild, 1981b), and the lower Sturgis Formation coals (Trinkle and others, 1931). The correspondence between total vitrinite lows and vitrinite reflectance highs was noted for the Manchester, Upper Elkhorn No. 1, and Upper Elkhorn No. 3 coals. Similar trends could exist for other coals for which we do not yet have sufficient data points (conversely, the trends mapped may be a consequence of the distribution of data points and may not represent real trends). Similar trends were observed for the Princess No. 3 and Princess No. 7 coals where the vitrinite low and

Table 7. — Mineralogy (Percentages) of Central-Eastern Kentucky Coals. (Standard Deviation is on Second Line.)

COAL	n	LTA%	QTZ	PYR	MARC	SID	PLAG	CAL	KAOL	ILL
Tip Top	1	7.47	15	1	-	-	1	1	+++	+
		-	-	-	-	-	-	-	-	-
Hindman	6	18.18	14.5	8.5	1.7	0.5	1.2	0.2	+	+
		8.45	6.8	8.6	2.4	1.2	1.3	0.4	-	-
Peach Orchard	2	13.93	19.5	4.5	1.0	1.0	0.5	1.0	++	+
		6.14	3.5	4.9	1.4	1.4	0.7	1.4	-	-
Upper	4	13.28	11.5	-	1.0	-	0.3	-	++	+
		6.29	4.5	-	1.2	-	0.5	-	-	-
Lower	4	14.74	15.0	4.3	0.6	-	1.3	0.5	++	+
		2.91	12.7	3.0	1.3	-	0.5	1.0	-	-
Francis	9	21.72	18.0	3.1	0.9	0.6	0.8	-	+	+
		10.10	4.2	5.1	2.3	0.9	1.0	-	-	-
Hazard 7	8	12.29	16.1	3.4	0.8	2.0	0.3	0.4	++	-
		6.01	5.3	5.4	1.5	3.0	0.6	0.5	-	-
Hazard 5A	9	13.46	18.0	6.8	0.4	0.4	0.9	-	++	+
		8.48	8.3	5.0	1.1	0.7	0.6	-	-	-
Taylor	3	31.74	13.0	8.0	2.5	2.0	1.5	-	+	++
		13.99	2.8	4.2	3.5	1.4	2.1	-	-	-
Fire Clay	21	18.78	13.0	3.1	tr	0.7	1.0	0.2	++	+
		11.06	3.4	4.1	-	2.0	1.2	0.4	-	-

reflectance high occur in coincidence with an anticline (Hower and Wild, 1980a, 1981a). Variations in rank may have been influenced by the regional tectonism near the time of maximum burial. Variations in maceral composition were probably influenced by the contemporaneous environments of peat accumulation.

The influence of penecontemporaneous tectonism on sedimentation in northeastern Kentucky has been discussed in Dever and others (1977). The existence of growing structures would have influenced coal petrography, in this case increasing the inert macerals in higher areas. If the tectonism continued, the rank could also have been influenced. As noted in the discussions of the Upper Elkhorn coals, the ash and sulfur lows (although not strictly correlative) show similar between-coal trends. The ash and sulfur lows appear to coincide with the vitrinite lows and reflectance highs.

Quartz, illite, and kaolinite are ubiquitous detrital minerals and make up the largest portion of the mineral matter. An important difference between eastern and western Kentucky coals is that in eastern Kentucky the kaolinite is more crystalline, suggestive of a devitrified volcanic ash origin. The presence of β-quartz and sanidine in certain coals, both of which are high-temperature minerals common to volcanic rocks, further attests to this origin (Robl and Bland, 1977). The sulfide minerals pyrite and marcasite are present in varying degrees in all coals. However, marcasite becomes the dominant sulfide in some localities as a result of pH conditions. Carbonates are generally minor components in eastern Kentucky coals, usually occurring in concretionary form as siderite or Mg-calcite. Cleat calcite is rarely seen. Rutile, plagioclase, and orthoclase (detrital minerals), and iron and calcium sulfate (secondary oxidation products) occur as accessory minerals.

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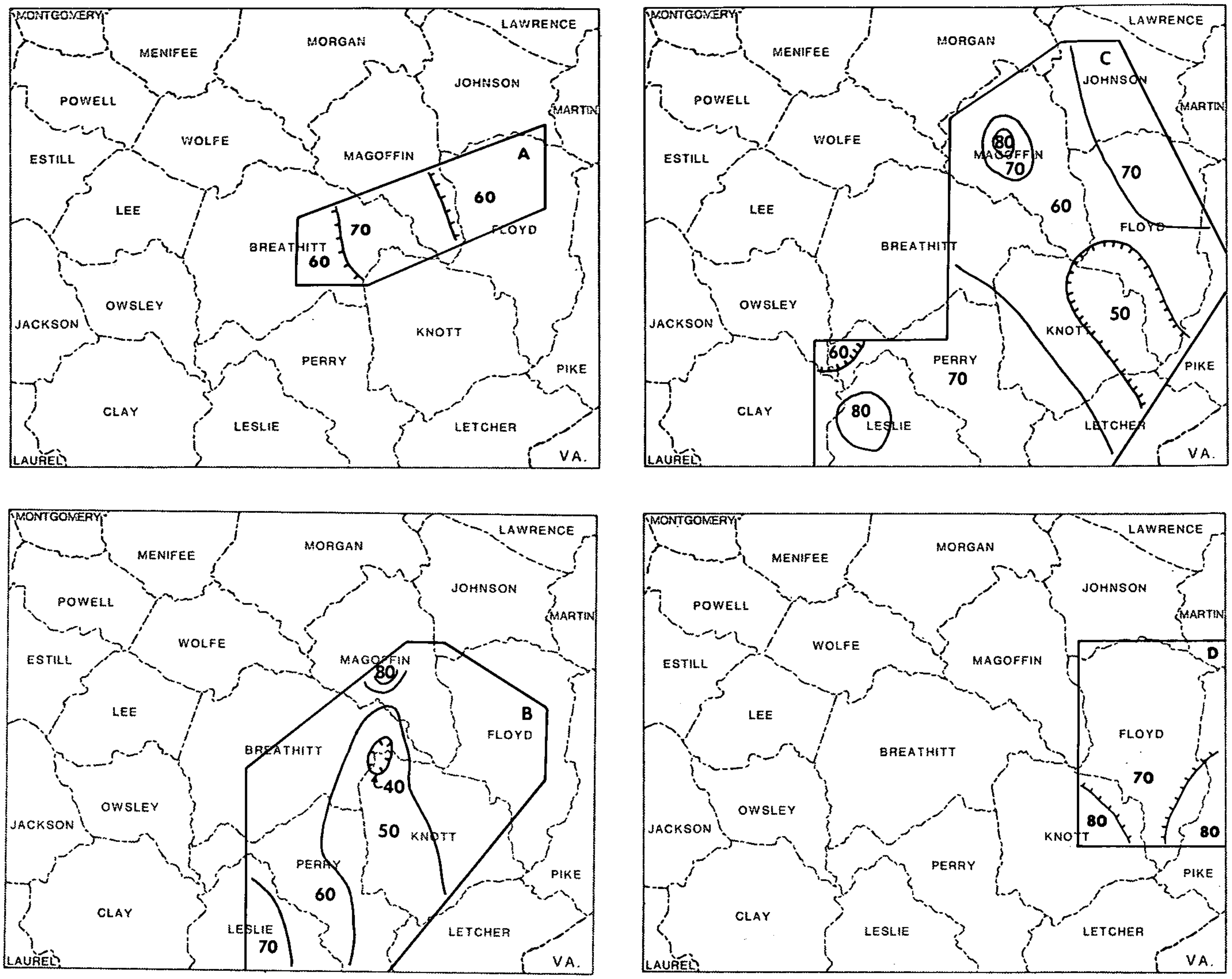

Figure 57. Total vitrinite percentages in study area. A = Richardson coal; B = Lower Peach Orchard-Hazard No. 7 coal; C = Fire Clay coal; D = Upper Elkhorn No. 3 coal; E = Upper Elkhorn No. 2 coal; F = Upper Elkhorn No. 1 coal; G = Manchester coal.

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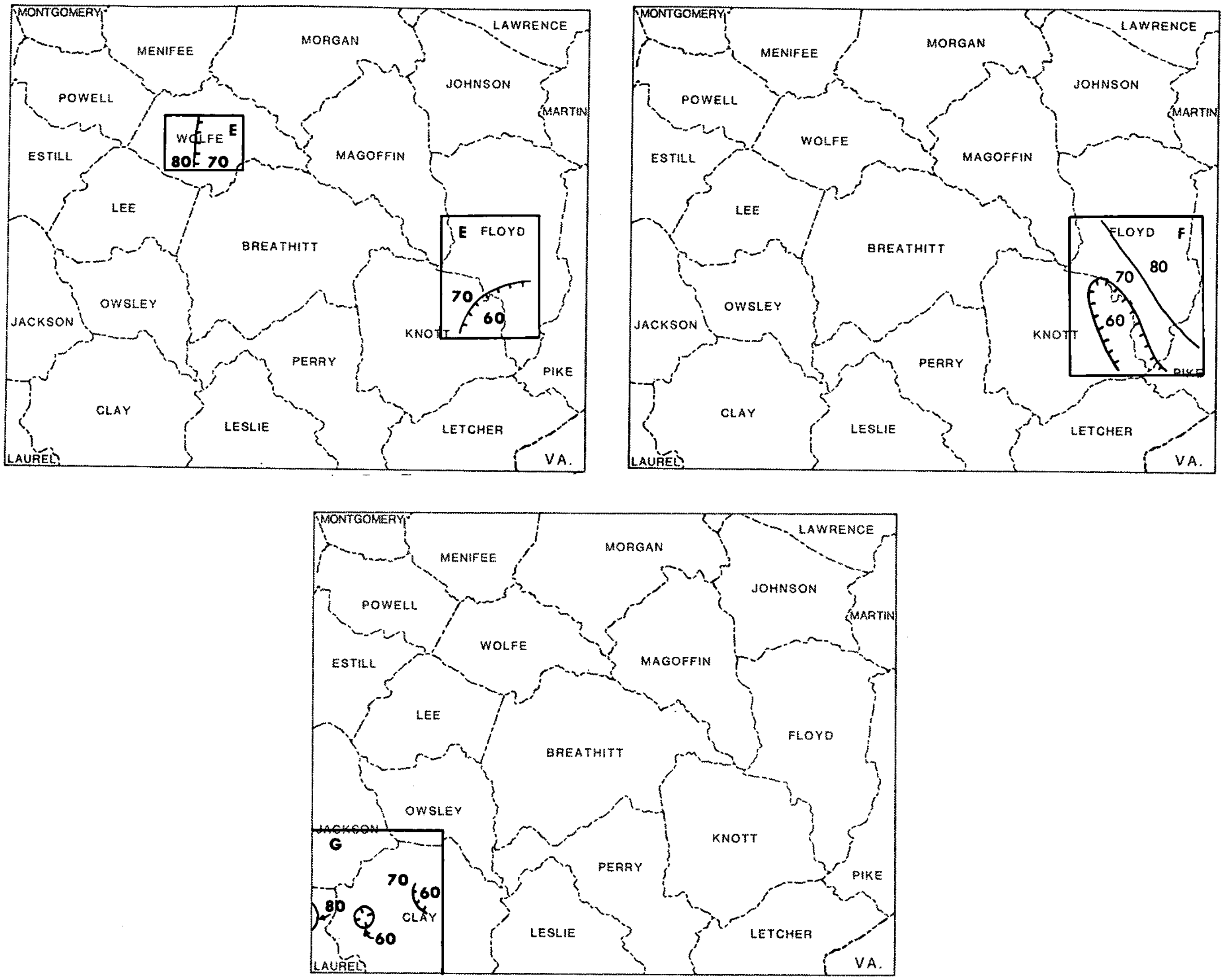

Figure 57. Continued.

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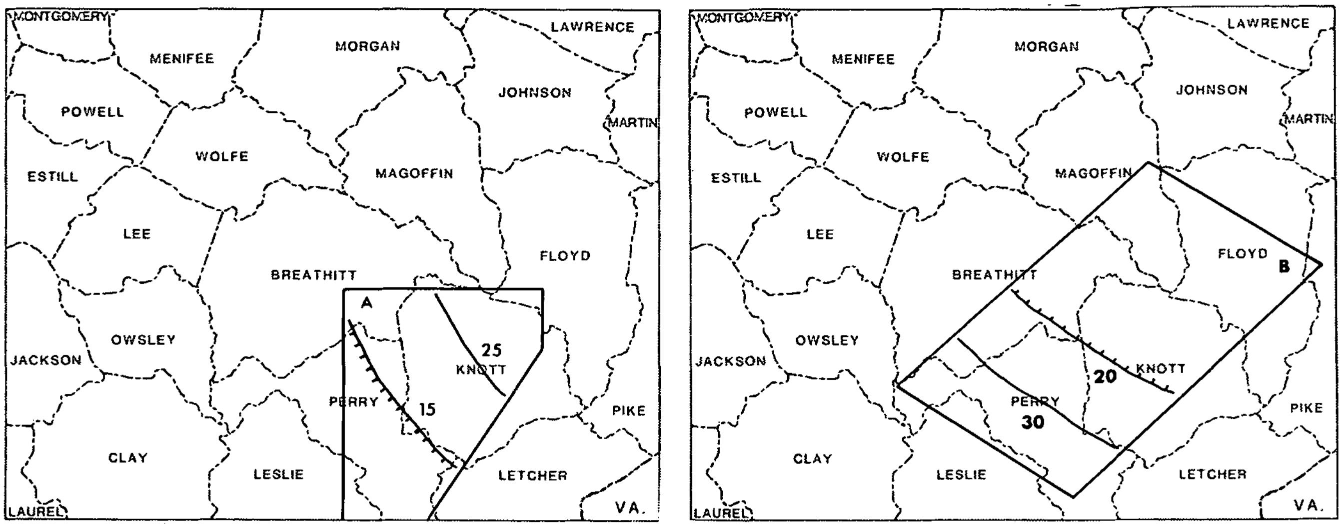

Figure 58. Low temperature ash percentages in study area. A = Hindman coal; B = Upper Peach Orchard-Francis coal.

Table 8. — Maceral Content and Maximum Vitrinite Reflectance of Coals at Stops 6 and 10.

	VITRINITE	PSEUDO-VITRINITE	FUSINITE	SEMI FUSINITE	MICRINITE	MACRINITE	EXINITE	RESINITE	R_{max}
14-J-76									
Hazard N									
Hindman	57.7	3.9	6.7	15.8	7.9	0.9	6.7	0.4	0.76
Francis	61.1	9.7	6.3	8.9	3.1	0	10.4	0.5	0.72
Upper	58.8	5.4	4.8	16.1	4.5	0.4	9.5	0.5	0.79
Lower	63.3	7.8	5.4	11.0	3.8	0.6	7.8	0.3	0.71
Hazard 7	61.8	5.2	5.6	14.3	5.0	0.6	7.5	0	0.86
Hazard 5A									
Upper	63.3	4.8	6.9	8.5	7.4	0	8.9	0.2	0.83
Lower	62.7	3.9	3.7	9.5	5.5	0.4	13.8	0.5	0.82
Haddix									
Upper	65.3	13.2	2.1	3.7	4.1	0	10.4	1.2	0.79
Lower	58.8	13.5	7.4	7.7	5.0	0.4	7.2	0	0.83
21-N-81									
Martin									
Peach Orchard									
Upper	62.4	6.3	6.0	9.6	6.9	0.5	5.8	2.5	0.78
Lower	61.6	4.1	5.5	8.5	8.8	0	9.4	2.8	0.77
Taylor									
Upper	71.9	11.2	0.3	0.3	9.4	0.1	4.1	2.7	0.64
Lower	71.7	8.1	2.4	1.9	6.2	0.1	8.8	0.8	0.68
Fire Clay									
Rider	60.9	6.6	7.1	7.6	9.3	0.2	6.1	2.2	0.73
	60.4	9.7	7.2	4.8	8.5	0.1	8.2	1.1	0.70
Upper	70.9	14.6	5.7	0.4	2.6	0.1	5.6	0.1	0.73
Lower	47.4	5.8	15.0	14.4	2.2	2.3	12.1	0.8	0.67
Unsplit	65.9	9.1	3.8	7.3	5.3	0.4	5.7	2.5	0.74
Little Fire Clay	66.2	8.6	4.7	4.0	6.5	0.3	6.4	3.3	0.72
Whitesburg	71.7	9.3	2.8	3.6	6.0	0.2	4.7	1.7	0.73
20-N-81									
U. Elkhorn #3	62.1	14.1	4.5	3.3	8.5	0.3	6.7	0.5	0.76
I-M-81									
U. Elkhorn #3	71.1	11.2	2.6	2.5	6.2	0.1	5.1	1.2	0.86

Table 9. – Geochemistry of Coals at Stops 6 and 10.

