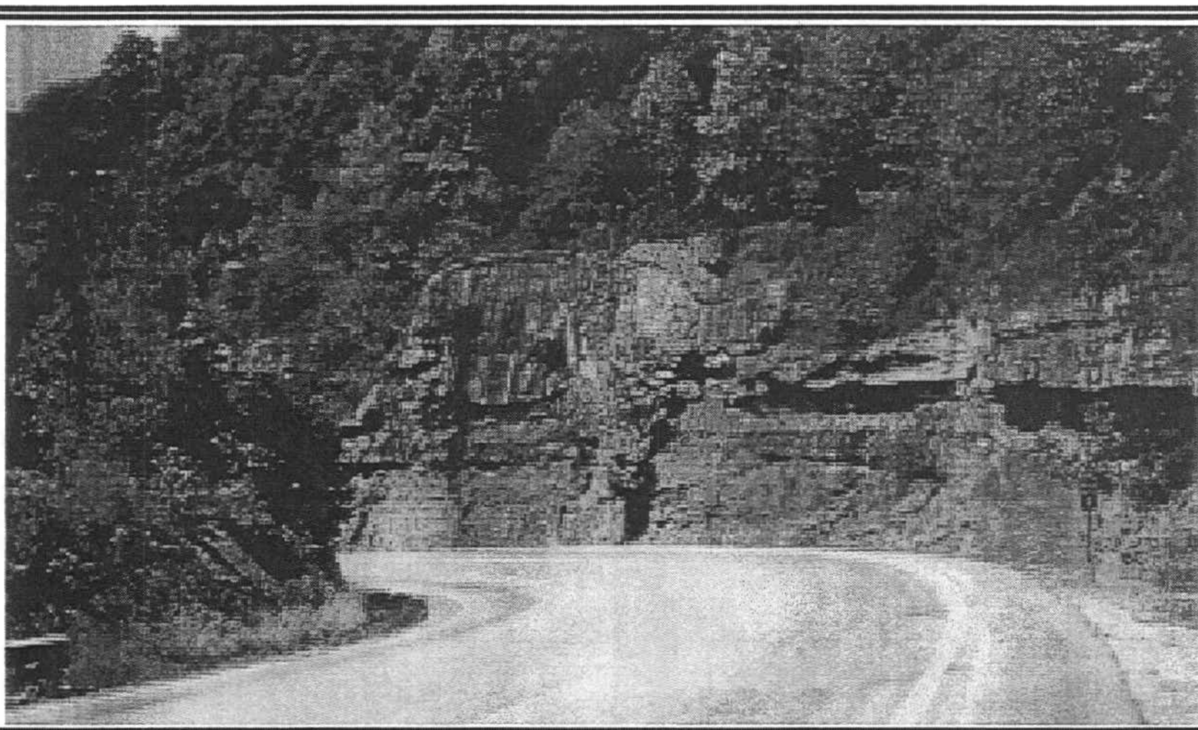
Coal Geology of the Eastern Kentucky Coal Field



Annual Field Conference of the
Geological Society of Kentucky
September 29-30, 1995

Cortland Eble
Stephen Greb
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Field Trip Leaders

Cortland Eble, *Kentucky Geological Survey*
Stephen Greb, *Kentucky Geological Survey*
Jim Hower, *Center for Applied Energy Research, University of Kentucky*

with contributions by:

John Kiefer, *Kentucky Geological Survey*
Donald Chesnut, Jr., *Kentucky Geological Survey*
J. Brett Benington, *Hofstra University*
William Andrews, Jr., *Department of Geological Sciences, University of Kentucky*

Foreward

This field trip is designed to showcase a few aspects of coal, and coal-related strata in the Eastern Kentucky Coal Field. As all of our stops will be at roadcuts we need you to **PLEASE BE CAREFUL!!!** When crossing roadways, remember that vehicles often travel at high rates of speed; make certain to look both ways before crossing lanes. Many of the outcrops we will stop at are multi-benched. If you wish to climb up to a bench above the road level for a closer look at a particular interval, please ascend and descend with caution. Also, be aware of other participants, especially those who may be below you. Even a small pebble that you dislodge when climbing can be injurious, or even fatal, to someone beneath you. The grassy areas around all of the outcrops we will see are occasionally inhabited by a snake or spider, some varieties of which are poisonous. "Watch where you walk" is a good rule-of-thumb to follow if, and when, you are in these areas. If you are in doubt about anything on this trip, please ask one of the field trip leaders for assistance. Above all, enjoy yourselves.

It should be noted that this field trip has built on the strong foundation provided by earlier field trips and guidebooks that have described coal and coal-related strata in the Eastern Kentucky Coal Field. The two most notable of these were a 1981 Geological Society of America field trip guidebook by Cobb and others, and a guidebook that was written for the 28th International Geological Congress in 1989 by Cecil and others. Also, a highway cross section of Kentucky Route 80 by Chesnut (1991) is included with this guidebook. This provides an excellent reference for the outcrops we will drive by, but not stop at, on this trip.

Biographies of the Field Trip Leaders

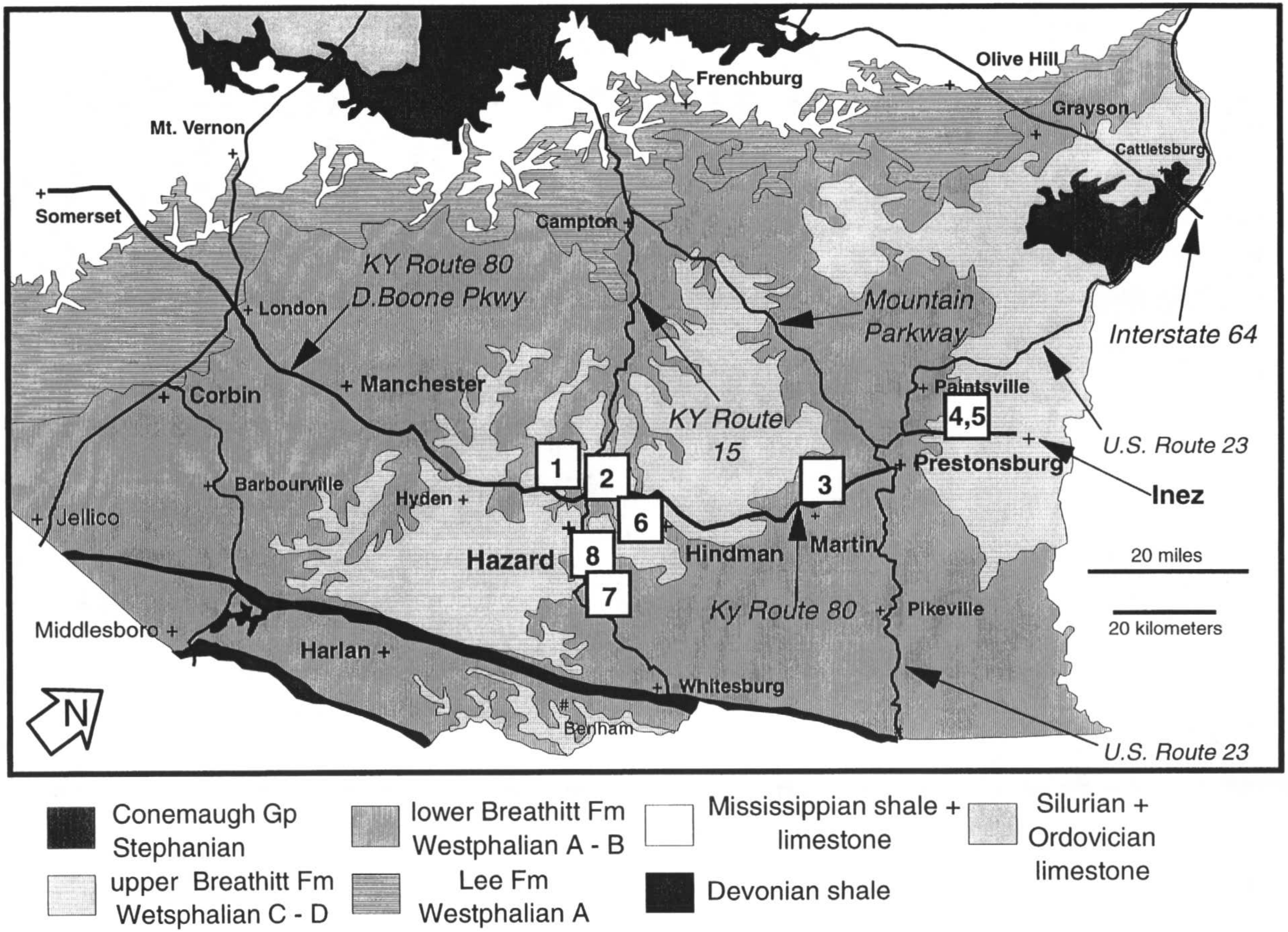
- ❑ ***Cortland Eble*** is a coal geologist with the Kentucky Geological Survey. He received his B.S. in Geology from Auburn University in Alabama 1n 1981, and his M.S. and Ph.D. degrees in geology from West Virginia University in 1985, and 1988 respectively. Following a brief post-doctoral appointment at the U.S. Geological Survey in Reston, Virginia, he joined the staff of the Kentucky Geological Survey in early 1990. Cortland's primary research interests are Carboniferous coal palynology and coal petrography.

- ❑ ***Stephen Greb*** is a coal geologist with the Kentucky Geological Survey. He received his B.S. in geology from the University of Illinois in 1982, and his M.S. and Ph.D. from the University of Kentucky in 1984 and 1992 respectively. Steve, who joined the staff of the Kentucky Geological Survey in 1982, has expertise in Pennsylvanian sedimentology, stratigraphy, and ichnology, in both the Eastern and Western Kentucky Coal Fields.

- ❑ ***Jim Hower*** is a senior coal petrologist with the Center for Applied Energy Research, which is affiliated with the University of Kentucky. Jim received his B.S. in geology from Millersville University in 1973, and his M.S. in geology from the Ohio State University in 1975. He then went on to complete a Ph.D. in geology from the Pennsylvania State University in 1978. Jim has extensive experience in applied coal petrology of coal and coal combustion by-products, and is the author of numerous coal-related scientific publications.

Acknowledgements

We would like to thank the staff and management of the Kentucky Geological Survey, and the Center for Applied Energy Research for the facilities and support that make endeavors such as this one possible. Without their assistance, this trip would not have been possible.



Map of eastern Kentucky showing the position of field trip stops

Introduction

The Eastern Kentucky Coal Field covers 10,500 square miles over parts, or all of 37 counties, and contains approximately 55 billion tons of remaining resources. Unfortunately, part of this resource cannot be recovered with present mining technology. The importance of coal to the Commonwealth of Kentucky, in terms of employment, and tax revenues cannot be overemphasized. Nearly 700 mines were in operation in the Eastern Kentucky Coal Field in 1992, employing more than 19,000 miners, or roughly 80 % of Kentucky's coal mining work force. These men and women produced 131 MM tons of coal that year, about three-quarters of Kentucky's total coal production (174.3 MM tons), and one-quarter of the total U.S. production (997.5 MM tons). During the 1992-93 fiscal year the production and sale of Kentucky coal brought $3.3 billion into Kentucky from out-of-state, and generated about $530 million in state tax revenues (1993-1994 Kentucky Coal Facts).

More than 95 % of Kentucky's electricity is generated from the combustion of coal. Electricity rates in Kentucky are among the lowest in the nation because coal is the lowest cost fossil fuel, and its price is also the most stable. In 1991 utilities in Kentucky generated about 76 billion kilowatt-hours of electricity, and exported 15 to 40 % of this figure to other states. Of the coal mined in eastern Kentucky, about 70 % was sold to electric utilities (Fig. 1). It is often difficult to comprehend just how much coal is consumed by coal-burning power plants. Consider that on a hot or cold day, one of the largest coal-fired power plants in Kentucky will consume 14,000 to 16,000 tons of coal to meet the electricity demands of its customers. At peak burn rates, that's 800 to 850 tons per hour.

Today, coal is being burned more cleanly than ever before. Historically, the two most common types of pollution associated with coal combustion were smoke and $S0_2$ emissions; the latter contributes to the formation of acid rain. Today, virtually all coal-burning power plants employ some form of particulate control. Particulates in flue gases are what makes "smoke" visible. Three common types are electrostatic precipitators (ESP), fabric filters, and baghouses. Since 1977, coal-fired power plants in the U.S. have reduced their $S0_2$ emissions by 28 %, even though power plants have increased their coal use by 61 %. In Kentucky, $S0_2$ emissions have been reduced by 54 % over the same time period. This has been largely achieved by using low sulfur coal, and installing $S0_2$ reduction devices, such as flue-gas desulfurization (FGD), and fluidized-bed combustors (FBC). Kentucky is second in the nation in installed scrubber capacity. Utilities in the Commonwealth have $S0_2$ reduction equipment on 42 % of their generating capacity, compared with the national average of 22 % (Kentucky Coal Facts, 1993-1994).

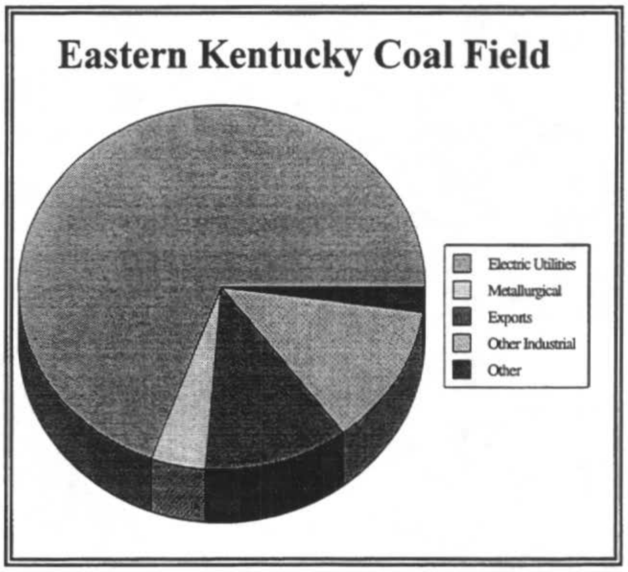


Figure 1 - Uses of eastern Kentucky coal

Although great strides have been made to burn coal in an environmentally-safe manner, there are new challenges. Title III of the Clean Air Act Amendments of 1990 has targeted 15 elements that naturally occur in bituminous coal as potential *"Hazardous Air*

Pollutants". Elemental emissions from coal combustion are a growing concern, and the subject of much study. We point you to a contributed article on trace elements in Eastern Kentucky coal in the back of this guidebook for more information on this important topic.

Lithostratigraphic Framework: Eastern Kentucky Coal Field

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Head, Coal and Minerals Section
Kentucky Geological Survey

The majority of Pennsylvanian rocks in eastern Kentucky are assigned to the Breathitt Group, with some younger strata in northeastern Kentucky belonging to the Late Pennsylvanian Conemaugh and Monongahela Groups (Fig. 2). Coals in the Conemaugh and Monongahela Formations typically are thin, and not of major economic importance. The Breathitt Group has been subdivided into eight formations by Chesnut (1992). The Breathitt Group thickens in a NW to SE direction; thickest sections occur in neighboring Virginia and West Virginia. The four stratigraphically oldest formations in the Breathitt Group are relatively thin, or in the case of the Pocahontas Formation, completely absent, in Kentucky. This is due to truncation of the Pocahontas Formation

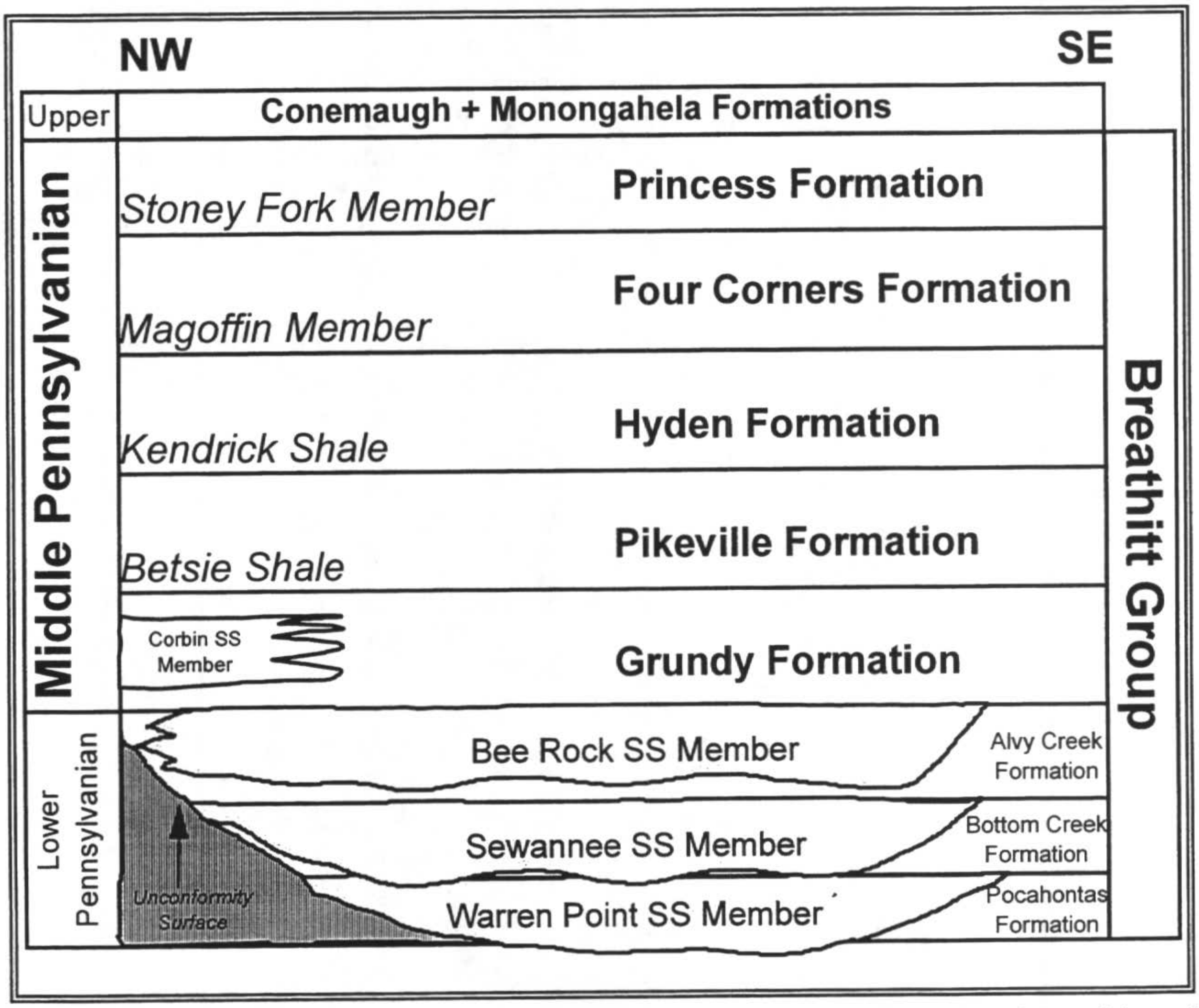

Figure 2 - Stratigraphic section of the Eastern Kentucky Coal Field showing the position of recognized formations within the Breathitt Group, and the position of important lithosrtatigraphic units (adapted from Chesnut, 1992).

by the Early Pennsylvanian unconformity, and by progressive onlap of the Bottom Creek, Alvy Creek, and Grundy Formation in a SE - NW direction. These four Early Pennsylvanian Formations primarily consist of thick (up to 150 m, 147 ft), wide (avg. 80 km, 50 mi) sandstone belts. In ascending order, they are the **Warren Point SS Member**, the **Sewanee SS Member**, the **Bee Rock Formation** (comprised of the Rockcastle and Pine Creek Sandstone Members), and the **Corbin SS Member**. These belts trend in a SW - NE direction, and onlap each other in the same direction. They are composed of individual sandstone beds, mostly 20 to 30 m (66 to 98 ft) thick, which are separated by thin beds of coal, underclay, shale and siltstone. They also truncate more heterolithic lithologies that are present in southeastern areas of the Central Appalachian Basin (Fig. 2).

Post Corbin SS Member lithologies are composed of shale, siltstone, argillaceous and lithic sandstone, and coal, usually arranged in repetitive sequence. Although some rocks of marine, or near-marine origin occur throughout the Breathitt Group, a few thick, widespread units are easily recognizable, and thus serve as convenient stratigraphic markers. In ascending order, they are the **Betsie Shale Member, Kendrick Shale Member, Magoffin Member,** and **Stoney Fork Member.** These marine beds provide the boundaries for the four major coal-bearing (producing) formations in eastern Kentucky, which are the, from oldest to youngest, **Pikeville Formation, Hyden Formation, Four Corners Formation**, and **Princess Formation**. (Fig. 2).

The lithologies of the Breathitt Group include those endemic to inland sea-fill, and coastal lowland environments. Current thinking envisions a series of shallow, parallel rivers prograding in a west - NW direction across the region, resulting in a digitate coastal plain. Mires, many widespread, formed during times of reduced sediment input, or in areas removed from active clastic activity. Some of these mires were terminated by renewed progradation, but many were drowned by marine transgressions from the west - SW. Approximately 50 progradation - mire - transgression cycles are recognized in the Breathitt, with an average duration of approximately 400,000 to 450,000 per cycle. These lithologic cycles are roughly equivalent to the average Illinois Basin cyclothem, and are inferred to have been controlled by the long earth periodicity (orbital eccentricity). The long earth periodicity is known to control glacial cycles. The major marine incursions, which represent extensive transgressions into the basins, and occur approximately every 2.5 Ma years, are also regular in occurrence, and may be related to tectonic and/or eustatic cyclicity in the basin.

The rocks we will observe on this trip are confined to the Hyden, Four Corners, and Princess Formations. Defining criteria, and characteristics of these formations are as follows:

- ❑ **Hyden Formation** (<850 ft; <260 m) - The Hyden Formation consists of important coal-bearing strata between the base of the Kendrick Shale Member, and the base of the Magoffin Member. The Kendrick and Magoffin Members are widespread units of marine origin. Coal beds in the Hyden Formation range from the Whitesburg through the Copland coal zones, and include the Fire Clay coal bed, which will be discussed in detail on this trip (Fig. 3). The Hyden Formation thins rapidly to the north, and is difficult to identify in the Princess Reserve

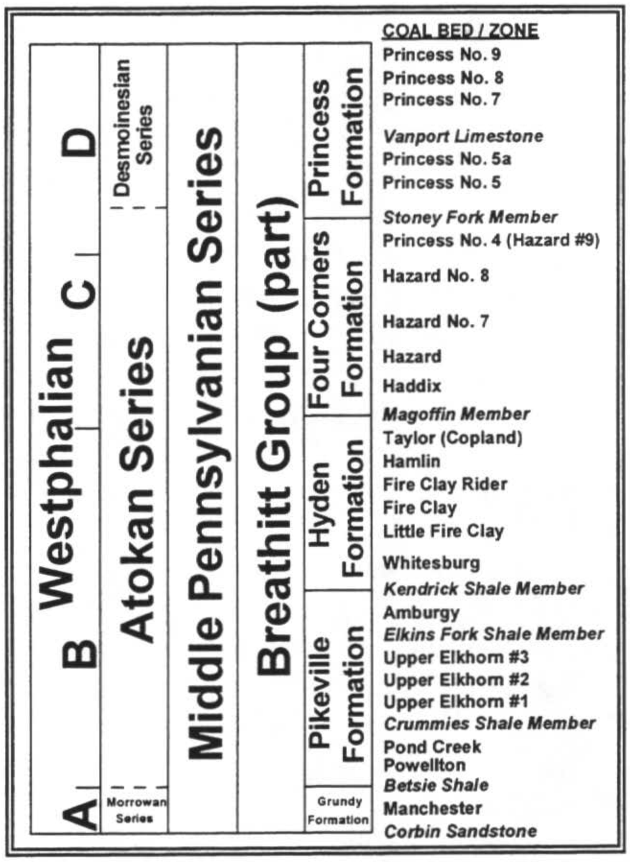

Figure 3 - Stratigraphic column showing the position of coal beds and marine units

District (Fig. 4).

- ❑ **Four Corners Formation** (<900 ft; <275 m) - The Four Corners Formation consists of coal-bearing strata between the base of the Magoffin Member, and the base of the Stoney Fork Member. The Four Corners Formation contains several economically-important coals, including the Haddix, Hazard, Hazard No. 7, Hazard No. 8 (Francis), and Hazard No. 9 (Hindman) coal zones (Fig. 3). We will see several of these coals on this trip. Like the underlying Hyden Formation, the Four Corners Formation thins to the north, and is difficult to identify in the Princess Reserve District (Fig. 4).

Princess Formation (<500 ft; <150 m) - The Princess Formation is the stratigraphically-youngest formation of the Breathitt Group, and is defined by the base of the Stoney Fork Member, and the Princess No. 9 coal bed (Fig. 3). In the Princess Reserve District, the base of the Princess Formation is placed at the top of the Princess No. 4 coal bed.

Stop Descriptions

Stop 1 - Hazard
John Kiefer
Assistant State Geologist
Kentucky Geological Survey

This stop is designed to emphasize the importance of local geologic knowledge, as it relates to construction of roads and buildings.

The Holiday Inn, located on top of the hill behind the Super 8 motel, represents (unfortunately) a classic example of one of the many geotechnical hazards that are endemic to eastern Kentucky. In eastern Kentucky, most of

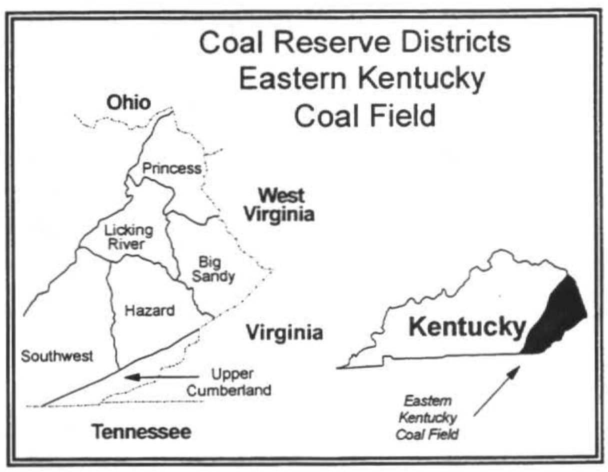

Figure 4 - Position of the six coal reserve districts in the Eastern Kentucky Coal Field.

the landscape is on a slope, and physiographically mature. Because of this, landslides and other forms of mass movement such as colluvial creep are also quite common in eastern Kentucky, and are a result of the slopes trying to reach a stable base level. This problem is exacerbated by both surface and underground mining, and the effects they have on the courses of surface and groundwaters.

