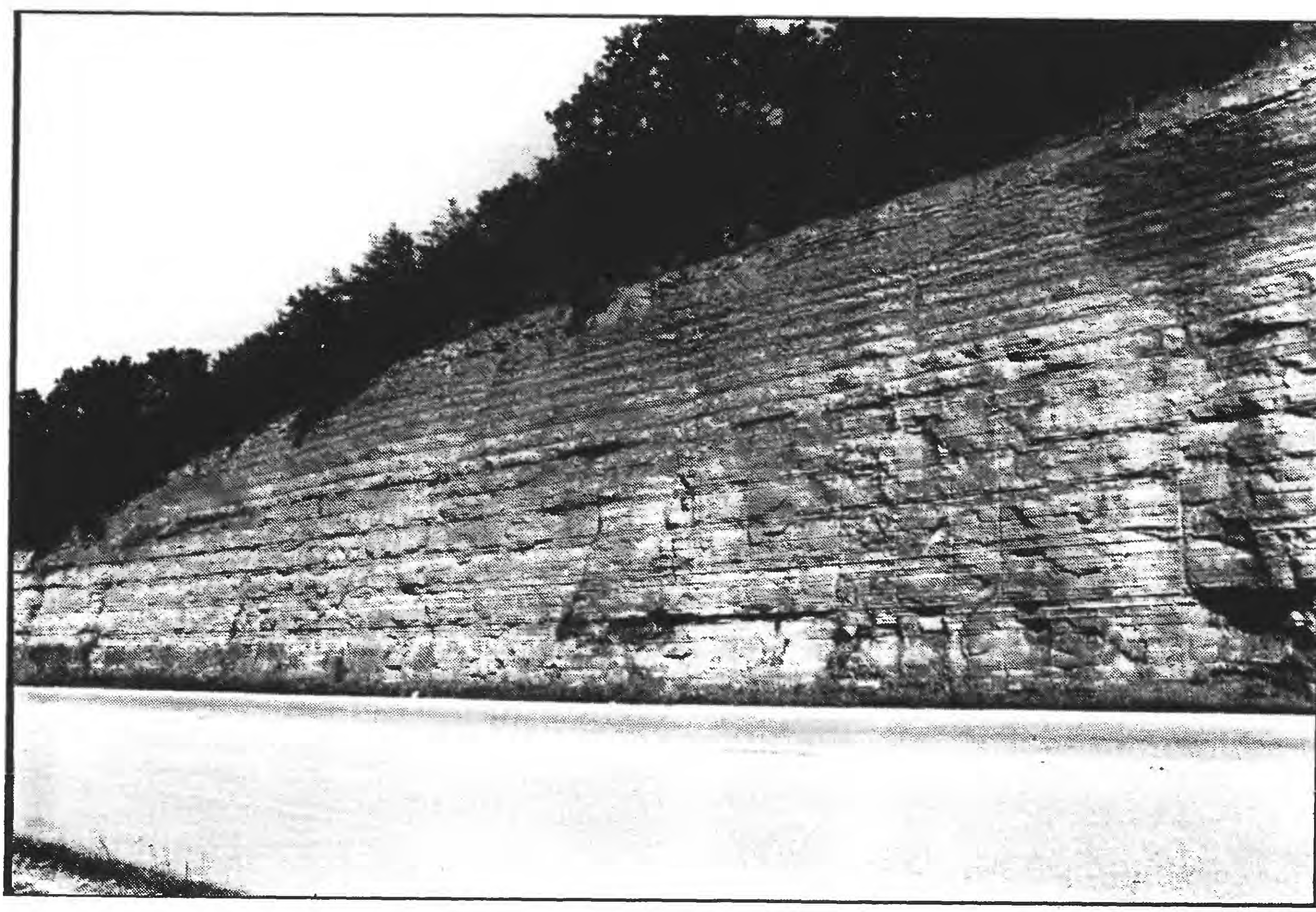
Regional Aspects of Pottsville and Allegheny Stratigraphy and Depositional Environments
Ohio and Kentucky

By Charles L. Rice, Ronald L. Martino, and Ernie R. Slucher



U.S. Geological Survey
Open-File Report 92-558
Prepared for the Annual Meeting of the
Geological Society of America
Cincinnati, Ohio
October 26–29, 1992

CINCINNATI

COVER PHOTO

Pennsylvanian estuarine tidal rhythmites
Interstate 64, Rowan-Carter County line,
northeastern Kentucky

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY
Open-File Report 92-558

REGIONAL ASPECTS OF POTTSVILLE AND ALLEGHENY STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS

OHIO AND KENTUCKY

By

Charles L. Rice, U.S. Geological Survey, Reston, VA 22092
Ronald L. Martino, Marshall University, Huntington, WV 25755
and
Ernie R. Slucher, Ohio Geological Survey, Columbus, OH 43224

with contributions by

Charles L. Ketering, Jr.
Laidlaw Waste Systems, Bryan, OH 43506

David F. Dominic
Wright State University, Dayton, OH 45435

J. Bret Bennington
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061

Donald R. Chesnut, Jr., Stephen F. Greb,
and Cortland Eble
Kentucky Geological Survey, Lexington, KY 40506

and
Dewey D. Sanderson
Marshall University, Huntington, WV 25755

1992

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Index map showing location of field trip stops.

INTRODUCTION

by
Charles L. Rice

A diverse succession of largely Middle Pennsylvanian rocks that unconformably overlie Mississippian strata is exposed in both southeastern Ohio and northeastern Kentucky. This field guidebook is intended to illustrate the mixed sequences of coal-bearing continental, estuarine, and marginal marine strata of Early to Middle Pennsylvanian age that interfinger along the northwest margin of the Appalachian basin. The main purpose of this field trip is to compare sections of (1) basal Pottsville strata newly exposed in roadcuts of U.S. Highway 35 near Jackson, Ohio (Stops 1-3, see Index Map), and (2) a section of basal Allegheny strata exposed in coal-, limestone-, and clay-stripping operations in the area east of Jackson (Stop 4), with equally well exposed roadcut sections of the same stratigraphic sequences in southeastern Ohio (Stop 7) and in the Breathitt Formation of northeastern Kentucky (Stops 5, 6, 8, 9, and 10).

Correlation of largely Middle Pennsylvanian units of the central Appalachian basin between the northern part (Ohio and Pennsylvania) and the central part (Kentucky, West Virginia, and Virginia) has been hampered not only by the use of completely different schemes of regional nomenclature, but by differences of lithofacies and interval thicknesses, by regional miscorrelations, and perhaps by unperceived disconformities in dense geologic sections. In the tri-State area of Kentucky, West Virginia, and Ohio, Phalen (1912) divided these strata into the Pottsville and Allegheny Formations, but his description of the section was so vague that continued use of those terms was long ago abandoned in Kentucky. For example, Phalen (1912) defined the base of the Allegheny Formation as it is in its type area in Pennsylvania as the top of the Homewood sandstone or as the base of the overlying Brookville coal bed. Type sections for both the sandstone and the coal bed are in western Pennsylvania. The Homewood cannot be traced from Pennsylvania and cannot be distinguished from among the many thick sandstone units in the tri-State area nor can the Brookville be distinguished from several coal beds there. It now seems doubtful that those Pennsylvanian units even extend into the tri-State area. In southeastern Ohio, Stout (1916), following Phalen's definition, initially placed the base of the Allegheny Formation at the base of the so-called "Brookville" coal bed of Ohio; unfortunately, this probably was the Winters coal, probably more than 10 m (33 ft) and several coals higher in the section. Stout (1927) briefly noted this error 11 years later, which had already affected the mapping, nomenclature, and correlations in five counties in southern Ohio.

Only one Middle Pennsylvanian stratigraphic term introduced by Phalen (1912) in the Kenova area has continued to be used--the "Vanport" limestone--and that unit also now appears to have been miscorrelated from its type section in western Pennsylvania. Wanless (1939, 1975) also made several attempts to unify the stratigraphy of the various regions of the Appalachian basin primarily by correlating extensive Pennsylvanian marine units. Unfortunately, at that time he had little useful paleontological information; thus, most of his correlations were slightly more than educated guesses, most of which are incorrect.

Despite the long history of mapping in the Ohio-Kentucky border area, much of the data are obsolete, mostly because of miscorrelation and nomenclature problems. Our reconnaissance has thus far shown that only three common stratigraphic units can be consistently identified between the two areas: the misnamed limestone unit previously called Vanport (called Obryan limestone in this report) and two clay units that are differently named in the two States, Sciotoville (Ohio)-Olive Hill (Ky.) flint clays, and the Lawrence (Ohio)-Hitchins (Ky.) clay beds (see Chart 1).

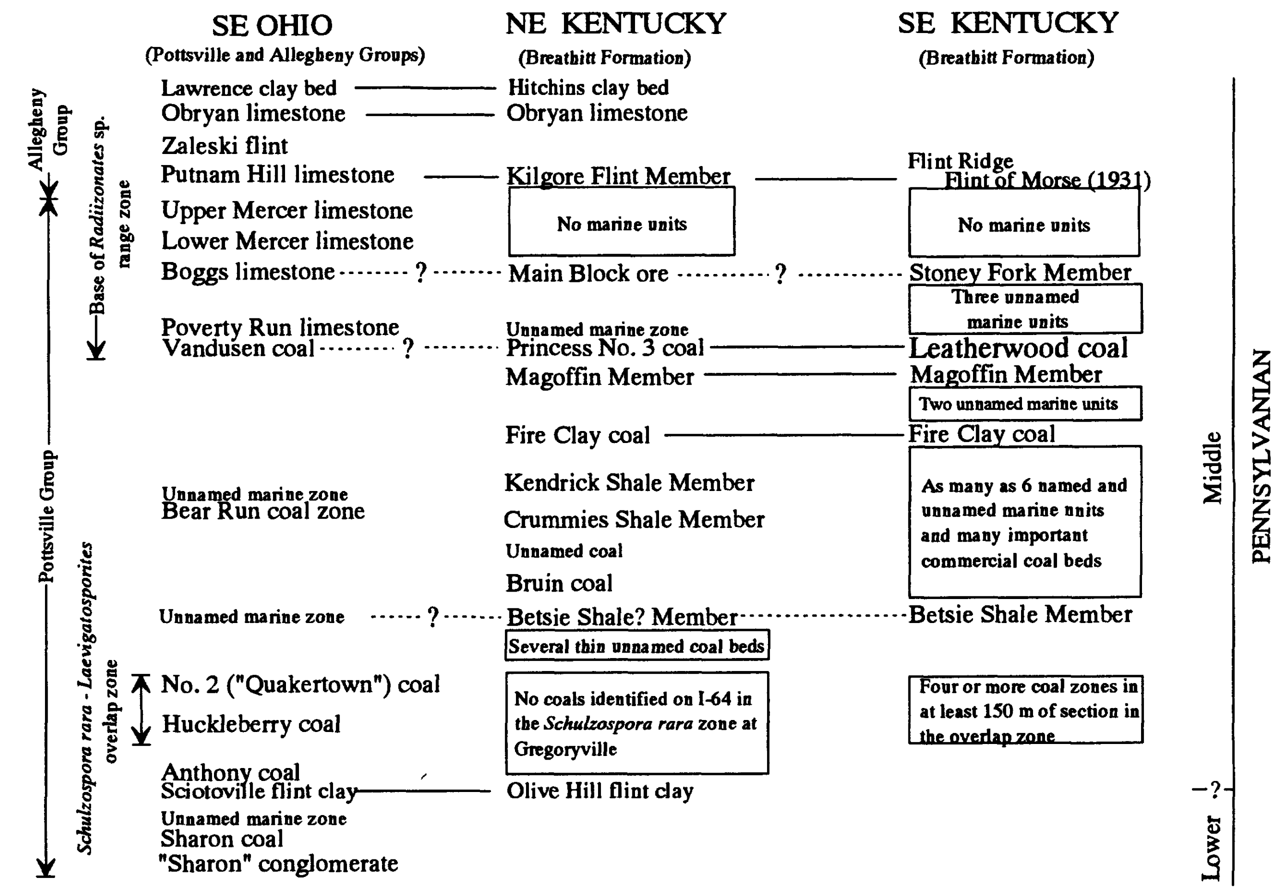

CHART 1. Correlation chart of major and minor stratigraphic units in rocks of Pottsville and early Allegheny age between southern Ohio and northeastern and southeastern Kentucky. Palynology of coal beds for southern Ohio and Kentucky is from recent unpublished work of Robert M. Kosanke (U.S. Geological Survey, Denver, CO, written commun., 1992); palynology of the coal beds in the Gregoryville section at Stop 9 is by Cortland Eble. The Boggs limestone has been identified only in central Ohio, but is included here because it contains the earliest occurrence of fusulinids in Ohio and is a correlative of the Stoney Fork Member of the Breathitt Formation in Kentucky.