	Mois	Ash	VM	FC	S_t	S_{py}	S_{sulf}	S_{org}	BTU	BTU (mmmf)	SiO_2	Al_2O_3	TiO_2	Fe_2O_3T[1]	CaO	MgO	K_2O	Na_2O	P_2O_5
				(As-Received)							(Moisture-free whole coal)								
14-J-76																			
Hazard N																			
Hindman	4.63[2]	10.63	36.3	48.4	1.52	.79	.13	.60	12240	13885	6.25	3.26	.21	.63	.14	.08	.22	.04	.02
Francis	4.58	23.85	32.4	39.2	4.13	1.61	.64	1.88	10140	13824	13.24	5.48	.29	4.25	.21	.27	.68	.05	.04
Upper	4.13	26.40	30.7	33.8	1.23	.51	.19	.53	9860	13919	16.13	7.18	.38	1.68	.15	.27	.82	.07	.06
Lower	3.94	15.15	38.2	42.7	5.74	2.12	.49	3.13	11680	14113	5.85	2.53	.10	5.93	.21	.15	.35	.06	.02
Hazard 7	4.59	16.69	31.8	46.9	.90	.22	.11	.57	11410	13991	10.53	4.52	.29	.93	.08	.17	.46	.04	.03
Hazard 5A																			
Upper	4.62	12.25	35.3	47.8	.79	.19	.06	.54	12250	14171	7.78	3.30	.20	.46	.18	.12	.27	.04	.07
Lower	3.56	10.27	37.0	49.2	1.13	.56	.05	.51	12760	14403	6.61	2.53	.21	.58	.10	.07	.24	.02	.01
Haddix																			
Upper	4.11	28.33	30.9	36.7	1.37	.34	.14	.89	9640	14032	16.24	8.78	.36	1.73	.12	.34	1.12	.11	.11
Lower	5.04	11.89	34.1	49.0	1.13	.42	.04	.57	12120	13962	7.03	3.71	.24	.58	.11	.13	.46	.04	.02
21-N-81																			
Martin																			
Peach Orchard																			
Upper	5.58	12.77	34.7	46.9	.80	.42	.03	.35	11870	13823	7.99	3.81	.26	.56	.11	.09	.29	.02	.01
Lower	13.57	11.89	38.8	35.7	.58	.20	.02	.36	9590	11040	6.86	4.18	.26	.93	.32	.24	.29	.02	.02
Taylor																			
Upper	2.58	9.52	45.3	42.6	4.09	1.97	.07	2.05	13000	14587	2.46	2.24	.03	3.65	.32	.06	.05	.02	.04
Lower	3.34	9.19	43.4	44.1	5.19	2.58	.21	2.40	12910	14445	1.95	1.02	.05	5.24	.25	.06	.10	.04	.01
Hazard 4																			
Rider	4.64	7.57	39.5	48.3	.99	.77	.05	.17	12740	12912	4.19	2.36	.13	.56	.13	.06	.18	.03	.03
(2)[3]	.35[4]	1.77	1.4	-	.02	.01	-	.02	57	58	1.17	.43	.04	.08	.01	.01	.04	.01	.02
Upper	2.43	31.65	29.7	36.2	.98	.39	.01	.58	9550	14673	18.08	9.85	.37	1.70	.15	.50	1.91	.11	.02
Lower	1.51	49.39	24.5	24.6	.36	.03	.01	.32	6300	13805	27.74	17.88	.95	.73	.17	.21	.68	.06	.05
Little Fire Clay	4.74	9.74	38.6	47.0	1.44	1.15	.08	.21	12440	13955	5.09	3.08	.12	.89	.16	.09	.27	.04	.01
Whitesburg	2.08	4.56	42.4	50.9	2.68	1.34	.04	1.30	13800	14570	2.45	1.52	.06	.24	.05	.03	.10	.03	<.01
1-M-81																			
Upper Elkhorn #3	2.22	4.06	36.8	56.9	.96	.61	.01	.34	13610	14261	1.74	1.31	.05	.40	.13	.06	.17	.05	.01
20-N-81																			
Upper Elkhorn #3	2.52	4.56	42.0	50 9	1.92	.65	.11	1.16	13720	14474	1.38	.73	.04	1.94	.10	.04	.09	.01	.01

1. Total iron calculated as Fe_2O_3
2. Mean
3. Number of Samples
4. Standard Deviation

Table 10. – Mineralogy of Coals at Stops 6 and 10.

	LTA%	QTZ	PYR	MARC	SID	PLAG	CAL	SUL	KAOL	ILL
Martin										
Fire Clay	21.01	13	-	-	-	-	-	-	++	-
Upper	35.65	16	4	-	3	4	-	-	+	++
Lower	58.39	12	-	-	-	-	-	-	++	
Hazard N										
Hindman	12.91	16	2	1	-	-	-	-	++	-
Francis	31.29	16	8	7	-	-	-	-	±	+
Upper	30.97	19	3	-	tr	1	-	-	+	++
Lower	20.54	14	21	16	-	-	-	-	-	-

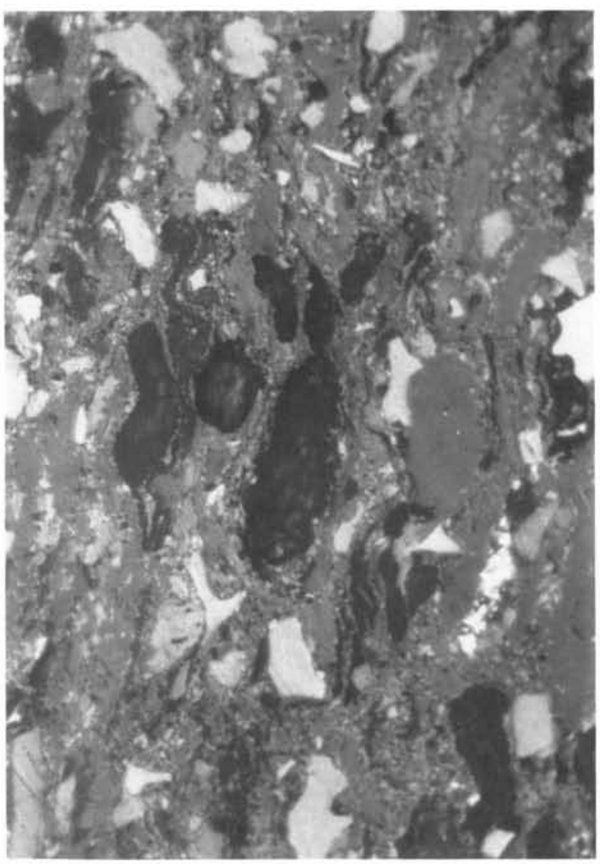

Figure 59. Detrital lithotype typical of the Taylor (Copland) coal in the Handshoe Quadrangle (KCER-4111).

Figure 60. "Pseudovitrinite" in the Upper Elkhorn No. 3 coal at Martin, Floyd County (KCER-3183).

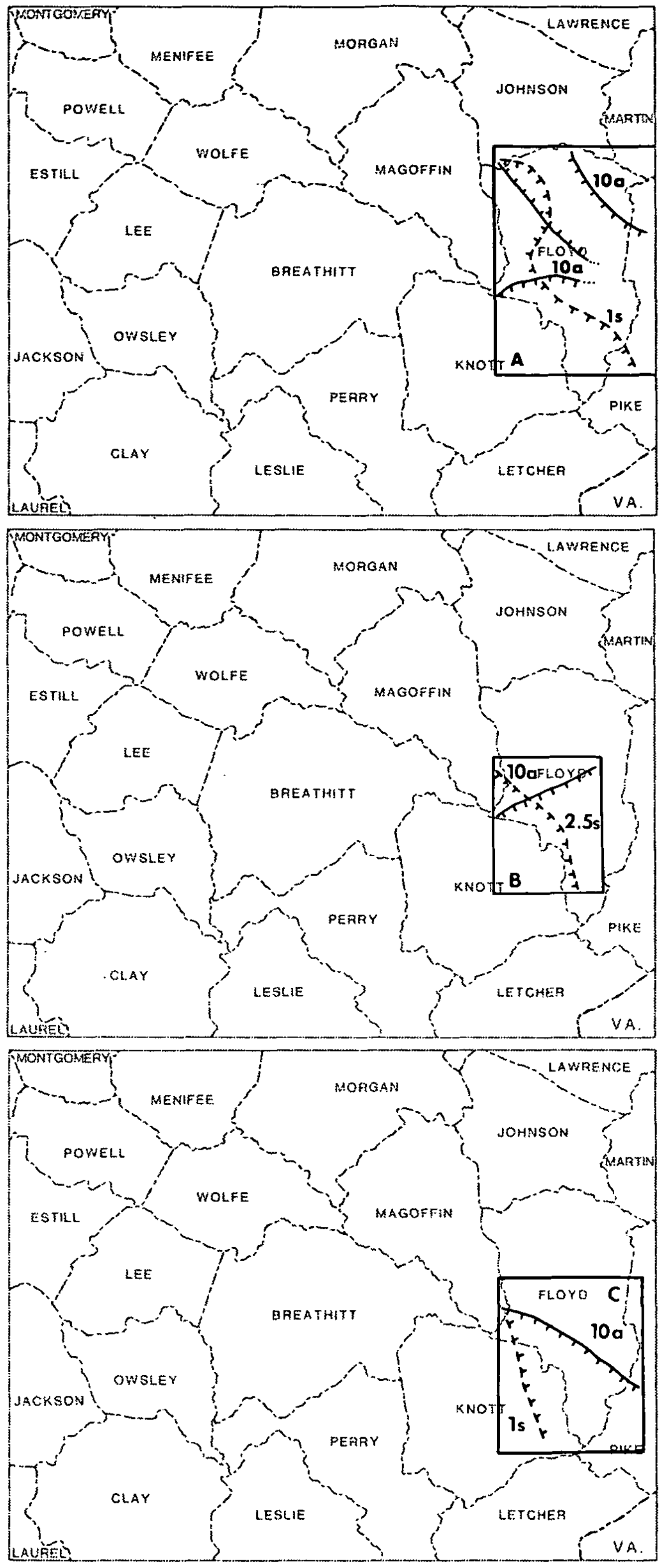

Figure 61. High temperature ash and total sulfur per centages in study area. A = Upper Elkhorn No. 3 coal; B = Upper Elkhorn No. 2 coal; C = Upper Elkhorn No. 1 coal.

PENNSYLVANIAN PLANTS OF EASTERN KENTUCKY: COMPRESSION FOSSILS FROM THE BREATHITT FORMATION NEAR HAZARD, KENTUCKY

James R. Jennings
Eastern Kentucky University

Despite the importance of fossil plants for correlation of coal deposits and for understanding their origin, very little information dealing with fossil plants of eastern Kentucky is currently available. Nearly all the work done previously concerns the comparative morphology of plant petrifactions preserved in coal-balls at three collecting sites (Brack, 1970, 1978; Frankenberg and Eggert, 1969; Good, 1971, 1975, 1977; Good and Taylor, 1970; Mickle, 1980; Millay and Taylor, 1977, 1978; Phillips and Chesnut, 1980; Rothwell, 1971; Rothwell and Taylor, 1971a, 1971b; Stubblefield and Rothwell, 1980; Taylor, 1967a, 1967b, 1969; Taylor and Stockey, 1976). Floral lists published by Lesquereux (1861) and Bode (1958) together with a few specimens described by White (1943) are the only studies in the older literature that deal with specimens of fossil plants from eastern Kentucky. Recently, studies by Spurgeon and Jennings (in press) have dealt with fossil plants from the clastic strata associated with a bed called the Jellico coal in eastern Kentucky. This report deals with fossil plants in the vicinity of Hazard, Kentucky.

The following sites have been examined in detail:

1. a. Shale and siltstone above the Hazard No. 7 coal at the junction of Kentucky Highways 80 and 15 (Carter coordinate location 14-J-76, 1,900 ft. FSL x 1,250 ft. FEL, Hazard North Quadrangle).
   b. Shale and siltstone above and parting within the Hazard No. 8 coal at the junction of Kentucky Highways 80 and 15 (Carter coordinate location 14-J-76, 1,900 ft. FSL x 1,250 ft. FEL, Hazard North Quadrangle).
2. Shale above an unnamed coal (informally known as the Hazard No. 8 1/2 or No. 8 rider) between the Hazard No. 8 and Hazard No. 9 coals in cut along Kentucky Highway 80, 0.7 mile east of junction with Ken tucky Highway 15 (Carter coordinate location 13-J-76, 3,725 ft. FSL x 3, 875 ft. FEL, Hazard North Quadrangle).
3. Siltstone and sandstone above the Hazard No. 7 coal in cut along Kentucky Highway 80, 1.1 mile east of junction with Kentucky Highway 15 (Carter coordinate location 13-J-76, 5,050 ft. FSL x 2,075 ft. FEL, Hazard North Quadrangle).
4. Sandstone and siltstone above the Hazard No. 7 coal along Kentucky Highway 80, 1.9 miles east of junction with Kentucky Highway 15 (Carter coordinate location 9-J-76, 775 ft. FSL x 3,300 ft. FEL, Hazard North Quadrangle).
5. Shale in parting in the Hazard No. 7 coal in cut along Kentucky Highway 80, 2.2 miles east of junction with Kentucky Highway 15 (Carter coordinate location 9-J-76, 1,250 ft. FSL x 100 ft. FEL, Hazard North Quadrangle).
6. Shale above Hazard No. 8 coal in cut along Kentucky Highway 80, 4.9 miles east of junction with Kentucky Highway 15 (Carter coordinate location 25-K-77, 2,200 ft. FSL x 2,950 ft. FEL, Hazard North Quadrangle).
7. Shale above Hazard No. 8 coal in cut along Kentucky Highway 80, 5.2 miles east of junction with Kentucky Highway 15 (Carter coordinate location 25-K-77, 775 ft. FSL x 1,525 ft. FEL, Hazard North Quadrangle).
8. Shale associated with unnamed coal (Hazard 5A coal zone) below the Hazard No. 7 coal exposed in cut along Kentucky Highway 80, 5.7 miles east of junction with Kentucky Highway 15 (Carter coordinate location 24-K-77, 2,150 ft. FSL x 4,325 ft. FEL, Hazard North Quadrangle).
9. Shale above Hazard No. 7 coal exposed in strip mine (Carter coordinate location 12-I-76, 750 ft. FSL x 2,700 ft. FEL, Hazard South Quadrangle).