Typically, any level, or near-level land in eastern Kentucky has already been built upon. The only other level areas occur along the flood plains of the rivers and streams that dissect the area, which precludes development because of frequent flooding. Therefore, the only way to obtain buildable land, in most cases, is to create it artificially. Done incorrectly, this can have disastrous consequences.

The Holiday Inn in Hazard, Kentucky was constructed in 1987, and scheduled to open late that year. A year later, the motel still hadn't opened. An Associated Press article dated 3 December, 1988 read, "The hotel had been scheduled to open a year ago, but structural problems, apparently stemming from the settling of land on a portion of the four-acre site, has stalled the opening...In some places the ground sank nearly a foot, severely damaging several rooms towards the rear of the complex. Large cracks are visible on the exterior of the building, and door and window frames have been bent. Wooden beams have been placed around the building to shore up the damaged section". Thirty six rooms had to be condemned before the motel opened, with an estimated revenue loss of $75,000 per month in 1988. One of the motels owners thought that the problem was a contractors error, rather then mine subsidence or settling, the Associated Press article went on to say.

In reality, the facility was damaged because part of the structure was built on bedrock (so-called "cut-area"), and part on valley-fill. The cut area probably originated as a surface mining bench, and the fill as a "head-of-hollow" fill, similar to many others seen in reclaimed areas throughout eastern Kentucky. As the fill material is very heterogeneous (i.e. a mixture of sandstone, siltstone, underclay, and shale in varying proportion and particle size) it tends to settle irregularly over time. In addition, because the fill occurs on a relatively steep slope, the possibility/probability of mass movement becomes a factor. To avoid this, good surface drainage, as well as placing internal drains in the fill, is critical. Improper drainage could cause the fill to fail catastrophically, or more likely, to continue to settle for an indefinite period of time.

Unfortunately, solutions to construction on a fill area such as this one are problematic at best. Structures founded on such widely differing material will always tend to settle irregularly. Using pilings to go through the fill, and set into underlying bedrock seems like a reasonable solution, but is extremely difficult to implement. A rigid, raft-like foundation would be expensive, and may not work either because of differential settlement.

Stop 2 - Four Corners

The Four Corners section is located at the intersection of Kentucky Routes 80 and 15, about 4 Km (2.6 mi) NW of Hazard, Kentucky. This stop offers a fine panorama of the Four Corners Formation at its type location. We will briefly outline the stratigraphy of the Eastern Kentucky Coal Field, and also provide an opportunity for inspection of the NE side of the exposure. The descriptions here are modified from Cobb and others (1981).

The named stratigraphic units at this stop are, in ascending order, the Magoffin Member, Haddix coal zone, Hazard coal zone, Hazard No. 7 coal, Hazard No. 8 coal, and Hindman coal bed (Fig. 5). The Magoffin Member is one of the widespread marine zones in the Eastern Kentucky Coal Field. This important stratigraphic unit will be discussed in more detail at subsequent stops today and

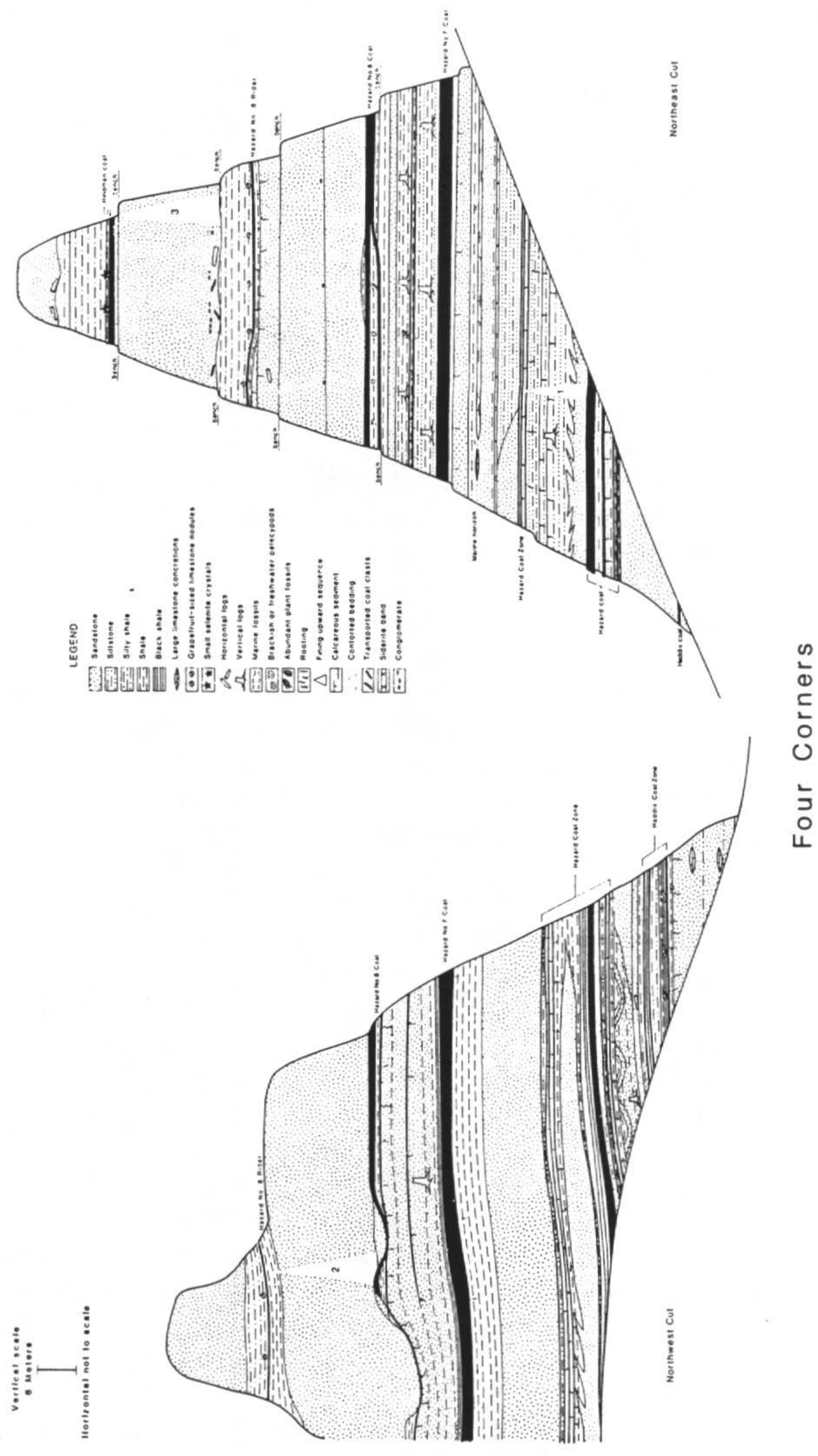

Figure 5 - Diagram of the roadcut exposure at Stop 2 From Cobb et al., 1981.

tomorrow. At this stop, the Magoffin is only exposed in the lower cuts along Kentucky Route 15, and in the exit ramp from KY Route 15 to the Daniel Boone Parkway. The Magoffin here is a dark gray shale with large calcareous concretions. It represents a widespread marine incursion into the basin, which was then filled with terrigenous clastics. The Haddix coal zone sits on top of the Magoffin. The Haddix tends to be high in ash and sulfur, but is mined locally in this area, and across the basin. At this location the pelecypod *Anthraconaia*, xenocanthid shark teeth, and other non-marine fish plates have been found in the dark shales between two of the Haddix coals, indicating that some brackish water probably influenced the Haddix paleomire during its development.

Crevasse-splay sediments containing log impressions, vertical stumps, and cut-and-fill structures extend up to the overlying Hazard coal zone. The Hazard coal zone consists of several coals separated by shales, siltstones, and fine-grained sandstones. The two thickest coals are 0.34 and 1.31 m (1.1 and 4.3 ft) thick. A fining-upward sequence (fining-upward sequence 1 in Fig. 5) overlies the upper-most coal, which is also the thickest coal in the zone. Accretion beds in the sandstone are indicative of fluvial processes. This interval contains vertical stumps, *Calamites*, and siderite nodules. The fining-upward sequence terminates in three thin coals all less than 0.09 m (0.3 ft) thick. These thin coals are overlain by a marine sequence that contains calcareous concretions, burrowed zones, and shell fragments.

The next coal in vertical sequence is the Hazard No. 7, which sits on argillaceous sandstone with siderite nodules and flaser bedding. The Hazard No. 7 is 2.2 m (7.1 ft) thick here, and is heavily-mined in several areas of the coal field, averaging 10.6 % ash yield, 0.84 % total sulfur content, and 12,686 BTU/lb. Typical of coals between the Magoffin and Stoney Fork marine members, the Hazard No. 7 contains a relatively low average vitrinite content (55.6 % mineral-matter free, mmf), moderate amounts of liptinite macerals (avg. 11.4 % mmf), and high percentages of inertinite macerals (avg. 33 % mmf). This type of maceral composition often contributes to a low Hardgrove Grindability Index (i.e. < 40), which can preclude its use in coal combustion furnaces, especially those with pulverized air injection configurations.

Siltstone, fine sandstone and shale with flaser bedding, lenticular bedding, siderite nodules, and plant fossils overlie the Hazard No. 7 coal. When first exposed, more than 20 vertical stumps and trunks were uncovered between the Hazard No. 7 and Hazard No. 8 coals, but most have been collected by paleontologists and amateur enthusiasts. The burial of these *in situ* stumps by overbank deposits is a good example of a clastic, lowland forest. There are, in fact, at least two preserved forests, being separated by a dark claystone, and thin coals at about the midpoint of this interval.

The Hazard No. 8 coal overlies the siltstone and shale above the Hazard No. 7 coal. This coal attains a maximum thickness of 2.6 m (8.6 ft) with a 0 to 0.9 m (0 to 3 ft) claystone parting, although the overlying sandstone erodes part, or all, of the coal in many places. The Hazard No. 8 coal is overlain by a thin, discontinuous claystone, and then a thick, coarse-grained sandstone. This sandstone fines upward (fining-upward sequence 2 in Fig. 5), and is capped by the Hazard No. 8 Rider coal. The coal is 0.2 m (0.7 ft) thick, and contains unusual grapefruit-size calcareous nodules that may be indicative of peat accumulation under brackish, to perhaps marine, conditions. A conglomeratic sandstone overlies the Hazard No. 8 Rider coal that fines upward (fining-upward sequence 3 in Fig. 5). This unit contains coal spar, pebbles, log impressions, and convoluted bedding.

The Hazard No. 9 coal bed sits on top of this fining-up interval, and is 0.9 m (3.1 ft) thick. It is overlain by a dark gray, silty shale, and a conglomeratic sandstone with log impressions. The shales and siltstones represent the Stoney Fork Member, and mark the base of the Princess Formation of the Breathitt Group. Although the Stoney Fork usually is fossiliferous, no marine fossils have been found at this location.

Stop 3 - Martin

This stop is located on Kentucky Route 80 at milepost 11 in Floyd County, approximately 2 km (1.2 mi) north of Martin, Kentucky. This stop provides an example of the Fire Clay coal where it is split by several partings, and cut out altogether by a coarse-grained sandstone. The strata exposed in this roadcut, in ascending order, are the Little Fire Clay coal bed, Fire Clay coal, Fire Clay Rider coal, Taylor coal zone, Magoffin Member, Hazard coal zone, and Peach Orchard (Hazard No. 7) coal zone. Strata exposed in this roadcut include five fining-upward sequences (Fig. 6), punctuated by two highly-fossiliferous marine zones, and one coarsening-upward sequence. The fining-upward sequences have the following characteristic features: 1) erosional bases with conglomeratic lag, and large-scale crossbeds in the lower - middle parts, 2) log impressions, and 3) small-scale trough- crossbeds in the upper parts. Each fining-upward sequence terminates in a coal zone.

A medium to coarse-grained sandstone (fining-upward sequence 1; Fig. 6) with large-scale crossbeds, coal spar, log impressions, and large, angular clasts of siltstone overlies the stratigraphically-older Little Fire Clay coal. The next coal bed in succession, the Fire Clay coal, consists of four benches of coal intercalated with inorganic partings, one of which contains flint clay (first parting above the base of the coal). Most workers consider the flint clay parting to represent an ancient volcanic ash fall (Chesnut, 1983), and radiometric dates on sanidine and plagioclase grains date the parting in eastern Kentucky at 311 Ma years. More extensive sampling in adjacent West Virginia and Tennessee have confirmed this age date (Rice et al., 1994). Tonstein isopachs and wind pattern reconstructions for the Pennsylvanian suggest either an east - southeast source (Chesnut, 1983; Rice et al., 1994), or western source (Lyons et al., 1992) for the ash fall. The Fire Clay tonstein is mainly cryptocrystalline, commonly aphanitic, and usually dark gray to dark brown in color. Kaolinite is the dominant mineral, and is an alteration product of the original volcanic ash. The non-clay portion of the flint clay is mostly quartz, mostly in the fine to very fine sand range (0.25 to 0.09 mm), with lesser amounts of sanidine, apatite, zircon, iron and titanium oxides, pyroxene, amphibole, monzanite, garnet, biotite, and various sulfides. It has been suggested that the ash fall originated from a rhyolitic magma (Rice et al., 1994). The Fire Clay tonstein is the most areally extensive and continuous of all known Middle Pennsylvanian tonsteins. This flint clay parting occurs in the Fire Clay coal throughout most of the Central Appalachian Basin, a factor which makes it a key stratigraphic marker bed.

Perhaps the most conspicuous feature at this stop is the complete removal by the Fire Clay coal by a massive, coarse-grained sandstone towards the south end of the exposure. These types of cut-outs are difficult to predict in advance of mining, and are an operational, and economic hazard, especially in underground operations. This cut-out is oriented NE - SW (~242^0) At this location, the Fire Clay coal bed is thick, but split by inorganic partings into four coal benches. In areas to the south - southeast, where the coal is better-developed, there generally are only two benches, separated by the flint clay parting. In areas where there is only one bench of Fire Clay coal, it most often is the upper bench. Splitting of the Upper bench may indicate that this location, which occurs on the NW margin of a thick pod of

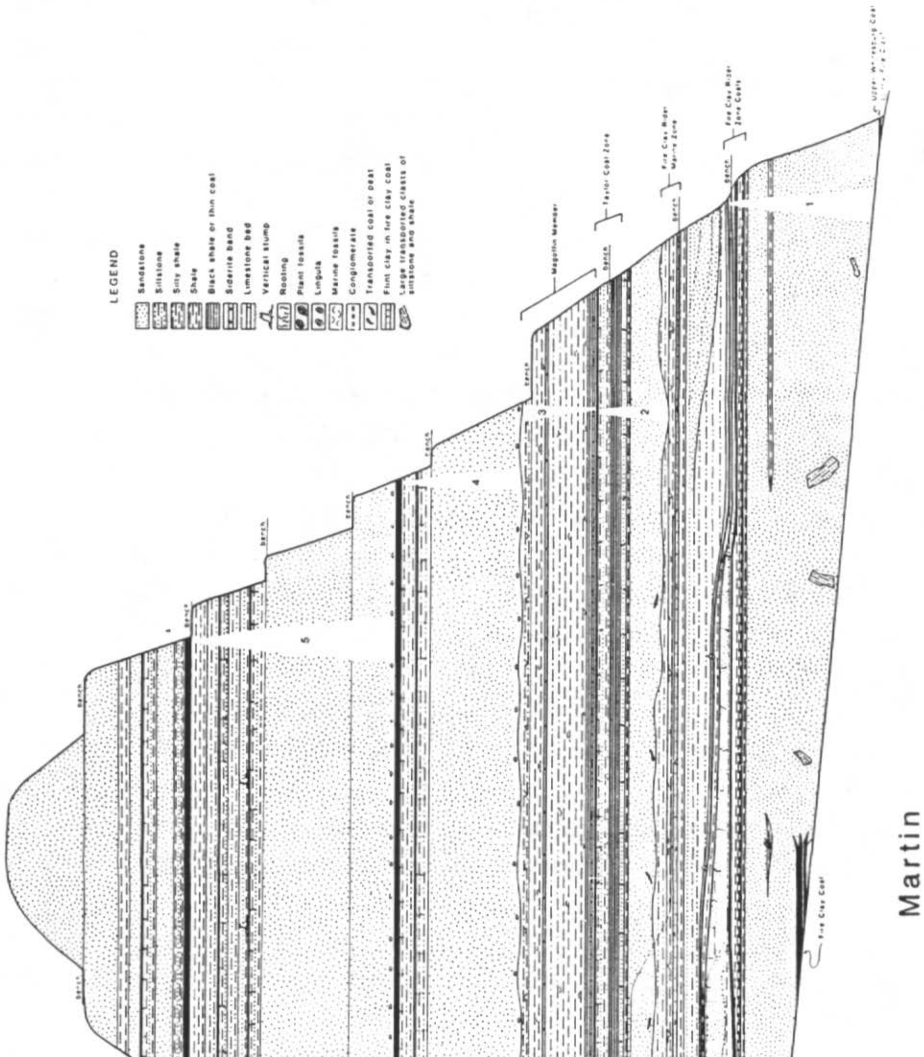

Figure 6 - Diagram of the road cut at Stop 3.

Fire Clay coal (Fig. 7), was marginal to syndepositional fluvial channels, which later cut across the paleomire, forming the cut-out. Paleoflow was to the west - southwest (240 - 250^0).

Overlying this scouring sandstone (fining-upward sequence 1, Fig. 6) is the Fire Clay Rider coal bed. The Rider coal lies flat along most of the roadcut, but fills a channel scour towards the north end of the cut. The Fire Clay Rider coal is 0.67 m (2.2 ft) thick in the deepest part of the channel, but thins to 27 cm (1.4 ft) in the flat-lying area. When the road was first cut, an *in situ* tree stump, 1.6 m (5.2 ft), and 0.4 m (1.3 ft) in diameter, was preserved in the center of the scour.

The Fire Clay Rider here, and in most parts of the coal field drapes the depositional system that buried the Fire Clay coal bed. The channel-filling nature of the Rider coal indicates that the mire accumulated in a topographic low. Rapid inundation is inferred by the presence of the large tree stump. If the entire channel was filled by peat, and the lateral thickening of the coal into the channel is inferred to represent compaction of the peat, then a 10:1 compaction ration is suggested (Cobb and others, 1981).

Burrowed and fossiliferous siltstone and sandstone, and a fossiliferous, impure limestone 0.3 (1.0 ft) thick occur above the Fire Clay Rider coal bed. Marine fauna in the limestone include *Derbyia, Anthracospirifer*, and *Composita*. *Derbyia* is so abundant in some layers as to form a *Derbyia*-pavement. These fossils suggest transgression followed the deposition of the Fire Clay Rider coal.

A coarse- to very coarse-grained sandstone (fining upward sequence 2 on Fig. 6) that contains coal spar, large-scale trough crossbeds, and an erosional base overlies the marine beds. This sequence is, in-turn, overlain by finer-grained beds (i.e. claystones and black shales), and thin coals of the Taylor (Copland) coal zone.

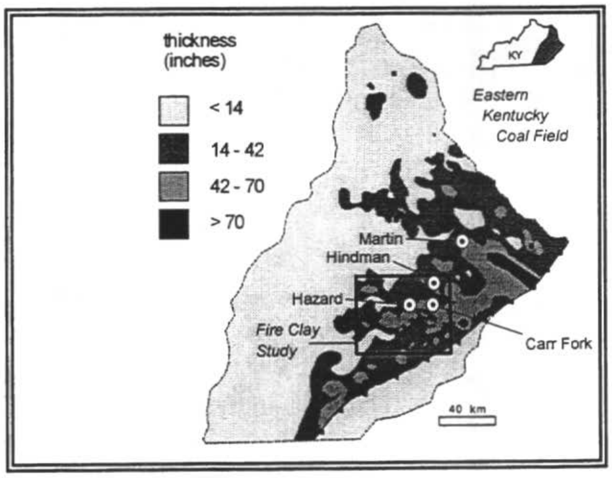

Figure 7 - Isopach map of the Fire Clay coal bed in eastern Kentucky.

The overlying Magoffin Member marine zone is 9.4 m (30.8 ft) thick, and consists of claystone, limestone, and silty shale in a coarsening-upward sequence. (sequence number 3 on Fig. 6). The Magoffin is extremely fossiliferous in this roadcut, and contains a wide variety of brachiopods, pelecypods, gastropods, some nautiloids, goniatites, echinoids, and crinoids.

Overlying the Magoffin Member is a very coarse-grained sandstone (fining-upward sequence 4 on Fig. 6), containing trough crossbeds, ripple beds, coal spar, log impressions, and an erosional base. Silty claystones, siltstones, and a thin coal 0.8 m (2.6 ft) thick above the sandstone mark the basal part of the Hazard coal zone.

A conglomeratic sandstone, succeeded by a series of claystones, thin sands, and thin coals (fining-upward sequence 5 on Fig. 6) of the Peach Orchard coal zone, overlies the Hazard coal zone. The sandstone contains marked cross-bedding and log impressions, and vertical stumps can be seen in the finer-grained sediments. The Peach Orchard coal zone at this location is correlative with the Hazard No. 7 and 8 coal beds.

Geochemistry of the Fire Clay Coal

The basal two coal benches, which straddle the flint clay parting and a claystone, are moderate to low in ash (11.3 and 6.35 %), and low in sulfur (0.8 and 1.1 %). In contrast, the next coal bench in vertical succession is high in ash (28.1 %), and low in sulfur (1.3 %). The top coal bench is the lowest in ash (5.5 %), and sulfur (0.75 %). The flint clay parting occurs directly above the lowest bench of coal, and appears as a carbonaceous shale (70 % ash yield) (Fig. 8).

Palynology of the Fire Clay Coal

All of the coal benches contain abundant *Lycospora*, which was produced by several of the large lycopod trees (e.g. *Lepidophloios, Lepidodendron*) (Fig. 9). The only sample that isn't dominated by *Lycospora orbicula* and *L. micropapillata* is the top coal increment (0 to 8 in, see Fig. 9), which represents the upper half of the thickest coal bench. In this increment *Lycospora pellucida, L. granulata* (both produced by *Lepidophloios*), and *L. pusilla* (produced by *Lepidodendron*) are the common species of *Lycospora*. *Densosporites*, which was produced by a subarborescent lycopod called *Bodeodendron*, *Punctatisporites minutus* and *Apiculatasporites saetiger*, two types of tree fern spores, *Granulatisporites*, a small fern spore, *Calamospora* and *Laevigatosporites minor*, calamite spores, and *Florinites*, which is cordaite pollen, are also more common in this increment.

The high percentages of *Lycospora orbicula* and *L. micropapillata* in all but the top coal increment indicate that *Paralycopodites* was probably the most abundant mire plant. *Paralycopodites* is thought to have been a colonizing lycopod, one of the first plants to occupy the mire (DiMichele and Phillips, 1985, 1994). More mire-centered lycopods, such as *Lepidophloios* and *Lepidodendron,* and usually some other non-lycopod plants (e.g. ferns), generally succeed *Paralycopodites* as peat accumulation progresses. This latter type of flora would be considered a more "mature" flora.

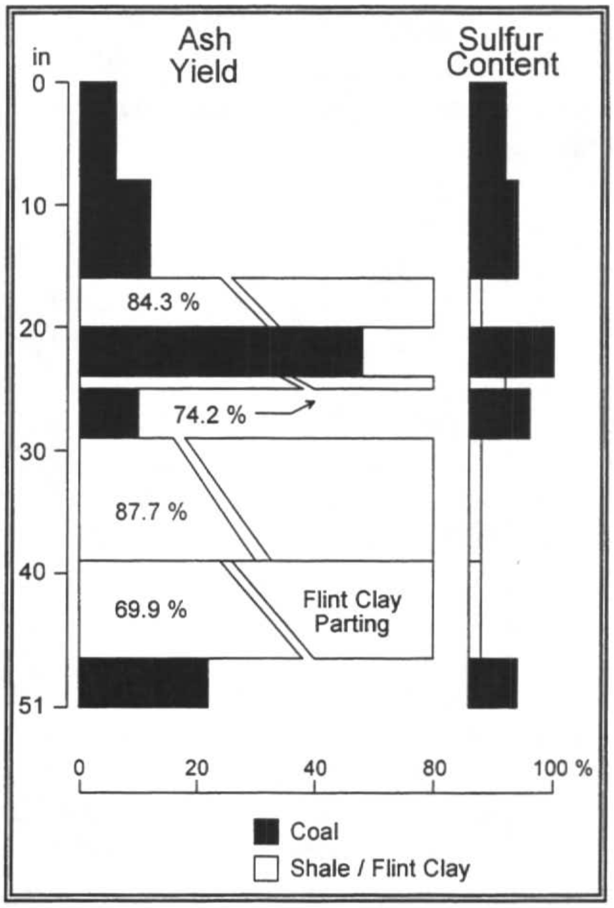

Figure 8 - Ash yield and total sulfur content profiles in the Fire Clay coal bed at Stop 3.

The high percentages of *Lycospora orbicula* and *L. micropapillata* agree well with the split-up nature of the Fire Clay coal at this location. Apparently, the mire was never able to progress from a colonizing *Paralycopodites* flora, to a more mature *Lepidophloios / Lepidodendron* flora because peat accumulation was regularly interrupted by clastic deposition. Only the top coal bench, which had the thickest accumulation of peat, shows the presence of a more mature paleoflora.