The numerous coal beds, particularly in the lower part of the Pennsylvanian section, are commonly discontinuous; due to poor exposures, identifiable stratigraphic sequences are very difficult to correlate from place to place.

The new roadcuts north and east of Jackson, Ohio, are remarkable because they expose the entire section from the basal Pottsville "Sharon" conglomerate to the sandstone overlying the Lower Mercer coal bed; thus, it is possible to identify all of Stout's (1916) named units and study the intervening sequences. In northeastern Kentucky, where the rocks have been mapped at a scale of 1:24,000, coal beds in the lower 30 m (100 ft) of the Pennsylvanian are generally too thin and discontinuous to be mapped, or otherwise identified. Well-exposed (some new) roadcuts now provide the opportunity to compare these strata and to develop a more coherent idea of the distribution of units in the basal part of the Pennsylvanian and their depositional environments. Resolving stratigraphic correlations between these widely separated areas, however, will require careful analysis of both the fauna of marine zones and the palynology of the coal beds and associated strata. Unfortunately, we have only begun to look at the paleontology of these units in detail.

Chart 1 is a diagram showing the most significant of the Lower and Middle Pennsylvanian stratigraphic units and tentative correlations between southern Ohio and northeastern and southeastern Kentucky. Analyses of the palynology of the coal beds in the Jackson bypass roadcuts on U.S. Highway 35 by R.M. Kosanke (written commun., 1992) help resolve some of the problems of correlation between sections of similar age but vastly different thicknesses. Thus, while the palynomorph *Schulzospora rara-Laevigatosporites* overlap zone is well developed in southern Ohio and southeastern Kentucky, it may not be present in northeasternmost Kentucky or southeasternmost Ohio because no coal beds have been identified in this zone in those areas. On the other hand, only the two coal beds of the Bear Run coal zone occupy the interval between the top of the overlap zone and the earliest occurrence or base of the palynomorph *Radiizonates* sp. range zone. In northeastern Kentucky, however, many coal beds and marine units occur within the latter interval, and in southeastern Kentucky this interval contains more than a dozen major coal zones and as many as eight marine units. The Boggs limestone of Ohio and the Stoney Fork Member of the Breathitt Formation are correlated on the basis of the fusulinids they contain (Douglass, 1987); the Main Block ore of northeastern Kentucky contains marine fossils and, on that basis and its apparent stratigraphic position, it is projected to correlate with those units. The Lower and Upper Mercer limestones of Ohio, which are important elements in Wanless' (1939, 1975) proposed basin-wide correlations, apparently have no known correlatives in Kentucky, West Virginia, or Virginia (Chart 1).

Most coal beds in the Jackson, Ohio, sections are overlain by brackish-water or marine units. Perhaps the most marine of these units is that above the No. 2 ("Quakertown") coal, which has not been previously identified. Although many shales and sandstones in the lower part of the Pennsylvanian sections show the influence of marine water in both Kentucky and Ohio, none have yet been traced between the isolated exposures. Absence of part of the section due to channeling and abrupt lateral facies changes makes tracing of units difficult between closely related outcrops or even within the same exposure. A major disconformity related to the marine unit (units?, see text for Stop 3) above the No. 2 ("Quakertown") coal bed appears to truncate the coal at the southernmost exposures of Stop 3 east of Jackson. The No. 2 coal has not been reported south of that point, but how much and what part of the section is missing is unknown. Seat rocks are well developed below the Bear Run, Vandusen, and Lower Mercer coal beds, but we need more data on the palynology of the coal beds and intervening strata to known where specific coal beds fit in the thick Pennsylvanian sections of southeastern Ken-tucky and where major parts of the strati-graphic section may be missing.

Of particular interest is the regional continuity of the clay units as recognizable stratigraphic marker beds. These units commonly consist of a mixture of plastic (illitic) and flint (relatively pure, well-crystallized kaolinite) clay beds. The Olive Hill flint clay commonly occurs at or near the base of the Pennsylvanian in northeastern Kentucky, but its correlative in Ohio, the Sciotoville flint clay, commonly is above the base of the Pennsylvanian, particularly in the paleovalleys occupied by the "Sharon" conglomerate or sandstone. It is possible that these flint clays may represent altered deposits of reworked volcanic ash concentrated in backwater areas of a coastal plain. Reworking of the ash deposits and the addition of other detritus might dilute the small number of volcanic phenocrysts present and make positive identification of the original source difficult or impossible. Such a scenario might help to explain the geometry of the flint clay deposits and their close association with deposits of semiflint and plastic clay.

The Lawrence and Hitchins clay beds are easily recognized in southeastern Ohio and northeastern Kentucky because of their proximity to the Obryan limestone, which is commonly a few meters below the clay beds or locally occurs as limestone nodules in the clay beds near the pinchout of the Obryan. The flint clay beds help to make that part of the section a distinctive stratigraphic unit that can be recognized and mapped. The Lawrence and Hitchins flint clays contain volcanic phenocrysts such as beta-form quartz, apatite, zircon, feldspar, and biotite: some of these clasts are euhedral. The inclusion of detrital quartz and rock grains in the flint clay deposits and the number of flint clay beds and partings suggest that they represent slightly reworked volcanic ash falls of perhaps several eruptions.

The origin of quartz arenites has been a controversial element in Carboniferous investigations for 20 years or more (Rice and Schwietering, 1988). The thick sequences of quartz arenites (locally more the 450 m (1,500 ft)) in the lower part of the Pennsylvanian of the Appalachian basin commonly have been cited as evidence of deposition in beach or barrier-bar environments. The unidirectional southwest current bedding in these sandstones was explained as the result of southwestward migration of tidal channels across the northwest-facing coastline (Miller, 1974). The lack of marine fossils in the sandstones was explained by rapid leaching of calcareous material prior to lithification of the sand. The idea that the quartz arenites were marine in origin was attractive and difficult top refute, particularly as the arenites generally were given a regional or cratonic setting (Ferm, 1974). However, wherever detailed studies of these thick sandstones have been made, the inevitable conclusion was that they were deposits of braided streams (see references listed in Rice and Schwietering, 1988). Our first stop views one of these conglomeratic quartz arenites, the "Sharon" conglomerate: here Ketering summarizes the previous studies and gives his analysis of this fluvial deposit.

More recently, Englund and Thomas (1990; see also Cecil and Englund, 1985) have argued that the Lower Pennsylvanian quartz arenites were deposited in a high-energy tidal environment. They attribute the sandstone to deposition in an Appalachian seaway postulated to extend from the Atlantic area onto and across the central part of the area described in this guidebook. But most paleotectonic maps show that the Atlantic and epicontinental seas of the North American craton were separated by a positive orogenic belt during Pennsylvanian time (for example, Eardley, 1951). Because of differences in assemblages, the fauna of the Atlantic area is generally considered to be distinct from that of the epicontinental seas and therefore the two areas are considered to have been isolated from one another during the Carboniferous (Raymond et al., 1985). Fur thermore, the sequences of strata of Pottsville age examined on the field trip in the Jackson area of Ohio and in northeastern Kentucky show no evidence of any such geomorphic or sedimentary feature. On the contrary, with the exception of the "Sharon" conglomerate, most of the sedimentary sequences are low-energy deposits and are thin and laterally discontinuous. Our last stop will view a thick sequence of estuarine tidal rhythmites, the westernmost marine deposits in this Appalachian outcrop belt. The remarkable completeness of the tidal cycles over a period of many years suggests a rather benign tidal environment, at least during that part of the Pennsylvanian.

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STOP 1: BASAL PENNSYLVANIAN SANDSTONES AND CONGLOMERATES NORTH OF JACKSON, OHIO

by

Charles L. Ketering, Jr.

The basal strata of the Lower Pennsylvanian Pottsville Group in southeastern Ohio are supermature quartzose sandstones and conglomerates. Petrographically and stratigraphically these rocks resemble the Sharon conglomerate of northeastern Ohio and western Pennsylvania; thus, they have also been identified from the earliest investigations as Sharon conglomerate. However, this unit in southeastern Ohio is areally restricted and is not continuously traceable into the Sharon to the north. Therefore, the supermature quartz arenites and conglomerates of southeastern Ohio are here referred to as "Sharon" conglomerate.

In the area of Jackson, Ohio, the "Sharon" conglomerate unconformably overlies the Mississippian Logan Formation with a relief of as much as 90 m (300 ft). At Stop 1 the unconformity has a local relief of perhaps as much as 7 m (23 ft), and the "Sharon" conglomerate, which consists primarily of sandstone, appears to occupy deep gullies cut into the underlying Logan Formation. Just above the sandstone is the Sharon coal, here overlain by a brackish-water to marine shale. Crossbeds are commonly defined by small quartz pebbles and hematite concentrations. South of this location, the "Sharon" is thicker and dominantly conglomeratic where it accumulated in the low areas of the dissected Mississippian surface. These stratigraphic and petrographic characteristics can be traced into the subsurface (Ketering, 1984).

Petrology

The "Sharon" is a supermature, fine- to coarse-grained quartz arenite and conglomerate. On fresh surfaces the "Sharon" conglomerate is white, buff, or yellow, and weathers to a dull brown or orange. The for-mation contains varying amounts of iron oxides ranging from iron stain on individual grains to massive hematite bands (up to several centimeters thick); iron oxide concretions are very rare. The hematite bands are purple to red-brown. Cements may be either hematite or clay. Where clay is the dominant cement, the rock is very friable and readily disaggregates when rubbed between the fingers. Conversely, where hematite is dominant, the rock is very well indurated. Sand grains in the "Sharon" are subangular to subrounded with abraded quartz overgrowths (Weiss, 1951). Mineralogically, the "Sharon" is 96 to 99 percent quartz, with minor amounts of feldspar and heavy minerals, including zircon, tourmaline, rutile, magnetite, and ilmenite.

Two distinct lithofacies are recognizable within the "Sharon," an upper, predominantly sandstone, and a lower, mainly pebble conglomerate. The contact between the two is abrupt, and the upper facies contains only scattered quartz pebbles. The lower facies contains abundant, rounded quartz pebbles in a coarse sandstone matrix and generally grades laterally into coarse sandstone. Imbrication is rare because of pebble sphericity and roundness. Couchot (1972) analyzed the texture of the two lithologies from outcrops in Jackson County, Ohio. His findings for the upper facies (in Folk and Ward measures) show a range of graphic means from 0.125 mm (fine sand) to 0.39 mm (medium sand), with an average graphic mean of 0.205 mm (fine sand). Sorting ranges from 0.44 ϕ to 0.76 ϕ, with a mean of 0.64 ϕ (moderately well sorted). Couchot (1972) mapped these data and found that areas with well-sorted rocks are flanked by areas with poorer sorting. Average skewness is -0.2 (negatively skewed), indicating a statistical excess of coarse material, and kurtosis averages 1.5 (leptokurtic: less tail sorting).

Couchot (1972) also found that the sandstone matrix of the lower facies differs markedly from the sand size of the upper facies. For the matrix of the lower facies, the graphic mean averages 0.53 mm (coarse sand), with a range from 0.205 mm (fine sand) to 4.9 mm (pebble). Smaller values always flank larger values. Sorting ranges from 0.81 ϕ (moderately sorted) to 0.16 ϕ (very well sorted), with an average of 0.74 ϕ (moderately sorted). Areas of poorly sorted sediments always flank areas with better sorted material. Average skewness is -0.1 (negatively skewed; coarse in excess), and kurtosis averages 1.2 (leptokurtic: tails less sorted). Couchot noted that the two facies are similar petrographically, but very different texturally. All values, both averages and ranges, are smaller in the upper sandstone, and this difference is attributable to a decrease in transport ability and less channel confinement compared to the lower conglomerate (matrix).

Discussion

Previous researchers have consistently reported the presence of a Mississippian-Pennsylvanian disconformity at the base of the "Sharon" (Weiss, 1951; Jessup, 1951; Hyde, 1953; Fuller, 1955; Couchot, 1972; Short, 1978; Bebel, 1982). These same researchers repeatedly report a lithologic change from the lower, conglomerate facies to the upper, sandstone facies as the formation overlaps progressively higher topography. Pebbles are scarce and a slightly finer sandstone predominates in the upper facies.