The fossil plants near Stops 6 and 7 of the field trip near Hazard (Plates 22-25) occur in clastic lithologies, primarily as casts or impressions of rooting organs that

PLATE 22

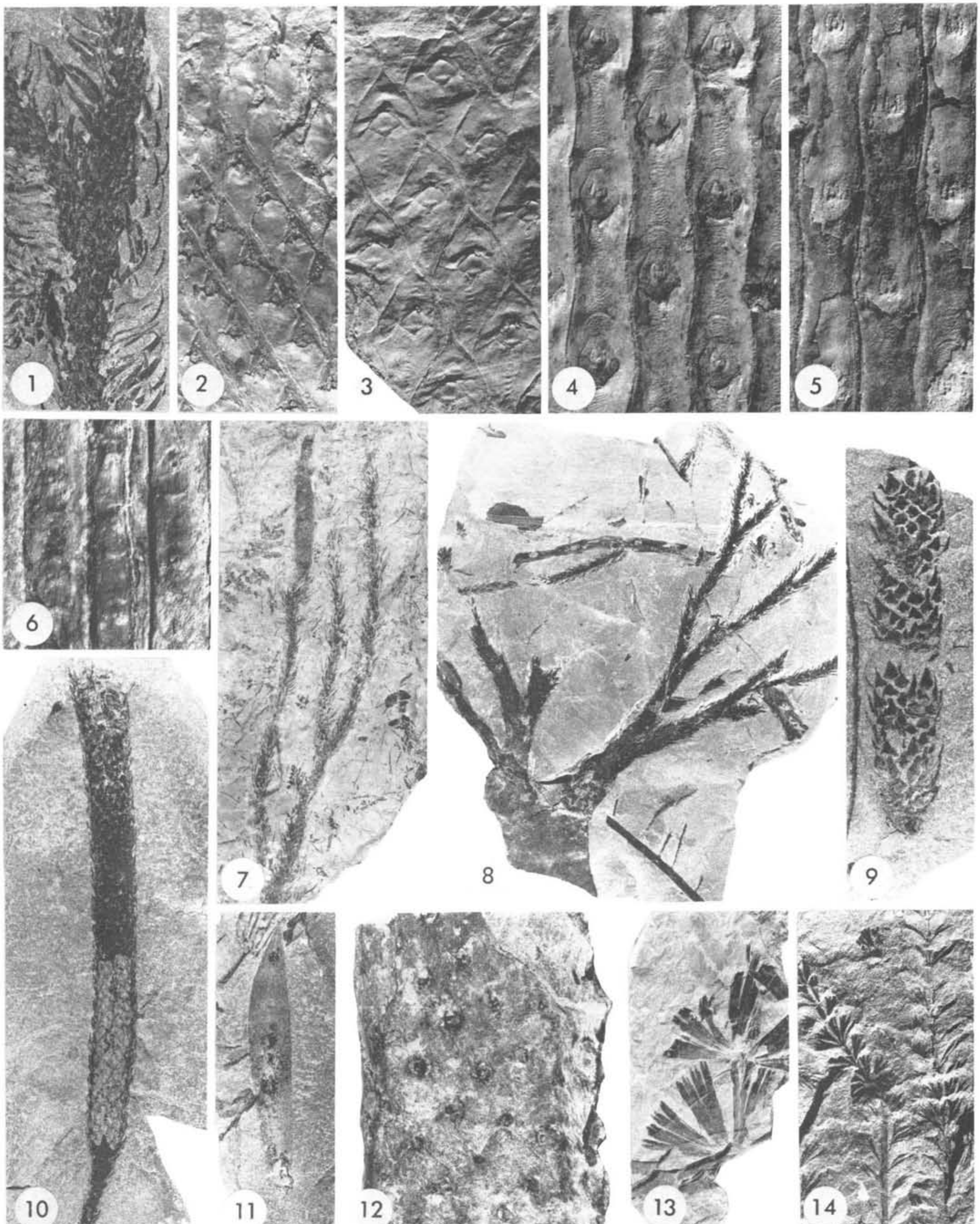

Plate 22. Fossil plants near Stops 6 and 7, near Hazard, Kentucky.

Figure 1. *Lepidodendron* sp. with attached leaves. X1 (site 1a).

Figure 2. *Lepidodendron* cf. *L. aculeatum*. X1 (site 1a).

Figure 3. *Lepidodendron aculeatum*. X1 (site 5).

Figure 4. *Sigillaria rugösa*. X1 (site 5).

Figure 5. *Sigillaria rugosa*, the counterpart of the specimen illustrated in Figure 4, showing a *Syringodendron*-type subsurface pattern. X1 (site 5).

Figure 6. *Sigillaria* cf. *S. ovata*. *X1 (site 1a).*

Figure 7. *Lepidodendron* sp. with attached cone (cf. *Lepidostrobus ornatus*). X0.25 (site 3).

Figure 8. *Bothrodendron minutifolium*. X0.5 (site 1a).

Figure 9. *Lepidostrobus* sp. X1 (site 1a).

Figure 10. Lycopod cone attached to foliage like that of *Bothrodendron*. X0.8 (site 1a).

Figure 11. *Lepidostrobophyllum lanceolatum*. X1 (site 1a).

Figure 12. *Stigmaria ficoides*. X1 (site 1a).

Figure 13. *Sphenophyllum majus*. X1 (site 1a).

Figure 14. *Sphenophyllum cuneifolium*. X1 (site 1a).

PLATE 23

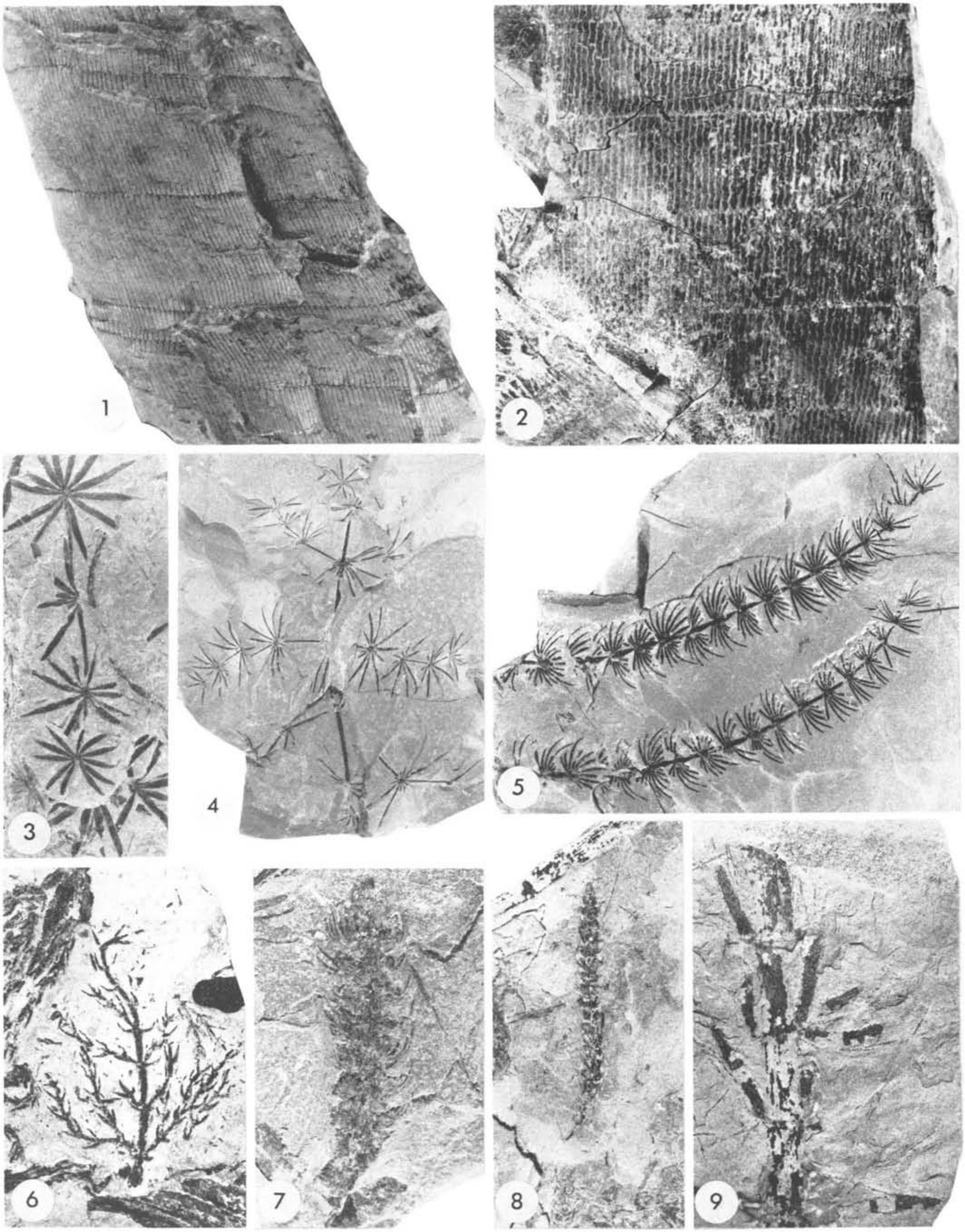

Plate 23. Fossil plants near Stops 6 and 7, near Hazard, Kentucky.

Figure 1. *Calamites cistii.* X0.5 (site 3).

Figure 2. *Calamites undulatus.* X0.5 (site 5).

Figure 3. *Annularia radiata.* X1 (site 2).

Figure 4. *Annularia radiata.* X0.5 (site 3).

Figure 5. *Asterophyllites equisetiformis.*

Figure 6. *Asterophyllites charaeformis.* X2 (site 7).3

Figure 7. *Calamostrachys germanica.* X2 (site 1a).

Figure 8. *Paleostachys elongata.* X1 (site 5).

Figure 9. *Paracalamostachys* sp. attached to the parent stem. X1 (site 3).

PLATE 24

Plate 24. Fossil plants near Stops 6 and 7, near Hazard, Kentucky.

Figure 1. *Pecopteris pennaeformis.* X1 (site 1a).

Figure 2. *Alloiopteris tenuissima.* X1 (site 8).

Figure 3. *Mariopteris* cf. *M. hirta.* X1 (site 7).

Figure 4. *Mariopteris* cf. *M. hirta.* X1 (site 1a).

Figure 5. *Neuropteris tenuifolia.* X0.5 (site 1a).

Figure 6. *Neuropteris tenuifolia.* X1 (site 1a).

Figure 7. *Neuropteris rarinervis.* X0.5 (site 3).

Figure 8. *Linopteris (Reticulopteris)* cf. *L. muensteri.* X1 (site 3).

Figure 9. *Linopteris (Reticulopteris* cf. *L. muensteri.* X2.0 (site 3).

Figure 10. *Alethopteris serlii.* X0.5 (site 9).

Figure 11. *Alethopteris arberi.* X1 (site 1a).

PLATE 25

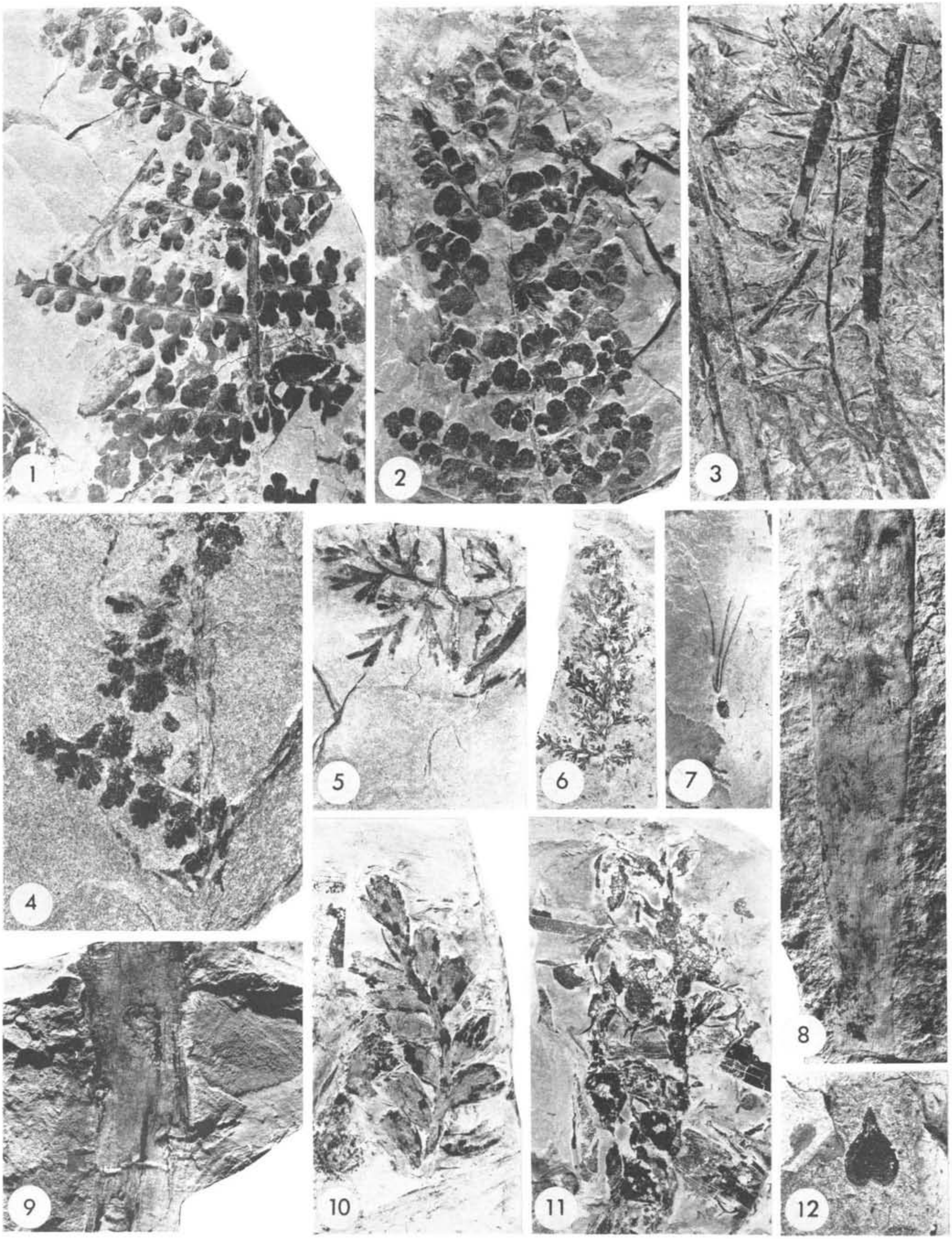

Plate 25. Fossil plants near Stops 6 and 7, near Hazard, Kentucky.

Figure 1. *Sphenopteris striata.* X1 (site 1a).

Figure 2. *Sphenopteris* cf. *St. striata.* X1 (site 1b).

Figure 3. *Sphenopteris ("Rhodea") subpetiolata.* X1 (site 1a).

Figure 4. *Sphenopteris footneri.* X2.0 (site 1b).

Figure 5. *Sphenopteris (Palmatopteris) furcata.* X1 (site 5).

Figure 6. *Sphenopteris souichi.* X1 (site 8).

Figure 7. *Gnetopsis anglica.* X1 (site 1a).

Figure 8. *Cordaites principalis.* X1 (site 8).

Figure 9. *Cordaicladus* sp. X1 (site 8).

Figure 10. *Cordaienthus major.* X1 (site 8).

Figure 11. *Cordaianthus* cf. *C. lindleyi,* bearing attached ovules. X1 (site 8).

Figure 12. *Cordaicarpus* sp. X1 (site 8).

penetrate bedding planes; as upright stumps; and as compressions preserved along bedding planes. The rooting organs are preserved primarily just below the coals, but some of the siltstones and sandstones overlying the coals contain a few rooting structures that penetrate bedding planes. Not surprisingly, many of these are associated with upright stumps. Indeed, some of the stumps (Fig. 62) bear large, intact roots that penetrate the siltstone. It is therefore clear that plant growth did not cease simultaneously with the termination of peat deposition everywhere in the Hazard area. The apparent scarcity of upright stumps in the comparatively fine-grained lithologies seems to suggest that close proximity to a source of terrigenous clastics was necessary for continued plant growth.

In the Hazard area, the most easily identified plant fossils are compressions preserved along the bedding planes of shales and siltstones that lie immediately above coal beds or form partings in a coal bed. The lower contact of these clastic bodies is frequently gradational, and its content of carbonaceous plant fossils decreases progressively upward. These plant fossils are allochthonous, but it seems highly unlikely, in view of their excellent preservation and the localized occurrence of many plant taxa, that many of the fossil plants could have been derived from a source outside the basin of deposition. The gradational lower contact of many of the shales and siltstones above the coals suggests strongly that the dominant source of the plant material in these strata was simply part of a peat swamp located farther up the paleoslope, an interpretation similar to that suggested by Richardson (1969) for the Francis Creek Shale, which is also a gray shale overlying a coal. The presence of the indigenous stumps and rooting organs indicates that environments other than swamps contributed to the flora preserved in the shales and siltstones. There is no obvious field evidence indicating a consistent succession of plants in a vertical section overlying a coal bed, a finding which corresponds to observations by Spurgeon and Jennings (in press) in strata above a coal identified as the Jellico coal.