Coal Petrography of the Fire Clay Coal

Petrographically, all but the top increment and bottom bench are dominated by vitrinite, with a nearly even distribution of well-preserved forms (telinite + telocollinite),

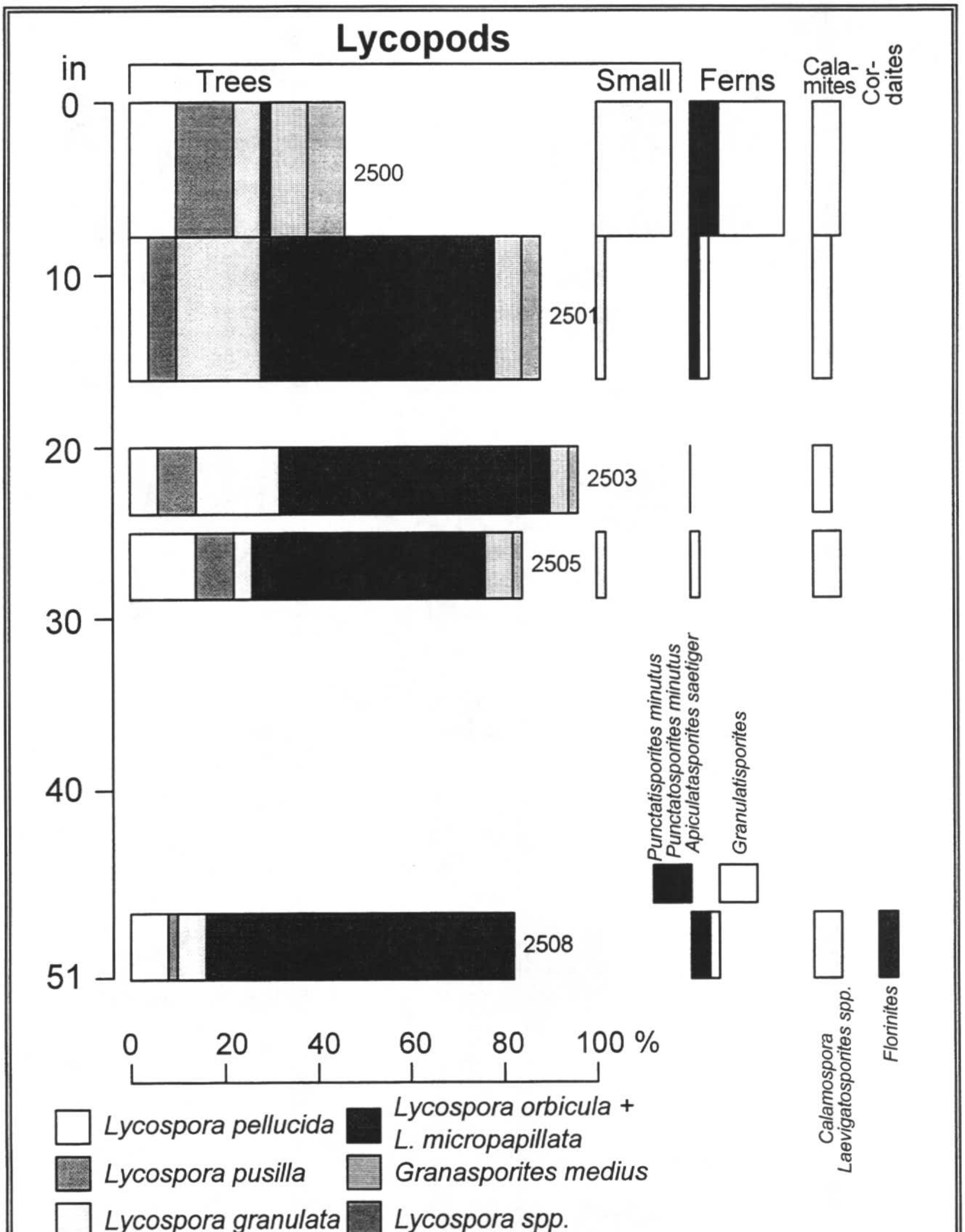

Figure 9 - Distribution of miospore taxa, grouped according to affinity, in the Fire Clay coal bed at Stop 3.

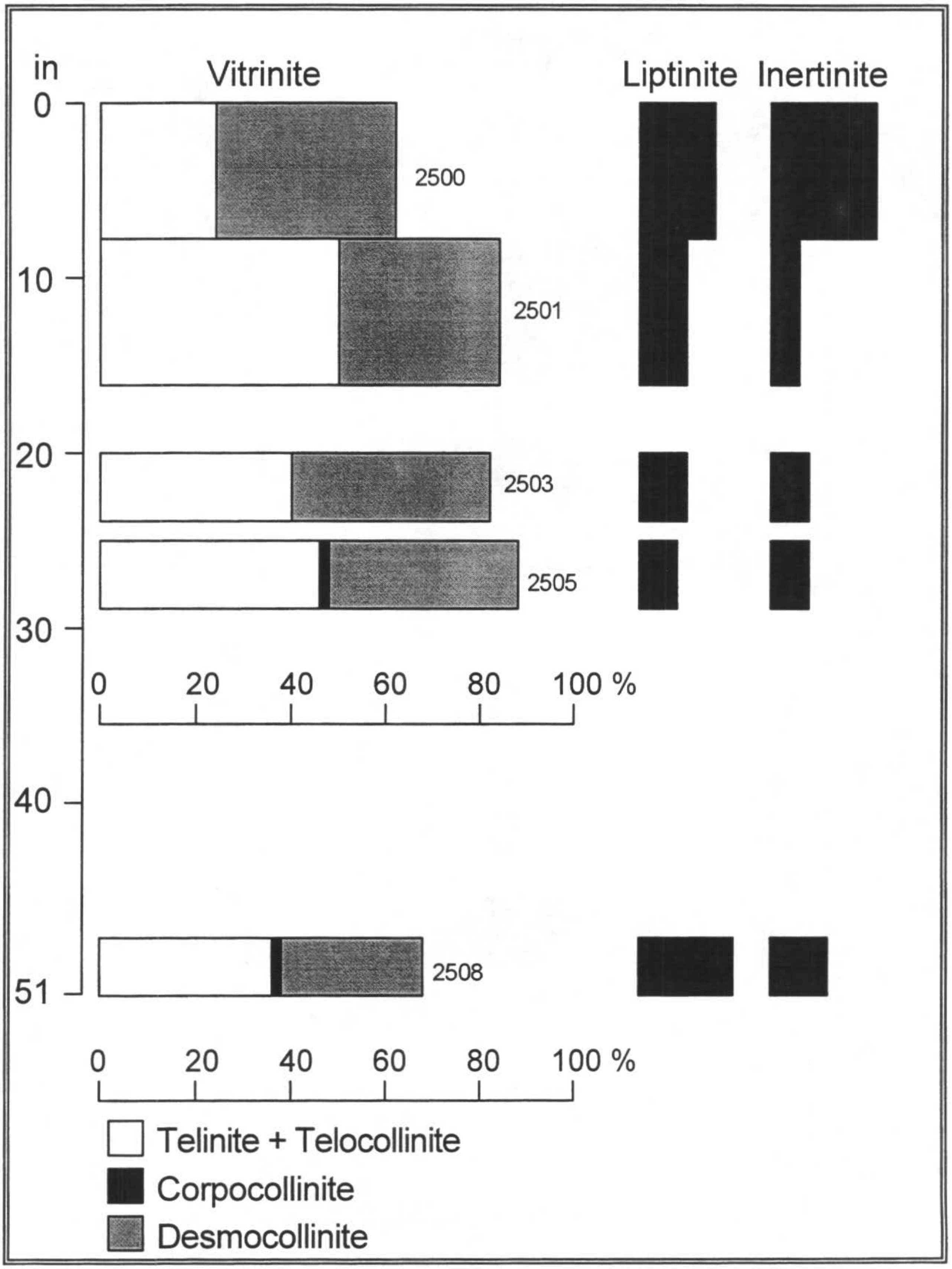

Figure 10 - Distribution of macerals in the Fire Clay coal bed at Stop 3.

and degraded vitrinite (desmocollinite, Fig. 10). The top increment of the top bench contains increased percentages of liptinite and inertinite macerals. The bottom bench has a high liptinite content (19.4 % mmf). These data indicate that the two middle coal benches, and the bottom increment of the top bench, probably formed in mires with a consistently flooded surface, as the formation of vitrinite is enhanced under aqueous, acidic conditions (Stach et al., 1982; Teichmuller, 1989). The nearly even distribution of telinite/telocollinite and desmocollinite indicates that much of the pre-vitrinite material in the plant litter was degraded prior to peatification/coalification.

The top coal increment, which contains higher liptinite and inertinite contents, also contains a higher proportion of desmocollinite, relative to telinite/telocollinite. This type of maceral distribution indicates that much of the plant litter was degraded and oxidized prior to becoming coal. The increased percentages of liptinites in this increment, and in the bottom coal bench, probably is the result of the liptinites being highly resistant to degradation; in other words, the liptinites increase in concentration because other plant components, namely pre-vitrinite materials, are being preferentially destroyed.

LUNCH BREAK, JENNY WILEY STATE PARK

Stop 4 - Kentucky Route 3, Inez Quadrangle

This portion of the trip occurs along the new (opened in 1991) section of Kentucky Route 3 from mileposts 2 to 5 in Martin County. Breathitt Group strata from below the Hamlin coal at milepost 5 to the base of the No. 5 Block coal high above the road way at milepost 2 are exposed. We will concentrate on the section exposed between mileposts 3 and 5, a near continuous series of roadcuts exposing approximately 500 ft of section.

Coalburg to Stockton coal beds...milepost 3.7 to 3.9

The Coalburg to Stockton interval at this exposure offers a wide variety of coal bed structures, post-coal slumping and erosional features. The lithologic description of the Coalburg coal bed, exposed along the southbound lane, is shown in Figure 11. In these exposures, the late-Middle Pennsylvanian Coalburg and Stockton coals (late Westphalian C - early

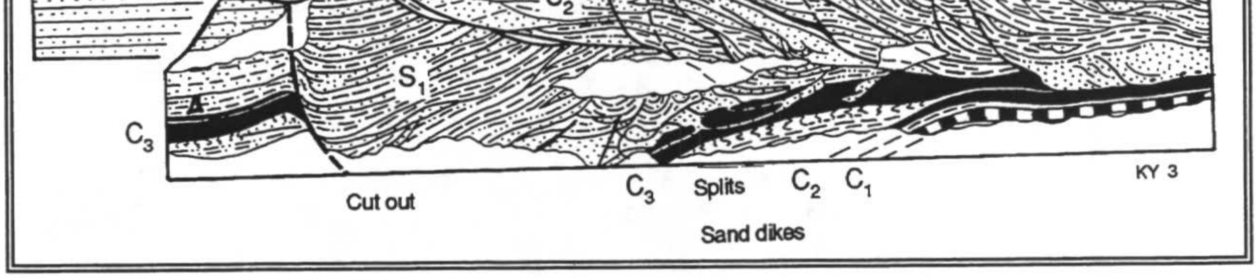

Figure 11 - Diagram of Roadcut at Stop 4. C_1 - C_3 = Coalburg coal. St = Stockton coal. S_1 and S_2 = paleoslumps. From Greb and Weisenfluh, *submitted.*

Westphalian D) are offset along a listric-normal glide plane.

The westernmost slump (S_1) above the Coalburg coal is truncated by a succession of eastward dipping, imbricated beds (S_2). The Coalburg coal beneath the dipping beds is significantly thicker than the coal west of the glide plane where the beds are horizontal. A basal bone coal (C_1), and shale and coal interval (C_2) do not occur west of the offset (Fig. 11). The second coal bench is also split by a shale wedge that thickens toward the offset. The third coal bench (C_3) is similar to the undisturbed coal. Where undisturbed, the main bench of the Coalburg coal is overlain by *in situ* lycopod stumps and heterolithic strata. Laterally it is offset or cutout, being split by clastic dikes (Figs.), and cutout by a cross-bedded sandstone. Successive sand dikes penetrate to a similar level in C_3 , and then pinch out or rise upward as contorted "boudinage" partings within the coal until they exit the coal toward the offset (Figs. 12a-b).

Interpretation

Differences in the Coalburg coal and parting thickness, slumping, and the elevation of the Stockton coal on either side of the offset suggest that the glide plane represents a syn-sedimentary fault. Movement along the fault was contemporaneous with peat accumulation and subsequent sedimentation. Figure 13 a-j is an interpretation of how movement affected peat accumulation and sedimentation. Tensional stresses (possibly related to larger structures to the northeast) resulted in listric rupture of the clays that preceded peat accumulation. The depositional low that resulted, was filled by a poorly-drained mire (C_1). Continued movement led to repeated drownings and re-establishment of mire conditions (Fig. 13a-c) and multiple coal benches and splits along the margin of the growth fault (C_2). Establishment of the main Coalburg paleomire may have led to short-term stabilization of the fault, possibly

Figure 12a - Sand-dike parting in the Coal Burg coal beneath paleoslump at Stop 4.

through extensive root penetration, or a lack of movement on the structure resulted in stable enough conditions for the main coal bench (Fig. 13d). The Coalburg coal was sampled from a Kentucky Department of Highways core where two benches of coal are present. The bottom bench is 39.6 cm (15.6 in) thick, and contains 16.5 % ash yield and 1.9 % total sulfur. The 66.8 cm (26.3 in) upper split is a bit cleaner, with 8.9 % ash, and 0.9 % sulfur.

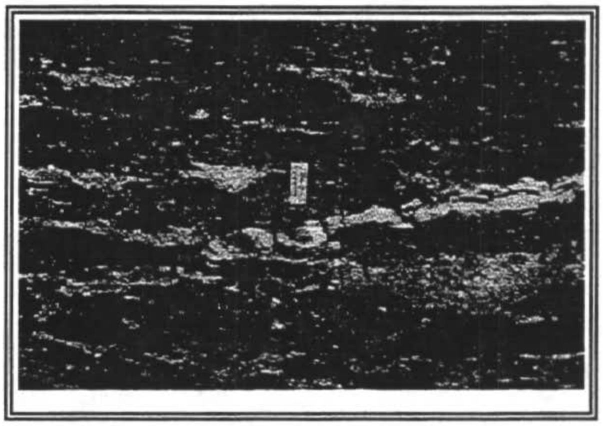

Figure 12b - Boudinage-like sand-dike in the Coalburg coal at Stop 4.

The peat was buried by levee or proximal floodplain sediments from a meandering channel. *In situ* stumps above the undisturbed coal indicate rapid sedimentation (Fig. 13e). Loading of channel margin sediments reinitiated slow movement along the growth fault resulting in headward thickening of strata (Fig. 13f). Ultimately extension led to rupture of the Coalburg peat and slumping (Fig. 13g).

Tensional stresses at the hinge point of downward rotation also caused the peat to tear (Fig. 13h). Tears were injected by sandstone from the overlying slump resulting in sand-dike partings. The downward terminus of several dikes midway through C_3 (at approximately the same height as the sandstone cutout) may indicate that the lower part of the peat was more compacted than the upper peat at the time of injection.

Continued growth, or normal depositional processes related to lateral migration of the fluvial channel, led to a series of sharp scours and lateral accretion surfaces bound by smaller slumps eastward (Fig. 13i), which were colonized by the younger Stockton paleomire

The Stockton coal exhibits uniform thickness on either side of the shear plane so that growth did not occur during peat accumulation. Burial and loading of sediment on the peat may have reinitiated movement (or initiated the development of a second growth structure above the first) and led to offset of the Stockton peat (Fig. 13j).

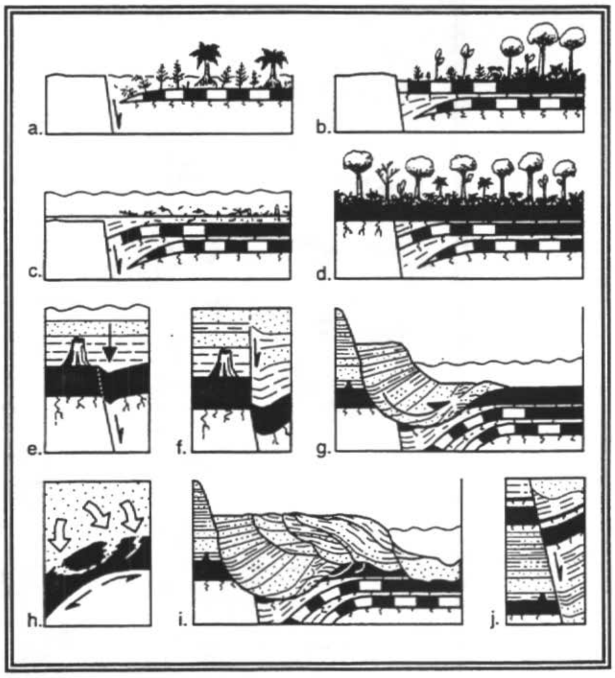

Figure 13 - Interpretation of how the Coalburg and Stockton coals, and intervening strata, formed at Stop 4. See discussion of 13a-j in the text. From Greb and Weisenfluh, *submitted.*

Paleoecology of the Stockton coal bed

The Stockton coal, like other coals between the Magoffin and Stoney Fork marine zones, tends to occur as a coal zone (i.e. several coal benches intercalated with clastic partings), rather than as a single, laterally persistent bed. Like the Fire Clay coal seen earlier today, vitrinite-rich benches of the Stockton contain high percentages of *Lycospora.* Unlike the Fire Clay, the Stockton has more durain coal lithotypes. Two types of durains are present in the Stockton, low ash durain, and high ash durain. Low ash durain, or what sometimes is called "splint coal", which is an old Scottish miners term for very hard, blocky coal that has a dull gray luster, poor banding, and tends to break irregularly, is interpreted to have formed in areas of the mire where the water table was below the surface much of the time. These areas couldn't support an arborescent lycopod vegetation, mainly because of the lycopods' specialized reproductive mechanism, which required standing water. Rather, less ecologically specific plants, such as tree ferns and small lycopods, occupied these areas. The high percentages of liptinite and inertinite macerals in the low ash durains indicates a high degree of oxidation of the plant litter, in the case of the inertinites, and concentration due to greater resistance, in the case of the liptinites. In addition, the amount of well-preserved vitrinite macerals in these lithotypes is usually quite low, indicating that much of the previtrinite material in the plant litter was degraded prior to burial and coalification.

The high ash durains are macroscopically similar to the low ash durains, or splint coal, contain much more ash (typically > 20 %, compared with the low ash durains, which are

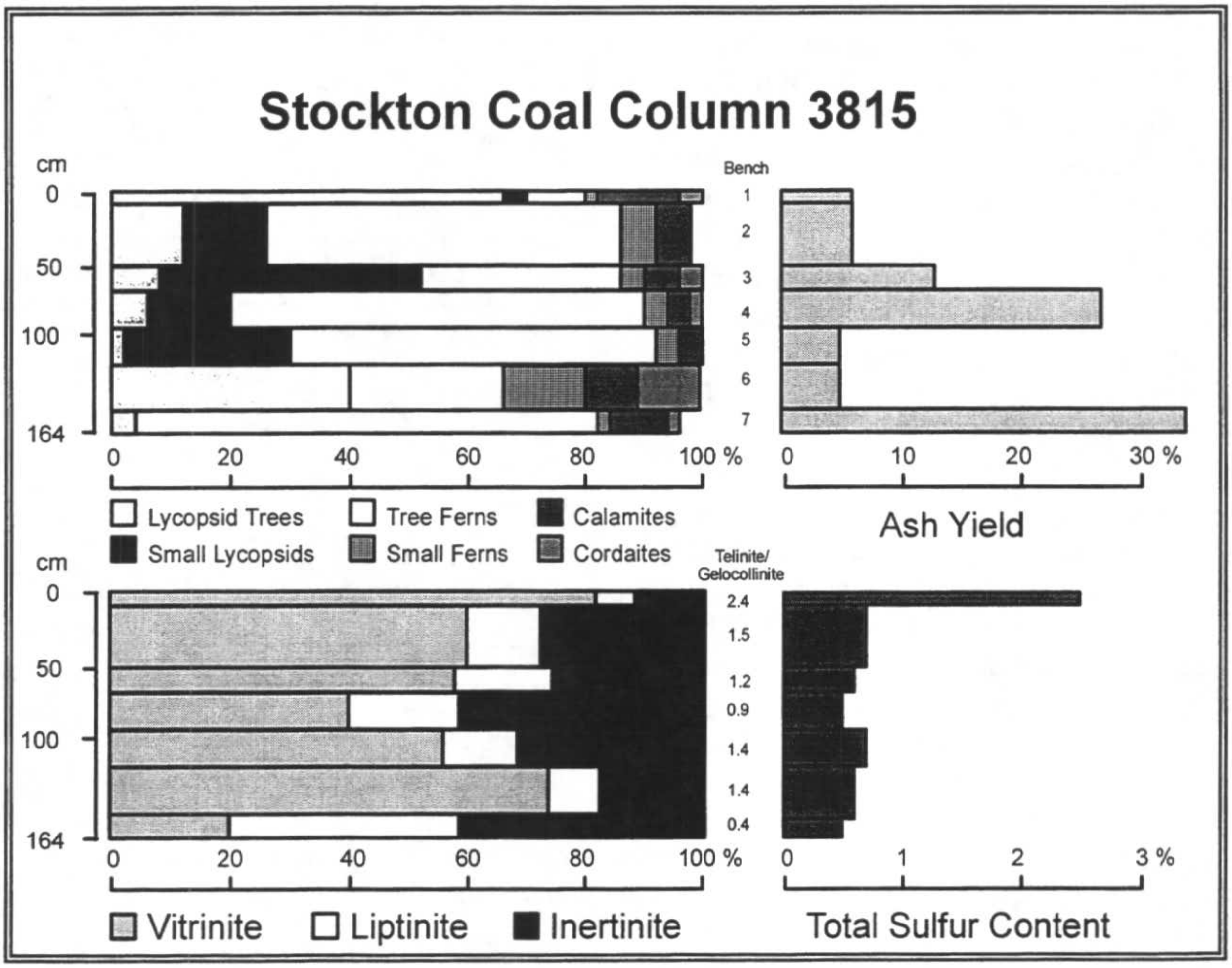

Figure 14 - Distribution of miospores, grouped together according to affinity, macerals, ash yield and total sulfur content in Stockton coal column 3815.

commonly < 5 % ash). The high ash durains appear to be the result of clastic influx into the mire. In this case, oxidation / degradation of the plant litter may have been accelerated by the introduction of extra-mire waters, which usually are more oxygenated then mire waters. Alternatively, some portion of the inertinite and liptinite fraction of the coal may be allochthonous, being transported into the mire as sedimentary particles. Some portion of the vitrinite fraction of the coal may owe its origin to this mechanism as well.

Petrographically, both the low ash, and high ash durains contain high percentages of liptinite and inertinite macerals, relative to bright-banded coal, which typically is dominated by vitrinite macerals. Palynologically, these lithotypes often contain abundant tree fern and small lycopod spores. Figures 14, 15, and 16 show the composition of the Stockton coal, collected from nearby outcrop, mine, and drill core locations. Note the abundance of liptinite and inertinite macerals, as well as the high percentages of tree fern and small lycopod spores in all of the columns.

To summarize, the Stockton coal exhibits a wide range of lithotypes, from bright-banded, *Lycospora-dominant* coal, to very dull, almost non-banded coal (low ash and high ash) that contains high percentages of tree fern and small lycopod spores. The heterogeneous mixture of these to disparate coal types differs from stratigraphically older beds, which tend to be more completely bright-band

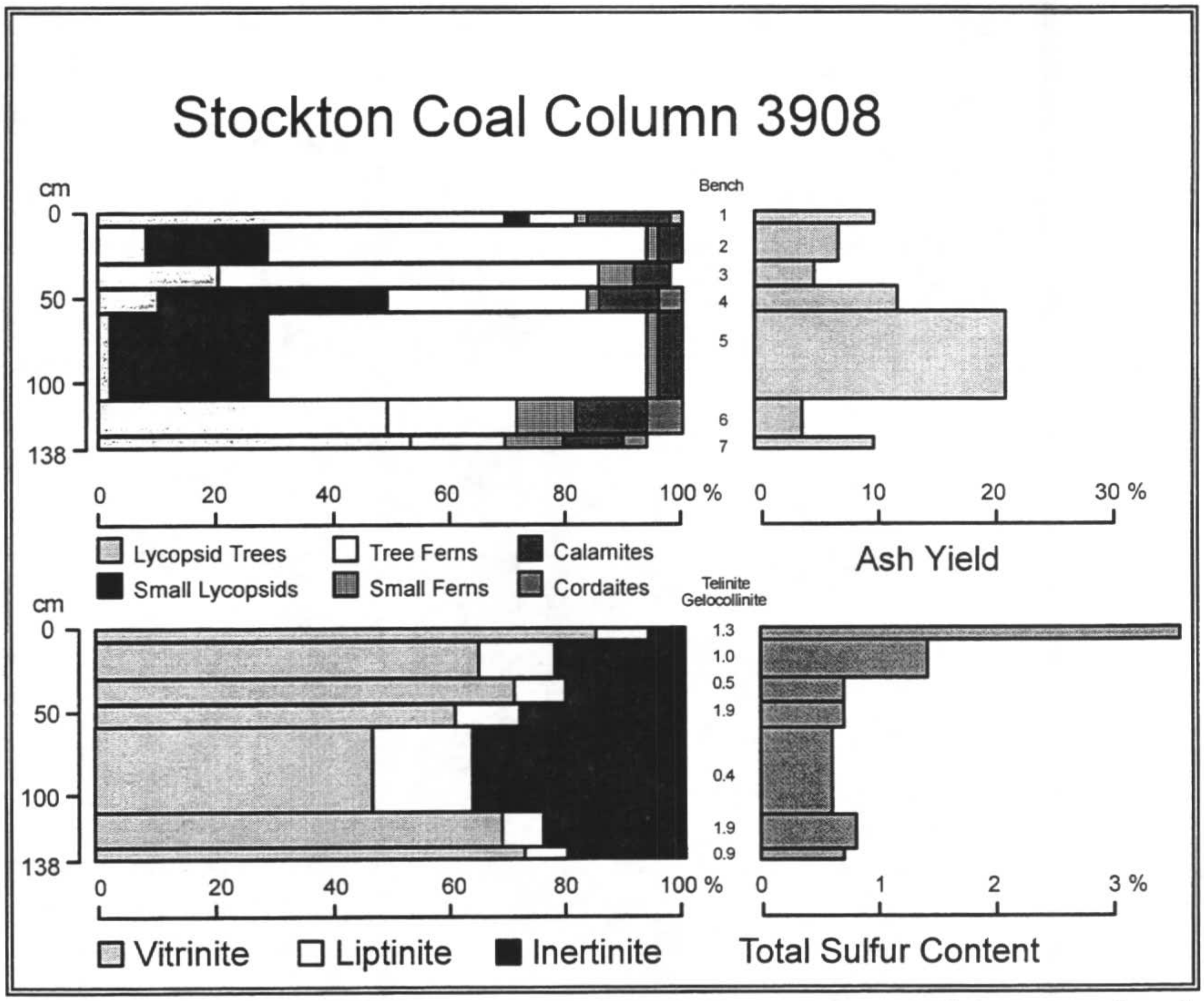

Figure 15 - Distribution of miospores, grouped together according to affinity, macerals, ash yield and total sulfur content in Stockton coal column 3908.

dominant. The high percentages of tree fern, and small lycopod spores in the Stockton coal, and coals between the Magoffin and Stoney Fork marine units, suggests that mire vegetation was somewhat different than the vegetation in Early and early Middle Pennsylvanian mires. The increase in inertinite and liptinite macerals further suggests that edaphic, and hydrologic conditions within the paleomires had also changed.