In northwestern Jackson County, Weiss (1951), Hyde (1953), Couchot (1972), and Bebel (1982) documented the presence of a paleovalley system, filled by the conglomerates and sandstones of the "Sharon." Jessup (1951) documented the continuation of this valley into Pike County, Ohio. A paleotopographic high is indicated south of this area (Couchot, 1972, Fig. 9; Bebel, 1982, Fig. 15). The crest part of this paleotopographic high is exposed in Section 9 of Scioto Township about 9.6 km (6 mi) west-southwest of Jackson, Ohio (Fig. 1.1A). In this region, the upper members of the Lower Mississippian Logan Formation crop out and are surrounded by "Sharon" deposits to the north and south. South of this area at progressively lower elevations, the outcrops of "Sharon" become more conglomeratic. This paleohigh extends eastward into the subsurface and has been defined by water well logs in Lick Township about 4.8 km (3 mi) south-southwest of Jackson.

Couchot (1972) and Bebel (1982) have demonstrated the unimodal character of the paleocurrents of both facies within the "Sharon." In northwestern Jackson County, the mean direction has an azimuth of 281.5^0 (Bebel, 1982). Couchot's (1972, Figs. 10 and 11) findings are generally similar, but include some southwesterly trending paleocurrents in the northwestern part of the county and adjacent parts of Pike and Ross Counties to the west. Couchot also reported southwesterly trending paleocurrents in southern Jackson County.

All previous studies of the "Sharon," except that of Stout (1916), attribute it to deposition in a fluvial environment. Weiss (1951) concluded that the source was southeast of Jackson Township. Couchot (1972) interpreted the "Sharon" as the deposit of east to west aggrading streams. Bebel (1982) concluded that the "Sharon" was deposited by braided streams, followed by a meandering stream phase after loss of stream restriction. Data from the shallow subsurface area immediately east of the outcrop area are relatively poor. Data points are abundant but lack sufficient detail to clearly outline the geometry of the "Sharon." Most logs record a "sand rock" within the predicted "Sharon" interval. Isolated logs indicate the presence of a "silicic sandstone with gravel." The logs provide the best evidence available that the "Sharon" continues into the shallow subsurface with the same composition as in the outcrop.

The paleotopographic high in west-central Jackson County (Fig. 1.1A) divides the study area into the two regions of diverging paleocurrents seen in outcrop. This paleohigh

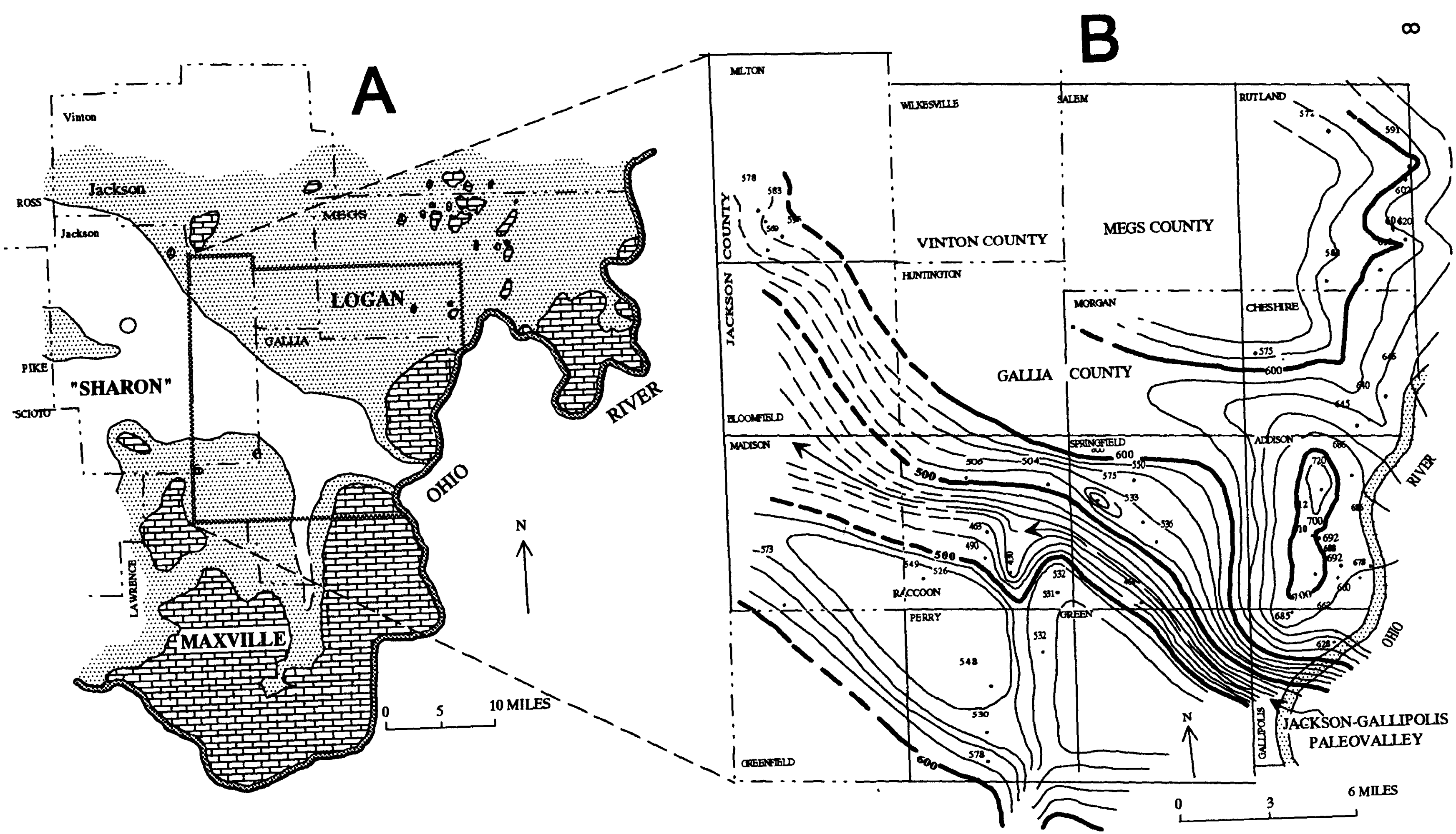

FIGURE 1.1. Maps showing (A) the subsurface geology after deposition of the "Sharon" conglomerate in Ohio and (B) the pre-Pennsylvanian surface in the eastern part of the study area by means of isopachs of the interval between the top of the Berea Sandstone and the base of the Pennsylvanian. Contour interval 20 ft (6 m). Circles are wells from which gamma-ray and neutron logs were collected. Sources of data are given in the text for Stop 1.

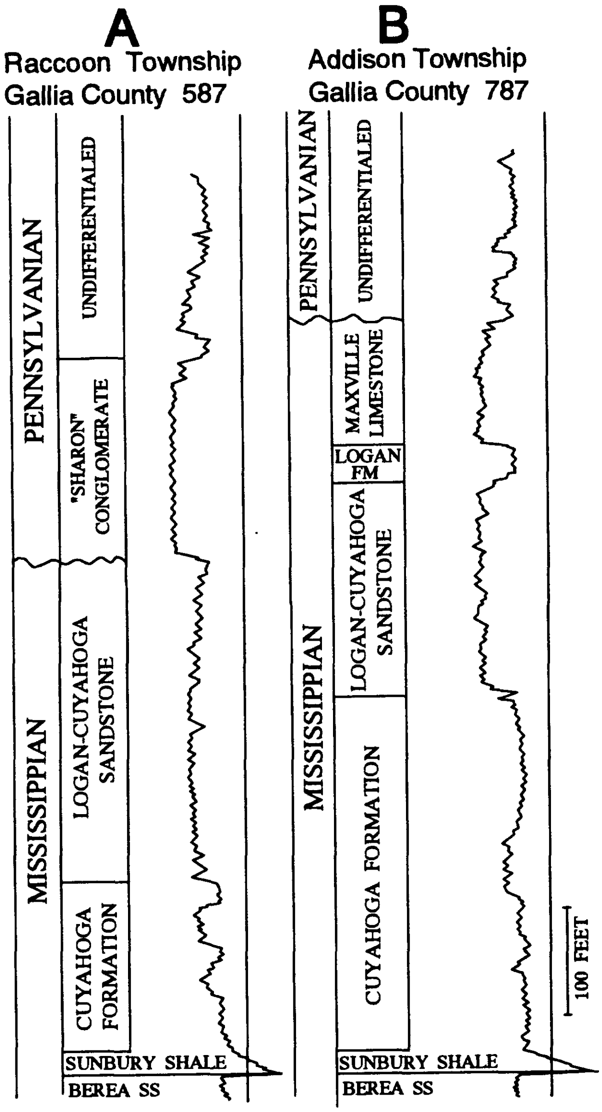

FIGURE 1.2. Comparison of gamma-ray logs from western (A) and eastern (B) parts of deep subsurface (see Fig. 1.1B). Note differences in elevation of systemic disconformity between the two logs. Gamma-ray intensity increases to the right.

is interpreted to be an erosional remnant within the paleovalley that diverted part of the flow to the southwest. Similar paleocurrent directions occur in Pike County (Couchot, 1972), indicating that northwest flow north of the paleohigh also eventually turns to the southwest. These paleocurrents appear to indicate that the northern flow rejoined the southwest-trending flow and continued into Scioto County, where south-trending paleocurrents occur (Stout, 1916; Short, 1978). These conclusions are in substantial agreement with conclusions of Rice (1984) and Rice and Schwietering (1988).

Figure 1.1A is a paleogeologic map illustrating the regional extent of the "Sharon" conglomerate in Ohio and the gross distribution of sub-Pennsylvanian Mississippian formations in the study area. Data from Ketering (1984) and from Uttley (1974) were used to locate the Logan-Maxville contact. The Logan-"Sharon" contact is generalized from previous studies (Couchot, 1972; Uttley, 1974), oil and gas well logs, and water well data. Of special interest are (1) the extension of a paleovalley (occupied by the Pennsylvanian "Sharon" conglomerate) into West Virginia and (2) a southern paleotributary within a reentrant in the Upper Mississippian Maxville Limestone (Greenbrier Limestone, in West Virginia). The limestone highland in eastern Ohio and western West Virginia corresponds to Rice's (1984) "carbonate cuesta," which supposedly influenced regional fluvial deposition during the Early Pennsylvanian. In Rutland Township and farther to the northwest, Uttley (1974) identified numerous limestone outliers that may have existed as highlands during the time of deposition of the "Sharon."

The paleogeography of the subsurface area has been reconstructed from available data, predominantly gamma-ray and neutron logs, which are unevenly distributed across the study area (see Fig. 1.1B). The most striking aspect of the data in northern Gallia County is the significant change in the character of geophysical logs from west to east. In the western part of the area, drill log data suggest that quartz-rich "Sharon" deposits occur above undifferentiated Mississippian (Logan and Cuyahoga) sandstones. In the eastern part of the area, however, Maxville Limestone occurs directly above the Logan Formation, and no trace of the typical "Sharon" gamma-ray signature is found in the geophysical logs. Figure 1.2 illustrates the difficulty of identifying the rock units between widely spaced gamma-

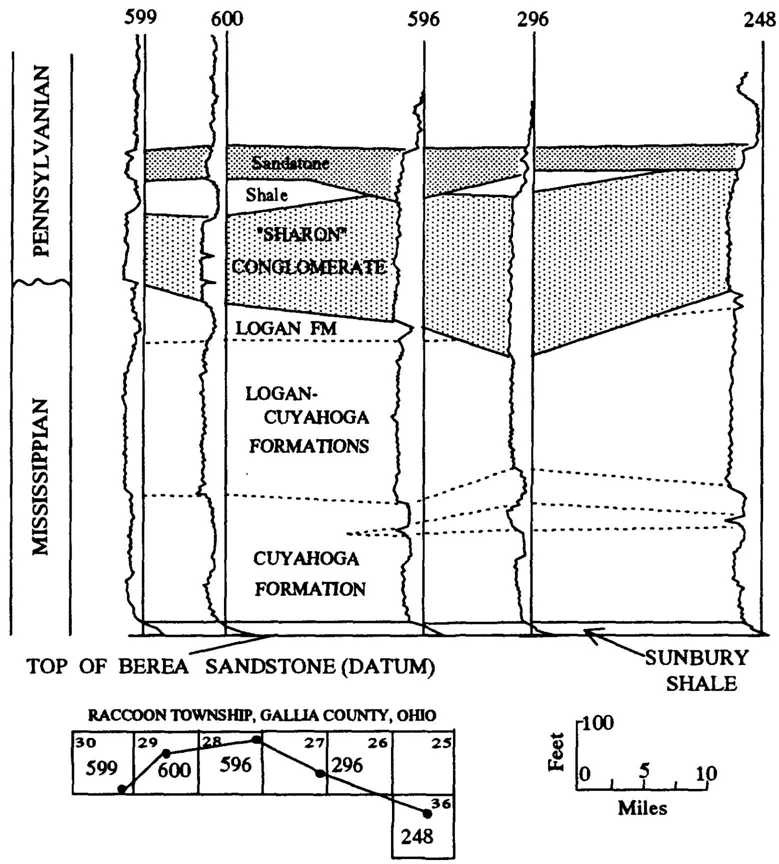

FIGURE 1.3. Cross section across Raccoon Township, Gallia County. "Sharon" conglomerate thickness increases from Section 30 to Section 27, then decreases southeastward to Section 36. Note anomalous "Sharon" thickness in well 596 caused by amalgamated sand bodies.

ray logs. Figure 1.2A shows a gamma-ray log from Raccoon Township (Gallia County), where the "Sharon" abruptly overlies a sandstone with a slightly higher response (intensity increases to the right), which, in turn, overlies the thick (undifferentiated) Logan/ Cuyahoga sandstone sequence. Figure 1.2B shows a gamma-ray log from Addison Township (Gallia County) where the Maxville Limestone and the upper part of the Logan Formation occupy the same stratigraphic position as the "Sharon" in Figure 1.2A. The Maxville is overlain by thin Pennsylvanian sandstones and shales of varying gamma-ray responses. Figure 1.3 is a section that intersects a north-trending tributary to a paleovalley, here designated the Jackson-Gallipolis paleovalley (see Fig. 1.1). The section crosses the southern part of Raccoon Township and shows the correlation of Mississippian and Pennsylvanian subsurface units in the western part of Gallia County. The "Sharon" is progressively thicker eastward of well 599, and eventually cuts through the underlying unit until it rests directly on the Logan/Cuyahoga sequence shown in well 296. Farther east, the "Sharon" again decreases in thickness as the eastern side of the tributary is reached.