Figure 62. Upright cast of *Calamites* with attached roots penetrating the surrounding matrix. X1/4.

Table 11 shows the occurrences of plant taxa found at each of the 10 collecting sites near the Hazard area. The flora of the Hazard area includes a diversity of lycopods, arthrophytes, ferns, seed ferns, and cordaiteans. The large, upright calamiteans are of particular interest, because they show that the large aerial shoot had the capacity to produce large roots (Fig. 58). Rhizomes appear to have been present, but may not have been necessary in a supportive function.

Many of the plant fossils in the Hazard area are forms that can be useful for purposes of correlation. The flora at Hazard is radically different from floras of the upper Pennington and lower Breathitt, which contain *Neuropteris pocahontas* and *Sphenopteris hoeninghausi*, species characteristic of Westphalian A, as their most abundant elements. The flora attributed to the Jellico coal is much more like the flora of the Hazard area; however, *Ulodendron majus*, *Asterophyllites longifolius*, *Paleostachya pedunculata*, and *Neuropteris heterophylla* have not been found at Hazard, and *Sigillaria rugosa*, *Sphenophyllum majus*, *Annularia radiata*, *Asterophyllites equisetiformis*, *Neuropteris rarinervis*, *Linopteris (Reticulopteris)* sp., *Alethopteris serlii*, *Sphenopteris striata*, and *S. subpetiolata* have not been found associated with the Jellico coal. These differences in the floras are consistent with a later age for the coals at Hazard, as suggested by lithostratigraphic interpretations (Smith and Rice, 1980).

When fossil plants of the Hazard area are compared with the stratigraphic ranges determined by European workers (Crookall, 1932, 1955, 1962, 1964, 1966, 1969, 1970, 1972; Kidston, 1923a, 1923b, 1923c, 1923d, 1925; Patteisky, 1957; Van Amerom, 1975; Wagner, 1965, 1968), their age can be established as Westphalian B, the only interval in which all of the ranges overlap. North American floras are not as well-known as European floras, but age equivalents exist in the Kanawha Formation of West Virginia (Gillespie and Pfefferkorn, 1979) and in the lower Tradewater Formation of western Kentucky.

ACKNOWLEDGMENTS

The author thanks Dr. N. C. Hester for suggesting this project, and Mr. D. Chesnut for contributing the specimen illustrated in Plate 22, Figures 4 and 5. Thanks

Table 11. — Occurrence of Fossil Plant Taxa in the Hazard Area.

	Collecting site									
	1a	1b	2	3	4	5	6	7	8	9
Lepidodendron aculeatum	x		x	x	x	x				
Sigillaria rugosa						x				
S. cf. *S. ovata*	x									
Bothrodendron minutifolium	x	x	x							x
Lepidostrobus sp.	x		x	x						
L. cf. *L. ornatus*	x			x						
Stigmaria ficoides	x	x		x		x				
Sphenophyllum majus	x						x			x
S. cuneifolium	x	x	x			x		x	x	
Calamites cistii	x	x	x	x	x	x	x			x
C. undulatus						x				
Annularia radiata	x	x	x	x		x		x		x
Asterophyllites equisetiformis	x									
A. charaeformis		x	x			x	x	x		
Calamostachys germanica	x									
Paleostachya elongata						x				
Paracalamostachys sp.				x						
Pecopteris pennaeformis	x	x	x					x	x	x
Alloiopteris tenuissima									x	
Mariopteris cf. *M. hirta*	x		x				x	x		
Neuropteris tenuifolia	x	x	x			x	x	x		
N. rarinervis	x		x	x	x	x		x	x	
Linopteris (Reticulopteris) sp.	x			x						
Alethopteris serlii	x					x				x
A. arberia	x									
Sphenopteris footneri		x								
S. (Palmatopteris) furcata						x				
S. souichi							x		x	
S. striata	x	x				x				
S. ("Rhodea") subpetiolata	x					x	x	x		
Trigonocarpus sp.						x				
Gnetopsis anglica	x									
Cordaites principalis					x				x	
Cordaicladus sp.									x	
Cordaianthus major		x							x	
C. cf. *C. lindleyi*									x	
Cordaicarpus sp.	x	x							x	

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THE MAGOFFIN MEMBER

Raphael V. Ketani
Exlog-Monaco

Roadcut outcrops of the Magoffin Member along the Daniel Boone Parkway in Leslie, Perry, and Knott Counties, Kentucky, consist of a thick sequence of calcareous silty shale, clayey siltstone with sandstone, thin limestone beds, large lenticular limestone concretions, siderite layers and nodules, and coal at the base. The very thinly bedded clayey siltstone with euryhaline fossil assemblages suggests deposition in the quiet subtidal environment of the interdistributary bay under conditions of good circulation and normal to slightly less than normal marine salinity.

Very thin to thick beds of sandstone, usually occurring in the upper part of the Member, occasionally exhibit planar and trough crossbedding. Invertebrate fossils (Chesnut, this volume) and burrows are present in some beds. The sands may have been deposited as delta front beds of distributary mouth bars, as crevasse splays, or perhaps as delta slope beds.

The limestone beds, thin to medium in thickness and often pinched-out, have a packstone texture of fossil fragments in an argillaceous micritic matrix. Brachiopods, bivalves, and echinoderms are the most common fossils and occur along with other euryhaline and stenohaline fossils. Bioturbation is most likely responsible for generating the abundant fossil fragments. The fine matrix and fauna suggest very low energy conditions in normal marine salinity, and probably deposition in the distal portion of the interdistributary bay.

Often one or more zones of large, lenticular limestone bodies (concretions?) occur in the clayey siltstone, usually above the limestone bed. The texture of these concretions varies from mudstone to a wackestone with a matrix of argillaceous micrite. Cone-in-cone structures are occasionally present in the top of each concretion. Brachiopods, echinoderms, and bivalve fragments are dominant, but only nuculoid clams, ostracodes, and foraminifera are present as whole fossils. Small burrows are common. The low diversity of the dominantly molluscan assemblage suggests that the salinity was low or even that the water was brackish (Stevens, 1966). The origin of these concretions is problematic.

Very thin siderite layers and layers of small siderite nodules are frequently present in the marine zone. Occasional brachiopod fragments and whole and fragmental fossils of nuculoid clams, ostracodes, gastropods, and foraminifera comprise the fauna, which is euryhaline in character (Stevens, 1966).

To the north in Morgan and Magoffin Counties, Kentucky, the Magoffin Member contains two fossil assemblages: the *Eolissochonetes* community and the *Linoproductus* community (Ketani, 1980). The *Eolissochonetes* community generally occurs in thin beds of very fine grained sandstone which are overlain by a thin limestone. The *Linoproductus* community is usually found in thick sequences of clayey siltstone. Eighty-six percent of the *Eolissochonetes* community consists of the brachiopod, *Eolissochonetes* 10 percent consists of the brachiopod, *Derbyia crassa*, while the remaining 4 percent consists of *Anthracospirifer* sp., a productoid, the bivalves, *Posidoniella*sp. and *Acanthopecten* sp., fenestrate bryozoan fragments, *Zoophycos* sp., and horizontal burrows.

The brachiopod, *Linoproductus* sp., makes up 33 percent of the fauna in the *Linoproductus* community. The productoid, *Desmoinesia* sp., makes up 18 percent, *Eolissochonetes* sp. contributes 15 percent, *Derbyia crassa*, 12 percent, *Anthracospirifer* sp., 9 percent, four other brachiopods, 10 1/2 percent, three bivalves, 3 percent, and *Pseudorthoceras* formed less than 1 percent. Branching bryozoans and crinoid columnals were found as fragments.

The limited diversity of the *Eolissochonetes* community, in which only one fossil is very abundant, characterizes a low grade (Johnson, 1972) opportunistic community which pioneers barren substrates during episodes of marine incursion (Rollins and Donahue, 1975). A wide variety of taxa and the absence of disproportionately abundant genera, exemplified by the *Linoproductus* community, are characteristic of a high grade (Johnson, 1972), mature community of the stable marine environment (Rollins and Donahue, 1975). Both communities are comprised mostly of low-level epifaunal suspension feeders (Walker and Bambach, 1974), but high-level epifaunal suspension feeders are more common in the *Linoproductus* community. The clastic and biogenic material in the marine zone represent a wide range of environments of deposition which are found within the interdistributary bay and along the margins of the bay.

FAUNAL LIST OF THE MAGOFFIN MEMBER FROM MORGAN AND MAGOFFIN COUNTIES, KENTUCKY

Brachiopods
- *Anthracospirifer cf. A. matheri*
- *Antiquatonia* sp?
- *Composita subtilita*
- *Derbyia crassa*
- *Desmoinesia cf. D. missouriensis*
- *Eolissochonetes* sp.
- *Juresania* sp.?
- *Linoproductus* sp.
- *Pulchratia* sp?
- *Punctospirifer kentuckyensis*

Bivalves
- *Acanthopecten* sp.
- *Astartella concentrica*
- *Aviculopecten* sp.
- *Nuculopsis* sp.
- *Phestia* sp.
- *Posidoniella* sp.

Gastropods
- *Euphemites cf. E. nodocarinatus*
- *Glabrocingulum cf. G. (Glabrocingulum) grayvillense*
- *Ianthinopsis* sp.
- pseudozygopleurid snail
- *Straparollus cf. S. (Amphiscapha) catilloides*

Cephalopods
- small coiled cephalopod
- *Pseudorthoceras knoxense*

Echinoderms
- echinoids
  - echinoid fragments
- pelmatozoans
  - *Diphuicrinus patina*
  - pelmatozoan fragments

Bryozoa
- branching types
  - *Rhabdomeson* sp.
  - *Sulcoretepora* sp.
- fenestrate types
- *Prismopora* sp.
- *Spinofenestella* sp.

Arthropods
- ostracods
  - *Bairdia* sp.
  - *Cavellina* sp.
  - *Monoceratina* sp.
  - *Pseudoparachites* sp.
  - *Shleesha pinguis*
- trilobites
  - fragments in thin section
  - pygidium

Foraminifera
- *Ammodiscus* sp.
- *Calcitornella* sp.
- *Endothyra* sp.
- *Endothyranella* sp.
- *Millerella* sp.
- *Monotaxinoides* .sp
- *Tetrataxis* sp.

Conodonts
- *Cavusgnathus* .sp
- *Gnathodus* sp.
- *Hindeodella* sp.
- *Idiognathodus* sp.
- *Lonchodina*
- *Neoprioniodus* sp.
- *Spathognathodus* sp.

Corals
- *Lophophyllidium* sp.

Sponges
- spicule fragments

Annelids
- scolecodonts

Vertebrates
- fish teeth and scales

Trace Fossils
- horizontal and sinuous burrows of various sizes
- *Zoophycos* sp.

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PALYNOMORPH CONTENT OF THE HAZARD NO. 7 COAL BED, KENTUCKY

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Samples were collected from the type locality of the Hazard No. 7 bed in the Hazard North Quadrangle (Carter coordinate location 23-J-76, 450 m FSL x 700 m FEL, Perry County, Kentucky) for palynological (spores and pollen grains) study. These samples yielded abundant palynomorphs and were assigned to U. S. Geological Survey paleobotanical locality number D3302 and to maceration series 5 A-E. Information on sample thickness and character of the coal is given in Figure 63. The palynomorph genera occurring in the Hazard No. 7 coal bed are illustrated in Plate 26.

The palynomorph content of the Hazard No. 7 coal bed is diversified but is characterized by a dominance of *Laevigatosporites* and *Densosporites* and by significant and rapid changes in abundance between samples, as shown in Figure 63. These changes reflect, for the most part, paleoecological or successional changes that took place during deposition in the coal swamp. One such change is illustrated in samples 5-A and 5-B at the thin rash layer (X), as shown in Figure 63. *Densosporites* represents 68.7 percent of the palynomorph assemblage in sample 5-A, and less than 2 percent in sample 5-B. Another such change is present between the seat rock sample 5-E and the bottom coal sample 5-D. In the seat rock sample *Lycospora* represents more than 50 percent of the assemblage, but in the basal coal sample this taxon is present in less than 6 percent of the sample. *Lycospora* is not abundant in the coal samples of the Hazard No. 7 coal bed from the type locality, nor is it abundant in a second set of Hazard No. 7 coal bed samples from the Hazard South Quadrangle. This scarcity of *Lycospora* contrasts markedly with the abundance of *Lycospora* in the Francis coal bed above the Hazard No. 7 coal bed and in the Leatherwood coal bed below.

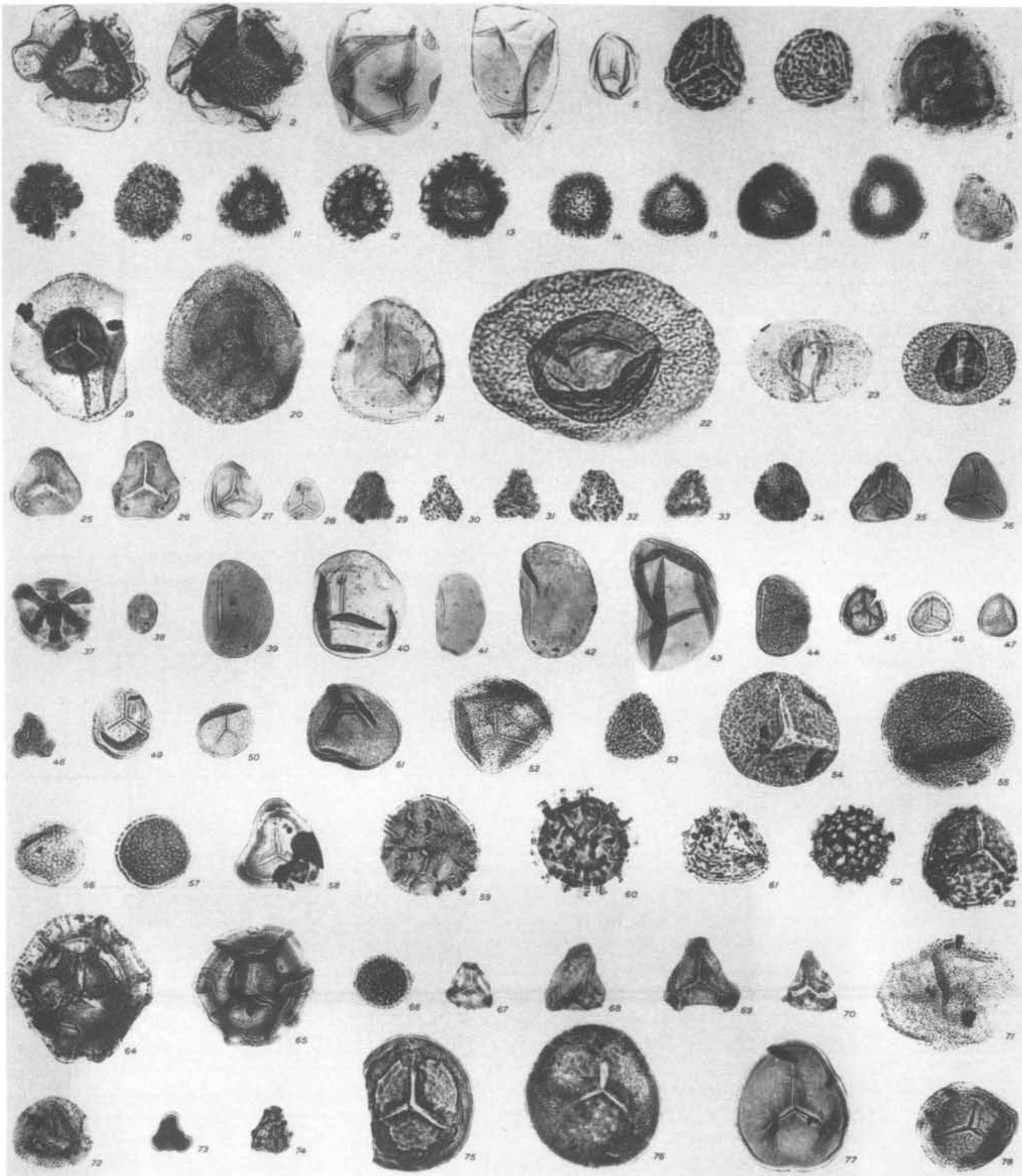
The abundant palynomorph genera in the Hazard No. 7 coal bed, as shown in the maceration series 5 A-E, are shown in Table 12. These data and those in Figure 63 clearly indicate that *Laevigatosporites* and *Densosporites* are the dominant genera of the Hazard No. 7 coal bed and that *Lycospora* is abundant only in the seat rock sample 5-E. In the Hazard No. 7 coal bed samples from the Hazard South Quadrangle, *Laevigatosporites* and *Densosporites* are the dominant taxa, as in the samples from the type locality.