Stop 5 - Roof Failure in a Stockton Coal Mine

The exposure provides an excellent example of the geologic controls on roof stability. State Highway 3 cuts through a room and pillar mine in the Stockton coal, which was mined from both ridges on either side of the road. The road bisects six entries, which have now been sealed. Look for old roof bolts along the exposed face above the collapsed adits.

The roof above the coal consists of two fine-grained, lenticular sand bodies that interfinger laterally toward the south-central part of the outcrop. The northeast sandstone lens is 6.5 m thick and the south sandstone lens is 3.5 m thick. The upper half of the sandstones exhibit lateral accretion surfaces and interfinger with sandy shale and shale. In the northeast lens, lateral accretion surfaces dip into a shale-

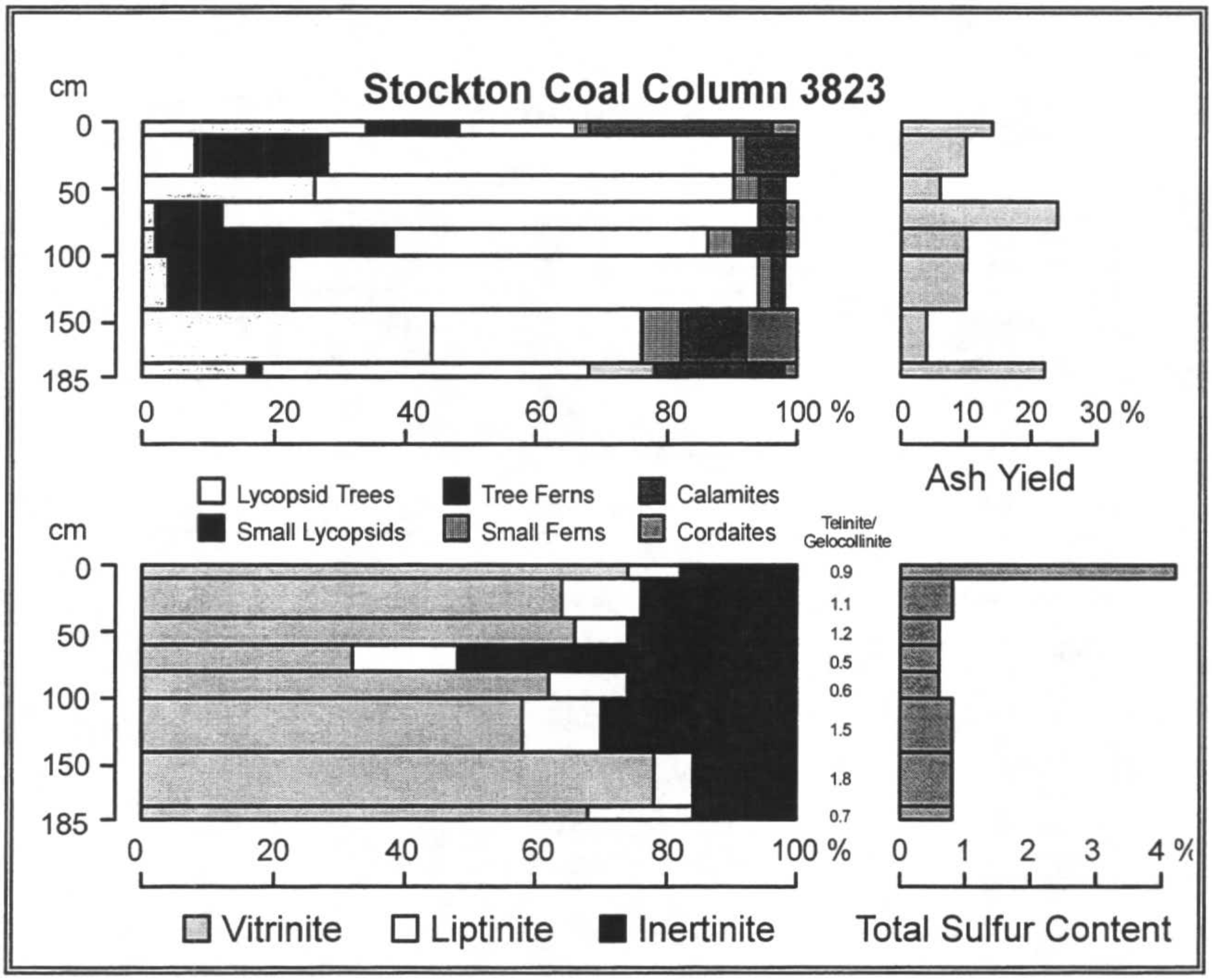

Figure 16 - Distribution of miospores, grouped together according to affinity, macerals, ash yield and total sulfur content in Stockton coal column 3823.

filled scour from both margins of the scour, in the upper third of the sandstone. Laterally the two sandstones grade into sheet-form sandstones and shales, with no single sandstone bed more than 1 m thick. In this zone a 38 m wide collapse has occurred above the old adits in the mine. The collapse affects all strata to the overlying sandstone (Fig. 17).

The coal is interpreted to have been buried in alluvial plain environments. The two lenticular sandstones represent two small, migrating channels that appear to have cut into, or meandered over sheet-form, distal- to medial-splay lobes. The northeastern channel was ultimately abandoned and filled with mud, similar to a clay plug in modern crevasses and small river channels (Fig. 18).

Where the roof consisted of less than 1.5 m of shale overlain by thick (>3m) splay sandstone, the roof held with the use of roof bolts, and is still holding (12 years later as of the writing of this report). However, between the two lenticular sandstones, the roof collapsed affecting an area 35 m wide and 7 to 10 m thick. The disturbed zone extends up to the capping sandstone and shows characteristic angular failure. The zone of failure represents a pressure arch above the old entry, which failed to the first competent beds, 8 to 10 m above the coal. It is impossible to say whether this wide an area would have been affected had the

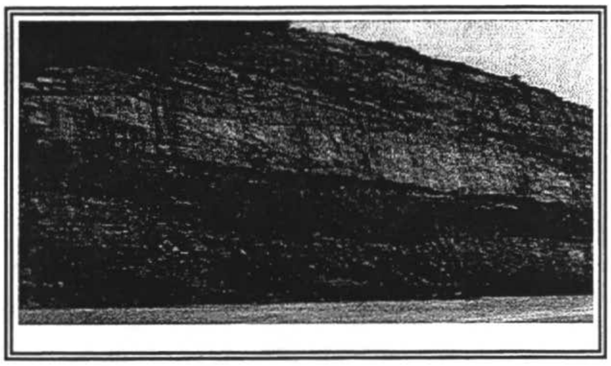

Figure 17 - Roof failure above the Stockton coal at Stop 5.

road not been cut, but smaller falls were typical in the mine (inferred to be related to similar roof facies) and similar geologic conditions are a common cause of roof failure in other eastern Kentucky coal mines (Horne and others, 1978; Hylbert, 1984; Ferm and Weisenfluh, 1989; Greb, 1991, 1992).

This exposure also shows the amount of coal that must often be left in the ground in room-and-pillar mines. In this case, approximately 20-foot entrys were cut between 40- to 50-foot wide pillars. The pillars were left in the ground because they were needed for roof support. In some mines, pillars are extracted on the way back out of the mine--a process called retreat mining. Longwall mining is another method that leaves no pillars in the ground. However, both of these types of mining require

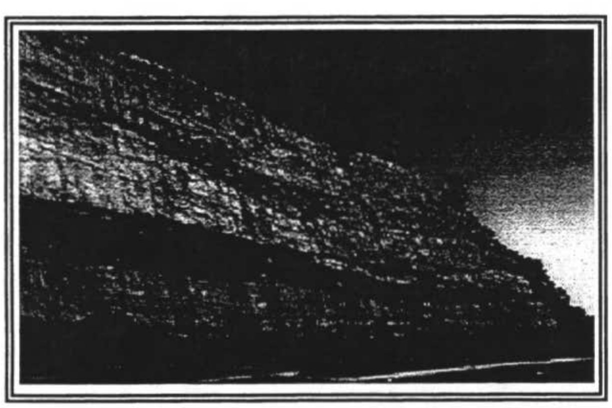

Figure 18 - North end of roadcut at Stop 5 showing adits, and an abandoned channel just below the first bench

specific conditions that were not encountered in this Stockton coal mine.

End of Day 1

Day 2

Stops on the second half-day of this trip will be spent examining exposures of the Fire Clay coal bed, which is the second most heavily-mined coal in eastern Kentucky. In 1990, the leaders of this field trip began a very detailed study of the Fire Clay coal in an eight 7.5 minute quadrangle area of the Eastern Kentucky Coal Field . This stop, and two others we will visit this morning, occur within this area, and are designed to provide examples of how the Fire Clay coal appears, and varies, in the Eastern Kentucky Coal Field.

Stop 6 - Thin Fire Clay Coal Bed without flint clay parting

The first stop of the morning is in a "box-cut" along the Hindman access road (Kentucky Route 160) approximately 1.6 km (1 mi) north of Hindman, Kentucky. This stop is an excellent example of the Fire Clay coal where it is "thin" (< 1 m), and also where the flint clay parting, normally present, is absent.

Geochemistry, Petrography, and Palynology

Two bench-sets of the coal were collected at this location, one on the corner adja-

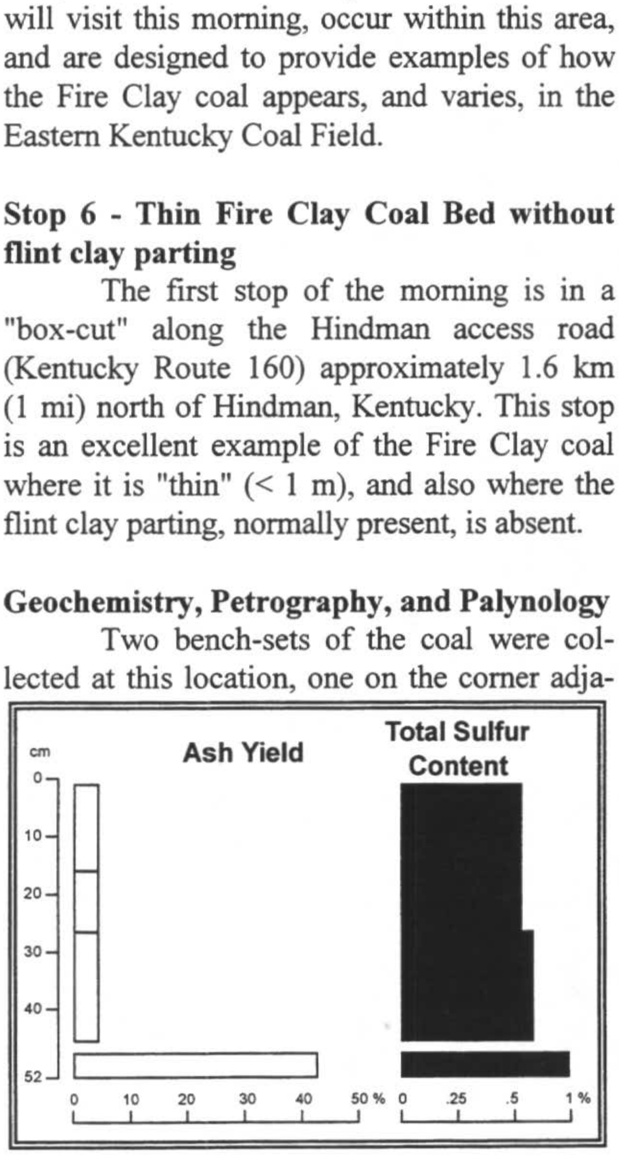

Figure 19 - Ash Yield and Total Sulfur content profiles in the Fire Clay coal at Stop 6. This column is located closest to the Hindman access road.

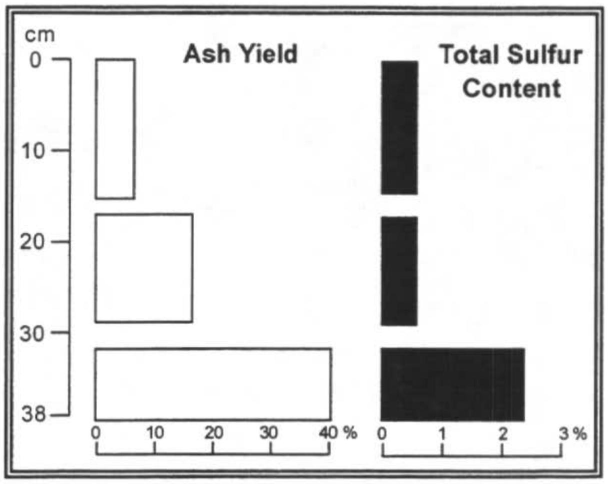

Figure 20 - Ash Yield and Total Sulfur content profiles in the Fire Clay coal at Stop 6. This column is located furthest away from the Hindman access road.

centcent to the access road, where the coal is thickest (52 cm, 20.5 in), and one approximately 100 m (328 ft) away from the road, where the coal is thinner (38 cm, 15 in). Even though the coal is thin here, all but the basal benches of both columns are low in ash yield and total sulfur content (Figs. 19 and 20). Petrographically, both columns display an upward-decreasing vitrinite profiles, and upward-increasing liptinite and inertinite profiles (Figs. 21 and 22). Palynologically, both columns have basal, high ash increments that contain high percentages of *Lycospora orbicula* and *L. micropapillata*, which is interpreted to represent a *Paralycopodites* - dominant pioneer flora in the mire (Figs. 23 and 24). This is similar to what was seen in the Fire Clay coal yesterday at the Martin stop (Stop 3). *Granasporites medius*, which was produced by two lycopod trees called *Diaphorodendron* and *Synchysidendron*, is also abundant in these increments.

The upward-decreasing vitrinite profile is paralleled by upward-decreasing *Lycospora*, and upward-increasing *Densosporites, Calamospora*, and tree fern spores (*Punctatisporites minutus, Punctatosporites minutus*, and

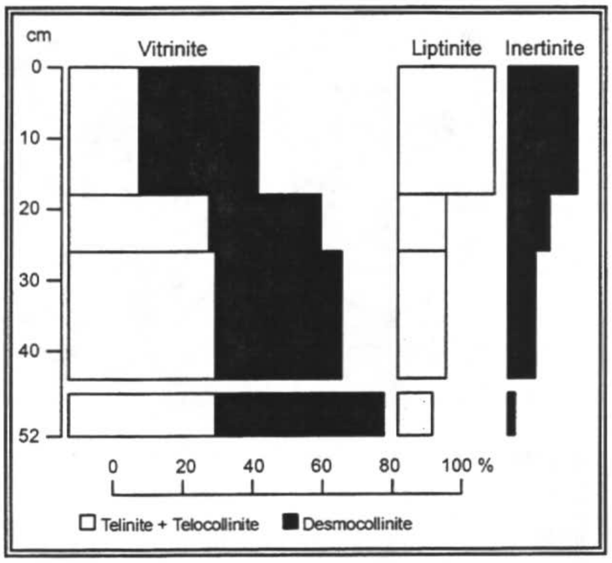

Figure 21 - Distribution of macerals in the Fire Clay coal at Stop 6. This column is located closest to the Hindman access road.

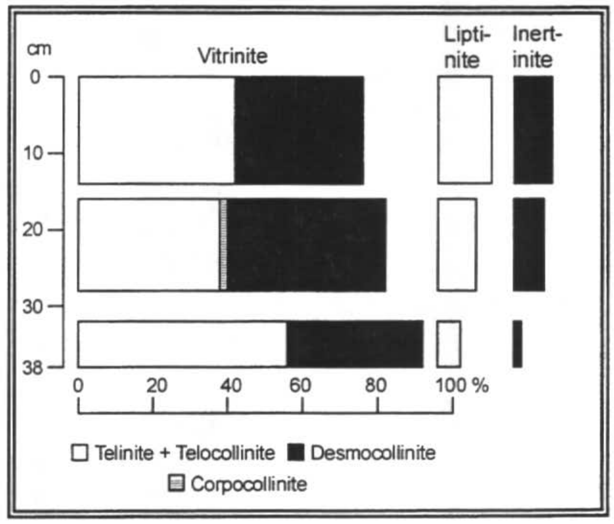

Figure 23 - Distribution of macerals in the Fire Clay coal at Stop 6. This column is located furthest away from the Hindman access road.

Apiculatasporites saetiger). This type of pattern is very common in many Breathitt Group coals. In this case, the low ash yields and total sulfur contents in the top portion of the bed indicate that detrital contamination was not an influencing factor. Rather, the temporal change from a *Lycospora*-dominant assemblage to one that is more heterogeneous probably indicates a change from a consistently-flooded surface to one that was more wet/dry (i.e. fluctuating water table). The increase in liptinite and inertinite, as well as an increase in desmocollinite (unstructured vitrinite) in the top increment of the column closest to the road, supports such an interpretation. As has been discussed previously, preservation of structured vitrinite

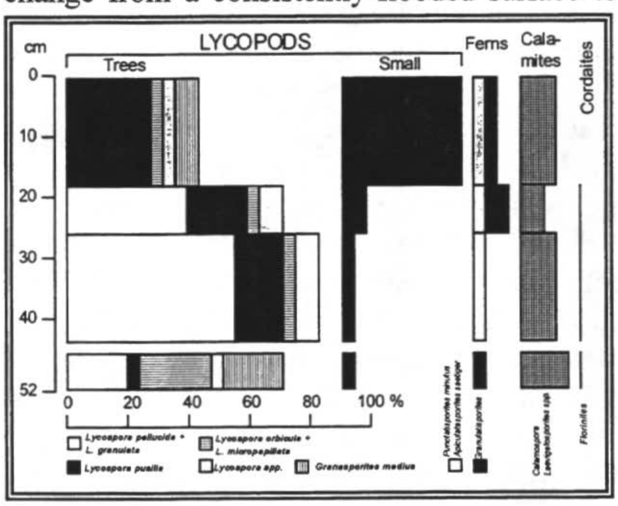

Figure 22 - Distribution of miospores, grouped together according to affinity, in the Fire Clay coal at Stop 6. This column is located closest to the Hindman access road.

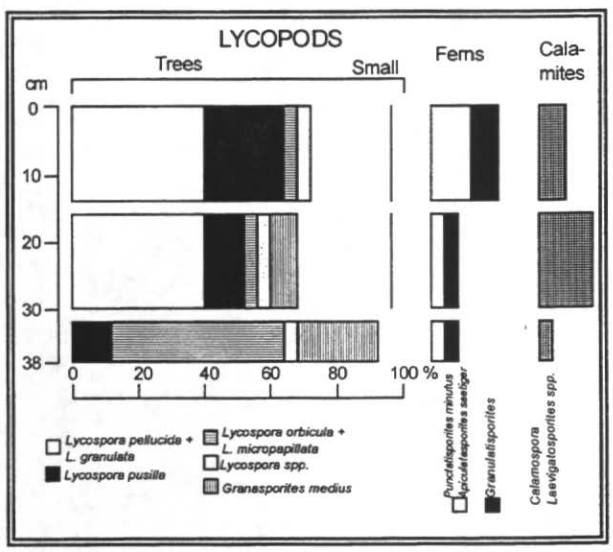

Figure 24 - Distribution of miospores, grouped together according to affinity, in the Fire Clay coal at Stop 6. This column is located furthest away from the Hindman access road.

(telinite + telocollinite) is enhanced when the plant litter is covered with acid, anoxic water, rather than being periodically dry, and exposed to air. We interpret the top bench of this column to represent a phase of peat accumulation where destruction of pre-vitrinite material, and increased oxidation of the plant litter occurred. liptinite macerals became concentrated because of their great resistance to degradation.

Sedimentology

At this location the coal overlies a thick sequence of interbedded fine-grained sandstone and shale. The lower bench of the coal is apparently split into a series of thin coals (each < 25 cm, 10 in), and root-penetrated claystones, which are absent less than a half mile to the west. The characteristic flint-clay that separates the lower and upper benches is also missing here. The main bench is 52 cm (20.5 in) thick along the road and thins to less than 17.8 cm (7 in) at the western edge of the outcrop. Locally, the coal is completely cut-out.

The coal is overlain by 6 to 9 m (19.5 to 29.3 ft) of medium- to coarse-grained sandstone. Along the by-pass the sandstone is two-storied, with the lower part showing lateral accretion beds oriented to the southeast (115^0 to 130^0), and the upper part with lateral accretion beds oriented to the northwest. Along the western margin of the boxcut well-developed lateral accretion surfaces dip to the southwest (230^0 to 240^0). Trough crossbeds and scour axes also dip to the southwest (185^0 to 220^0)

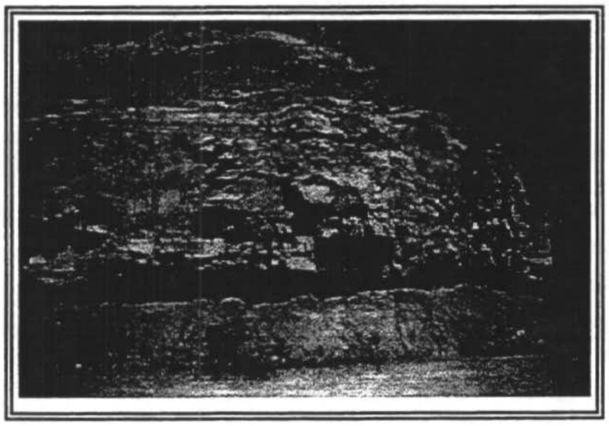

Figure 25 - Fire Clay coal exposed at Stop 6. Note the single rider coal above the sandstone that caps the Fire Clay coal.

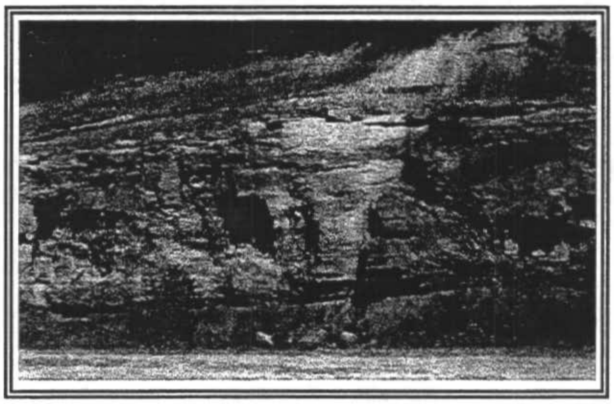

Figure 26 - Fire Clay coal at Stop 6, being truncated by the overlying sandstone. The coal is 17.8 cm (7 in) thick at the arrow.

Contrary to what was seen at the Martin cut yesterday, the sandstone at this location is capped by a single-benched rider coal, rather than 4 benches of coal.

Interpretation

Regional mapping of the Fire Clay coal shows that the location of this stop corresponds to a major northeast/southwest-oriented line of thinning, presumed to mark a fault or fracture that influenced peat accumulation (Greb and others, in review). The coal here is cutout by a sandstone inferred to have been deposited in a series of sandy meandering streams. Point bars within the streams show variable orientations, reflecting some degree of sinuosity. Overall flow directions, however, are oriented to the southwest. Cutouts of the coal occur all along the northeast-southwest trend and in a belt that cuts across the northern part of the Hindman Quadrangle oriented roughly northwest / southeast. Mining in this area is restricted mostly to an area a mile south of this stop, and west of the inferred structure.

Stop 6 - Carr Fork Lake - Thick Fire Clay coal with well-developed upper and lower benches

In the Carr Fork Lake area the Fire Clay coal is of uniform thickness, and has been completely mined-out from all of the surrounding ridges. In contrast to the boxcut stop, both the lower bench of the coal bed, and the flint clay parting are well-developed here. Along much of Highway 15 the seat rock of the coal occurs on dark shale with calcareous concretions. At this stop, the seat rock also bisects a sandstone channel that is ripple-bedded, and exhibits rare horizontal burrows.

The flint clay parting, which occurs in an interval 81.3 cm to 96.5 cm (32 to 38 in) down from the top of the bed. consists of all clastic material between the lower and main bench of Fire Clay coal. Generally it consists of a gray silty shale or coaly shale overlain by the flint clay. By definition, the parting is restricted to the area where the underlying lower coal bench occurs. Where it sits directly on underclay, as will be shown at the next stop, the flint clay parting is more properly termed a flint clay bed. In many areas where the underlying bench splits or thins, the flint clay parting itself also pinches out, as seen in the boxcut exposure at stop 6. The thickness of the flint clay part of the parting is extremely consistent across the area where the lower bench occurs, varying only between 5.1 and 15.2 cm (2 and 6 inches).