Figure 1.1B depicts the sub-Pennsylvanian surface in the eastern part of the study area by contouring the stratigraphic interval between the top of the Berea Sandstone and the base of the Pennsylvanian. The paleotopographic map is dominated by a long, linear valley, the Jackson-Gallipolis paleovalley, in which the lower Pennsylvanian sediments accumulated. Local relief is about 80 m (260 ft), slightly less than that of the outcrop belt to the west. South of the valley, the surface is a broad, low bench. A tributary stream valley is also inferred as extending toward the south, based on (1) the presence of relatively thick "Sharon" deposits in this region, (2) the odd distribution of contours in the core of the valley (Raccoon Township), and (3) the presence of a reentrant in the Maxville Limestone in southern Gallia County (Uttley, 1974).

The Jackson-Gallipolis paleovalley is inferred to extend into West Virginia through Gallipolis Township because drillers' logs in Green and Gallipolis Townships indicate the presence of thick sandstones in the projected "Sharon" interval. In West Virginia, Flowers (1956) indicated an erosional valley in the Greenbrier Limestone (Maxville Limestone of Ohio) that connects with the Jackson-Gallipolis paleovalley. Those valleys, which also contain Pottsville sandstone and conglomerate (Flowers, 1956), were formed during pre-Pennsylvanian erosion that removed the Mauch Chunk Formation from much of western West Virginia.

The eastern part of the paleotopographic map (Fig. 1.1B) is dominated by Maxville and Logan highlands. Maxville Limestone caps the hills and shows an irregular, eroded surface. The Logan Formation, and rarely the upper part of the Logan/Cuyahoga Sandstone, forms the paleovalley walls. North of the Jackson-Gallipolis paleovalley, a broad, low, positive paleofeature composed largely of Logan strata is inferred about 185 m (600 ft) above datum. Cross sections constructed with gamma-ray well logs along the entire boundary between typical "Sharon" and this highland show a distinct and rapid thinning of the "Sharon" northward from the paleovalley.

The paleogeographic relationships identified by Ketering (1984) agree with the regional paleodrainage patterns documented by Rice and Schwietering (1988, Fig. 1). Streams brought "Sharon" sediments into the area, and additional material was transported by a tributary stream from southern Gallia County into the Jackson-Gallipolis paleovalley. As the streams flowed to the northwest, the valley widened and was split by a Logan highland in western Jackson County. Paleocurrent data indicate that the streams flowed around the hill and were diverted to the south (Stout, 1916; Couchot, 1972; Short, 1978; Bebel, 1982). The Waverly Arch may have been responsible for diverting the streams to the south (Michael Hansen, Clark Scheerens, oral communications, 1984; see also Uttley, 1974). The streams continued south through Scioto County (Stout, 1916; Short, 1978), and into Kentucky (Rice, 1984; Rice and Schwietering, 1988).

Early in the depositional history of the "Sharon," sedimentation was restricted to the deepest part of the valley. As these valleys lows filled with coarse sediment, stream restriction decreased, the flows spread laterally and lost competence, and the streams changed from a braided to a meandering habit (Couchot, 1972; Bebel, 1982). This resulted in changes in both deposition (from conglomerates to sandstones) and facies (from areally restricted to laterally extensive).

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STOP 2: BASAL PENNSYLVANIAN STRATA NEAR JACKSON, OHIO

by
Ronald L. Martino, Charles L. Rice, and Ernie R. Slucher

(See Index Map and Fig. 2.1 for location.)

Section M1

A regional unconformity is present near the base of this outcrop (Fig. 2.2) separating the "Sharon" conglomerate (Early Pennsylvanian) from the underlying Logan Formation (Early Mississippian). Here the Logan consists of greenish-gray, very fine grained sandstone and mud rocks. Parallel lamination and hummocky cross-stratification occur within the sand units, and trace fossils of the deposit feeders *Scalarituba* and *Helminthopsis* are common. Similar facies characteristics are found in the Cowbell Member of the Borden Formation (Logan equivalent) in northeastern Kentucky and are consistent with a delta front depositional setting (Chaplin, 1980).

The "Sharon" conglomerate is a fluvial channel fill containing fine- to coarse-grained quartz arenite and quartz pebble conglomerate in the lower 1 m (3.3 ft). Small- to large-scale crossbeds indicate a paleocurrent toward the northwest (332° average). Numerous pebble-lined scour surfaces and internal sedimentary structures suggest flashy discharge that is consistent with the braided river interpretation suggested by previous workers (see Ketering, this volume).

The Sharon coal zone contains three bony coal to carbonaceous shale beds 15-40 cm (6-16 in.) thick separated by very fine grained sandstone and shale with root traces. The Sharon coal has been mined about 1.6 km (1 mi) south of this location.

The Sharon coal zone is overlain by interbedded thin dark-gray shale and siderite. Anemone resting burrows (*Conostichus*) and *Lingula* occur at the base of this brackish to marine coastal bay facies, which apparently drowned the Sharon coastal swamp. The regular spacing of siderite beds suggests periodic influx of freshwater into saline water that may correspond to seasonal increases in freshwater runoff.

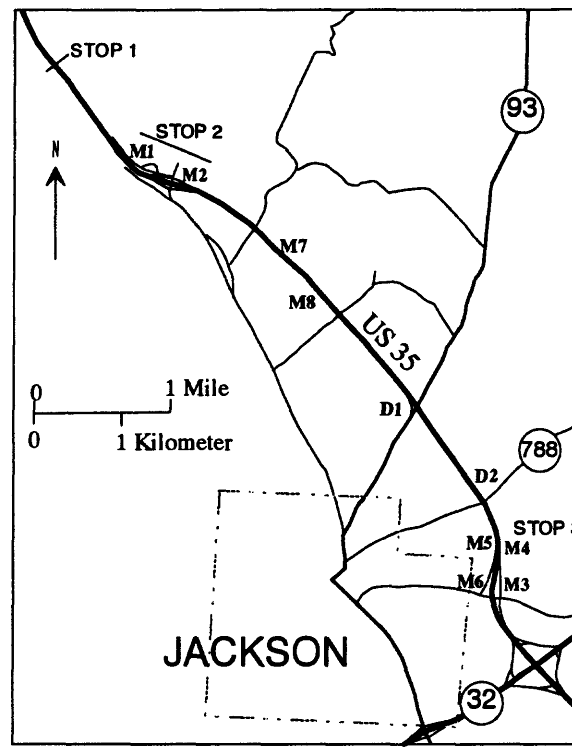
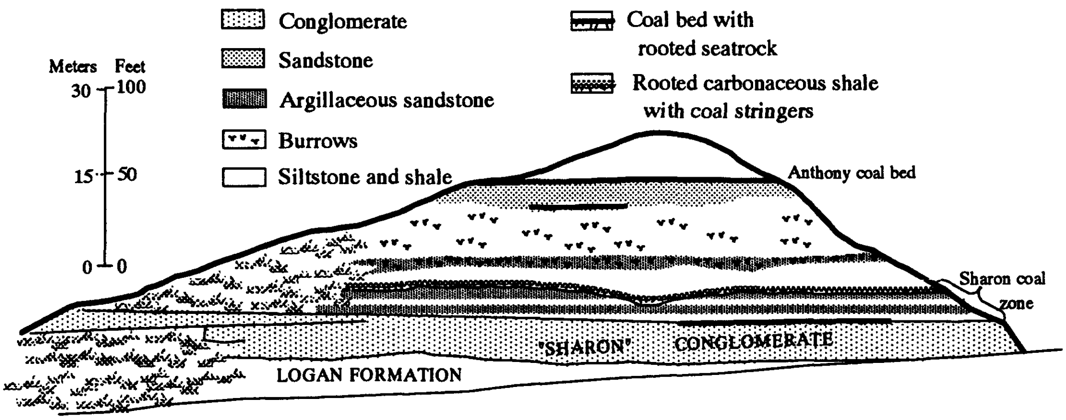


FIGURE 2.1. Index map showing field trip stops on U.S. Highway 35 in vicinity of Jackson, Ohio. Sections M1 through M8 are described in text and were measured by Martino. Sections D1 and D2 were measured and are described in text by Dominic.

The bay shales are truncated by about 10 m (33 ft) of burrowed, very fine grained sandstone and shale. Quartz pebbles 1-2 cm (3/8-3/4 in.) in diameter are present in the lower 10 cm (4 in.) of this unit. Siderite-cemented burrows and nodules are common. Burrows of deposit feeders are abundant including *Teichichnus*, *Phycodes*, *Asterosoma*, and *Planolites*. Lenticular and wavy ripple bedding is locally preserved. This facies is interpreted as a tidally influenced (estuarine?) channel fill. Similar estuarine channel-fill facies have been described from the Breathitt Formation of eastern Kentucky by Greb and Chesnut (1992) and Martino and Sanderson (in press).

STOP 2



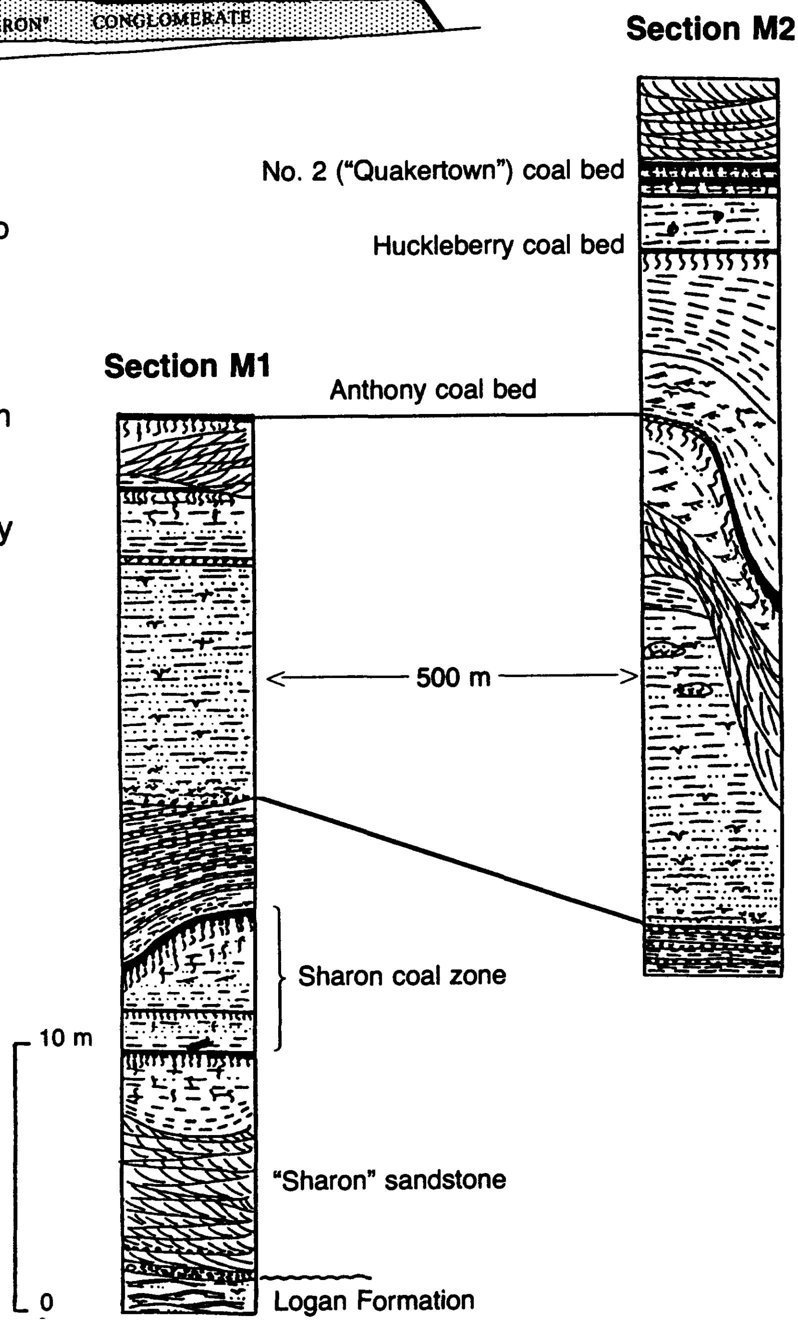


FIGURE 2.2. Diagram showing the lithologic relations of the major outcrop at Stop 2, just northeast of U.S. Highway 35 on a small parallel road (see Fig. 2.1); detailed depictions of lithology are shown in section M1 and are described in the text. About 500 m (1650 ft) southeast of section M1 and just east of the overpass, section M2 combines the outcrop on U.S. Highway 35 with the outcrop along the northbound exit ramp of U.S. Highway 35.