Radiizonates is present in one sample of the Leatherwood coal bed, occurs in samples 5-A and 5-B of the Hazard No. 7 coal bed, and is present in most younger coals to the level of the Richardson, Skyline, and Princess coal beds of eastern Kentucky. The dominance of *Laevigatosporites* and *Densosporites* together with the diminution of the percentage of *Lycospora* in the coal samples, and the occurrence of specific palynomorphs help differentiate the Hazard No. 7 coal bed from other coal beds above and below it.

Table 12. Palynomorph Genera in the Hazard No. 7 Coal Bed.

Sample	Densosporites	Laevigatosporites	Lycospora	Combined total
A	68.7%	22.5%	4.4%	95.6%
B	1.2	79.7	5.1	86.0
C	30.5	58.0	3.0	91.5
D	11.1	75.8	5.6	92.5
E	0	23.4	51.7	75.1

PLATE 26



0 50 100 MICRONS

Plate 26. Palynomorph genera occurring in the Hazard No. 7 coal.

USGS Paleobotanical locality D3302; four segments and the underclay of the Hazard No. 7 coal at its type locality: Hazard North Quadrangle, Carter coordinate location 23-J-76, 1475' FSL x 2300' FEL, Perry County, Kentucky.

Figures 1-2: *Alatisporites*
3-5: *Calamospora*
6-7: *Callisporites* = *Savitrisporites* of Sullivan (1964)
8: *Cirratriradites*
9-10: *Convolutispora*
11-13: *Radiizonates*
14-17: *Densosporites*
18: *Dictyotriletes*
19-21: *Endosporites*
22-24: *Florinites*
25-36: *Granulatisporites*
37: *Knoxisporites*
38-44: *Laevigatosporites*
45-57: *Lycospora*
48: *Murospora*
49-57: *Punctatisporites*
58: *Simozonotriletes* = *Murospora* of Playford (1962)
59-61: *Raistrickia*
62-66: *Reticulatisporites*
67-70: *Triquitrites*
71-72: *Wilsonites*
73-78: unassigned trilete spores

Not illustrated are several fragments of spores belonging to the genus *Vestispora*.

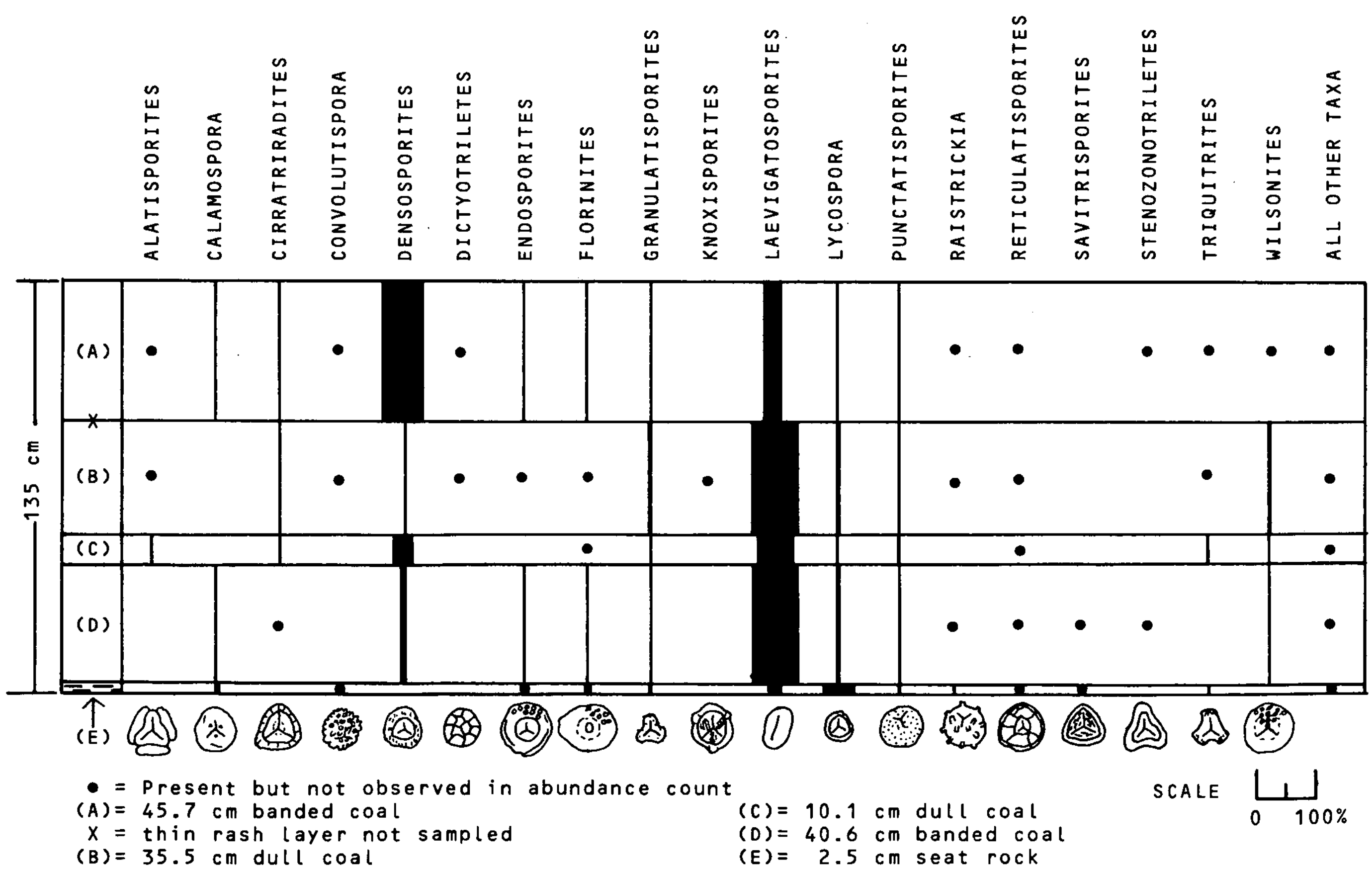


Figure 63. Distribution of palynomorphs in the Hazard No. 7 coal from the type locality. U. S. Geological Survey Paleobotanical Locality D3302, Maceration Series 5 A-E.

STREAM PIRACY NEAR IVYTON IN EASTERN KENTUCKY

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U. S. Geological Survey

The capture of the headwaters of Burning Fork of Licking River by tributaries of the Big Sandy River (Fig. 64) is one of the best and most obvious examples of stream piracy in eastern Kentucky. In the captured area (shaded area on Fig. 64), tributaries of Middle Creek and Jennys Creek join the main channels at angles that falsely suggest westward to northwestward stream flow. The piracy has resulted from the slow westward migration of drainage divides at the heads of Middle Creek and Jennys Creek and the subsequent capture of

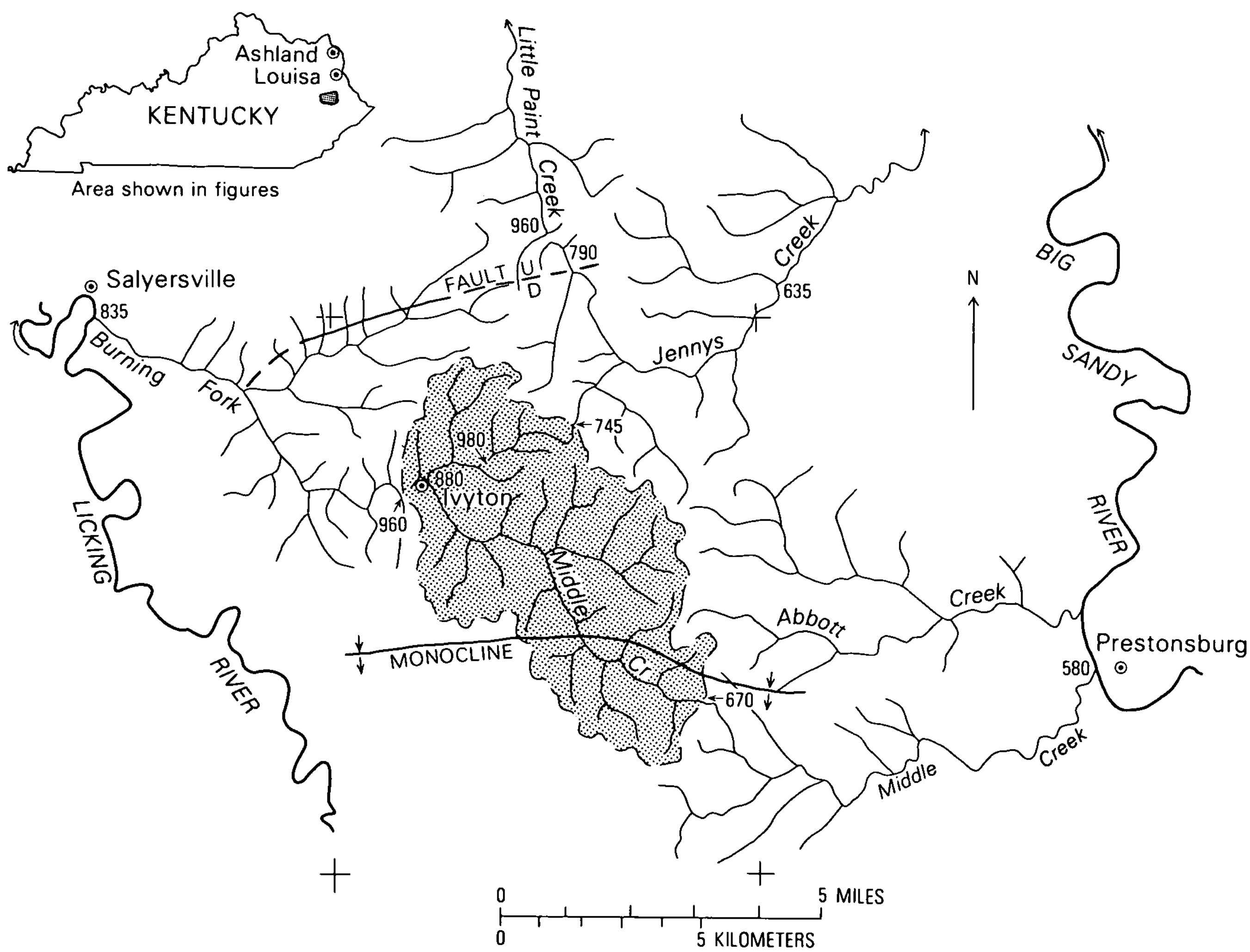

Figure 64. Stream drainage in the area between Prestonsburg and Salyersville, eastern Kentucky, showing quadrangle intersections, selected altitudes (in feet), and major structural features. Shaded area is the area captured by tributaries of the Big Sandy from the headwaters of Burning Fork of Licking River. U = upthrown; D = downthrown.

successively lower tributaries of Burning Fork. The upper reaches of Middle Creek and Jennys Creek Valleys are deeply incised and V-shaped. By contrast, downstream from the initial capture points (altitudes 670 and 745 ft.) the valleys are open and have flood plains. Jillson (1919), who first noted the piracy, described the wagon roads in the captured parts of the valleys as being confined to narrow, locally cliff-bordered, gravel- and boulder-choked creek beds. In contrast, Burning Fork has a broad flood plain immediately downstream from the point where it was beheaded (altitude 964 ft.), suggesting that prior to capture the valley was the site of a much larger stream. Currently, Kentucky Highway 114 follows the Middle Creek Valley from Prestonsburg to Ivyton and the Burning Fork Valley to Salyersville.

Two important factors that have contributed to the stream captures are related directly to the rivers. First, the Big Sandy River is bigger than the Licking River and has a drainage basin upstream from the study area 15 times larger than that of the Licking River. The greater stream discharge of the Big Sandy has facilitated the lowering of its base level in this area about 250 ft. (75 m) below that of the Licking River. Second, the Big Sandy makes its closest approach to the Licking River drainage basin at Prestonsburg. Gradients of tributaries extending toward the margin of the latter basin are steepest in this area and headward erosion could have proceeded more rapidly. Probably, either Abbott Creek or the larger Middle Creek (not shown in its entirety on Fig. 64) would be the first tributary of the Big Sandy to encroach on the Licking River drainage.

Jillson (1919) suggested that lithology and structure played important roles in aiding Middle Creek to pirate the larger part of the captured area. He noted that Ivyton was near the center of a domal structure and suggested that Middle Creek was favored by flowing down the steepest side of the structure where he thought strata were less resistant. All outcropping rocks in the region are assigned to the Breathitt Formation and are characterized by alternating sequences of sandstone and siltstone that contain minor amounts of shale and coal. Although the lithology regionally has great lateral variability, in the small area of this study, most sandstone beds are laterally persistent and roughly tabular. Locally the sandstone/siltstone ratios of nearby equivalent stratigraphic sections are similar, but no doubt, enough differences in resistant and erodable rock types exist to account for different rates of erosion in the two streams.

The geologic structure of the area is shown on U. S. Geological Survey geologic quadrangle maps for the Ivyton (Rice, 1969), Prestonsburg (Rice, 1967), Salyersville South (Spengler, 1977), and Oil Springs (Outerbridge, 1967) Quadrangles (Fig. 65). Structure contours on the base of the Magoffin Member of the Breathitt Formation show that Ivyton is near the center of a northwestwardly elongated domal structure that is flanked on the north and northwest by a small normal fault, on the south by a gentle southwardly inclined monoclinal flexure, and on the northeast by a broad irregularly deformed structural slope. Except that the headwaters of Middle Creek and Jennys Creek are near the central part of the domal structure, Figure 65 does not illustrate a clear relation between structure and stream patterns.

Despite the lack of evidence supporting structural control of the stream captures, it is interesting to speculate that faulting and uplift may have influenced the captures. Figure 64 shows that Jennys Creek has beheaded Little Paint Creek, also a tributary of the Big Sandy River, in the vicinity of the fault. The age of the faulting is unknown. Evidence of late Cenozoic tectonism in eastern Kentucky is lacking, and post-Pennsylvanian movement on the Irving-Paint Creek Fault, which is about 7 miles (11 km) north of the study area, is only about 200 ft. (64 m) (Howard and others, 1978); any late Cenozoic movement would be small and difficult to detect. South of the Irving-Paint Creek Fault and along the 35-mile (55-km) common border between the drainage basins of the Big Sandy and Licking Rivers, streams have been captured only in the vicinity of the domal structure. This localization of stream capture suggests that late Cenozoic domal uplift and faulting may have controlled the captures.