The roof rock at this stop consists of gray shale with disseminated plant material and siderite nodules, coarsening upward into even-bedded silty shales, and sheet-form, fine-grained sandstones (2.7 to 3.1 m; 9 to 10 ft thick). The sandstones thins to the east, and are overlain by 1.5 to 1.8 m (5 to 6 ft) of gray shale that, in-turn, is capped by a thin (< 15 cm; 6 in) coal. The coal is cut-out along part of the outcrop by a thin (< 3.1 m; 10 ft) sandstone lens, which is capped by a thicker sandstone (3.1 to

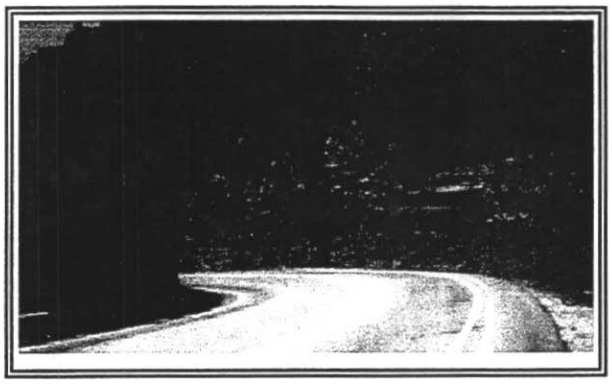

Figure 27 - Fire Clay coal at Stop 7 overlain by a lenticular sandstone, which in turn, is draped by the Fire Clay Rider coal.

3.7 m; 10 to 12 ft). This sandstone is draped by the Fire Clay Rider coal, which drops in elevation off of the thick, lenticular sandstone onto the sheet sandstones (Fig. 27). The Rider coal rises in elevation eastward along State Highway 15 where a thick, cross-bedded sandstone (similar in appearance to the sandstone at the box cut) occurs in the roof. To the south the Fire Clay Rider comes to within 3 feet of the top of the Fire Clay coal, and the two coals are often surface mined together.

Interpretation

The dark shale and bioturbated sandstone between the Upper Whitesburg and Fire Clay coals are inferred to have been deposited in a marine- or brackish-water bay or lagoon. The fact that the seat rock bisects both the channel and lateral shales, probably indicates exposure of the underlying strata with some hiatus in deposition, rather than a facies relationship between the coal and underlying lagoonal facies. In at least one mine we have visited, the coal rests directly on large calcareous concretions, which here occur more than 5 m (16.4 ft) below the coal.

Also, the lower bench is almost everywhere capped by a flint clay with little thickness variation, indicating that it accumulated on a relatively flat surface. Lower bench peat accumulation may have ceased prior to the

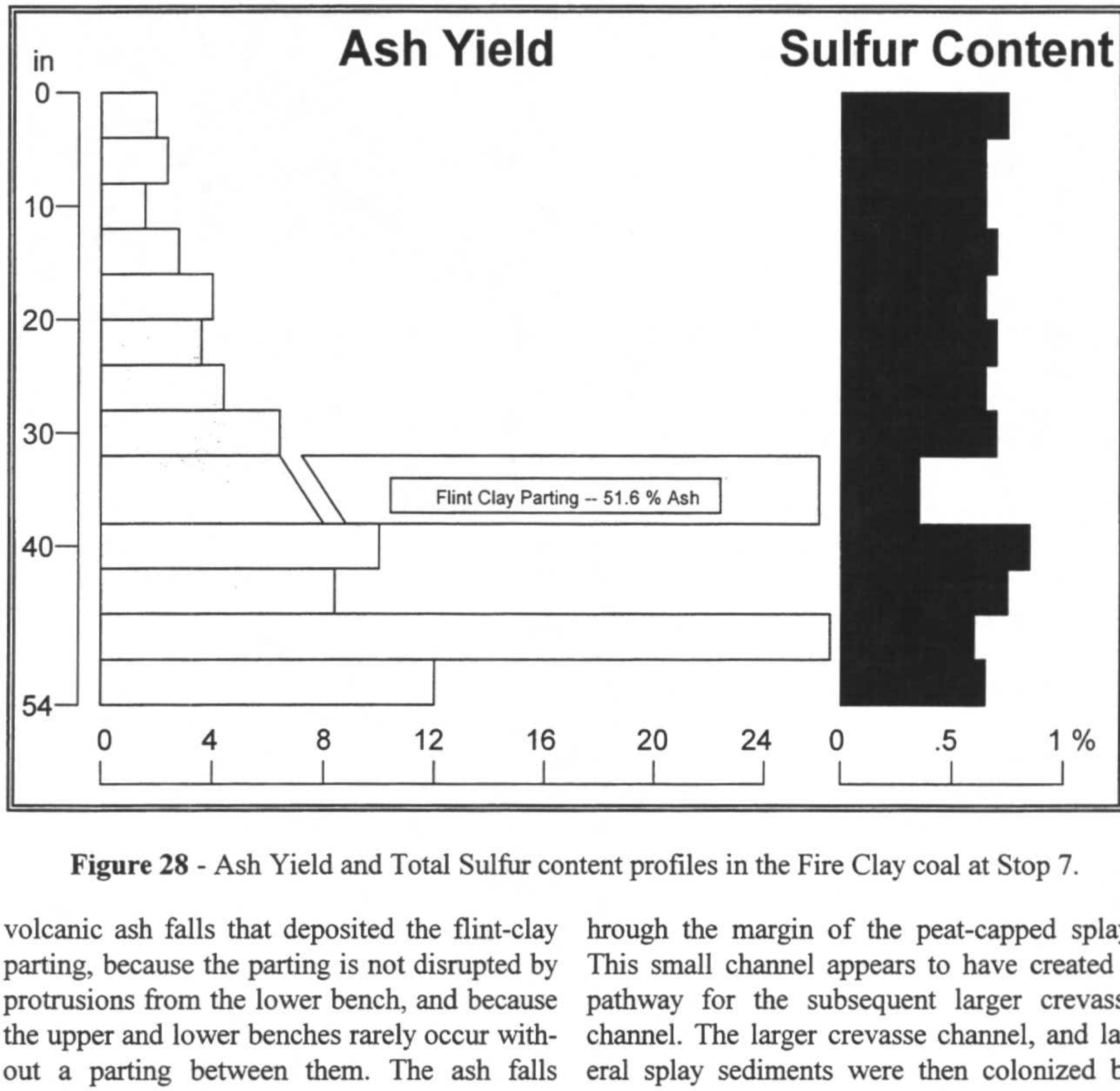

Figure 28 - Ash Yield and Total Sulfur content profiles in the Fire Clay coal at Stop 7.

volcanic ash falls that deposited the flint-clay parting, because the parting is not disrupted by protrusions from the lower bench, and because the upper and lower benches rarely occur without a parting between them. The ash falls caused ponding and the accumulation of muds and clastic swamps prior to renewed peat accumulation, and also may have controlled the accumulation of local cannel coals at the base of the upper bench.

The coarsening-upward sequence is interpreted to represent burial by floodplain and splay sediments, the sheet sandstones representing the distal lobes of splays. Following deposition, the splays began accumulating peat, which later became the first thin rider coal. The small channel that cuts out the rider in the middle of the outcrop may represent a crevasse, or small floodplain channel that cut hrough the margin of the peat-capped splay. This small channel appears to have created a pathway for the subsequent larger crevasse channel. The larger crevasse channel, and lateral splay sediments were then colonized by multiple peats of the Fire Clay Rider paleomire.

Fire Clay coal paleoecology

This location provides an excellent example of the palynologic, petrographic, and geochemical differences between the upper and lower benches of the Fire Clay coal. Here the upper bench, 81.3 cm (32 in) thick, has an ash yield of 3.4 %, and a total sulfur content of 0.68 %. The top 30.5 cm (1 ft) of the coal here is only 2 % ash! (Fig. 28). In contrast, the lower bench has an ash yield of 13.9 %, and a total sulfur content of 0.71 %. The flint clay

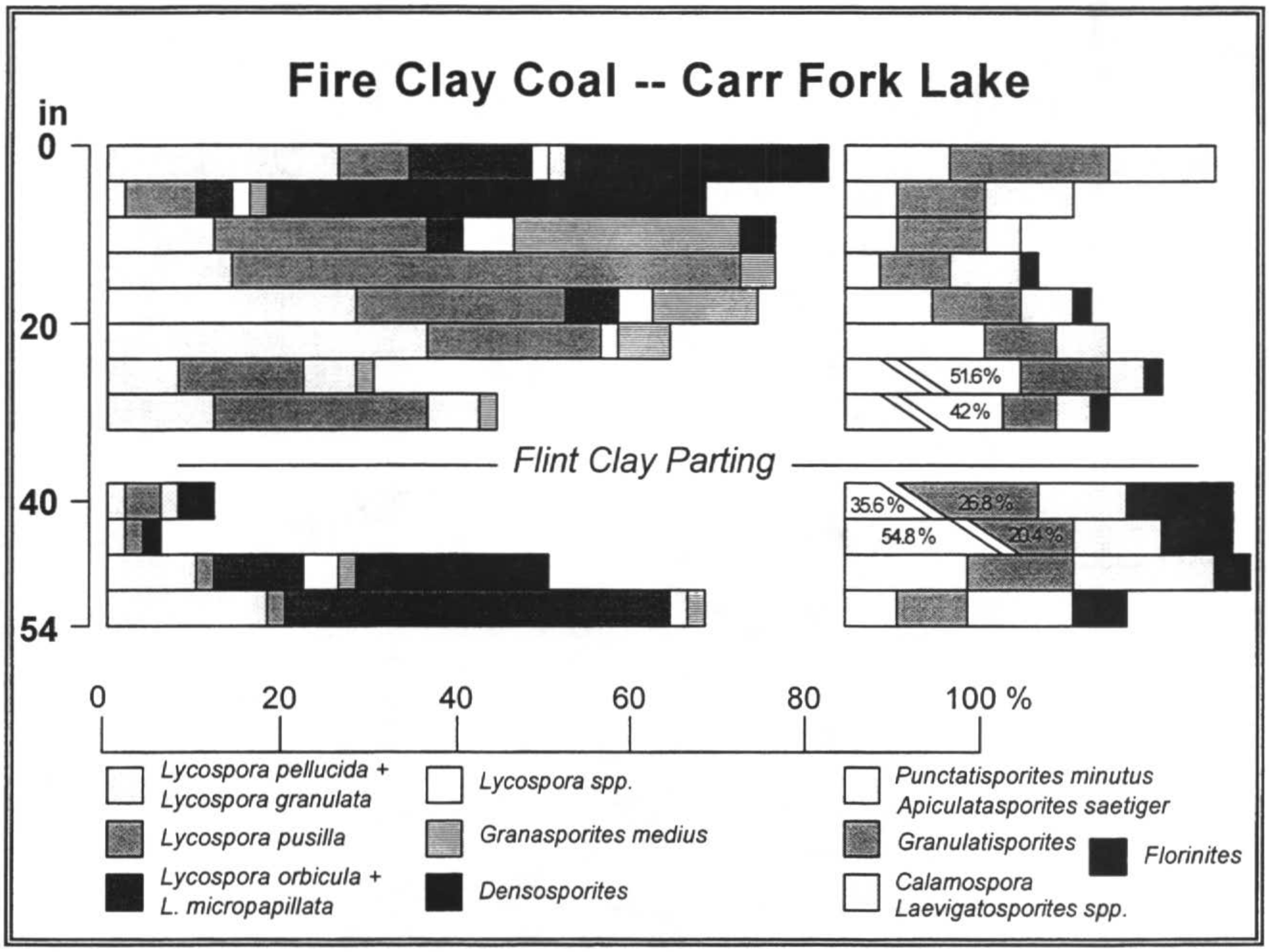

Figure 29 - Distribution of miospores, grouped together according to affinity, in the Fire Clay coal at Stop 7.

parting, located at 81.3 to 91.4 cm from the top of the bed, is highly carbonaceous, having an ash yield of only 51.6%.

At this location, the lower bench of the Fire Clay coal starts out as a lycopod-dominant mire, with abundant *Lycospora orbicula* and *L. micropapillata* (both produced by the colonizing lycopod *Paralycopodites*). This is the third column of Fire Clay coal we have seen that contains abundant *Lycospora orbicula* and *L. micropapillata* in the basal portions of the bed. However, the remaining three increment samples at this location contain a much more diverse palynoflora with abundant *Densosporites, Laevigatosporites*, *Granulatisporites*, and tree fern spores (e.g. *Punctatisporites minutus, Spinosporites exiguus*, and *Apiculatasporites saetiger*). Cordaite pollen, *Florinites*, is also abundant in these increments (Fig. 29). This type of heterogeneous palynoflora probably indicates that edaphic conditions within the lower bench paleomire were not static, but dynamic to the point where no one set of conditions that may have favored the proliferation one type of plant over another, persisted for any length of time. Frequent subareal exposure is suggested by the high percentages of small fern spores in these three increments. These plants required an exposed substrate, at least part of the time, to complete their reproductive cycle. They also could not exist in areas with any great depth of water because they would drown.

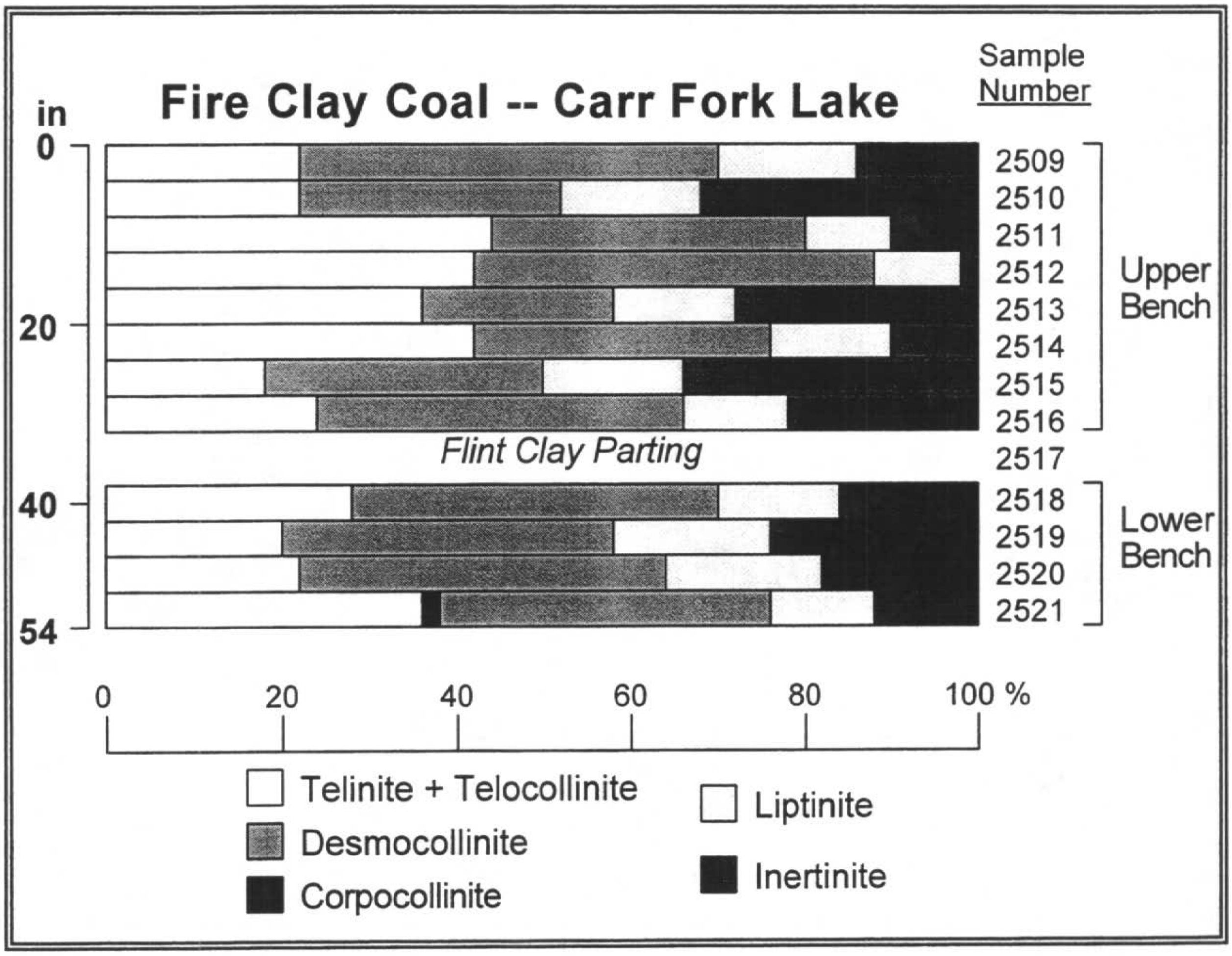

Figure 30 - Distribution of macerals in the Fire Clay coal at Stop 7.

The moderate to high percentages of inertinite macerals in these three increments also supports the interpretation that the paleomire was subject to frequent subareal exposure, and oxidation of the plant litter, which produced more inertinite macerals. These increments contain abundant desmocollinite, relative to telinite/telocollinite, which indicates that the previtrinite material in the peat was also subject to high levels of degradation prior to burial and coalification. The high levels of liptinite are probably also a result of this; liptinite macerals are more resistant to degradation than other plant tissues, and tend to concentrate by default (Fig. 30).

The paleomire that produced the upper bench of coal starts out (basal two increments) with a tree fern-dominant palynoflora, which in some respects resembles the flora of the lower bench. These two increments also contain high percentages of inertinite, suggesting that the initial peat of the upper bench was subject to frequent exposure and oxidation. In contrast, the next four increments in vertical succession are dominated by *Lycospora*, especially *L. pellucida, L. granulata* (both produced by *Lepidophloios*), *L. pusilla* (produced by *Lepidodendron*), and *Granasporites medius* (produced by *Diaphorodendron* and *Synchysidendron*). This indicates that lycopod trees became the dominant flora. These increments also contain higher percentages of vitrinite. Collectively, these data indicate that the mire surface became more consistently-flooded, which would favor the proliferation of the lycopod trees, and promote the formation of vitrinite macerals. The abundance of well-preserved vitrinite (telinite / telocollinite), relative to poorly-preserved vitrinite (desmocollinite), in these increments probably is a two-fold function of being the peat being covered by water much of the time, and also the decay-resistant nature of lycopod periderm. Unlike modern trees, the lycopod "trunk" was mainly comprised of bark tissue, rather than true wood (secondary xylem).

Edaphic conditions within the paleomire apparently changed as the top two increments of the upper bench contain a palynoflora dominated by *Densosporites* and fern taxa (both trees and small varieties). These benches also contain much higher percentages of liptinite and inertinite macerals. *Densosporites* probably is the most "notorious" spore in Pennsylvanian coal beds. One plant that produced *Densosporites* was *Bodeodendron / Sporangiostrobus*, the former name referring to vegetative portions of the plant, and the latter name to fertile parts. Although it had the stature of a small tree (Wagner, 1989), it possessed little, if any, secondary tissue. Like the larger lycopods, the stem was mostly bark tissue.

Densosporites was regarded by A.H.V. Smith, a British palynologist / petrographer, to be representative of ombrogenous portions of domed peat systems, areas he believed to be subject to a fluctuating water table. Subsequent research at The Pennsylvania State University regarded *Densosporites* (along with some tree ferns) to represent a specialized saliferrous flora that developed in response to marine transgression. The nearly ubiquitous association of abundant *Densosporites* with high liptinite and inertinite contents suggests that *Bodeodendron / Sporangiostrobus* occupied areas of Pennsylvanian mires that were stressed, either due to a depressed water table, salinity, nutrient deficiency, or clastic influx. Limited competition may have been an important factor. It probably is incorrect to regard the plant (by itself) as a domed peat, or marine-influenced peat indicator.

In this case, however, there probably is some justification for interpreting this part of the upper bench as having been derived from a domed, ombrogenous mire. In this area, and in areas to the SE, the upper bench is consistently thick, low in ash and sulfur, and contains very few inorganic partings. Domed peats, such as the ones presently developing in parts of coastal Malaysia and Indonesia, are naturally low in ash (< 5 %), and sulfur (< 1 %), in part, because they are ombrogenous (fed strictly by rain water). Rain water generally contains very low concentrations of inorganic solutes. They also are low in ash and sulfur because their natural positive relief inhibits the introduction of clastic material from adjacent river systems (i.e. crevasse splays). Put another way, it is hard to make water run uphill. Consider that the top two benches have an average ash yield of 2 %, and an average total sulfur content of 0.71 %. It stands to reason that you have to start out with a very clean peat, and then not introduce any inorganic material during peat accumulation, to arrive at a coal with so little ash. This is especially true in light of the approximate doubling of ash upon conversion to bituminous coal (Cecil et al., 1982).

Stop 8 - Fireclay at Hazard bypass - Fire Clay coal with no lower bench

The first bench of the exposure is the Fire Clay coal. The coal is mostly covered by talus but several openings from entries of an old underground mine can be seen. The Fire Clay coal has been mined in all of the ridges around Hazard have been mined. At this location the lower bench of the coal has thinned to a rooted carbonaceous shale and the coal consists of a thick upper bench resting on top of the jackrock parting.

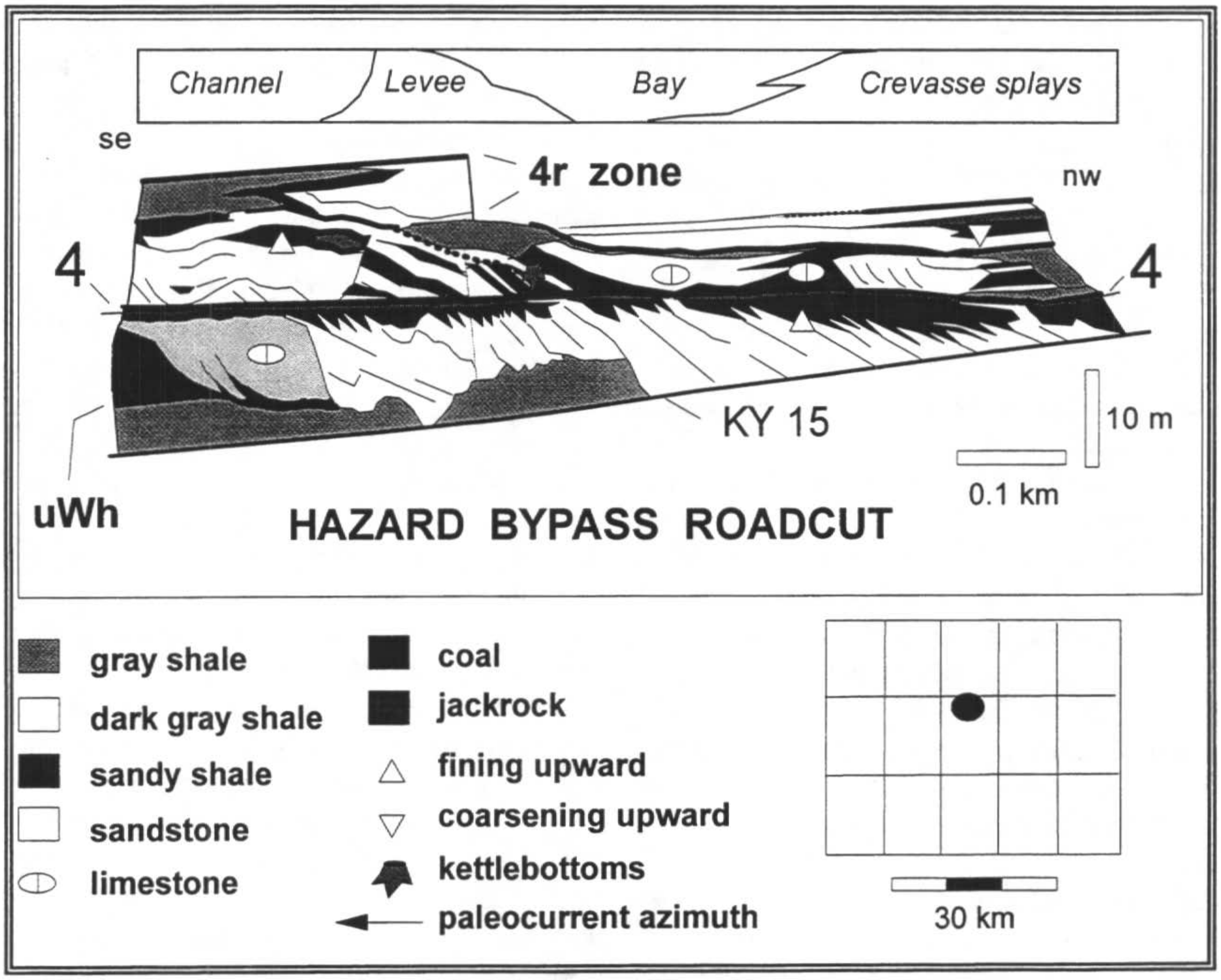

Figure 31 - Diagram illustrating the geology from the Upper Whitesburg coal (uWh) to the Fire Clay Rider coal (4r). Interpretations of the depositional environments above the Fire Clay coal (4) are shown across the top of the diagram. Modified from Greb et al., *submitted*.

On the southeast end of the crop and in the Hardees parking lot the coal is overlain by 6 to 9 m of cross-bedded, medium to coarse-grained sandstone. This sandstone is extensive above the coal for at least another two miles to the south along KY 15, and can be seen in the outcrop to the north (Fig. 31). Trough crossbeds in the sandstone dip to the northwest. The sandstone is overlain by a thin coal, and is sharply juxtaposed against moderately dipping sandstones and interbedded sandy shales. This heterolithic facies dips to the northeast, and contains numerous in situ fossil tree stumps. Stumps are tallest at the toes of the inclined strata and thin upward. The heterolithic strata is juxtaposed northwestward by dark gray laminated shales which contain calcareous concretions. Toward the north end of the exposure at least two lenticular sandstones interfinger with the dark shale.