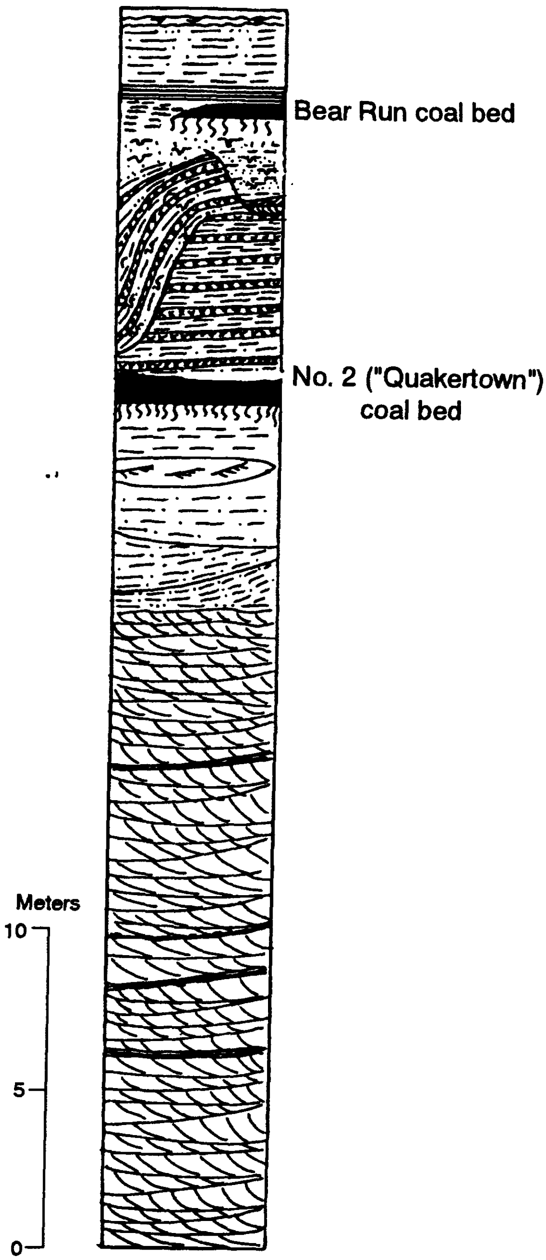


FIGURE 2.3. Composite of sections M7 and M8 (see Fig. 2.1 for locations) showing thin-bedded very fine grained sandstone-shale tidal channel facies overlying the No. 2 coal bed. Tidal channel fills are sideritic and burrowed, and some beds contain brachiopods.

The Anthony is the upper of two coal beds at the top of this cut; the Sciotoville clay, which commonly underlies the Anthony coal, is absent. The two coal beds, 10-12 cm (4-5 in.) thick, are separated by as much as 2.5 m (8.2 ft) of compound cross-stratified quartz arenite (indicating flow to the northwest).

Section M2 (see Figs. 2.1 and 2.2)

The lower part of section M2 is exposed beneath and north of the overpass (about 500 m (1650 ft) southeast of M1) and contains coastal bay shale and burrowed estuarine channel-fill facies between the Sharon and Anthony coal zones. These facies are partially truncated south of the overpass by a large channel-fill complex. The Sciotoville clay is a light-gray flint clay where it underlies the Anthony just east of and at about road level with the overpass. Where the Anthony coal passes under U.S. Highway 35 east of the overpass (and east of a small fault), the Sciotoville flint clay is almost black and ranges from 0.5 to 1 m (1.6-3.3 ft) in thickness. Along the northbound exit ramp and north of the overpass, the Anthony coal is partly or entirely truncated beneath a transgressive sideritic lag containing coal and underclay rip-ups. The lag is overlain by 2.7 m (8.9 ft) of dark-gray, sandy, sideritic shale that grades up into interlaminated very fine grained sandstone and shale. Burrows are common including *Curvolithus*, *Teichichnus*, *Planolites*, and *?Helminthopsis*. Lenticular ripple bedding and ripple cross-lamination are common. A restricted, marginal marine setting is suggested. The trace fossils are comparable to those found in similar facies in the Middle Pennsylvanian Kanawha Formation of West Virginia (Martino, 1989).

This marine-influenced sequence is overlain by mudrocks, carbonaceous shale, the thin Huckleberry coal, and the No. 2 ("Quakertown") coal zone. This sequence is exposed along the northbound exit ramp where it is offset by a normal fault (or possibly a paleoslump). Two coal beds 30 cm (12 in.) thick are separated by root-mottled sandstone. The No. 2 coal zone is capped by a cross-stratified, fluvial channel-fill sandstone at the top of the cut.

Toward the southeast (M7 and M8, Fig. 2.1) along U.S. Highway 35, the No. 2 coal zone is represented by a single bed of bright to semibright, blocky coal as much as 1 m (3.3 ft) thick. As Figure 2.3 shows, the No. 2 coal is underlain by a crossbedded, multistory channel-fill sandstone facies as much as 23 m (75 ft) thick. Tidal channel fills occur above the No. 2 coal at M7 and have locally truncated the coal bed about 4 km (2.5 mi) to the southeast at Stop 3. At M7, the tidal-channel facies is as much as 4.3 m (14 ft) thick and is filled by thin-bedded, very fine sandstone and silty shale that is sideritic and burrowed and has productid brachiopods in some beds. The bedding is inclined as much as 11° degrees; the inclination may have been produced by lateral accretion of a tidal creek point bar.

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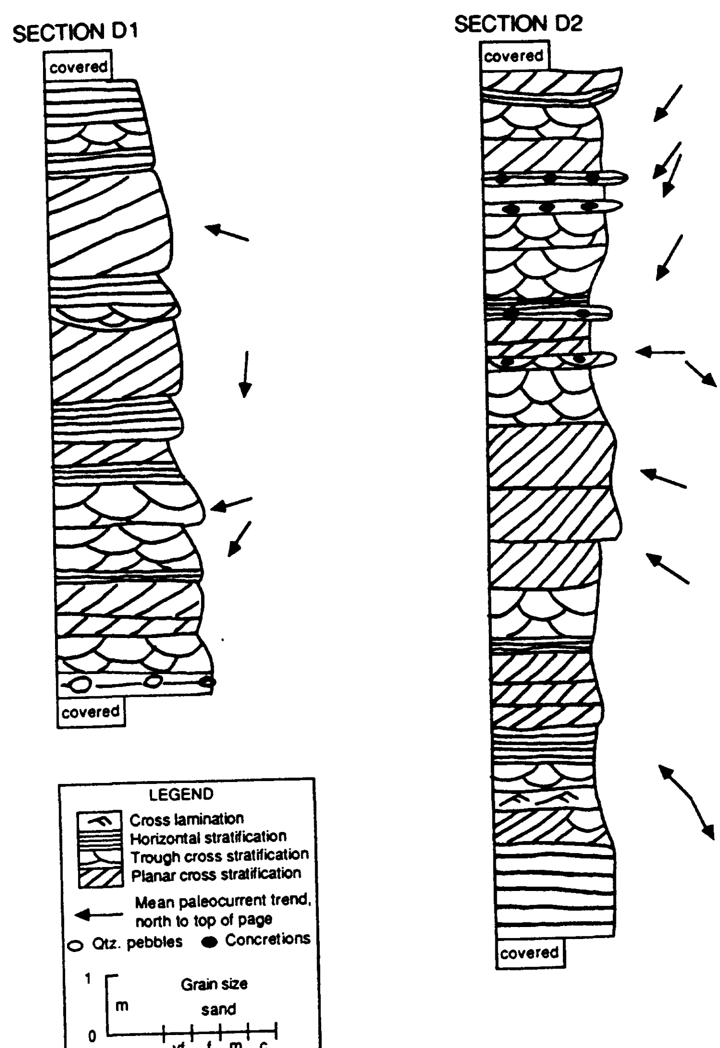

FIGURE 2.4. Examples of detailed sedimentologic logs from sandstone outcrops at Ohio Route 93 (D1) and Ohio Route 788 (D2) on U.S. Highway 35. Location of log D1 is shown on Figure 2.5.

FACIES ARCHITECTURE OF SANDSTONES BELOW THE NO. 2 COAL BED BETWEEN STOPS 2 AND 3, JACKSON COUNTY, OHIO

by
David F. Dominic

This study describes and interprets the internal geometry of sandstones below the No. 2 ("Quakertown") coal bed in the laterally extensive new exposures along U.S. Highway 35 near Jackson, Ohio. Weathering of these rocks brings out the detailed bedding so that individual beds and bedsets, each composed of one or more facies, can be identified and traced within the sandstone bodies. The preservation of these bedding features and their bounding discontinuities reveals the style of deposition and details of their environmental setting.

The two sandstone exposures described here underlie the No. 2 ("Quakertown") coal. The first exposure (D1) is adjacent to the exit ramp from the eastbound lane of U.S. Highway 35 at Ohio Route 93 (see Fig. 2.1). Here the sandstone is approximately 10 m (30 ft) thick, overlies a gray silty shale, and is interbedded in its upper meter (3 ft) with a dark-gray, thinly bedded siltstone and carbonaceous shale. The second exposure (D2) is adjacent to the westbound lane of U.S. Highway 35 at the overpass of Ohio Route 788, approximately 1 km (0.6 mi) southeast of the first exposure. The base of the sandstone at D2 is not exposed, but its upper meter is similarly interbedded with dark-gray siltstone and shale. Both sandstone bodies occur at the same stratigraphic level and are treated as the same unit although there is a lack of continuity between the two exposures.

Methods of study

Detailed sedimentologic measurements were made in accessible vertical sections. From these, lateral variations in lithofacies, grain size, and paleocurrents were mapped on photomosaics of the outcrops. Particular attention was given to the minor erosion surfaces separating lithofacies bedsets. These surfaces, bounding architectural elements (Allen, 1983; Miall, 1985), were delineated on line-drawing overlays of the photomosaics. Representative detailed sedimentologic logs are shown in Figure 2.4; portions of the line-drawing overlays are shown for section D1 in Figure 2.5. In describing the lithofacies and architecture of these sandstones, I use the lithofacies classification scheme of Miall (1978), a hierarchy of bounding surfaces from Miall (1988), and the architectural element classification scheme of Miall (1985).

Description

The silty shale that underlies the first sandstone body at D1 differs from the siltstones of the Mississippian Logan Formation, exposed elsewhere in the area, in its darker color, absence of *Scalarituba* trace fossils, and presence of red (ironstone) nodules and macerated organic debris. This sandstone is not, therefore, the basal Pennsylvanian "Sharon" even though it contains scattered quartz pebbles throughout its lower 2-3 m (6.6-10 ft).