Data are not available to establish when the captures took place. The original drainages and divides of the two rivers probably date from a time before a regional uplift brought about rejuvenation of stream activity in late Miocene-early Pliocene time (Ray, 1974, p. 11). High-level terrace deposits of sand and gravel assigned to the Pliocene and Pleistocence have been traced along the Big Sandy between Louisa, Kentucky, about 35 miles (55 km) north of Prestonsburg, northward to Ashland, Kentucky (Phalen, 1912; Dobrovolny and others, 1963). These deposits range in altitude from 650 to 700 feet (200 to 215 m) and are about 200 feet (64 m) above the present channel of the Big Sandy. As shown on the Ivyton topographic map (U. S. Geological Survey, 1962), the present channel of Middle Creek at the initial capture point (altitude 670 ft.) is more than 500 feet (150 m) below the present average altitude of passes in the ridge through which it has cut. The apparently greater amount of downcutting by Middle Creek since initial capture of the headwaters of Burning Fork suggests that the capture predates the high level terrace deposits along the Big Sandy River and may possibly be related to the late Miocene-early Pliocene

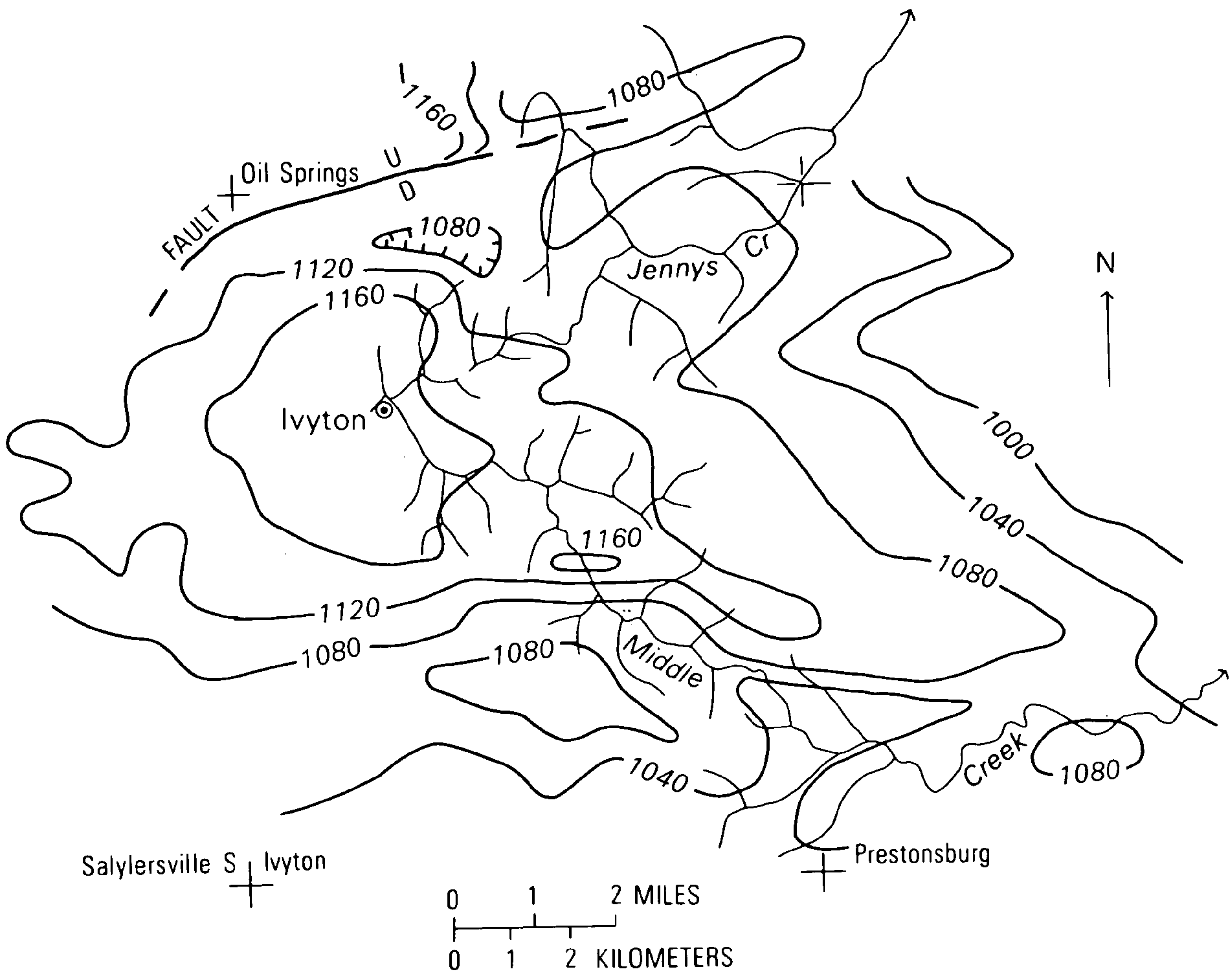

Figure 65. Structure map of study area showing geologic quadrangle names at intersections. Structure contours are in feet and are drawn on the base of the Magoffin Member of the Breathitt Formation. U = upthrown; D = downthrown; maximum throw on fault is 80 feet (25 m).

regional uplift.

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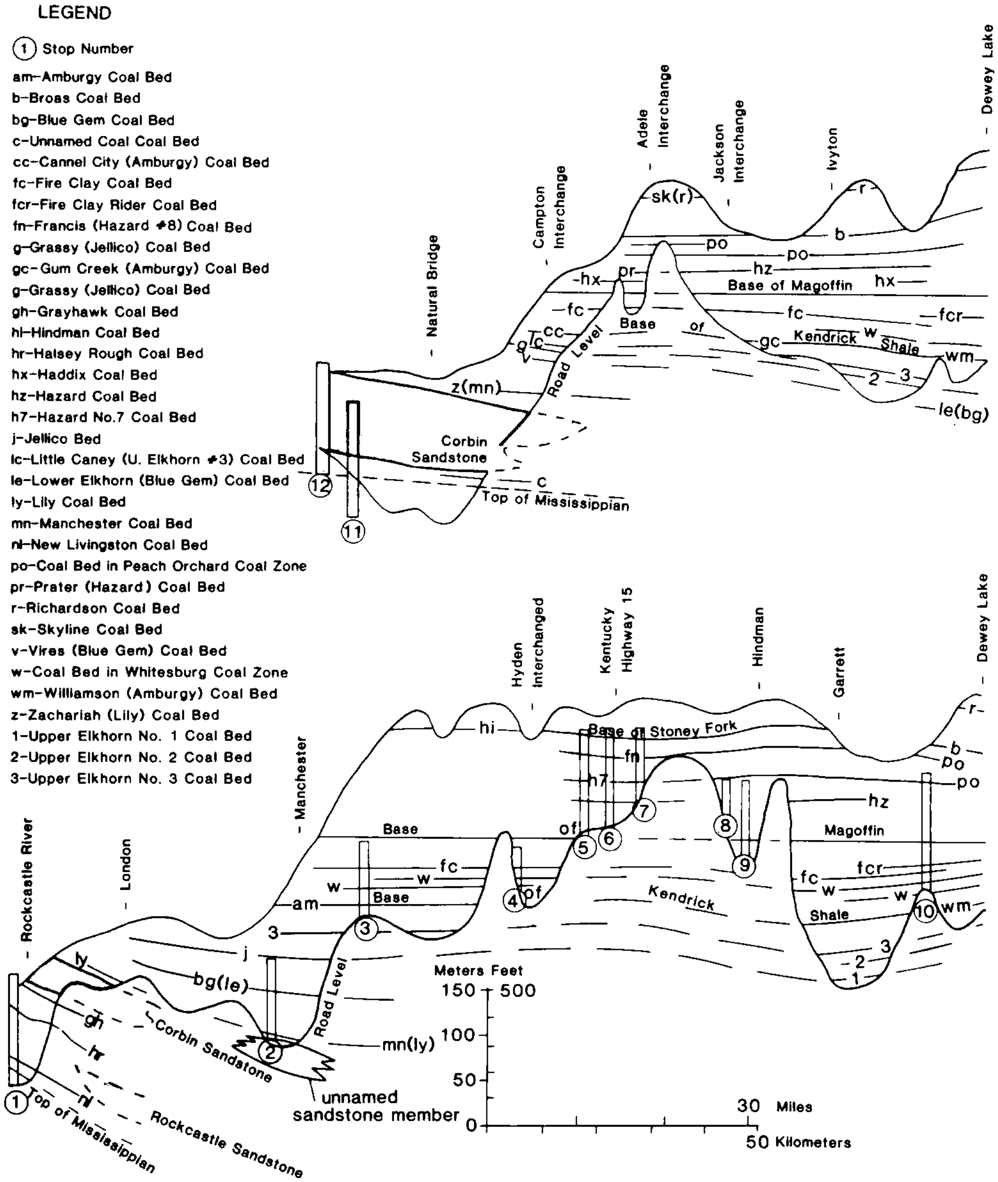
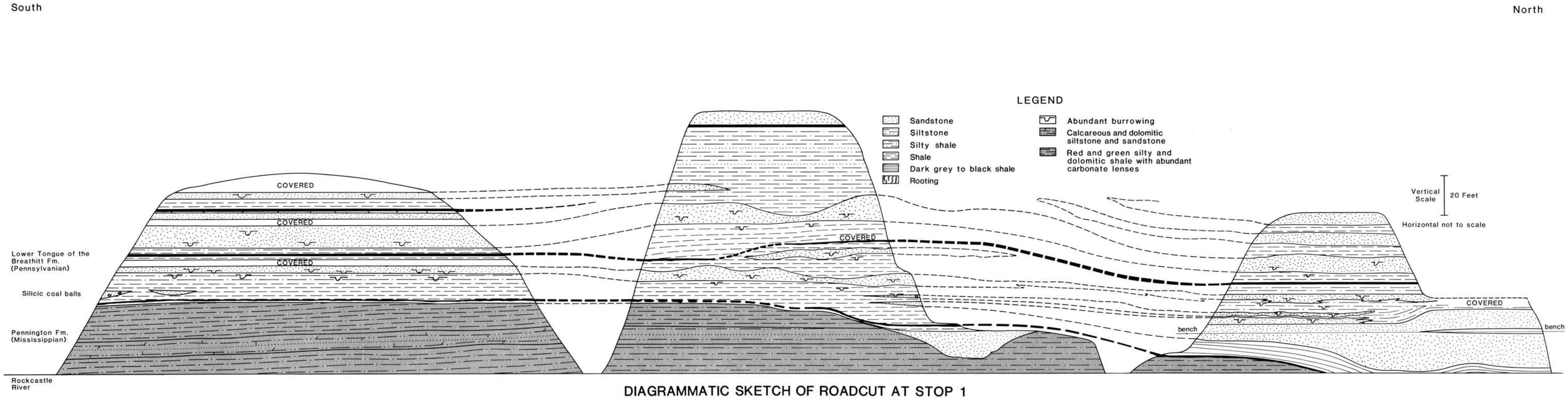


AFTER RICE, THIS VOLUME

CROSS-SECTIONS THROUGH THE EASTERN KENTUCKY COAL FIELD

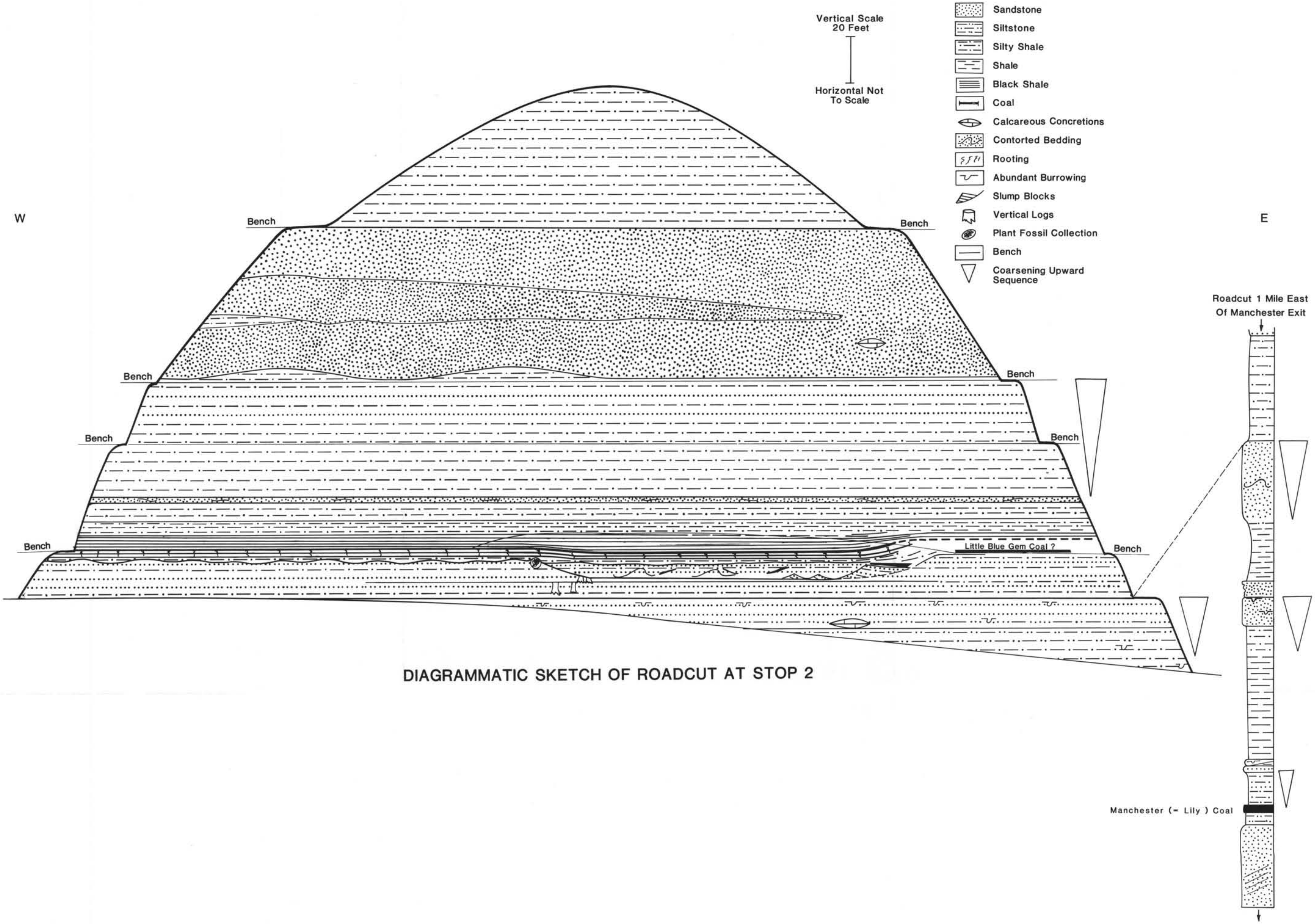
ALONG THE ROUTE OF THE FIELD TRIP

PLATE 1



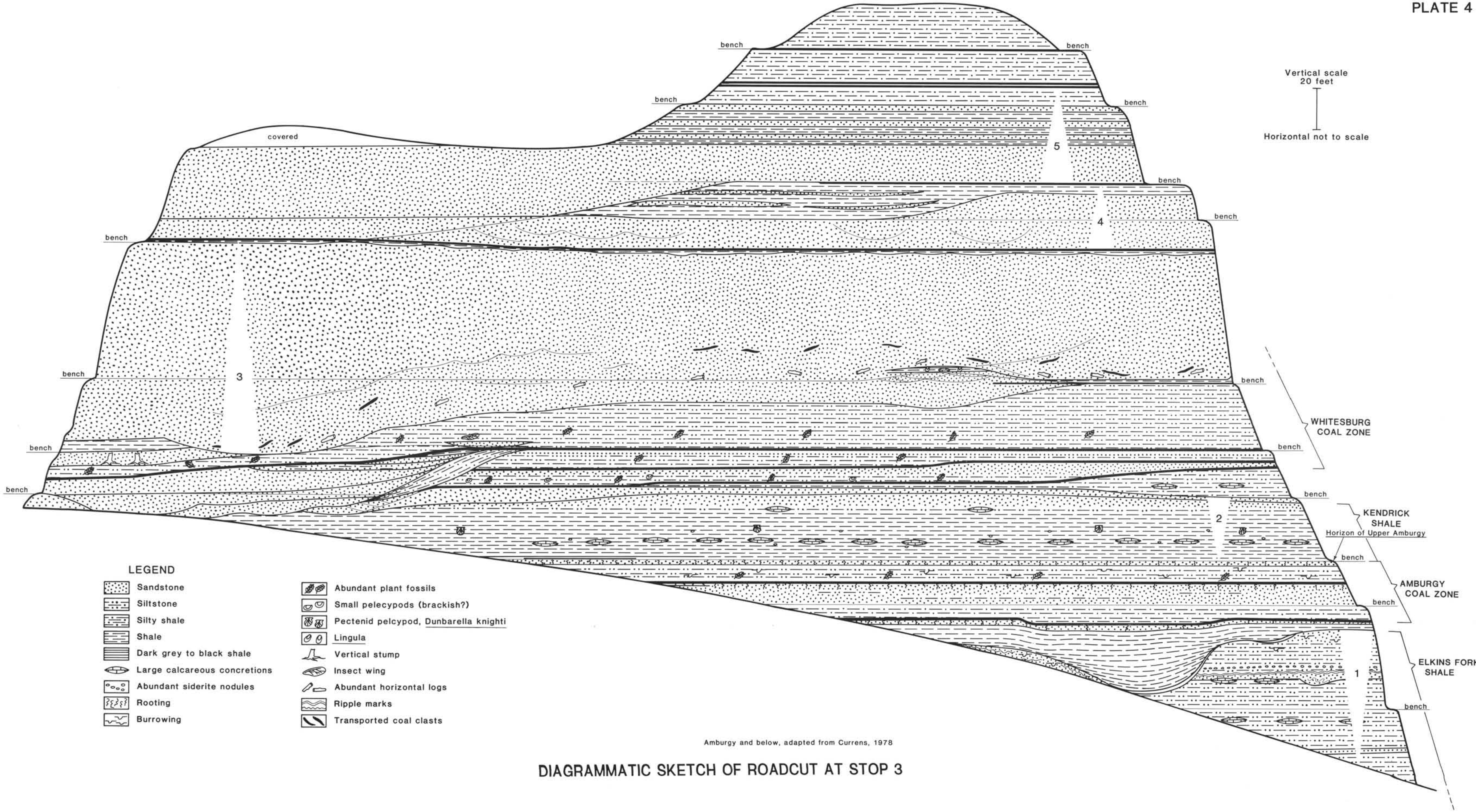
DIAGRAMMATIC SKETCH OF ROADCUT AT STOP 1