Interpretation

This exposure provides a classic example of channel and marginal channel facies. It also provides a typical roof model for the Fire Clay coal. The sandstone on the southeast end of the exposure is interpreted to represent part of a sandy, meandering fluvial channel. The channel flowed to the northwest. Bounding heterolithic strata represent a levee along the

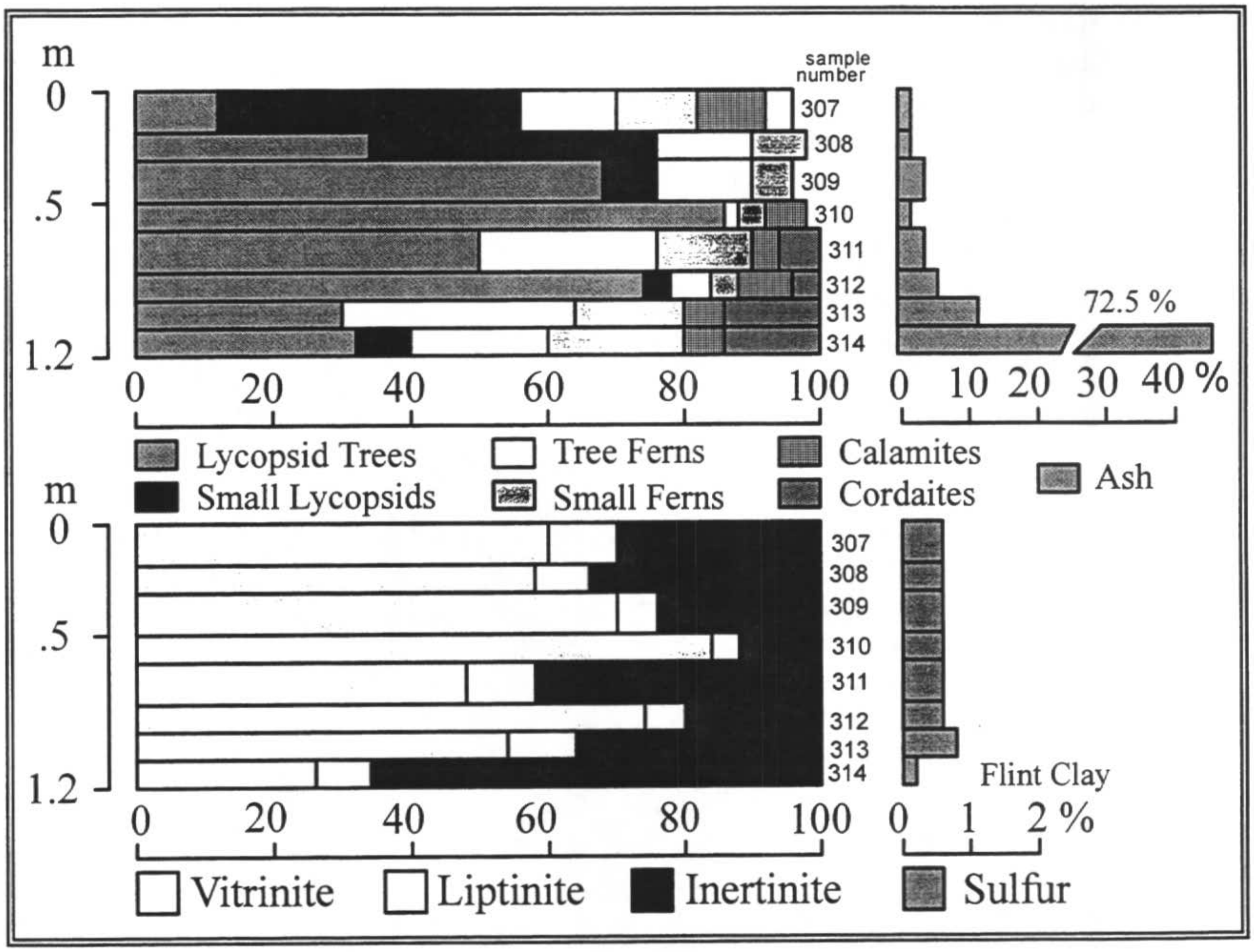

Figure 32 - Distribution of miospores, grouped together according to affinity, macerals ash yield, and total sulfur content in the Fire Clay coal at Stop 8.

northwest flank of the river. This exposure is one of a few in the coal field where levee facies can be observed. Natural levees do not have a high preservation potential, because they are generally eroded by lateral migration of bounding channels. This levee was colonized by lycopod trees, which thrived in standing water at the base of the levee, but which were inhibited (probably by drier conditions) up onto the levee. The dark gray shale facies is similar to lagoonal and bay-fill shales and is inferred to represent deposition in a marginal marine body of shallow water. The lenticular sandstones on the north end of the outcrop represent proximal crevasse channels, probably related to breaches in the levee on the south end of the cut. Interfingering sandstones represent truncated, proximal splay sandstones, which are significantly more widespread north and west of this location.

As at stop 6, this exposure also shows the importance of lateral roof variability on underground mining. The largest collapses occur in the heterolithic strata in the crevasse-splay facies on the north end of the exposure. Large falls also occur where the sandstone channel facies truncates the levee facies. No maps are available for this mine, but the fairly abundant lycopod stumps in the immediate roof of the coal within the levee facies probably resulted in kettlebottoms within the mine.

Paleoecology of the Fire Clay coal

The upper bench of the Fire Clay coal at this stop has ash and sulfur profiles that are very similar to Fire Clay seen at the previous stop (Fig. 32). The paleomire here is initially *Lycospora*-dominant with moderate to high percentages of vitrinite, in contrast to the underlying flint clay parting, which contains more fern spore taxa (trees and small forms). This probably represents initial peat formation in a paleomire with a generally flooded surface. Unlike the previous Fire Clay stops, the dominant species of *Lycospora* are *L. pellucida* and *L. granulata*, indicating that *Lepidophloios* probably was the dominant lycopod tree (Fig. 32). At the other Fire Clay locations, the mire is initially dominated by *Lycospora orbicula* and *L. micropapillata,* which represent the pioneering lycopod, *Paralycopodites*. The next increment in vertical succession is more like the flint clay, containing high percentages of fern spores. This increment is also much higher in liptinite and inertinite macerals, suggesting that the local water table fluctuated more during the accumulation of this increment (Fig. 32).

The paleomire again becomes more consistently flooded as the next two increments again become *Lycospora*- and vitrinite-dominant. The dominant species of *Lycospora* in these increments are *L. pellucida, L. granulata,* and *L. pusilla*. *Granasporites medius* is also common, and resembles the lycopod spore distribution seen in the *Lycospora*- vitrinite-dominant increments of the upper bench at the previous stop.

The top two benches at this location contain high percentages of *Densosporites* and fern spores, and have increased amounts of liptinite and inertinite macerals. This indicates that the paleomire water table once again became inconsistent, allowing for exposure of the surficial peat, and degradation / oxidation of the plant litter.

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Contributed Articles

COAL QUALITY TRENDS AND DISTRIBUTION OF TITLE III TRACE ELEMENTS IN EASTERN KENTUCKY COALS

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INTRODUCTION

The Clean Air Act Amendments of 1990 (Title III and Title IV) have placed increasingly stringent limits on the type and grade of coal that can be mined and marketed. Because of these limitations it has become increasingly important to understand the coal quality characteristics of coal in Kentucky from a utilization perspective, both on an geographic and stratigraphic basis. This paper will focus on quality characteristics, and the distribution of selected elements in eastern Kentucky coals. Much of the resource in this geographic area occurs as compliance (< 1.2 pounds SO_2 / million BTU), or near-compliance coal (< 2 pounds SO_2 / million BTU) and, as such, will remain a valued fuel resource for the rest of this century, and well into the next.

SPATIAL DISTRIBUTION OF COAL IN THE EASTERN KENTUCKY COAL FIELD

The Eastern Kentucky Coal Field covers 10,500 square miles over parts of 37 counties, and contains approximately 54.6 billion tons of remaining resources. Unfortunately, less than half of this figure is minable using present technology. Kentucky produced 174.3 million tons of coal in 1992 from 752 active mines. This represents 16.2 % of the total United States production (997.5 million tons) during that year. Production from the Eastern Kentucky Coal Field during 1992 was 119.4 million tons, which is 69 % of the state total, and 12 % of the national total [1].

Geographically, the Eastern Kentucky Coal Field is subdivided into five (5) *Reserve Districts*, those being the Princess, Big Sandy, Licking River, Hazard, Southwest, and Upper Cumberland (Fig. 1). Coal thickness and quality vary from district to district. On average, the thickest and best quality coal is found in the Big Sandy and Upper Cumberland Reserve Districts. Coal in these two districts averages 36.5 in (92.8 cm), 9.6 % ash yield, 1.3 % total sulfur, and 13,011 BTU/lb. The average final ash fusion temperature for these two districts is 2,684 °F (Table 1).

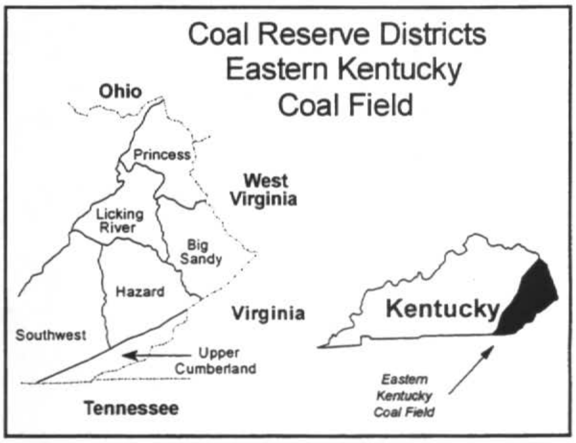

Figure 1 - Coal Reserve Districts in the Eastern Kentucky Coal Field.

Table 1 - Distribution of Coal Quality Parameters by Reserve District in Eastern Kentucky

	Thickness	Ash Yield	Total Sulfur	BTU/lb	Fusion
Big Sandy	37.7	9.9	1.4	12815	2686
Upper Cumberland	35.4	9.3	1.2	13206	2682
Hazard	29.6	11	1.6	12608	2663
Licking River	23.1	9	1.7	12428	2543
Princess	20.9	11.4	2.1	11805	2605
Southwest	22.2	7.4	2.1	13237	2467

Thinner coal occurs in the Hazard and Licking River Reserve Districts. Coal from these two districts has an average thickness of 26.4 in (67 cm), an average ash yield of 10 %, an average total sulfur content of 1.6 %, and an average calorific value of 12,518 BTU/lb. The average final ash fusion temperature for these two districts is 2603 °F. Still thinner coal occurs in the Princess and Southwest Reserve Districts. Coal in these two districts averages 21.6 in (54.8 cm), 9.4 % ash, 2.1 % total sulfur, and 12,521 BTU/lb. The average final ash fusion temperature for these two districts is 2,536 °F (Table 1).

The reason for this spatial distribution is most-likely a function of the Big Sandy and Upper Cumberland Reserve Districts being situated in closer proximity to the axis of the Allegheny structural front of the Central Appalachian Basin. Geologically, this area subsided more rapidly during the Pennsylvanian, accumulating not only a greater thickness of sediment, but also a greater average thickness of coal, and number of individual coal beds [2] [3].

In contrast, the positions of the Hazard and Licking River Reserve Districts are more distal to the orogenic front. The total sediment package in this area is thinner, as are the individual coal beds. This part of the coal field apparently subsided less rapidly, thus providing less accommodation space for sediment. The relative thinness, and total number, of individual coal beds in these Districts also appears to be related to subsidence. In this case, decreased rates of subsidence provided less accommodation space for sediments, including coal beds. Coal beds in the Princess and Southwest Reserve Districts follow this trend. These districts occur along the outer margins of the coal field, an area that had the least subsidence, and consequently least accumulation of sediment, of any area in the coal field.

TEMPORAL TRENDS IN COAL QUALITY

Coal-bearing strata in the Eastern Kentucky Coal Field are Pennsylvanian in age, with all of economically-important coal beds being assigned to the Breathitt Formation (Fig. 2). Although more than 100 individual coals have been named, it is common for many, if not most, to exist as part of a coal zone or group, with several closely-spaced coal beds being intercalated with inorganic partings. Given this, it is necessary to discuss coals in the Eastern Kentucky Coal Field in terms of *coal groups*, based on stratigraphic position. For the purposes of this study, we have divided the major coal-producing interval of the Breathitt Formation into thirteen stratigraphic groups. In stratigraphically -descending order, they are the: Princess 6 - 9 zone, Skyline/Richardson zone, Broas zone, Peach Orchard zone, Hazard zone, Hamlin zone, Fire Clay/Fire Clay Rider zone, Whitesburg zone, Amburgy Zone, Upper Elkhorn #3 zone, Alma zone, Pond Creek zone, and Manchester zone. Two stratigraphically-older zones, the Barren Fork, and Stearns zone (Fig. 2) are also shown, but do not represent significant resources.

Research on Kentucky's remaining coal resources has shown that resource abundance varies with the relative stratigraphic position of the resource to major marine zones. Major marine zones are the principle lithostratigraphic marker beds in the Eastern Kentucky Coal Field, and represent widespread marine incursions into the coal field. As these units can be traced laterally into neighboring states, these marine incursions represent basin-wide events, and are most likely related to tectonic, and/or glacio - eustatic events.Coal beds that occur immediately adjacent to the major marine beds have fewer resources than coal beds that occur in the middle parts of intervals between the marine zones. Likewise, slightly higher total sulfur contents in each coal zone are found in individual coal beds that lie adjacent to the major marine beds. An example of this is the interval between (and including) the Kendrick Shale, and the Magoffin Member. The best-developed coals of this interval are the Fire Clay and Fire Clay Rider, which occur in the middle of this interval. In contrast, coal beds adjacent to the Kendrick and Magoffin, the Whitesburg and Taylor,

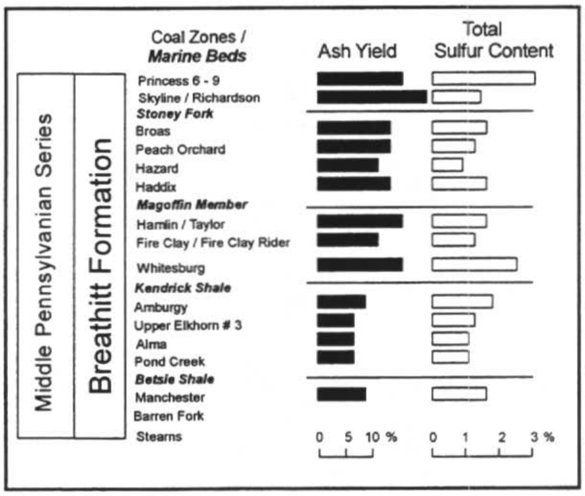

Figure 2 - Generalized stratigraphic column for the Eastern Kentucky Coal Field showing the position of coal groups and major marine

are less well-developed. In general, ash yields increase in a stratigraphically-younger direction; for example, the Manchester and Pond Creek coal zones, on average, have lower ash yields than the Peach Orchard and Broas zones (Fig. 2).

TRACE ELEMENTS IN EASTERN KENTUCKY COAL

Title III of the Clean Air Act Amendments of 1990, which is entitled, "*Hazardous Air Pollutants*", lists 189 substances (mainly chemical compounds) that may require monitoring with the implementation of Phase 1 in 1995. Of these 189 substances, there are fifteen elements that naturally occur in trace amounts in Kentucky coal. Thirteen of these elements, and their average distributions are shown in Figure 3. The two remaining elements not shown in Figure 3 are chlorine and phosphorus, whose average abundance in eastern Kentucky coals are 1143 and 118 parts per million respectively (both figures on a whole-coal basis). In eastern Kentucky coals, the elements with the highest average occurrences are arsenic, cobalt, chlorine, chromium, manganese, nickel, lead, and phosphorus. The elements with the lowest average occurrences are cadmium, mercury, and antimony. However, as limitations on these elements have not been proposed, the average concentrations are relative.

Temporal Trends

Some Title III elements, notably cadmium, chromium, lead, and selenium, increase in concentration in a stratigraphically older to younger direction (Fig. 4). This trend parallels the stratigraphic distribution of ash and sulfur, and suggests that these elements are dominantly associated with the mineral fraction in coal. Chlorine, in contrast, decreases in abundance in an older to younger direction, indicating that it probably is associated with the organic portion of coal (Fig. 5). Coal with a high chlorine content usually is considered detrimental as it contributes to accelerated corrosion of internal boiler parts. Some elements, notably arsenic, manganese, mercury, cobalt, and, to a lesser extent, phosphorus, show spikes of concentration in coal beds directly above, or below, major marine zones (Fig. 6). As these beds also tend to contain increased total sulfur contents, it is likely that arsenic, mercury, and cobalt are associated with disulfide minerals in eastern Kentucky coal. This occurrence has been noted previously for other coal beds in different areas [4] [5]. The elevated percentages of manganese and phosphorus in proximity to the marine zones may be a result of increased amounts of carbonate and phosphate minerals associated with the marine incursions.

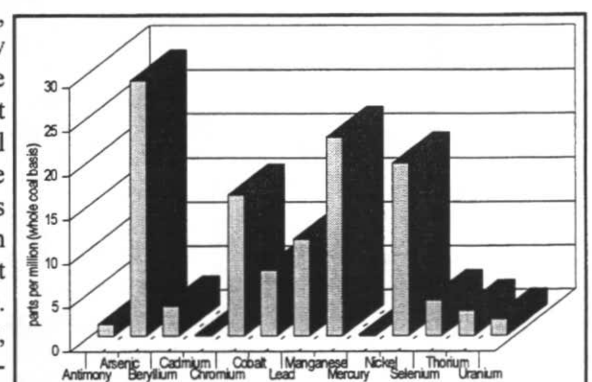

Figure 3 - Average concentrations of 13 Title III elements in eastern Kentucky coals.

Spatial Trends

The average values for some elements, notably arsenic, cadmium, lead, mercury, and nickel also vary directly with total sulfur content spatially. High average concentrations for these elements occur in the Princess, Licking River, and Southwest Reserve Districts, districts that also have the highest average total sulfur contents (Table 2). This is understandable considering that both arsenic and nickel typically are associated with pyrite in coal [4] [5].

Table 2 - Distribution of Title III Elements by Reserve District in eastern Kentucky

	As	Be	Cd	Cl	Co	Cr	Hg	Mn	Ni	P	Pb	Sb	Se	Th	U
BS	20.7	3.8	0.05	1196	7.4	15.6	0.14	18.7	15.4	77.6	8	1.1	4.7	3.1	1.5
UC	24.7	1.7	0.06	234	5.3	14.2	0.14	16.7	11.8	268	6.3	0.9	3.4	2.8	1.4
HZ	22.8	3.6	0.07	1037	8.1	18.1	0.18	16.8	17.3	128	9	1.2	4.6	3.5	1.9
LR	27.5	4.2	0.07	571	7.9	16.1	0.17	20.8	22.2	86.6	11.7	1.3	5.2	2.5	1.4
PR	35.9	4.2	0.11	483	7.6	16.8	0.25	22.7	18.1	157	15.1	1.9	5.5	4.7	2.2
SW	42.1	2.9	0.06	1913	7.2	12.4	0.19	15.6	19.1	147	7.9	1.5	2.8	2	1.5

TRACE ELEMENTS IN EASTERN KENTUCKY COAL -- COMPARISON WITH OTHER APPALACHIAN COAL-PRODUCING STATES

Table 3 shows a comparison of average concentrations of Title III elements in coal beds from selected Appalachian states. Some elements, notably beryllium, cadmium, cobalt, mercury, lead, antimony, selenium, thorium, and uranium show a rather uniform distribution from state to state. Some other elements, arsenic, chromium, nickel, manganese, and phosphorus, are more diverse, with chlorine showing the most variability between states. Pending regulation would have a varied impact depending on which elements are targeted, and the severity of the limitation. Of the three most volatile elements, chlorine, mercury, and selenium, strict chlorine limitations would have the greatest disparity of impact. Southern West Virginia, eastern Kentucky, and Ohio, which have the highest average chlorine concentrations, would conceivably be affected the most. The other two volatile elements, mercury and selenium, are more uniform in distribution; thus, it stands to reason that potential impacts would also be uniform between the states.

Table 3 - Distribution of Title III elements, by state, in Appalachian coals

	As	Be	Cd	Cl	Co	Cr	Hg	Mn	Ni	P	Pb	Sb	Se	Th	U
AL	72.3	2.2	0.1	286	7.7	18	0.2	39.4	17	221	6.9	2.6	2.8	2.9	1.7
TN	21.8	1.4	0.1	NA	4.9	11.6	0.2	14.3	9	312	6.9	0.8	2.8	2	1.3
VA	20.1	1.8	0.1	502	6.1	12	0.1	20.5	11.2	127	5.5	0.9	2.7	2.6	1.3
WV[1]	12	2.9	0.1	1188	7.4	15	0.1	21.5	15.4	121	7.4	1.2	3.9	2.9	1.5
WV[2]	15.1	1.3	0.1	507	4.8	13.6	0.2	40	9.3	168	4.4	0.6	2.3	2	1.5
OH	24.8	2.6	0.1	738	6.2	16.2	0.2	30.9	17.1	130	8.5	0.9	4	2.3	1.9
PA[1]	34.2	2.6	0.1	991	7.6	20.9	0.3	25.3	20.6	220	10.9	1.4	3.7	3	1.6
PA[2]	7.8	2.3	0.1	371	8.3	26.7	0.2	34	21.1	154	11.5	1.2	4.7	6.3	2.2
EKY	29.1	3.4	0.1	1161	7.4	15.4	0.2	17.9	17.3	136	9.1	1.3	4.2	3	1.7

Source: U.S. Geological Survey Open File Report 94-205

WVA[1] -- Southern West Virginia coals
WVA[2] -- Northern West Virginia coals
PA[1] -- Western Pennsylvania coals
PA[2] -- Eastern Pennsylvania coals (anthracites)

Of the twelve metals listed in Title III, which are moderately volatile and mainly trapped with bottom and, in particular, fly ash after combustion, arsenic, chromium, nickel, manganese, and phosphorus would have the most varied impact. Average arsenic concentrations are highest in Alabama, eastern Kentucky, and Ohio coals; they are lowest in West Virginia (southern and northern field coals), and Pennsylvania anthracites. Average chromium concentrations are highest in Alabama and Pennsylvania coals (western field coals and anthracites). Lowest average chromium concentrations are found in Tennessee and Virginia coals. Average nickel concentrations are highest in Pennsylvania coals (western field coals and anthracites), and lowest in Tennessee, Virginia, and southern West Virginia coals. Average manganese concentrations are highest in Alabama, northern West Virginia, Ohio, and southwestern Pennsylvania coals. Lowest manganese concentrations occur in Tennessee and eastern Kentucky coals. Average phosphorus concentrations are highest in Tennessee, Alabama, and eastern Pennsylvania (anthracites) coals, and lowest in Virginia, northern West Virginia, and Ohio coals.

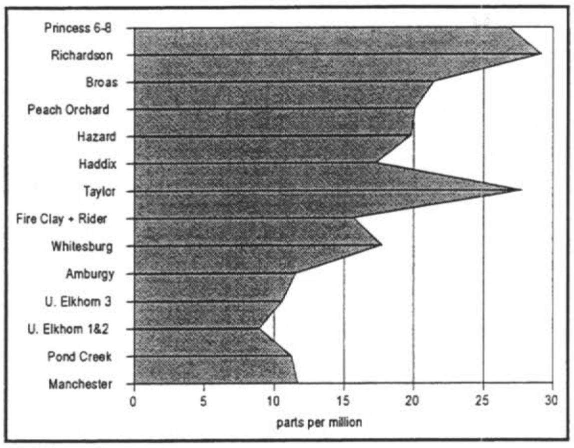

Figure 4 - Stratigraphic distribution of chromium in eastern Kentucky coals.

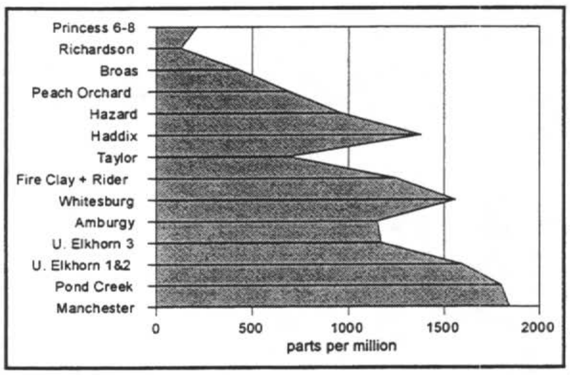

Figure 5 - Stratigraphic distribution of chlorine in eastern Kentucky coals.

SUMMARY -- MAJOR POINTS

The quality characteristics of eastern Kentucky coal beds vary both spatially and stratigraphically. Average total sulfur contents are lowest, and calorific values highest, in the Big Sandy and Upper Cumberland Reserve Districts. Average coal thickness is greatest in these two districts as well. Conversely, the thinnest coal with the highest total sulfur content, and lowest calorific value, on average, occurs in the Princess and Southwest Reserve Districts. Several Title III trace elements, notably arsenic, cadmium, lead, mercury, and nickel, mirror this distribution (lower average concentrations in the Big Sandy and Upper Cumberland Districts, higher average concentrations in the Princess and Southwest Districts), probably because these elements are primarily associated with sulfide minerals in coal.

Ash yields and total sulfur contents are observed to increase in a stratigraphically older to younger direction. Several Title III elements, notably cadmium, chromium, lead, and selenium follow this trend, with average concentrations being higher in younger coals. Average chlorine concentration shows a reciprocal distribution, being more abundant in older coals. Some elements, such as arsenic, manganese, mercury, cobalt, and, to a lesser extent, phosphorus show concentration spikes in coal beds directly above, or below, major marine zones.

With a few exceptions, average Title III trace element concentrations for eastern Kentucky coals are comparable with element distributions in other Appalachian coal-producing states.

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A brief guide to the Magoffin Marine Unit in Eastern Kentucky

J. Bret Bennington

Introduction

Appalachian Basin marine units are relatively thin stratigraphic intervals of marginal to open marine strata found within the sequence of predominantly terrestrial deposits of the Appalachian coal field. Because they are distinctive and uncommon in the stratigraphic sequence, major marine units have traditionally been used as marker horizons for regional correlations of coal zones (Wanless, 1939). The most widely correlated of the Middle Pennsylvanian marine units in the Appalachian Basin include the Betsie Shale, Elkins Fork Shale, Kendrick Shale, Magoffin Member, and Stoney Fork Member marine units, first named for occurrences in eastern Kentucky. These marine units all lie within the Middle Pennsylvanian Breathitt Formation (Figure 2 and 3). As well as having been extensively correlated in outcrop, major marine units have been identified in geophysical well logs and are confidently correlated in the coal fields where exploration has generated abundant well data (Cobb and Smath, 1981). In most cases, marine units occur either directly, or nearly above coal beds. Named major marine units are relatively thick and widespread, while minor marine units are more discontinuous and usually are referred to by the coal bed with which they are associated. Recently, Chesnut (1991b) has shown that there are marine influenced strata associated with every coal bed or coal zone within the Breathitt Formation.