The sandstone fines upwards, from medium-grained sandstone containing rounded quartz pebbles to medium- and fine-grained sandstone. More distinct changes in grain size are seen across minor erosion surfaces, upon which a lag can sometimes be found. Such lags include quartz pebbles, coalified plant fragments (coal spars), and red lithoclasts or nodules. These minor erosion surfaces are the third-order bounding surfaces defined by Miall (1988). One set of third-order surfaces with consistent ~10° dips define lateral accretion bedding that is about 3 m (10 ft) thick. Most third-order surfaces, however, are more nearly horizontal with less than 2 m (6.6 ft) of relief. They can be traced laterally for as much as 100 m (330 ft) and locally merge to create

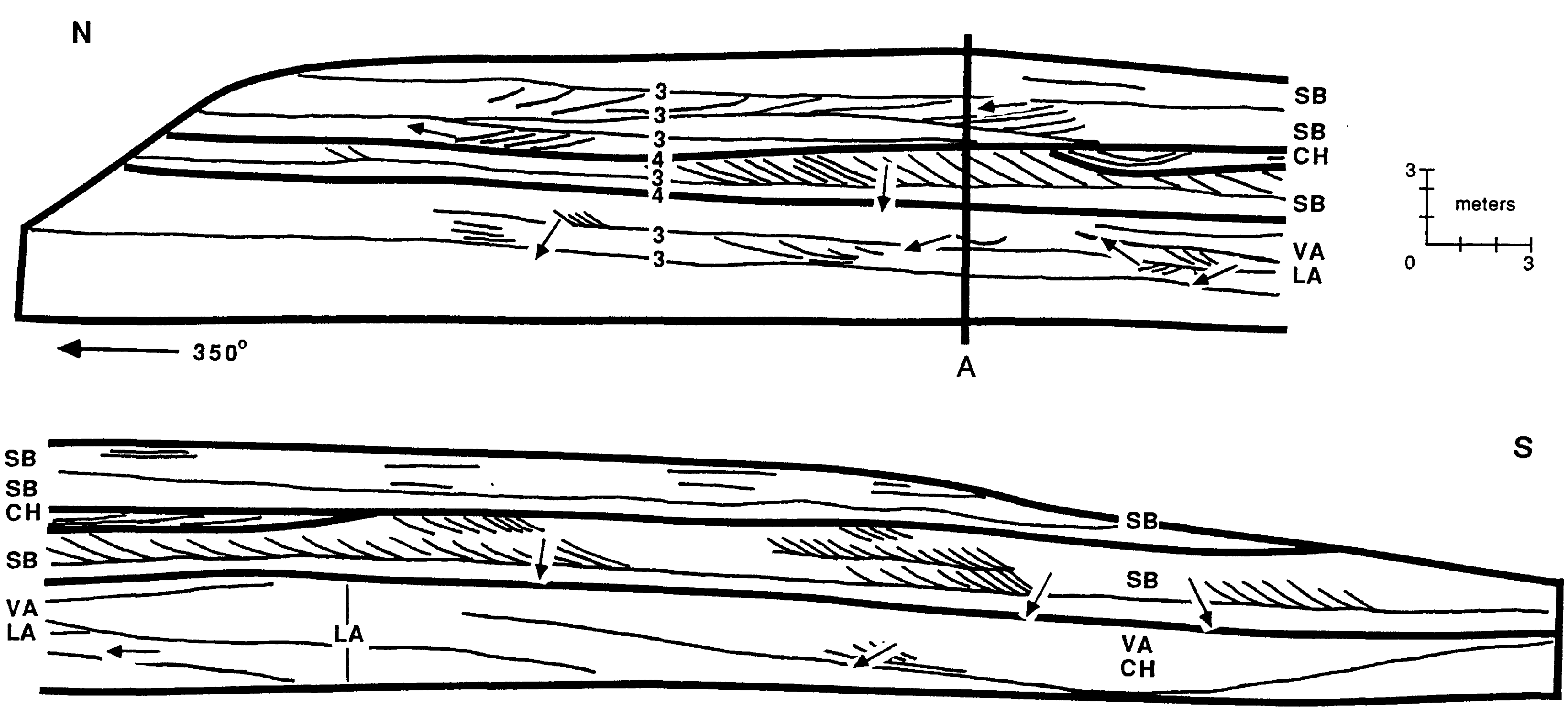

FIGURE 2.5. Line drawing of photomosaic from outcrop D1 at Ohio Route 93 on U.S. Highway 35. Heavy lines show fourth-order bounding surfaces (4) separating sandstone storeys; lighter lines mark third order bounding surfaces (3) within storeys and prominent first- and second-order surfaces within bedforms. Also shown are lateral accretion (LA), vertical accretion (VA), sandy bedforms (SB), and channel (CH) architectural elements. Arrows show local paleocurrent trend (north to top of page). Location of detailed sedimentologic log (Fig. 2.4) shown by vertical line (A).

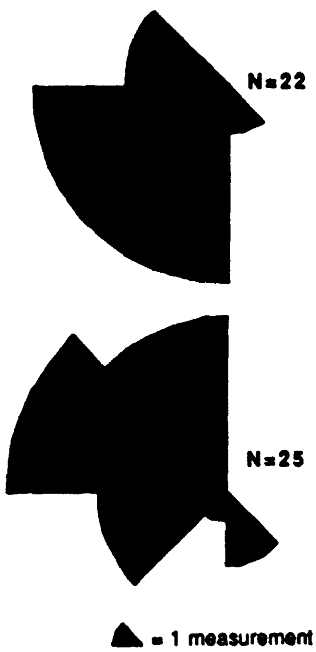

FIGURE 2.6. Current rose diagram for sandstone outcrops at D1, Ohio Route 93 (top) and D2, Ohio Route 788 (bottom) On U.S. Highway 35.

fourth-order bounding surfaces that separate the sandstone into storeys with differing paleoflow directions.

Bedsets between third-order bounding surfaces are dominated by large-scale planar cross-stratification (Sp) in sets that range from decimeters to meters (yards) in thickness. Large-scale trough cross-stratification (St) also occurs but is much less common. Where present, trough sets are generally 20-50 cm (8-20 in.) thick and most troughs are 1-3 m (3-10 ft) wide. Other common sedimentary structures include horizontal stratification (Sh) and small-scale trough cross-stratification (Sr).

Paleocurrents were measured from the large-scale cross stratification throughout the outcrops. As shown on Figure 2.4 and on the summary rose diagram of Figure 2.6, westerly paleocurrents predominate. The paleoflow direction of adjacent storeys generally differs by less than 45°. Within storeys, however, the paleoflow direction of St sets occasionally diverges from that of the Sp sets into which

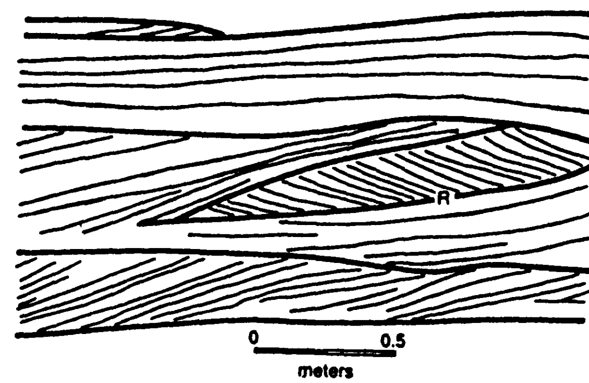

FIGURE 2.7. Bedding and sedimentary structures in sandstone. Note large-scale cross stratification climbing a discontiuity (reactivation) surface (R) in a larger set of cross stratification. Current directions for these two sets diverge by 170° . Drawing was made from a field photograph.

they are cut by as much as 90°. In several places, reactivation surfaces within planar foresets are associated with large-scale cross-stratification climbing in the opposite direction. One such example is shown in Figure 2.7.

Interpretation

The single set of dipping third-order bounding surfaces defines the only example of lateral accretion. This lateral accretion can be traced to a channel filled with coarse- to medium-grained sandstone and is interpreted to have formed by deposition on a side-attached bar in a laterally migrating channel. Because the associated elements are sandy bedforms in laterally extensive sheets, a deep channel within a multi-channel stream seems more likely than a curved, single-channel (meandering) stream. Bridge et al. (1986) and Bridge and Gabel (1992) have described such channels in the multi-channel Calamus River in Nebraska. The coarse nature of the associated channel fill suggests low sinuosity with gradual rather than abrupt channel abandonment (Bridge, 1985).

The large sets of planar cross-stratification are interpreted to represent isolated dunes or downstream-migrating bars. The fourth-order bounding surfaces do not appear to define downstream accreting macroforms (Miall, 1988) and are thought to separate episodes of deposition on sandy bedform sheets.

The unimodal paleocurrent directions suggest fluvial deposition, and the low divergence between storeys also suggests low sinuosity. The 90° to 180° divergence of paleocurrents within bedsets, together with the presence of discontinuity surfaces, suggests fairly rapid fluctuations of flow stage. Although such fluctuations could be attributed to runoff variations in a strictly fluvial setting, they could also result from tidal influence in an estuarine system. The absence of mud drapes and tidal bundles suggests that any tidally influenced deposition occurred no further downstream than the tidal-fluvial transition of the inner estuary.

Conclusions

Although unimodal northwesterly paleoflow directions predominate, a few prominent composite sets of large-scale cross-stratification show a divergence of 90° to nearly 180°, suggesting rapid fluctuations in flow strength and direction. Lateral accretion bedding is restricted to one 3-m-thick (10-ft-thick) set, suggesting that deposition was not the result of point-bar deposition in curved, single-channel (meandering) streams. The predominance of bedsets composed of planar cross-stratification separated by laterally extensive minor erosion surfaces suggests deposition in low-sinuosity, multi-channel streams.

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STOP 3: SECTION ABOVE NO. 2 COAL BED NEAR JACKSON, OHIO, IN MEASURED SECTIONS M3, M4, M5, AND M6

by
Ronald L. Martino, Charles L. Rice, and Ernie R. Slucher

(See Index Map and Fig. 2.1 for location.)

Roadcuts along U.S. Highway 35 at Ohio Route 788 (Fig. 2.1) provide an excellent three-dimensional view of lithofacies beginning just below the No. 2 coal and ending at the No. 3 or Lower Mercer coal. The lowermost 14 m (46 ft) of the section is exposed along the south-bound exit ramp (M6). It is composed of interlaminated to thin-bedded, very fine grained sandstone and shale representing an estuarine channel fill. Bedding is inclined as much as 13° (epsilon cross-bedding; composite section, Fig. 3.1) toward the northwest (320°). Ripple cross-lamination indicates flow toward the southwest (230°). Toward the north end of the exit ramp, the epsilon cross-strata grade laterally into a thin-bedded sideritic shale plug that is indicative of channel abandonment. Close examination of the epsilon cross-strata shows alternating sand-dominated and mud-dominated intervals; these include centimeter-scale bundles of clay-draped sand and silt laminations. These bundles resemble those described from tidal rhythmite facies from the Pennsylvanian of Indiana (Fishbaugh et al., 1989) and Alabama (Demko, 1990). One difference is that the deposits along the exit ramp are associated with lateral accretion rather than vertical accretion deposits. Similar tidal bedding within mud-filled estuarine channel facies occurs in Cretaceous strata of Alberta, Canada (Rahmani, 1988).

The northbound entrance ramp to U.S. Highway 35 cuts through the shale-filled portion of the estuarine channel. At the north end of these exposures (M4, Fig. 2.1; 3.1), the estuarine channel fill is capped by seat earth and bright to semibright blocky coal as much as 15 cm (6 in.) thick (No. 2 coal zone or its equivalent). Detailed work has revealed that several coals occur locally at this level and occupy separate swale fills which are truncated by subsequent tidal channeling. Tidal channel facies, which are interbedded with and overlie the coals, consist of crude, thin-bedded, sideritic, very fine grained sandstone with carbonaceous mud partings. These deposits are extensively burrowed and productid brachiopods are present locally (M5, Fig. 2.1; 3.1).