PLATE 3



DIAGRAMMATIC SKETCH OF ROADCUT AT STOP 2

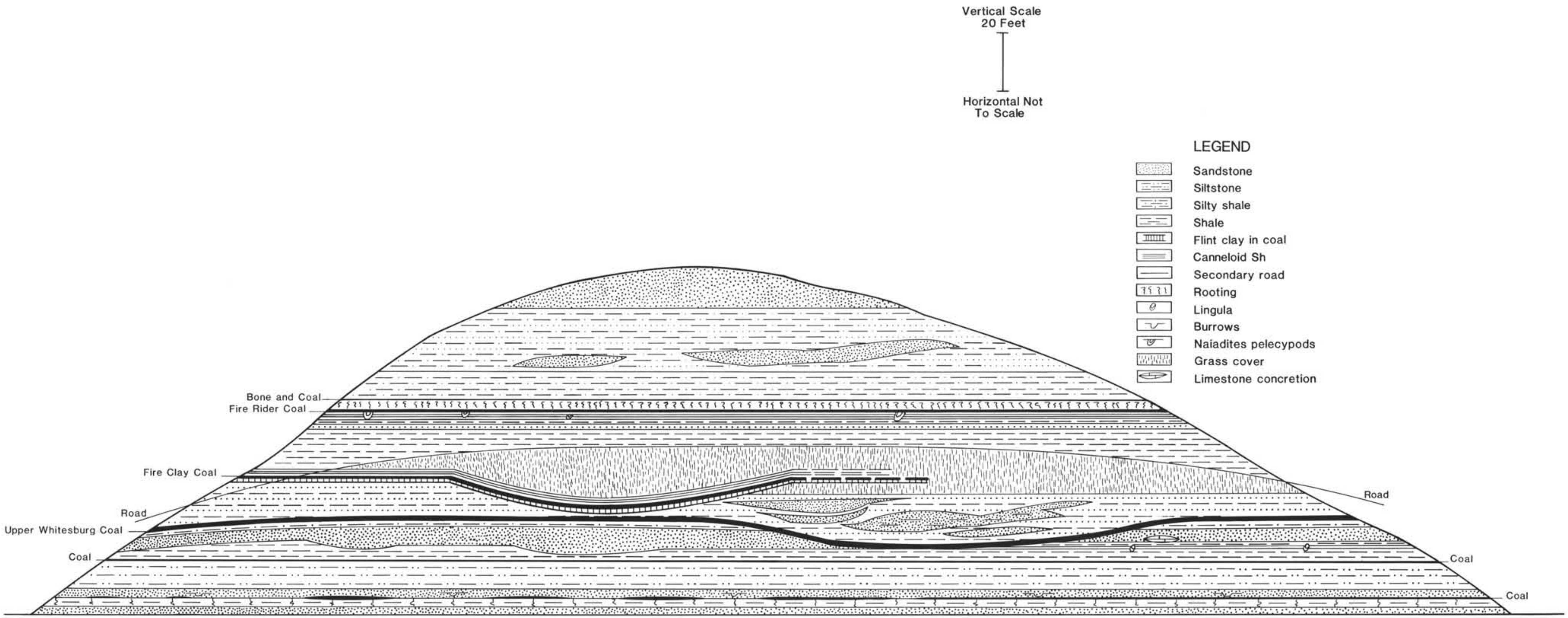
PLATE 4



Amburgy and below, adapted from Currens, 1978

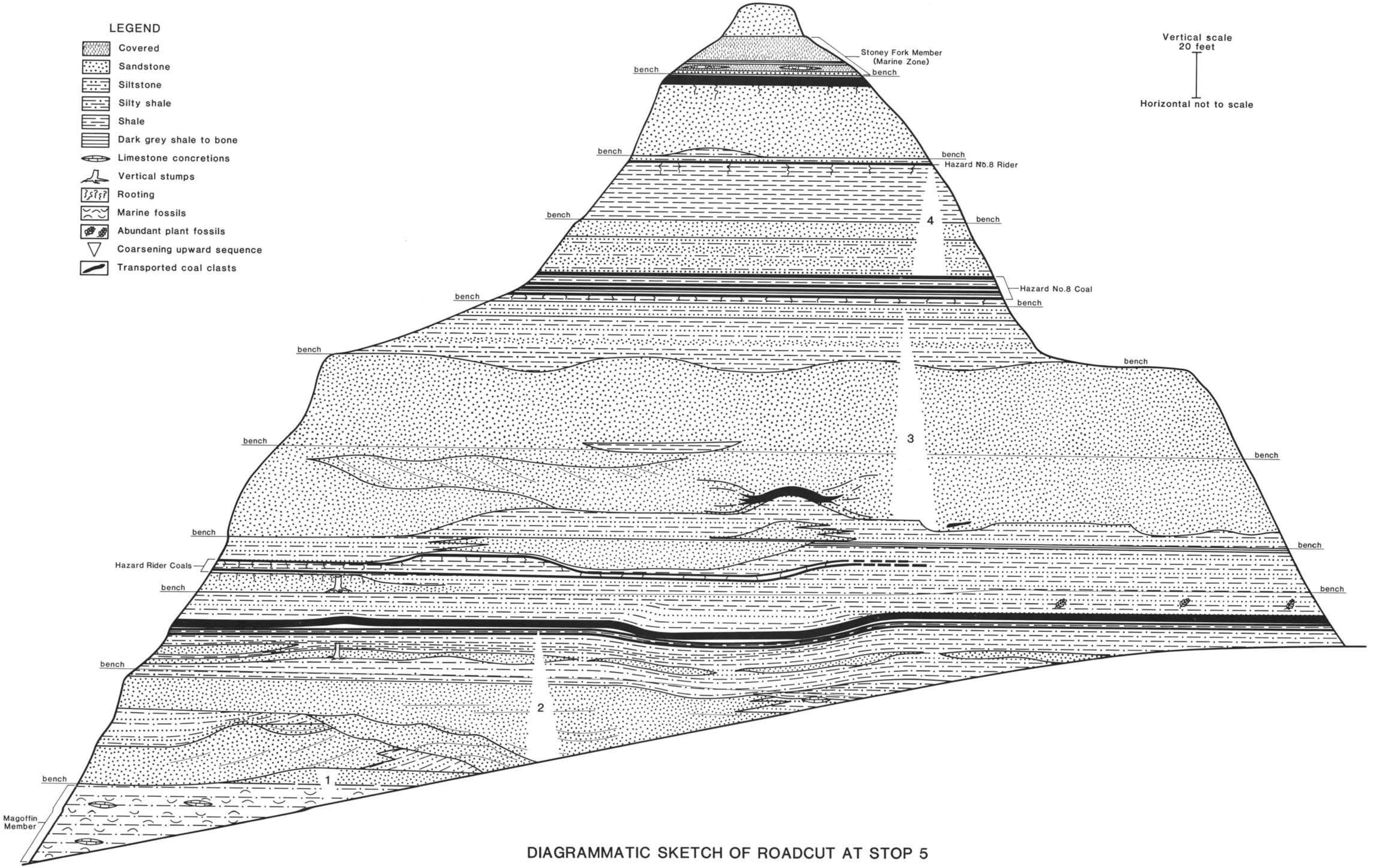
DIAGRAMMATIC SKETCH OF ROADCUT AT STOP 3

PLATE 5



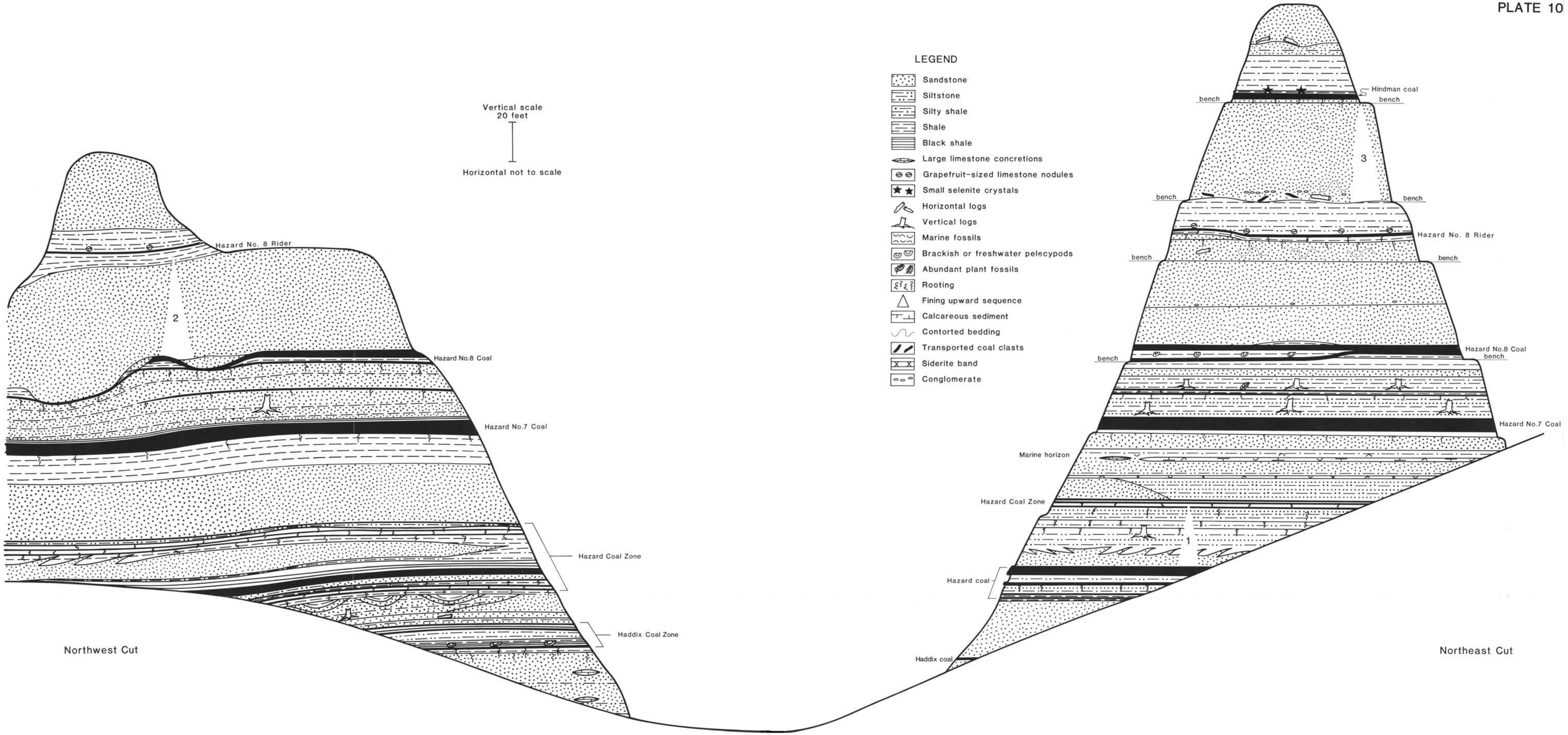
DIAGRAMMATIC SKETCH OF ROADCUT AT STOP 4