The Magoffin Member is the most geographically extensive of the Breathitt Formation marine units, and has been reported from almost every quadrangle in eastern Kentucky. In southwest Virginia, Miller (1969) reports the Magoffin to be the "most distinctive and reliable horizon marker in the Wise Formation" (partially equivalent to the Breathitt Group). To the northeast in West Virginia, the Magoffin correlative Winifrede marine unit is "one of the most distinct and widespread marine units in the Kanawha Formation" (White and Martino, 1992).

Of all of the Middle Pennsylvanian marine units the Magoffin is the most accessable, being exposed in a number of roadcuts along major highways that extend from the northeast to the southwest of the Appalachian basin outcrop belt in eastern Kentucky. When first seen in outcrop at various places in the Appalachian coal field, the Magoffin appears to be highly variable in it's stratigraphy. However, this is true only in detail. Overall, the Magoffin marine unit shows a definate and geographically recurring sequence of facies that can be correlated throughout its extent. Much of the variability in Magoffin stratigraphy can be explained by a pattern of increasingly high rates of deposition into the Magoffin seaway that is seen as one moves from the northeastern to southwestern ends of the basin. During this field trip, you will have the opportunity to observe excellent exposures of the Magoffin marine unit in three roadcuts that form a northeast to southwest transect across the Appalachian Basin in eastern Kentucky. Moving from the stop near Inez, Kentucky on Highway 3, to the stop near Martin, Kentucky on Highway 80, to the stop along the Hindman Access Road, the major facies of the

Magoffin can be observed and followed as they vary in response to changing rates of clastic input into the basin.

Field trip stop descriptions

The following are brief descriptions of the Magoffin marine unit as it can be observed at three field trip stops that form a northeast to southwest transect along the axis of the Breathitt outcrop belt.

Inez

Outcrops of the Magoffin marine unit exposed along Kentucky Highway 3 east of Inez are relatively easy to spot, forming a band of dark shale from one to three meters thick with a distinctive horizon of limestone concretions or a continuous bed of concreted limestone in the upper part. The basal fossiliferous limestone forms a distinct protruding layer approximately six cm thick at the base of the dark shale. Along parts of roadcuts where there is heavy seepage of groundwater this limestone may be locally absent. The basal limestone is a thin (4 - 15 cm), muddy, bioclastic packstone containing abundant brachiopod and crinoid debris that rests directly above the Taylor coal or coaly shales and rooted mudstones within the Taylor coal zone.

Excavation of the shales directly above the limestone reveals a thin (6 - 12 cm) interval of very fissile black shale. Bed surfaces in the lower part of the shale contain gastropods and small bivalves (*Pleurophorella* assemblage - Fig. 2). Upper beds of the fissile black shale tend to be dominated by the thin-shelled bivalve *Posidonia* (*Posidonia* assemblage - Fig. 2). As the shale loses its fissility upsection fossils become scarce except in occasional thin, concentrated horizons where the ossicles of the stemless crinoid *Paragassizocrinus* and small nuculoid bivalves are found (Nuculoid Bivalve assemblage - Fig. 2). Also present in this interval are branching, horizontal burrows and small nodules of diagenetic calcium carbonate.

Stepping back from the outcrop a few feet, and observing it along the length of the roadcut, the medium dark gray mudstone between the lower and upper limestone horizons can be seen to lighten to medium gray about a meter above the basal limestone. This color change occurs without any obvious change in lithology of the shale and suggests a reduction in the amount of organic carbon contained within the shale (Potter et al., 1980). Accompanying the change in color is a distinct change in fauna back to one dominated by articulate brachiopods (Brachiopod assemblage). In the upper part of the second meter of Magoffin section the mudstone becomes densely fossiliferous, and in many places cemented into large calcium carbonate concretions or a continuous ledge of limestone. The great increase in density of individuals of the brachiopod assemblage from the lower to the upper part of the medium gray mudstone appears to have been caused by a decrease in the rate of clastic deposition resulting in a somewhat condensed fossiliferous interval.

Above the upper fossiliferous limestone there is an rapid transition to dark gray shales with siderite concretions and a complete loss of the invertebrate fossil fauna. In some places a thin layer of dark shale containing only the small chonetid brachiopod *Rugosochonetes* (*Rugosochonetes* assemblage - Figure 2) is intercalated between the fossiliferous and sideritic lithologies, but in most places the transition to unfossiliferous conditions is very abrupt, with the upper surface of the fossiliferous interval itself sideritized. Siderite is a diagenetic mineral that cannot form in the presence of marine sulfide and bicarbonate (Berner, 1981) and its appearance suggests abrupt termination of marine conditions by drowning under pulses of hyposaline deltaic runoff (Maples, 1986). At this locality, as at most of the Magoffin localities, the appearance of siderite marks the beginning of a thick, coarsening-upward sequence of thin, tabular bedded mudstones, siltstones, and sandstones.

Martin

Having observed the Magoffin along Highway 3 near Inez, the Magoffin section exposed in a large roadcut along Highway 80 near Martin, Kentucky should seem familiar because it is almost exactly the same sequence of facies. There are only three major differences between the Martin and the Inez sections. First, the Martin section is much thicker, with a fossiliferous interval that is almost four times as thick as the one observed at Inez. Second, at Martin there is almost a meter of section between the Taylor coal and the overlying basal limestone that records the transition from non-marine to fully marine conditions at the beginning of Magoffin deposition. This is an unusual occurrance - at almost all other Magoffin localities the basal limestone rests directly above non-marine strata. Finally, at the Martin locality the coarsening-upward sequence at the top of the Magoffin that was seen near Inez is missing, having been removed by the erosion of a subsequent fluvial channel down to the basal sideritic shales. The channel deposit itself is a massive cross-bedded sandstone with layers of reworked siderite nodules at its base that can be observed in the highwall of the third bench of the roadcut.

In spite of the difference in thickness between the Martin and the Inez sections, the facies found in both places are the same and are easily correlated. In fact, the Martin locality is one of the best places to observe the distinctive faunas that mark the different Magoffin depositional environments. To begin, the interval between the Taylor coal and the basal limestone is a medium dark gray, silty mudstone that becomes increasingly rich in very fine sand upsection toward the limestone. Splitting the mudstone directly above the coal reveals a poorly preserved and depauperate fauna of gastropods and small bivalves. Midway upsection toward the limestone the articulate brachiopod *Rugosochonetes* appears first, followed upsection by a high diversity fauna dominated by the articulate brachiopod genera *Anthracospirifer, Antiquatonia, Composita,* and *Derbyia*. Also found are abundant large crinoid ossicles and epifaunal bivalves such as *Parallelodon* and *Aviculopecten*. This fauna appears to persist into and to form the skeletal matrix of the basal Magoffin limestone.

At the east end of the Martin locality the basal limestone is approximately at eye level above the second bench of the roadcut. The limestone can be seen to become increasingly darker and more fissile upsection as it grades rapidly into a distinctive fissile, black shale. This black shale is very calcareous and somewhat bioturbated at its gradational contact with the underlying limestone, becoming less calcareous and increasingly fissile upsection. Its upper contact with the overlying dark mudstone is transitional over less than three cm, with the black shale becoming lighter in color and bioturbated. The faunas within the black shale are distinctive. The lower, calcareous interval grades from the brachiopod-dominated assemblage at the limestone contact into a mollusk-dominated assemblage consisting mostly of the gastropods *Glabrocingulum* and *Trepospira* and the bivalve *Pleurophorella*. As the black shale becomes increasingly fissile, all fauna disappear except for the thin shelled bivalve *Posidonia*. Bed surfaces of the fissile black shale contain moderate numbers of large *Posidonia* interspersed with many small valves that are apparently juvenile *Posidonia.* Some bed surfaces are densely covered with juvenile specimens.

Above the fissile black shale is an interval of medium dark gray mudstone with a fauna dominated by small nuculoid bivalves. Dominant genera include the bivalves *Nuculoidea* and

Phestia and the gastropods *Glabrocingulum* and *Trepospira*. At the Martin locality the medium dark gray mudstone interval is thick and fossils are relatively sparse except along distinct, thin, shell horizons. Sparsely fossiliferous intervals often contain pyritized, branched horizontal burrows.

As at the localities near Inez, the top of the nuculoid bivalve dominated interval of medium dark gray mudstone at the Martin locality is marked by an abrupt change in color to a lighter medium gray that can be seen along the length of the outcrop. This change in color is accompanied by a return of the brachiopod-dominated fauna. At the top of the highwall of the second bench of the roadcut is a horizon of large limestone concretions marking a densely fossiliferous interval of strata of approximately one half meter thickness. Above this interval there is a change in lithology to darker gray shales accompanied by a change in fauna to one consisting almost exclusively of the brachiopods *Rugosochonetes* and *Orbiculoidea*. The disappearance of this fauna is marked upsection by the first appearance of distinct layers of siderite nodules near the top of the Magoffin exposure.

Hindman

The stratigraphy of the Magoffin marine unit seen in the large roadcut along the Hindman Access Road south of Kentucky Highway 80 is typical of Magoffin localities exposed along highways to the southwest of Martin, Kentucky. In this region, the fossiliferous lower part of the Magoffin is reduced to a thin interval at its base, and the much thicker overall coarsening-upward sequence of the upper part of the Magoffin is seen to consist of two coarsening-upward sequences in stratigraphic succession. The boundary between the two coarsening sequences is marked at all localities by some evidence for deepening, a reduction in the rate of deposition, or an increase in marine influence in the area. For example, at some southwestern localities interlayered tabular beds of sandstone and coarse siltstone at the top of the lower coarsening sequence change upsection to sideritic beds of finer-grained shaley siltstone, which then coarsen back to tabular sandstones. At other localities a transition from unfossiliferous sideritic to fossiliferous non-sideritic silty shales suggests a decrease in runoff and sedimentation and a return to a more open marine environment. Additional evidence for the return of more marine conditions midway through the overall Magoffin coarsening sequence includes the appearance of calcite concretions, often associated with a change to finer-grained lithologies, seen at several localities.

At the Hindman Access roadcut the base of the Magoffin is difficult to observe closely as it is exposed in the middle of the highwall above the first bench in the roadcut. However, a gully at the extreme south end of the cut permits the base of the Magoffin to be sampled where it is found to consist of the same thin, bioclastic packstone seen at the previous two localities resting above the Taylor coal and a thin bed of coaly shale. Above the thin basal limestone is a thin (6 - 8 cm) layer of dark gray mudstone with a dense fauna of small gastropods and nuculoid bivalves. This is the same fauna seen above the fissile black shale at the previous localities. The fissile black shale, with its *Pleurophorella* and *Posidonia* assemblages, is absent at most of the southwestern Magoffin localities. Immediately upsection of the densely fossiliferous dark gray mudstone the fauna rapidly becomes sparse with the appearance of the first horizon of siderite nodules. As suggested previously, the siderite indicates the onset of rapid deposition as deltaic sediments began flooding into the Magoffin seaway.

Above the thin fossiliferous base of the Magoffin at Hindman are some 20 meters of silty shales coarsening into siltstones interbedded with very fine sandstones. The top of this sequence is marked by a continuous horizon of large limestone concretions at the top of the third highwall in the roadcut. This concretion horizon can be observed closely at the extreme south end of the roadcut where it is accessable by climbing up from the second bench. Below the base of the concretion horizon there is a change in lithology from tabular, interbedded siltstone and very fine sandstone to bioturbated silty mudstones. At the level of the concretions a thin (12 cm) interval of mudstone contains abundant articulate brachiopods (*Desmoinesia*, *Anthracospirifer*, *Derbyia*, *Antiquationia*) and gastropods (*Worthenia*, bellerophontids). Above this interval fossils become increasingly sparse and disappear with the appearance of sideritic shales and thin, tabular beds of siderite and siltstone marking the onset of the second coarsening-upward sequence. Above the third bench of the roadcut at this locality is 10 meters of distubed, slumped section that appears to be a continuation of the Magoffin coarsening sequence (Cobb et al., 1981).

Discussion

As a sequence of marine strata sandwiched within overlying and underlying non-marine strata there can be little doubt that the Magoffin marine unit represents an episode of marine transgression. The interesting problem is to determine the timing and geographic pattern of transgression and subsequent regression, and to try and relate the somewhat different stratigraphic sequences seen in the northeast and southwest exposures of the Magoffin. Based on its extensive geographic distribution, the Magoffin appears to represent a period of widespread marine innundation. The Magoffin also contains a greater variety of facies and distinctive fossil faunas in stratigraphic sequence than any other marine unit investigated by the author. This shows a transition through a greater number of depositional environments, suggesting a more developed episode of transgression and subsequent regression than is seen in other marine units. The basal Magoffin limestone is very similar throughout eastern Kentucky and appears uninfluenced by the type of non-marine facies it overlies.

Evidence for the pattern of transgression and regression in the Magoffin can be found in the stratigraphic pattern of biofacies that is particularly well exposed at the Martin locality. Listed in stratigraphic sequence.

Rugosochonetes
brachiopod
Nuculoid bivalve
Posidonia
Pleurophorella
brachiopod
Rugosochonetes

the Magoffin fossil assemblages form a single cycle of biofacies with the *Posidonia* - dominated fissile black shale at the midpoint. Although different in many aspects, the fissile black shale in the Magoffin marine unit appears to be analogous to the fissile black shales of the Upper Pennsylvanian midcontinent cyclothems. The midcontinent black shales have been cogently argued to represent oxygen deficient, maximum water depth deposits in the succession of facies that compose Upper Pennsylvanian cyclothems (Boardman et al., 1984; Heckel, 1977; Heckel, 1986; Heckel, 1991; Heckel and Baesemann, 1975). Particularly compelling is a list of 'evidences' for deep water origin of the midcontinent black shale compiled by Boardman et al. (1984). Several of these 'evidences' also apply to the Magoffin black shale. For example, the midcontinent black shales form a midpoint of lithic symmetry between two shallow water limestones, a lower transgressive limestone and an upper regressive limestone. Although the Magoffin lacks a true upper limestone, it does contain an upper limestone concretion horizon with a brachiopod dominated fauna similar to that in the basal transgressive limestone. Furthermore, the fissile black shale in the Magoffin also forms a midpoint of symmetry within bioturbated, mollusk-dominated mudstones, which are found both below and above the fissile interval of black shale. This is also the case for the midcontinent fissile black shales, which lie within mollusk-dominated gray shales that together form the 'core shales' within the limestones of the cyclothems (Boardman et al., 1984). In the southwestern Magoffin localities the variety of biofacies is reduced, but the condensed, nuculoid bivalve assemblage remains as a 'core' biofacies underlain and overlain by brachiopod-dominated faunas. Thus, as in the midcontinent cyclothems, the sequence of lithologies and biofacies in the Magoffin can be most parsimoniously explained by invoking a single cycle of transgression and regression.

The overall pattern of Magoffin deposition suggested by the sequence of facies seen in the Magoffin sections in this report is presented in the correlation diagram in Figure 3. The initial transgression was rapid and widespread, resulting in the deposition of the basal Magoffin limestone generated from the accumulation of stenohaline invertebrate shelly material in a nearshore environment with low clastic input. Continued transgression and deepening resulted in the deposition of thin, fossiliferous mudstones with a mollusk-dominated fauna. Transgression culminated in the production of an oxygen deficient benthic environment and associated black shale facies. A breakdown in the conditions that formed the black shale allowed the return of a mollusk-dominated fauna. In the southwest of the study area the extremely condensed nature of the mollusk-dominated facies suggests that the black shale facies may not have been preserved due to much lower levels of clastic input than in the northeast. It is also possible that water depths sufficient to cause the deposition of the black shale were not realized to the southwest.

Following deposition of the mollusk-dominated facies the immediate onset of rapid sedimentation in the southwest shows the return of nearby, actively prograding shoreline deltas. Contemporary depositional rates were only moderate to the northeast. Evidence for a later decrease in the rate of deposition is seen as an interruption in the coarsening sequence to the southwest and in the formation of a correlative, densely fossiliferous horizon to the northeast. This could have resulted from a minor episode of transgression superimposed on the overall regressive trend. Such a transgression would have partially flooded existing deltaic distributary systems, causing deltaic deposition to backstep away from the center of the seaway, resulting in a temporary decrease in the rate of deposition and a decrease in the size of the sediments being delivered to a particular area. However, it is also possible that the decrease in deposition could have resulted from a period of dry climate with reduced precipitation and runoff resulting in a decrease in clastics delivered to the basin (Cecil, 1990; Cecil et al., 1985).

The re-initiation of rapid sediment input into the basin following the interruption in deposition resulted in coarsening back to terrestrial conditions throughout the Magoffin seaway. At many localities the final transition to non-marine sedimentation was subsequently eroded away by fluvial incision during sea level lowstand.

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Deposition of the Taylor coal bed, Martin and Johnson counties, eastern Kentucky

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ABSTRACT

This study investigated the Taylor coal bed in Johnson and Martin counties, eastern Kentucky, using field and petrographic techniques to develop a depositional model of the coal bed. Petrography and chemistry of the coal bed was examined. Multiple benches of the Taylor coal bed were correlated over a 5 km. distance. Two sites were studied in detail. The coal at the eastern site (C) was relatively thin and was split by a thick clastic parting. The coal at the western site (B) was thick and unsplit. Two major clastic partings have been identified locally in the Taylor coal bed. Each represents a separate and distinct fluvial splay. The Taylor is interpreted to have developed on a coastal plain with periodic flooding from nearby fluvial systems.

BACKGROUND

This study examined the Taylor coal bed in Martin and Johnson counties, eastern Kentucky. Fresh roadcuts along Kentucky Highway 3 were mapped, and the coal seam was described and sampled. Petrographic, ash and sulfur analyses were performed, and this data was combined with field observations in order to develop a model of the depositional history and geologic setting of the coal bed in this area (Andrews, *et al.*, in press).

The Taylor coal bed, though often split or discontinuous, occurs throughout much of the Eastern Kentucky Coal Field in the Central Appalachian Basin. This bed can be found within the Middle Pennsylvanian Breathitt Formation, directly underlying the Magoffin Marine Member (Rice and Hiett, 1994) (Fig. 1). The Magoffin is the most continuous and widespread marine rock unit within the Breathitt Formation in eastern Kentucky (Bennington, in press). Chesnut (1992) has proposed a new nomenclature for rocks of the Eastern Kentucky Coal Field that would raise the Breathitt to Group status. The Taylor-

Magoffin contact is the boundary between Chesnut's Hyden Formation and the overlying Four Corners Formation (Fig. 1).

Due to its often thin, high-sulfur, and discontinuous nature, the Taylor coal bed is infrequently mined. The instability of the overlying Magoffin shales also discourages underground mining. Most of the surface mines in Kentucky in which the Taylor is mined are located in Pike and Martin counties, and it is removed only incidentally while targeting higher quality coals lying beneath.

METHODS

The study area is located in Martin County, Kentucky, along the recently improved Kentucky Highway 3 (Fig. 2). Roadcut exposures were sampled and described in the spring of 1993. Two roadcut exposures were mapped and the Taylor coal was sampled. Sample thickness was determined by lithotype when possible.

All samples were analyzed at the University of Kentucky Center for Applied Energy Research (CAER). Dry ash and dry total sulfur were determined using ASTM methods. Maceral composition was determined using a technique described by Moore and Stanton (1985), tabulating maceral categories as found in Stach *et al.* (1982).

OBSERVATIONS

Figure 2 shows the location of the present study area. The sites analyzed in this study roughly parallel regional depositional slope (Chesnut, 1992; Powell, 1979), as well as the general trend of the paleoshoreline in this area as inferred by Powell (1979). The sample sites lie between the axes of the Paintsville-Warfield Anticline and the Eastern Kentucky Syncline (using Fig. 5 of Powell, 1979), and lie within the southernmost Rome Trough, near the extended transition between the Pike County Uplift and Floyd County Channel of Ammerman and Keller (1979) (Fig. 2a).

The results of the petrographic, sulfur, and ash analyses are shown in Table 1, and lithotype descriptions, along with petrographic profiles, are shown in Figure 3. Based on macroscopic descriptions, coal bed splits and partings, and laboratory analyses, the Taylor coal bed was separated into six correlative intervals. These intervals were used to interpret the depositional history. Sites (B) and (C) are approximately 5 km. apart.

Site B

Site B is the western site of this study (Fig. 4). The Taylor coal is immediately underlain by a light gray rooted clay. Underlying lithologies were not exposed, but nearby Kentucky Department of Transportation planning cores indicate at least 2 m of silty shale underlies the coal bed. No major partings interrupt the coal bed. The fossiliferous beds of the Magoffin are separated from the coal by 18 cm of gray, non-fossiliferous clay, and 10 cm of carbonaceous shale (Fig. 3). The lower part of the coal bed is split by two clay partings (2.0 cm and 0.25 cm), and another "soft," fusain-rich zone approximately 0.5 cm thick. Dry ash yield is lowest in the middle of coal bed, and increases toward the top of the coal bed.

Site C

The stratigraphy of site C is shown in Figure 5. The Taylor coal and its underclay are underlain by 15 m of fine-grained crossbedded sandstone that grades laterally into siltstone and shale. A light gray rooted clay beneath the coal. The coal bed elevation rises somewhat (<2 m) over the sandstone-siltstone transition. Paleocurrent directions measured from trough crossbeds in the sandstone (Fig. 5) trend WNW. The coal bed contains one major split of shale and medium-grained sandstone. Crossbeds in the sandstone parting exposed on the face of the roadcut trend to the southwest, but crossbeds on another highway cut 100 m to the northeast (east side of KY 3) show a southeasterly direction.

The upper bench (not sampled) is canneloid, and is immediately overlain by the fossiliferous paper shales of the Magoffin. The lower bench is split by two minor clay partings (each approximately 0.25 cm); a 0.5 cm "soft," fusain-rich zone; and a sandy clay parting (0.5 cm). The top of the lower bench has two medium-grained brown crossbedded sandstone partings (9.5 and 6.5 cm), which contain coal streaks, but show no evidence of rooting.

Sulfur content is lowest within the middle of the lower bench (0.7%), and generally increases toward the top and bottom of the bench. The petrographic analysis shows an increase in total vitrinite upward, with a decrease in inertinite macerals and ash yield upward in the coal bed.

DISCUSSION

The clastic interval beneath the Taylor coal bed represents fluvial systems with associated overbank deposits. The fluvial system is identified by the gradational sandstones, siltstones, shales, their sedimentary structures, and the orientations of crossbeds. The west-northwest paleocurrent directions measured from trough cross-beds in the sandstone at site C are consistent with the assumption of a generally NE-SW shoreline trend for this area (Powell, 1979).

Differential compaction of the underlying clastic may have caused the lateral variations observed within coal intervals 1, 2, and 3. Intervals 1, 2, and 3 show higher inertinite contents, and are much thinner to the east above the thicker sandstone, with generally higher liptinite contents and thicker splits to the west. The two lowermost clay partings and the "soft" zone are found at both sites, and are all thinner at the eastern site (C), but are never-the-less thin at both sites. These clay splits were probably caused by "coast-parallel" events such as minor transgressions or storms, based on their relatively uniform presence at both sites. The minor differences could simply be due to preservation effects or minor relief on the swamp surface. The "soft," fusain-rich zone is relatively uniform throughout, and may represent a variation of "fire splay" as discussed by Cohen *et al.* (1987). The data for the fourth interval indicates relative uniformity between the two sites.

After deposition of the fourth coal interval the coal swamp was inundated with clastic material from the west. A shale split 3 m thick is present in Taylor coal exposures several kilometers westward, and probably correlates with a sandy clay split (0.5 cm thick) at the eastern site (C). At the central site (B), a hard durain , somewhat thicker than the durain at the top of zone 4 at site A, occupies this approximate stratigraphic position, and may represent either subaerial exposure (and hence non-deposition or erosion of the split); or the effects of sediment-poor, oxygenated water flowing over the swamp surface) (Moore, 1991). This split is interpreted to be fluvial in origin, due to the lack of a relative increase in sulfur content in the underlying coal (Cohen *et al.*, 1987; Rimmer and Davis, 1988).

The coal swamp was re-established over the clastic material of the first major split, reflecting the wedge-shaped topography of the splay deposit. High inertinite contents and high ash yields west of the study area result from a topographic "high" over the thickest (3 m) part of the deposit. The coal at the two sites of this discussion (B and C) is relatively similar (between the two sites) and was relatively unaffected by the thin, centimeter-scale to non-existent/non-preserved nature of the split at these sites.

After deposition of interval 5, clastic material inundated the coal swamp again, forming the second major parting. The parting is persistent across the study area, being best developed at the eastern site (C). Medium-grained brown crossbedded sandstones with coal clasts immediately overlie the coal bed, and in some places split the coal inferred to be in interval 5. The sandstone partings are discontinuous, cut across coal banding, and do not appear to be rooted. The sandstones "invaded" the peat mat from above, perhaps by tearing or *in situ* rafting (floating) of pieces of the peat mat by flowing water, after deposition of the interval 5 coal. These sandstones are thickest at the northeastern end of the site C roadcut (2 m), and thin to the southwestern end of the same cut (0.6 m). A non-fossiliferous gray shale overlies this sandstone, and thickens from 0.7 m at the northeastern end of site C to 1.0 m at the southwestern end of site C, possibly as a result of the thinning of the sandstone immediately below. The gray shale correlates with the 18 cm gray shale at site B, which thins westward.

Crossbeds in the post-interval-5 sandstone exposed on the face of the site C roadcut trend to the southwest. Crossbeds on another highway cut 100 m to the northeast indicate a southeasterly direction. From these trends, and the thickness and lithologic trends observed elsewhere along the highway, the source area for the second major clastic influx is inferred to lie somewhere to the east or northeast. Based on the lithologies, sedimentary structures, and the lack of high sulfur values in the underlying coal, this clastic package is interpreted as a fluvial splay from a river system.

The coal swamp partly re-established itself on top of the second splay. Relatively high-vitrinite (but also high sulfur and ash) coal is found west of the current study area, but only 10 cm of carbonaceous shale are found at the western site (B). In the roadcut at the eastern site (C), a thin cannel varies in thickness across the cut, showing an inverse relationship with the thickness of the sandstone from the last splay system. The cannel thins from 12.5 cm in the southwestern part of the cut (thinner sandstone) to non-existent at the northeastern end of the cut (thicker sandstone). At the northeastern end, the horizon of the cannel is represented by abundant rooting structures in the underlying shale. Esterle and Ferm (1986) noted a similar cannel coal at the top of the Upper Hance coal bed, in Bell

County, Kentucky, where the thickness of the cannel varied inversely to the thickness of the underlying splay deposit.