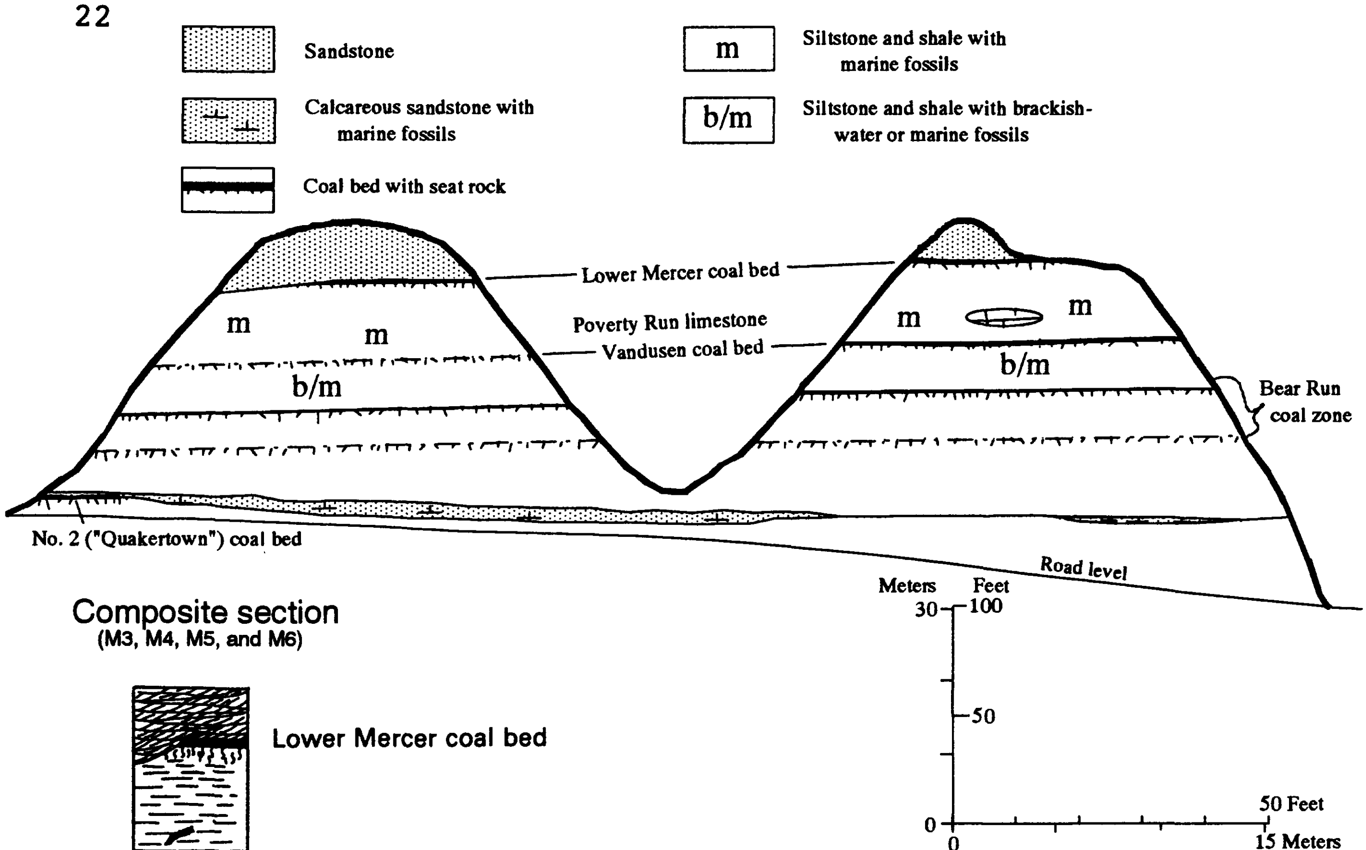
At the north end of the southbound exit ramp, the No. 2 coal is overlain by 1.1 m (3.6 ft) of tidal creek sandstone that grades up into shale containing micritic limestone nodules. The shale also contains a sparse marine fauna including orbiculoid and calcareous brachiopods, bivalves, and gastropods. This unit is truncated toward the south along the exit ramp by another tidal creek deposit whose base is rooted.

The interval between the No. 2 and Bear Run coal zones is occupied by dark-gray, silty shale containing siderite nodules. Coarsening occurs upward in this interval, and the unit becomes a ripple cross-laminated and micro-hummocky cross-laminated sandstone at the top. The interval is sparsely burrowed and contains *Helminthopsis*. These features suggest deposition in a restricted coastal bay with shoaling at the top.

The Bear Run coal zone overlies a light-gray seat earth as much as 1.2 m (4 ft) thick. It consists of an 85-cm-thick (33-in.-thick) carbonaceous shale/bone coal and a 10-cm-thick (4-in.-thick) coal separated by horizontally laminated sandstone and shale.

The Bear Run and Vandusen coal zones are separated by brackish-water siltstone and shale containing *Lingula* and rare bivalves. The Vandusen coal is as much as 25 cm (10 in.) thick and overlies a 1.8-m-thick (5.9-ft-thick) paleosol with red and gray mottling in the lower part.

STOP 3 (east side U.S. Highway 35 at Jackson, Ohio)



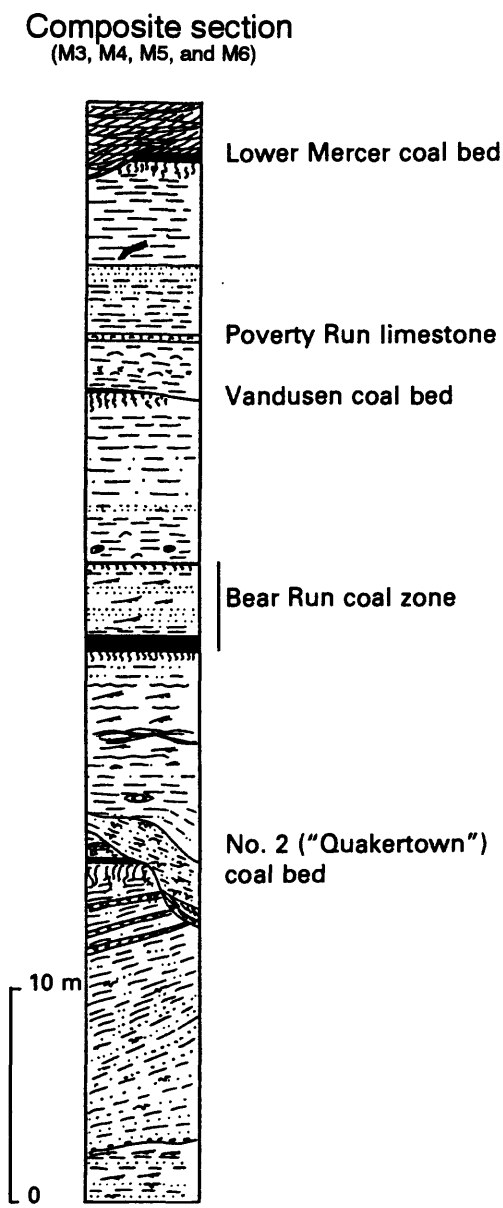


FIGURE 3.1. Diagram showing the stratigraphic relations of coal beds, brackish-water, and marine shales on the east side of U.S. Highway 35 at Jackson, Ohio. Detailed lithologic column is a composite of measured sections M3, M4, M5, and M6 (see Fig. 2.1 for locations). See text for lithologic descriptions. North is to the left.

The Vandusen coal is truncated by the base of the Lowellville/Poverty Run marine unit. This unit is mostly dark-gray shale with a 23-cm-thick (9-in.-thick) bed of biomicrite in the lower part. Marine invertebrates are abundant and include chonetid brachiopods, crinoid stems, bivalves, and gastropods. The marine unit coarsens upward into very fine grained sandstone that is capped by shale containing plant fossils. A seat earth and 30-cm-thick (12-in.-thick) coal (Lower Mercer) overlie the plant-bearing shales. The Lower Mercer coal is overlain and locally truncated by crossbedded channel-fill sandstone that caps the hilltop in the cuts northeast and east of the interchange of U.S. Highway 35 and Ohio Route 788.

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STOP 4: LOWER PART OF THE ALLEGHENY GROUP, SOUTHEASTERN OHIO

by
Charles L. Rice

In recent years, much of the coal mining in south-central Ohio has been concentrated in the lower part of the Allegheny Group as defined in Ohio. Most, if not all, of this mining has been by strip mines along the outcrop belt. Modern earth-moving equipment and coal cleaning plants have allowed efficient strip mining of the Allegheny coal deposits, many of which previously may have been considered too thin or too costly for underground mining. Mining in the area east of Jackson, Ohio, includes as many as six coal beds in a single strip pit. From oldest to youngest, these are the No 4 (Newland), Ogan, Winters, No. 4A, No. 5, and No. 6 coal beds. The base of the No. 4 coal, commonly misidentified as the "Brookville" coal in Ohio, is the nominal base of the Allegheny (see Fig. 4.1). In the Jackson area, particularly south of U.S. Highway 50, the Allegheny section contains a limestone bed as much as 3 m (10 ft) thick. It was called the Ferriferous limestone in the early part of this century because of an overlying bed of iron ore. The limestone has also been called "Vanport" or "southern Vanport" because of the uncertainty of its correlation with the limestone of that name in central and northern Ohio and the type area near Vanport, Pennsylvania. The limestone has been renamed the Obryan Limestone Member of the Breathitt Formation (Rice et al., in press), which is the name used in this report. The Obryan limestone is used as road metal and aggregate. Because of its high quality, the limestone may be used in fluidized-bed furnaces being developed to reduce sulfur dioxide emissions of coal-burning powerplants.

This part of the Allegheny section also contains sequences of commercial ceramic shale and clay beds such as the Lawrence and Oak Hill flint clay beds, associated plastic clay beds, and the underclays of the No. 4A and No. 5 coal beds. Ceramic companies test and identify clay units useful for their purposes. These are then segregated during mining of the coal beds and are stored in large loaf-like mounds (on the order of 50 by 15 m (164 by 50 ft)) until needed.

The Lawrence and Oak Hill flint clay beds, as much as 0.7 and 0.9 m (2.3 and 3 ft) thick, respectively (Stout, 1916; Stout et al., 1931), are composed largely of well-crystallized kaolinite. They also commonly contain a small percentage of fine to very fine grained mineral crystals of mostly quartz. In some localities, as much as 75 percent of the accessory mineral grains of these flint clays are igneous in origin, consisting of phenocrysts of beta-form quartz, feldspar, biotite, and zircon. About 10 percent of the igneous grains are euhedral. The occurrence of those minerals in the relatively thin but wide-spread deposits suggests that the flint clays represent altered volcanic ash falls. However, other mineral grains, which appear to be detrital (Rice et al., in press), locally are so abundant as to mask the occurrence of the volcanic minerals. This suggests that these deposits have been reworked and contaminated by detrital grains from other sources.

Although flint clay is mostly light gray to very light gray, the Lawrence clay bed is commonly dark colored, and is generally a semi-flint clay in southern Ohio. Similar thin beds of flint clay occur locally in the shales and underclays above and below the No. 5 and Lawrence coal beds, as well as in partings within those coal beds (Dobrovolny et al., 1963; Carlson, 1965). These deposits probably represent several relatively closely spaced (time wise) volcanic eruptions from sources probably along the eastern margin of the continent. Although the deposits are discontinuous and in many places are channeled