PLATE 6

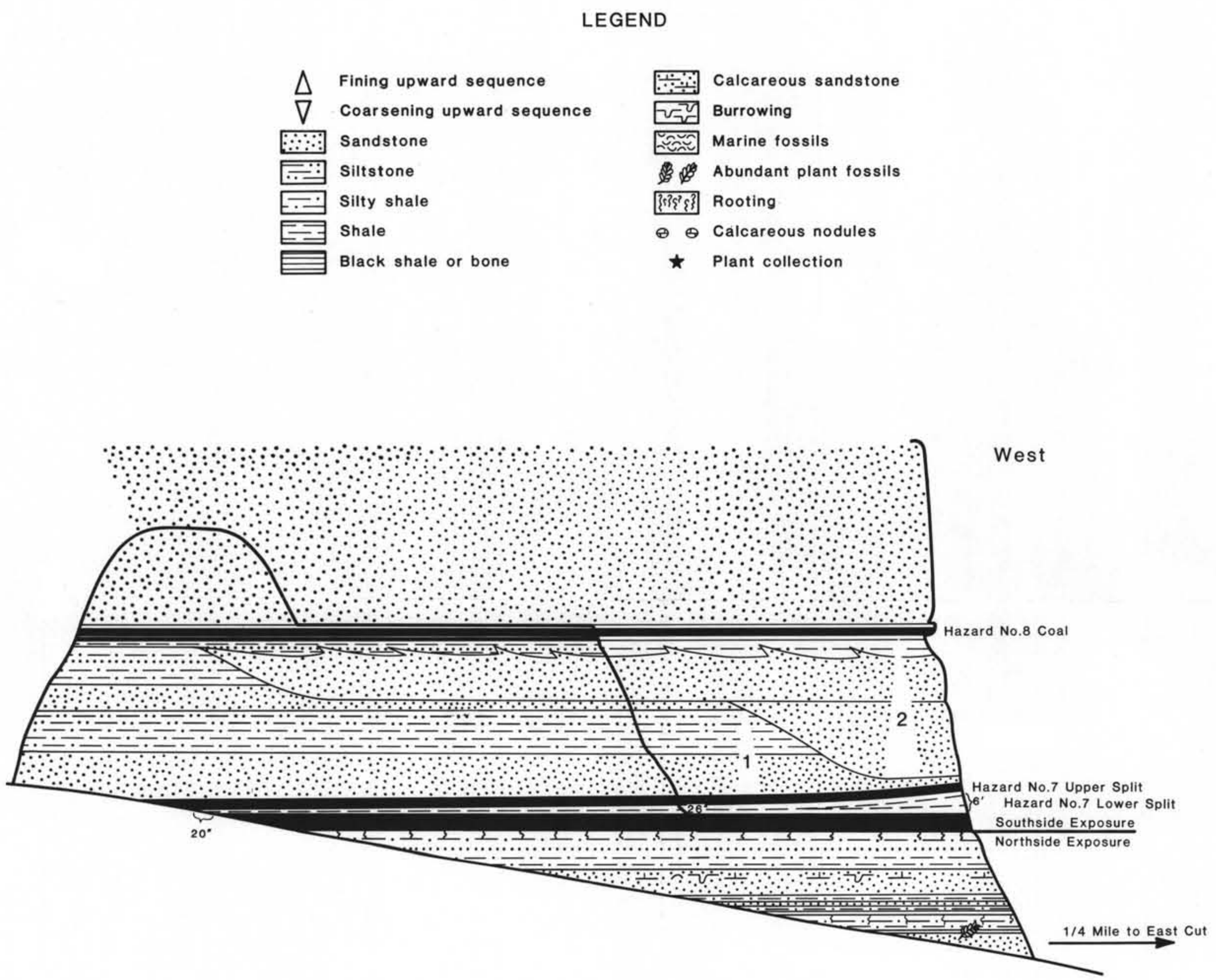


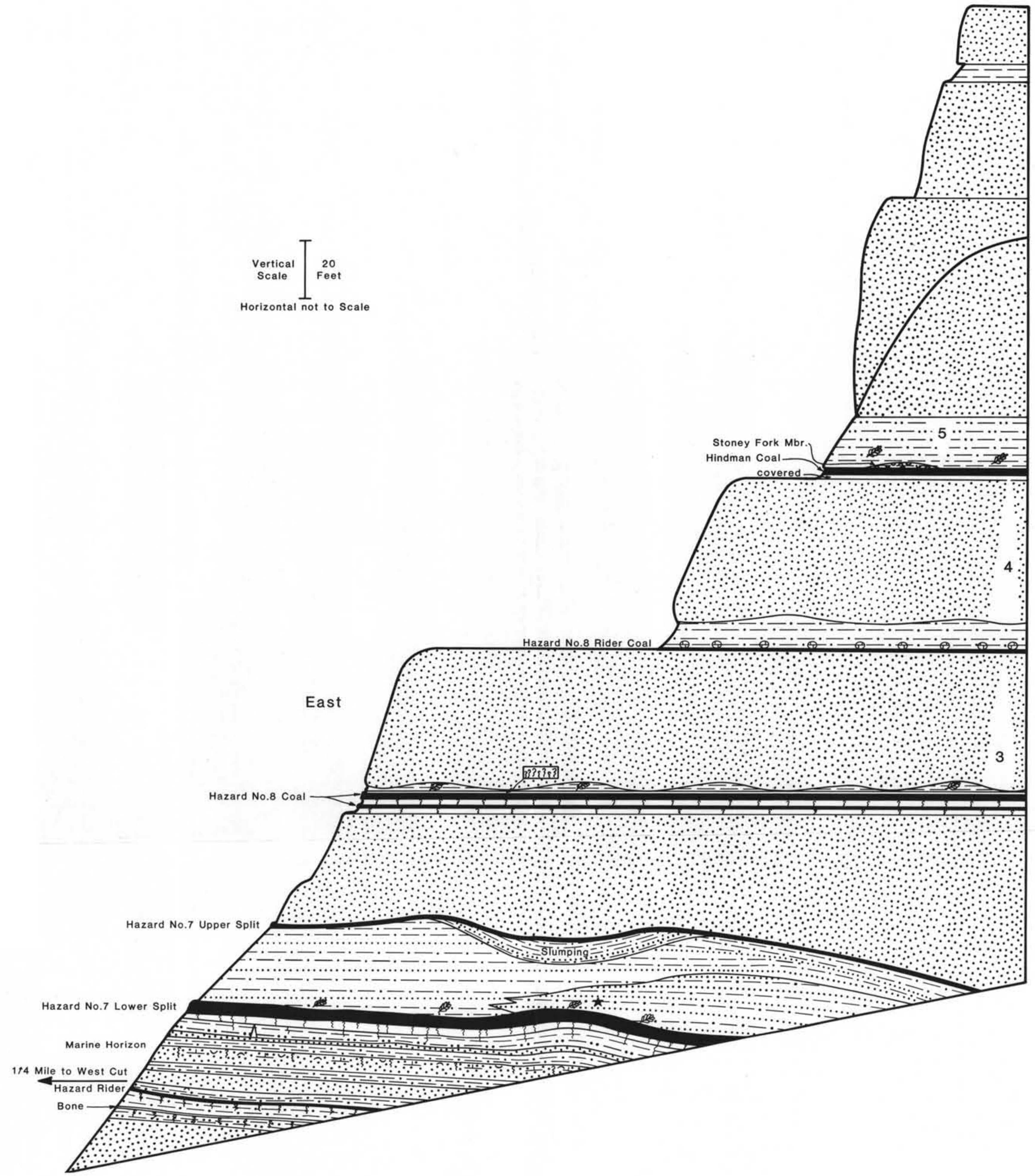
DIAGRAMMATIC SKETCH OF ROADCUT AT STOP 5

PLATE 10



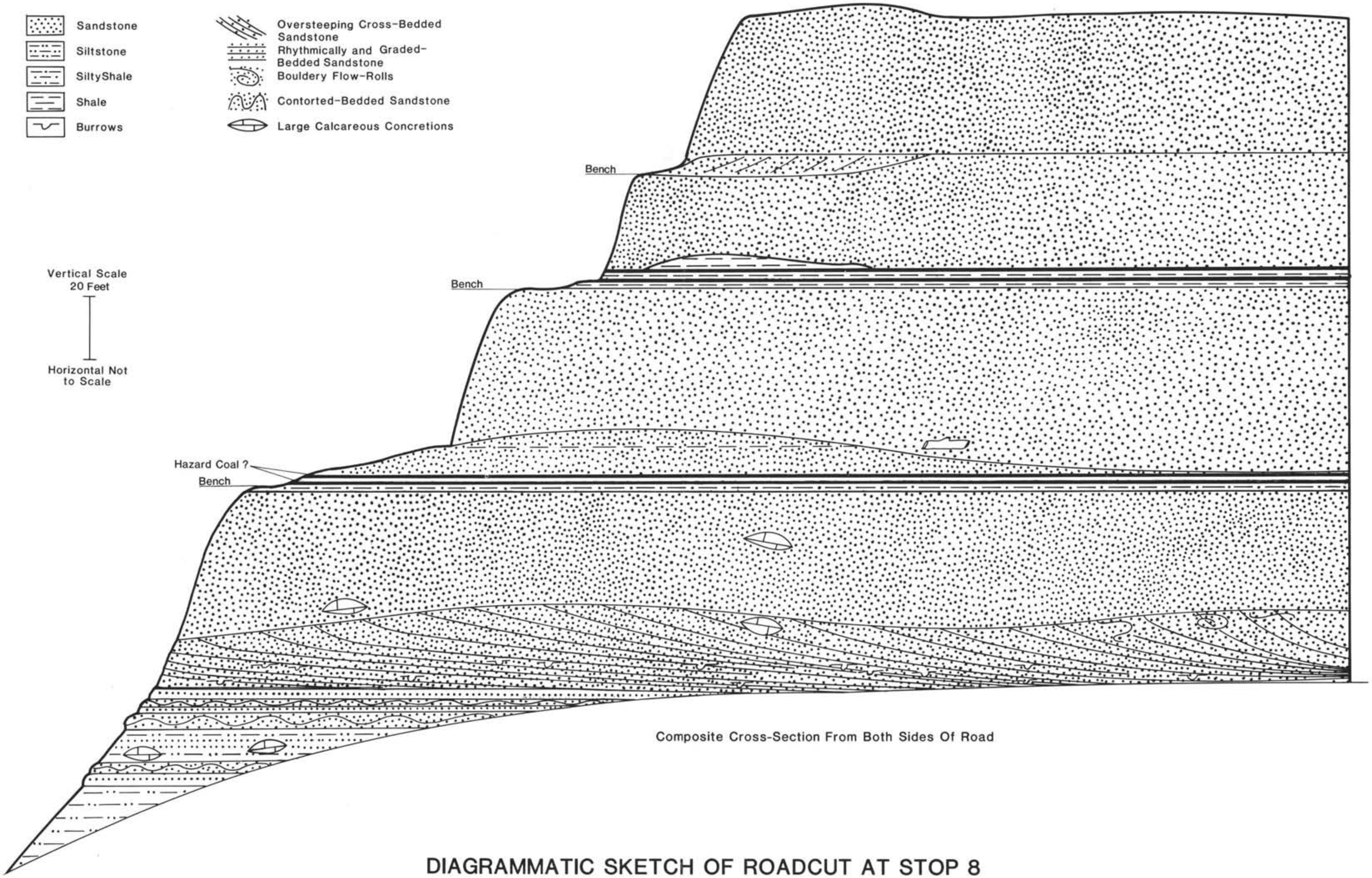
DIAGRAMMATIC SKETCH OF ROADCUT AT STOP 6



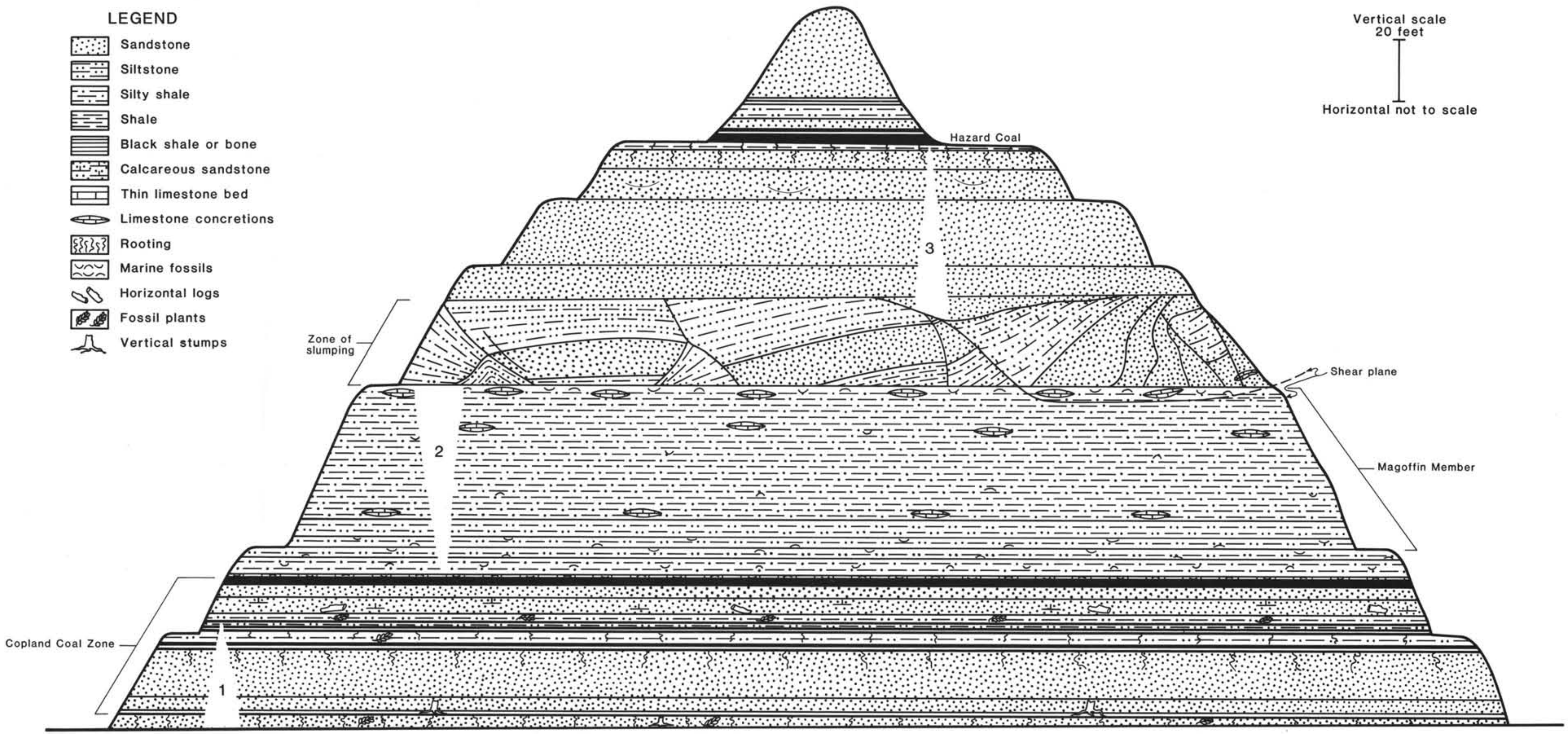


DIAGRAMMATIC SKETCH OF ROADCUT AT STOP 7

PLATE 14

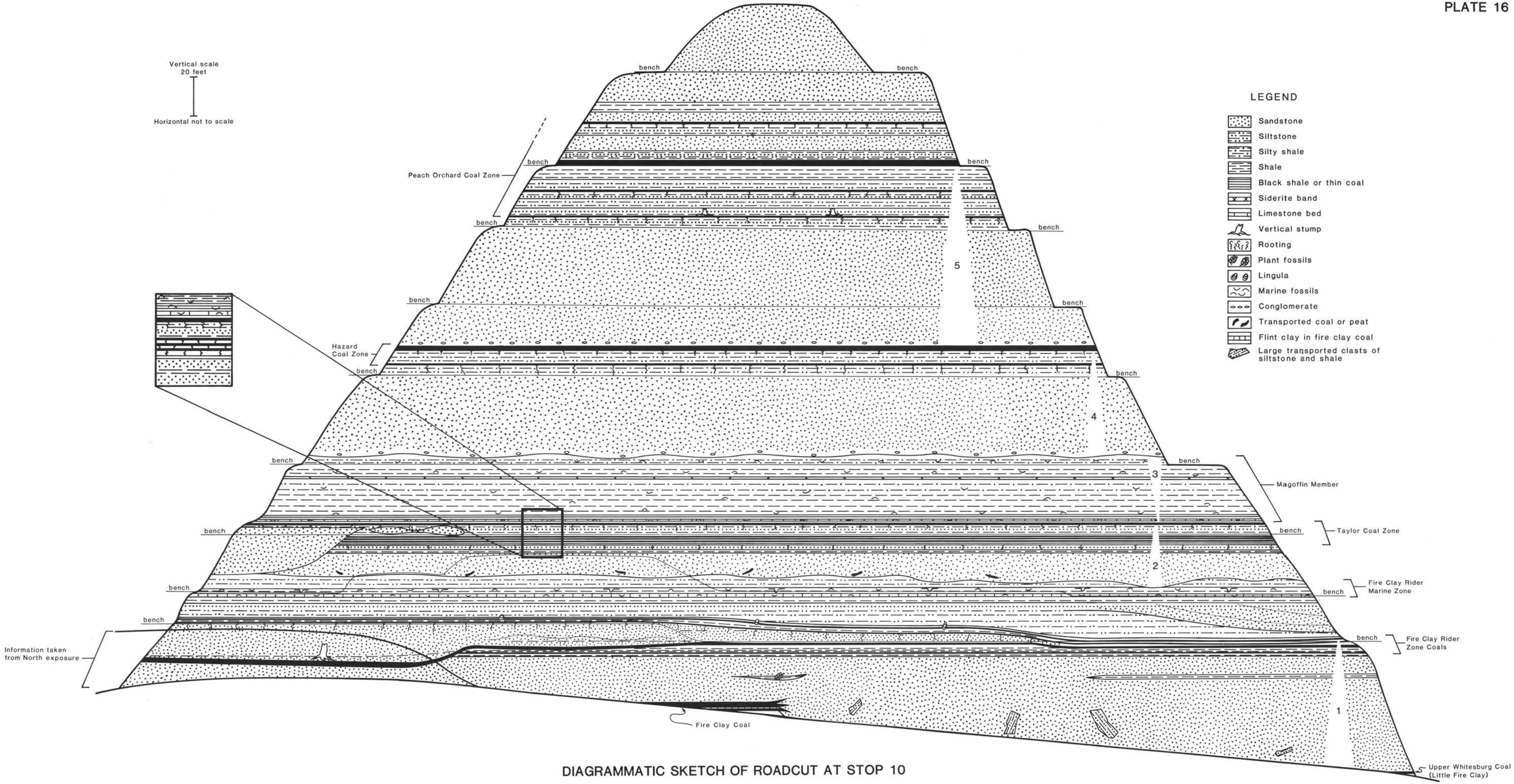


DIAGRAMMATIC SKETCH OF ROADCUT AT STOP 8



DIAGRAMMATIC SKETCH OF ROADCUT AT STOP 9

PLATE 16



DIAGRAMMATIC SKETCH OF ROADCUT AT STOP 10