The beginning of the Magoffin transgression immediately followed the deposition of this last coal interval. Fissile carbonaceous shales with sulfide mineralization and iron staining, and a thin, shaly limestone overly the coal bed across the entire profile (see Bennington, this volume).

The stratigraphic and lithologic relationships observed in this study allow the possibility of a coastal plain setting for the deposition of the Taylor coal. The rapid subsidence attributed to deposition of the Magoffin (Tankard, 1986) would enable preservation of the peat. Without this subsidence, the Taylor peats would either have been eroded with the next sea level regression, or have been reworked into later deposits during transgression.

CONCLUSIONS

The Taylor coal bed is divided into six correlative intervals (Table 1; Fig. 3)-- based on partings, lithotypes, and petrography--which were used to interpret the depositional history of the coal. Pre-depositional topography appears to play a significant role in determining coal quality. Two major fluvial partings observed within the Taylor in Johnson and Martin counties are stratigraphically distinct and separate. The Taylor coal is interpreted to have been deposited in a tectonically active coastal plain setting, adjacent to structurally-controlled fluvial systems.

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Table 1. Results of petrographic, ash, and sulfur analyses on the Taylor coal bed. Key for column headings: cm, thickness; VIT, total vitrinite; INT, total inertinite; fus, fusinite; sfs, semifusinite; mic, micrinite; LIP, total liptinite.

Site	Interval	Sample ID	cm	**VIT(t)**	**INT(t)**	fus	sfs	mic	**LIP(t)**	Dry Ash	Dry S
B		31090	2.0							87.91	0.13
B	6	31091	10.0							85.82	4.86
B		31092	18.0							52.72	0.88
B	5	31093	13.0	35.0	55.0	14.9	25.5	14.6	10.0	23.14	1.30
B	5	31094	21.0	55.0	35.4	11.0	12.8	11.6	9.6	10.98	1.23
B	4	31095	8.0	42.1	44.7	13.4	18.2	13.1	13.2	13.09	1.47
B	4	31096	20.0	62.3	29.2	6.8	10.8	11.6	8.5	13.34	1.17
B	3	31097	18.0	76.4	15.4	6.2	4.3	4.9	8.2	17.91	1.31
B	2	31098	12.0	77.3	11.8	4.5	3.2	4.1	10.9	26.60	1.40
B	1	31099	10.0	75.0	15.7	6.4	4.1	5.2	9.3	33.62	3.42
B		31100	2.0							92.91	0.23
C		31078	2.0							93.30	0.08
C	5	31079	5.5	80.9	9.6	0.3	1.6	7.7	9.5	7.33	1.10
C		31080	6.5							96.46	0.02
C	5	31081	4.5	79.6	10.5	1.0	2.9	6.6	9.9	6.28	1.52
C		31082	9.5							97.88	0.01
C	5	31083	7.0	70.1	21.3	5.1	6.7	9.5	8.6	10.86	0.76
C	4	31084	14.0	56.4	30.1	10.5	9.0	10.6	13.5	14.14	0.66
C	4	31085	13.5	60.0	31.8	10.0	8.9	12.9	8.2	9.14	0.78
C	3	31086	10.0	56.0	33.7	11.2	14.4	8.1	10.3	11.87	0.84
C	2	31087	16.0	36.2	44.3	14.0	21.9	8.4	19.5	15.21	1.69
C	1	31088	3.5	70.4	19.8	5.7	5.8	8.3	9.8	44.91	2.08
C		31089	2.0							92.25	0.03

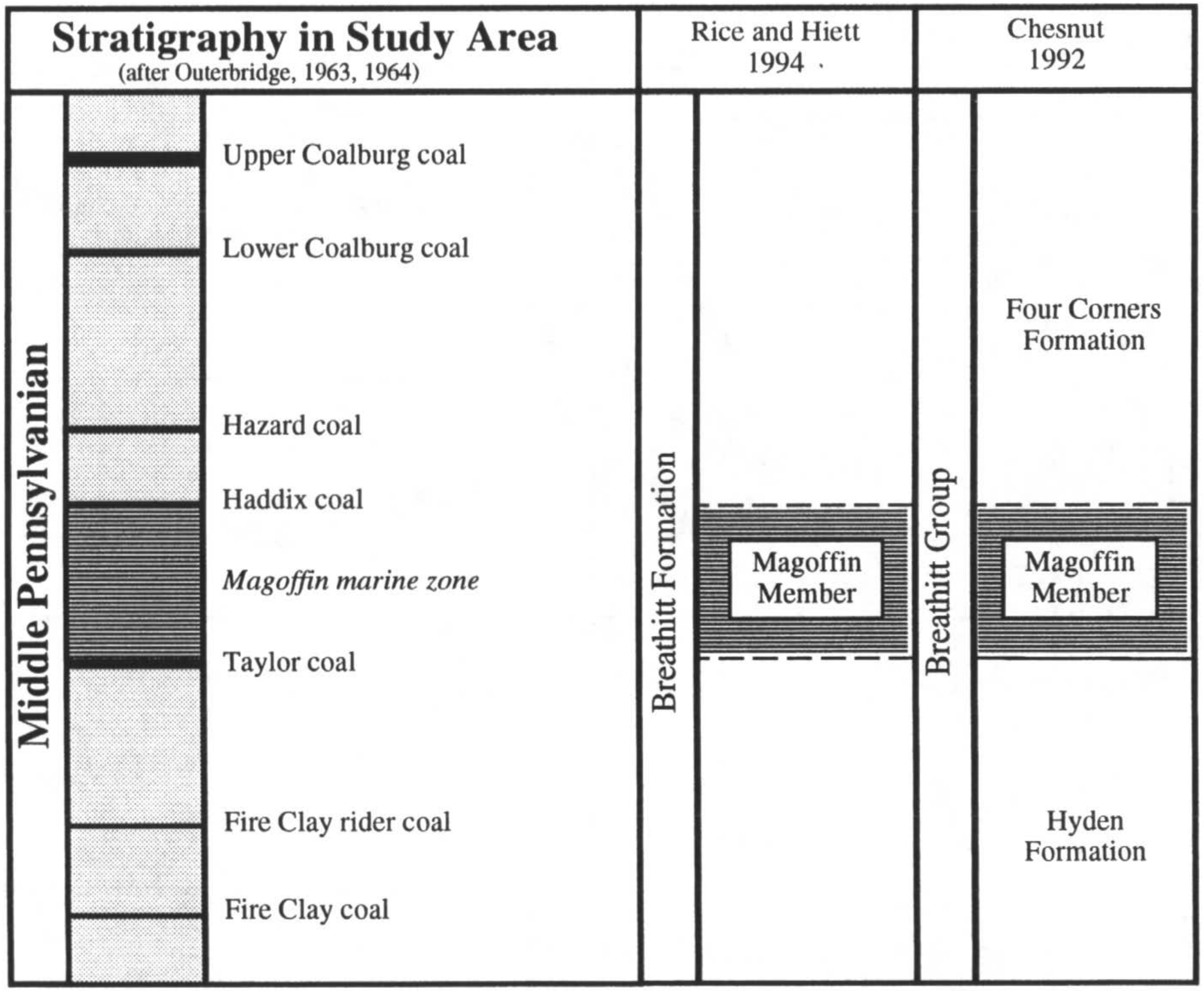
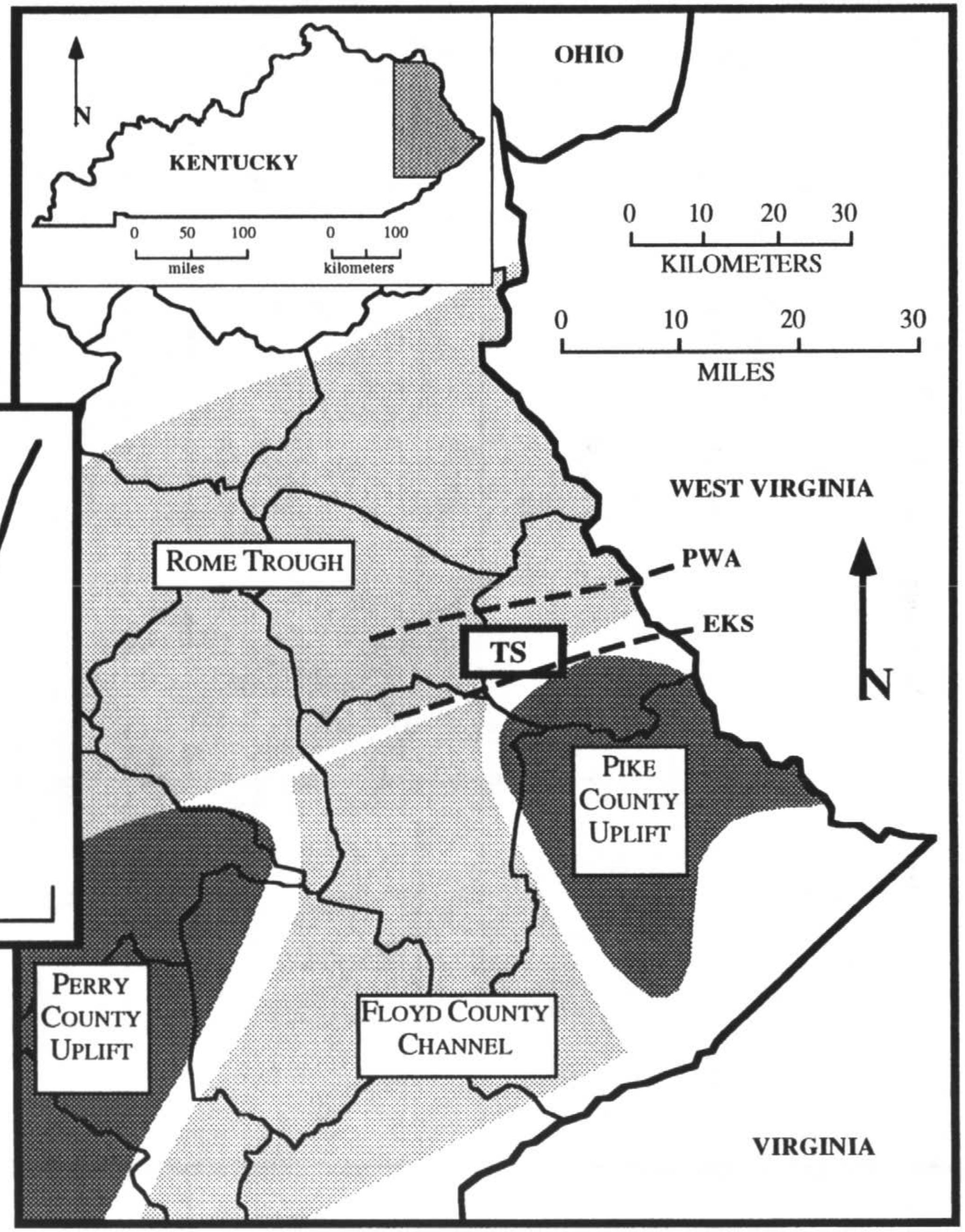
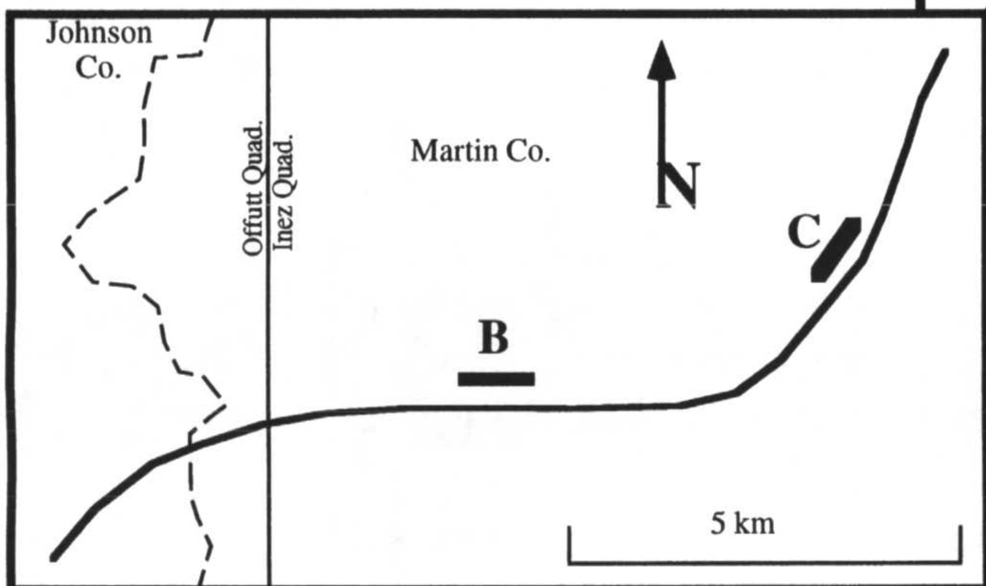


Figure 1. Stratigraphy of Middle Pennsylvanian rocks in the study area, related to regional stratigraphic nomenclature used by Rice and Hiett (1994) and Chesnut (1992).

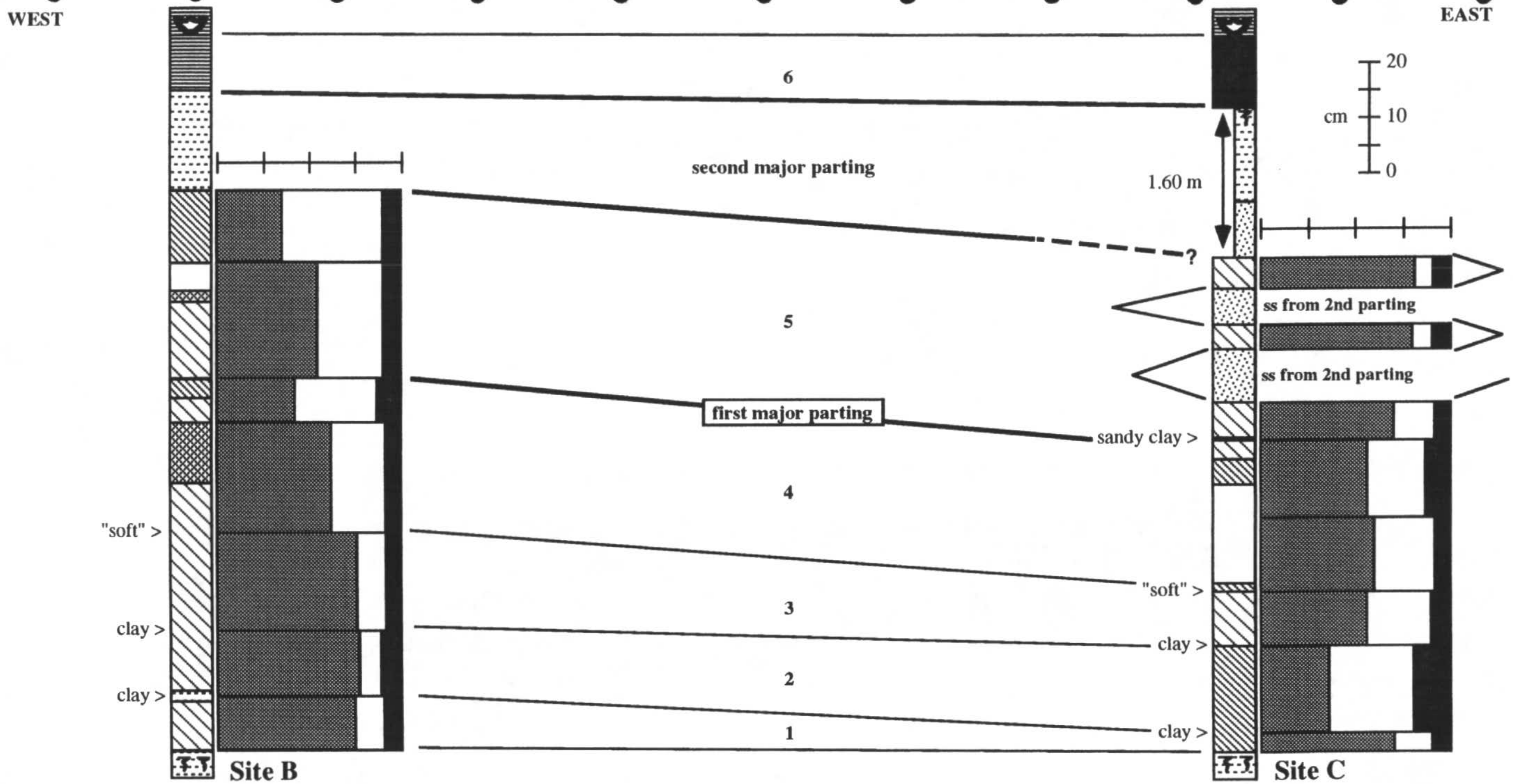
2a





2b

Figure 2. a) Location of study area in eastern Kentucky shown by box **TS**. Geophysical features from Ammerman and Keller (1979) are shaded. **PWA** and **EKS**: Paintsville-Warfield Anticline and East Kentucky Syncline, generalized locations shown only in vicinity of study area. b) Enlarged map of study area, shown by box **TS** in Figure 2a.



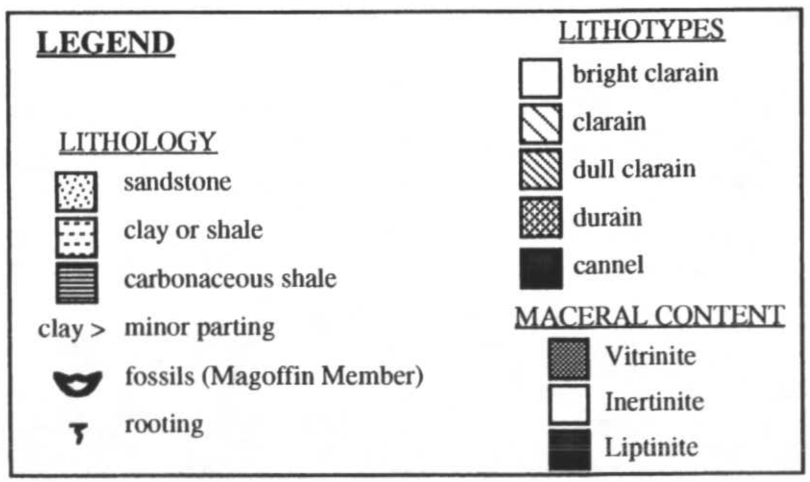


Figure 3. Lithotype descriptions and petrographic profiles of the two sites discussed in this study. Profile is west to east; total profile length is approximately 5 km. Bold numbers refer to correlated intervals.

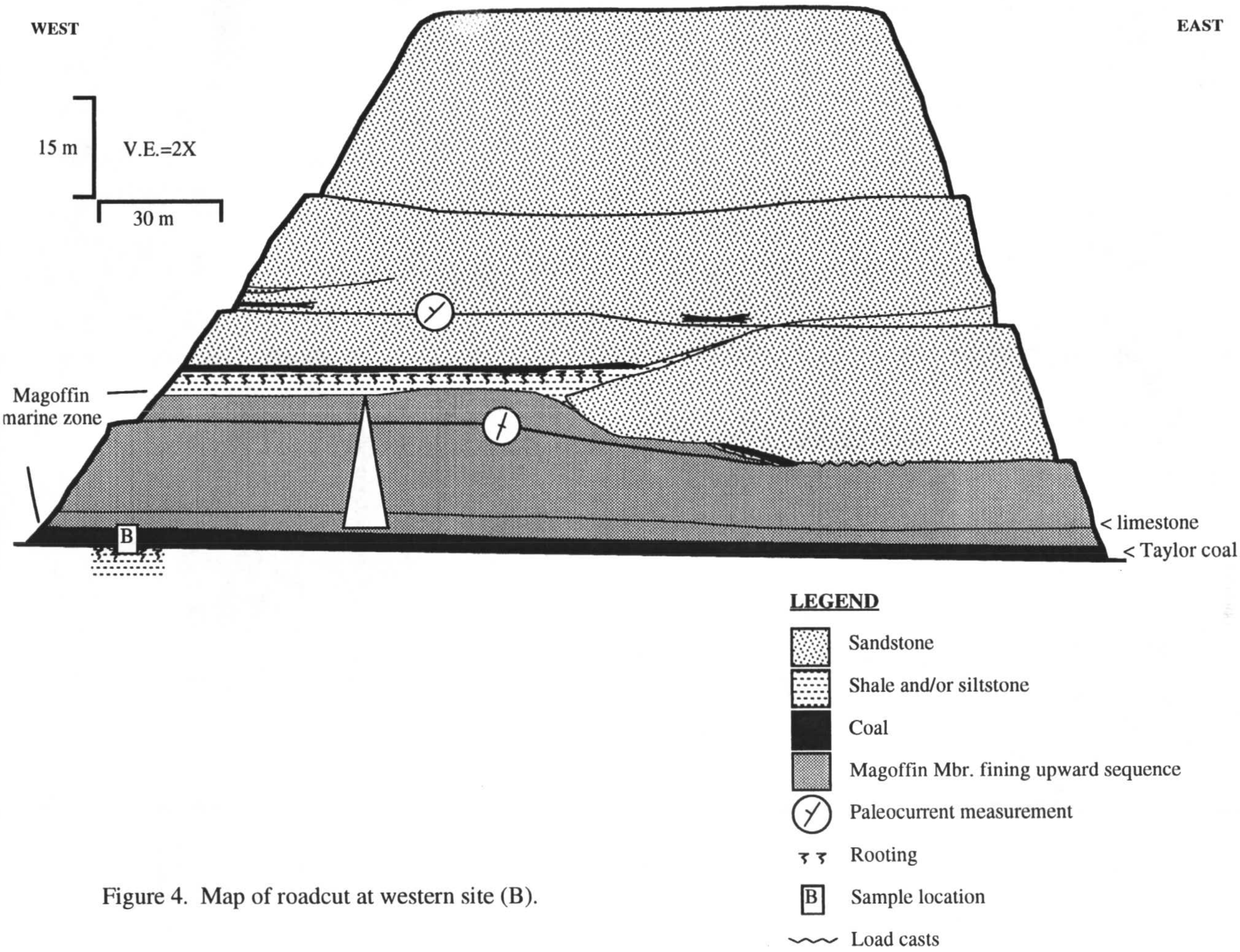


Figure 4. Map of roadcut at western site (B).

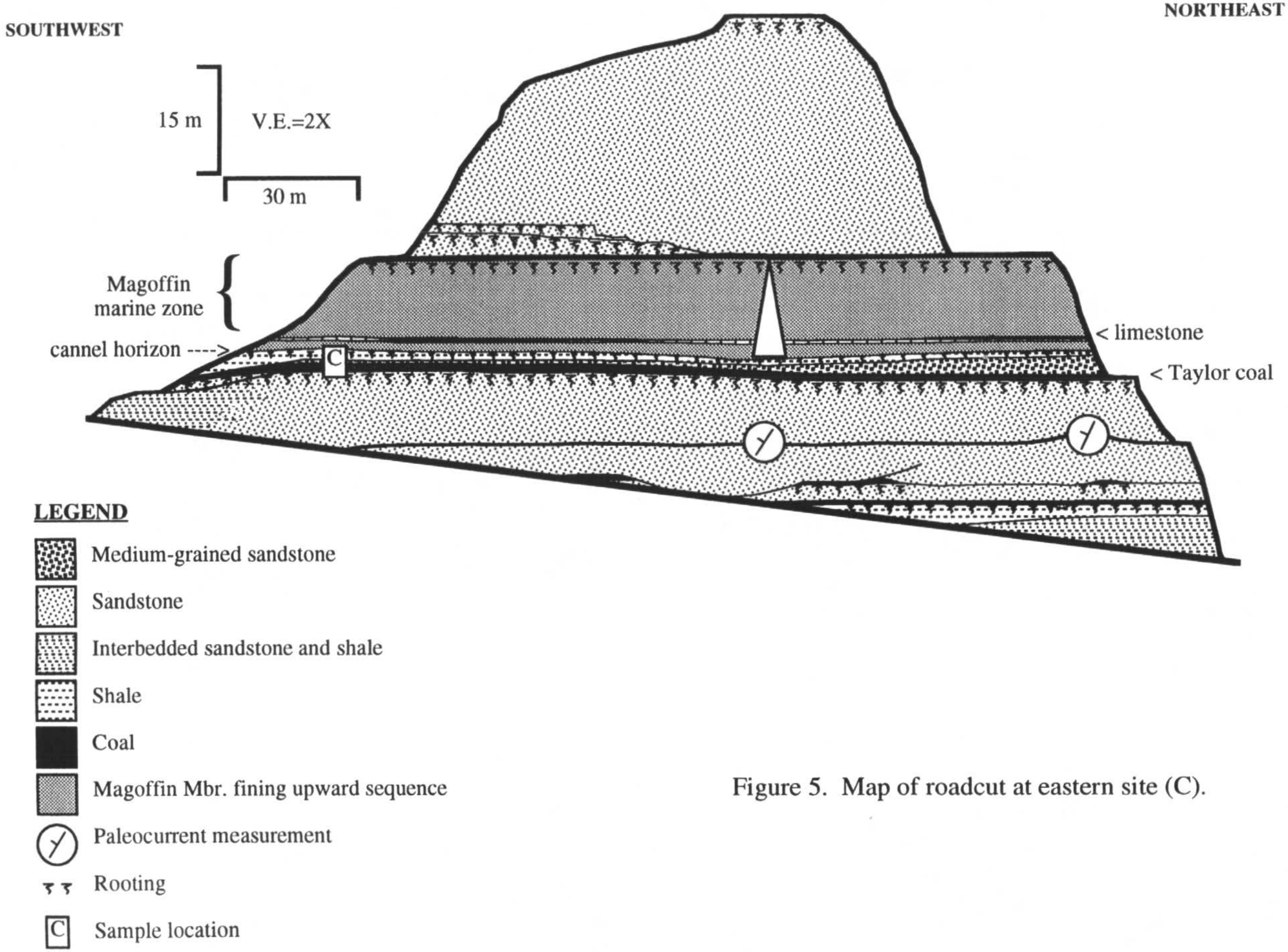


Figure 5. Map of roadcut at eastern site (C).