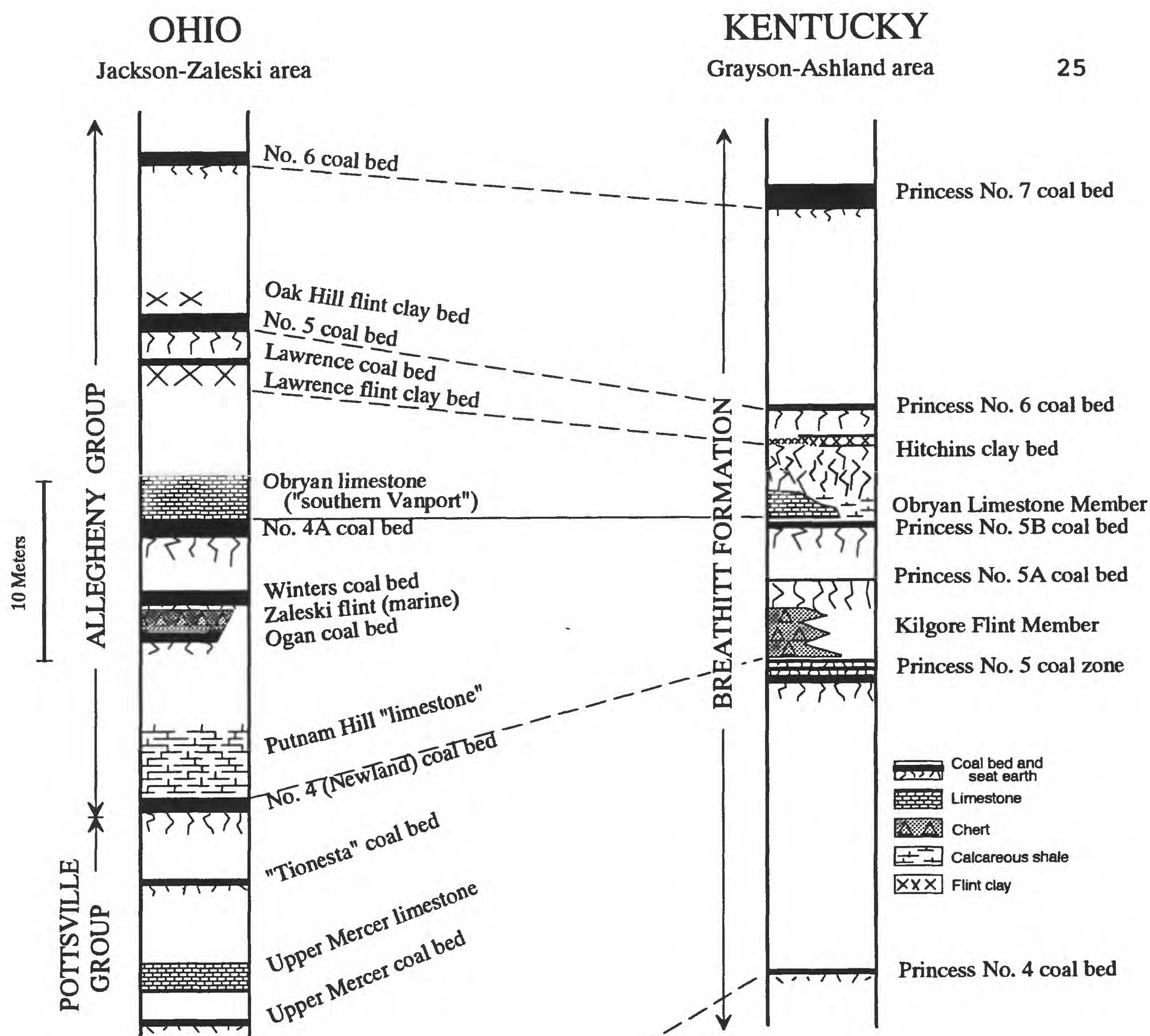

FIGURE 4.1. A comparison of Middle Pennsylvanian stratigraphic sections showing the correlation of coal beds and marine units from south-central Ohio to northeastern Kentucky. Intervals showing no lithologic pattern represent largely siltstone and shale with some thick but discontinuous sandstones.

and replaced by sandstones and shales, they appear to be traceable across large areas of the central Appalachian basin in Pennsylvania, Maryland, West Virginia, Kentucky, and Ohio. Taken together, they are an important stratigraphic marker zone for this part of the Allegheny section.

Figure 4.2 shows a strip pit approximately 5 km (3 mi) west-southwest of Zaleski, Ohio (about 29 km (18 mi) northeast of Jackson), as it appeared in early June 1992. In this area, both the Zaleski flint and the Obryan limestone are discontinuous, the Zaleski pinching out to the south and the Obryan pinching out to the north. Only a few blocks of the Zaleski flint, as much as 1 m (3.3 ft) thick, can be seen in Figure 4.2B. Miners report that the chert thickens northward (into the picture) to as much as 3 m (10 ft) within a distance of 70 m (230 ft). The Zaleski is locally very fossilifer-

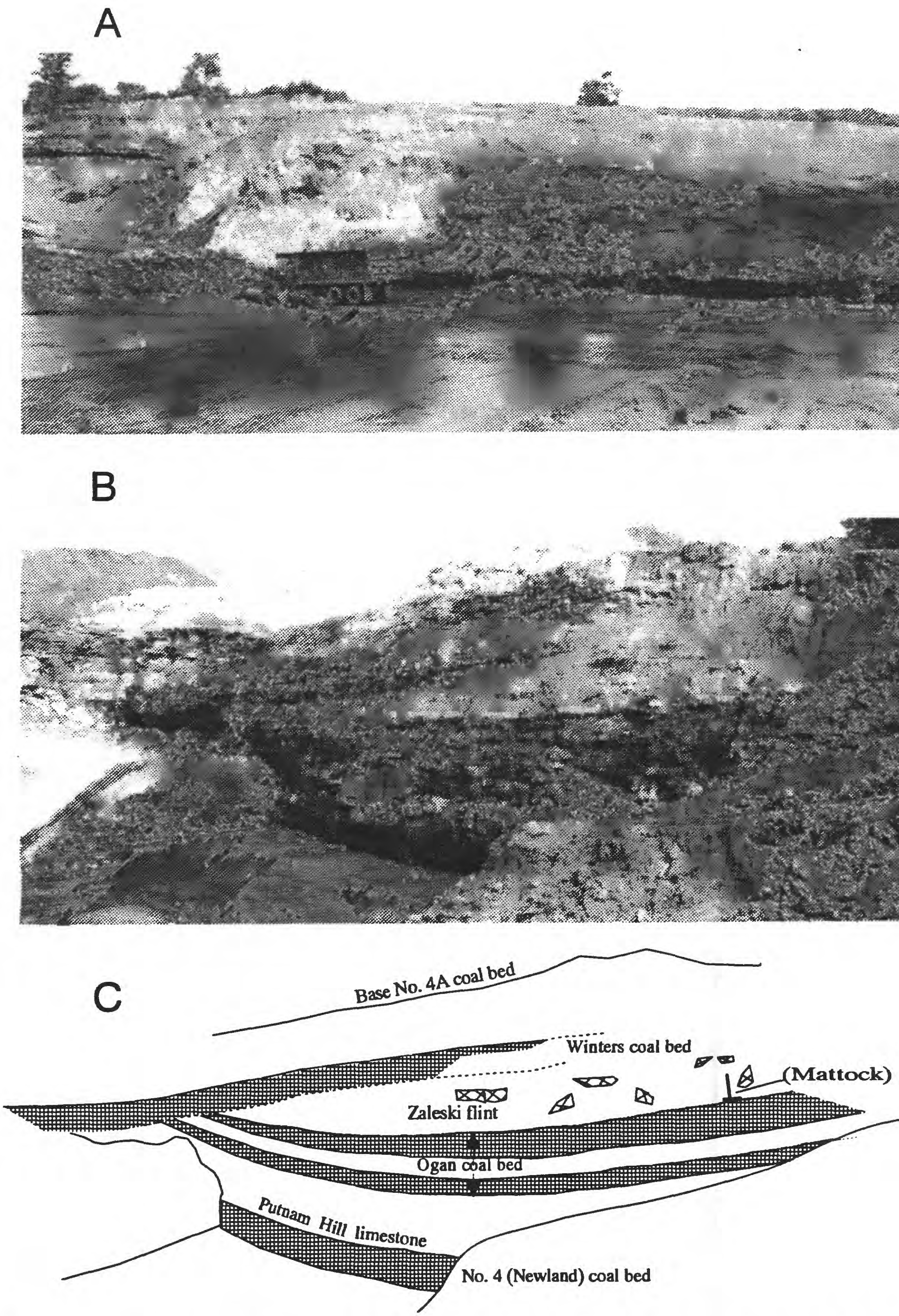

FIGURE 4.2. Multibenched strip pit southwest of Zaleski, Ohio (June 1992). (A) Upper part showing the No. 5 coal in highwall to left and the No. 4A coal at base. Obryan limestone (25 cm (10 in.) thick) is about 7 meters above No. 4A coal at base of sandstone. (B) Lower part of strip pit showing the base of the Allegheny Group. (C) Diagram of B showing the pinchout of the Ogan coal and the marine Zaleski flint (shown as blocks between the Ogan and Winters coal beds) against the base of the Winters coal.

ous and contains a variety of marine fossils such as productid brachiopods, bryozoa, and crinoid segments. The chert may occur with or without either the overlying Winters or the underlying Ogan coal beds. Only the chert facies of this marine unit has been reported in the outcrop area in southern Ohio. It was reported by Stout (1916) to locally overlie the Putnam Hill limestone where the Ogan is absent. The Putnam Hill member (Fig 4.2B) is a fossiliferous calcareous shale or argillaceous limestone, 2.5-3.5 m (8.2-11 ft) thick that contains chonetid and productid brachiopods, bryozoa, and crinoid segments. The Obryan limestone is as much as 25 cm (10 in.) thick at the base of the sandstone about 7-8 m (23-26 ft) above the No. 4A coal bed in the area shown in Figure 4.2A; it has not been reported north of that area. Because of the rapidity of modern mining, all of the area shown in the photographs probably will be reclaimed by the end of October 1992. Additionally, the lower coal beds and marine units shown in Figure 4.2B will probably not be exposed in any strip mines accessible to the field trip; however, these will be seen at Stops 7 and 8 in southeastern Ohio and northeastern Kentucky.

Figure 4.1 also shows the correlation of some coal and clay beds and marine units between Ohio and areas in Kentucky which will be visited later in the field trip. As the figure indicates, the Putnam Hill "limestone" of Ohio is correlated with the Kilgore Flint Member of the Breathitt Formation in Kentucky on the bases of the palynology of the underlying coal beds and the mapping of Webb (1963). Although Wanless (1975) correlated the Kilgore and the Zaleski flints, these appear to be deposits of two different high-stands of the sea in small isolated embayments along a low, west-facing coast during early Alleghenian time. The marked thinning of this part of the Pennsylvanian section from Ohio to northeastern Kentucky suggests the presence of a depositional basin in central Ohio that is distinct from the Appalachian foreland basin, which was southeast of the Ashland area in Kentucky at that time.

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STOP 5: BASAL PENNSYLVANIAN STRATA, KENTUCKY AA HIGHWAY, 0.5 KM (0.3 MI) WEST OF KENTUCKY ROUTE 7

by
Ronald L. Martino and Charles L. Rice

The upper Borden Formation (Cowbell Member, Early Mississippian) and lower portion of the Breathitt Formation (probably Middle Pennsylvanian) will be examined at Stop 5. The regional systemic unconformity is well exposed and is shown in Figure 5.1 by a channel cutting from left to right down through the Borden shale and siltstone. In the base of the channel are conglomerates more than 1 m (3.3 ft) thick. The channel- and valley-fill deposits above the unconformity will be compared with those at about the same stratigraphic position about 5 km (3 mi) further west along the Kentucky AA Highway. Figure 5.2 is a stratigraphic section measured from the eastern edge of the roadcut to the top of the exposure on the north side of the highway.

The Borden Formation makes up the lower 21-25.5 m (69-84 ft) of the section. It is characterized by mostly medium bedded, light-gray siltstone grading to very fine grained sandstone, with subordinate sandy shale. Parallel, horizontal to low-angle lamination and hummocky cross-lamination are well developed. Parallel-laminated units commonly have sharp bases and burrowed tops. Trace fossils show moderate diversity with preliminary identification of *Zoophycos*, *Helminthopsis*, *Cylindrichnus*, and *Rosselia*. These facies attributes are consistent with a storm-dominated shelf or delta front setting.

A thin discontinuous lag deposit occurs in the Borden strata at 21 m above the exposed base. It contains mud rip-ups as well as shell fragments, including crinoid plates and brachiopods. This unit may be a transgressive interval. At the top of the Borden is a dark-gray shale as much as 4.5 m (15 ft) thick with *Zoophycos*? and brachiopods near the base.

Above the systemic regional unconformity, five vertically stacked channel fills with intervening rooted seat earths make up the lower 6-10.5 m (20-34 ft) of the Pennsylvanian section at this stop. Channels are incised at least 5 m (16 ft) into underlying Mississippian strata. Channel lags as much as 1.5 m (5 ft) thick include pebbles and cobbles as much as 25 cm (10 in.) in diameter. These clasts are reworked Borden siltstone and silicified St. Louis limestone (Slade Formation). Very fine grained carbonaceous quartzose sandstone overlies the channel lags; the sandstone is thin bedded with carbonaceous partings. Scour-fill surfaces and lateral-accretion bedding are common. Coal spars and *Stigmaria* are common within this interval. The facies attributes suggest recurrent strong flow in shallow channels followed by abandonment and establishment of coastal plain swamps. The absence of bioturbation or marine fossils is suggestive of a freshwater setting.

The stacked alluvial channel-fill sequence is overlain by coal, carbonaceous shale, and claystones that are paleosols (shown by cross-hatches on Fig. 5.2). The irregular bed of red and gray flint clay, as much as 1 m (3.3 ft) thick, that occurs at 6-10.5 m (20-34 ft) above the unconformity may be the Olive Hill clay bed, according to the mapping of Sharps (1966), or it may be related to the flint clay beds found in slump blocks above the Olive Hill flint clay in exposures at Stop 6 to the west. The coals are thickest (60 cm (24 in.)) at the east end of the cut on the north side of the road. The flint clay is reddish in places and at the top of a rooted claystone (Fig. 5.2); the flint clay and claystone are underlain and overlain by bony coal or carbonaceous shales. The flint clay and associated paleosols are truncated toward the west end of the cut beneath a large shale-filled scour.

A 10.5-m-thick (34-ft-thick), dominantly

A

B

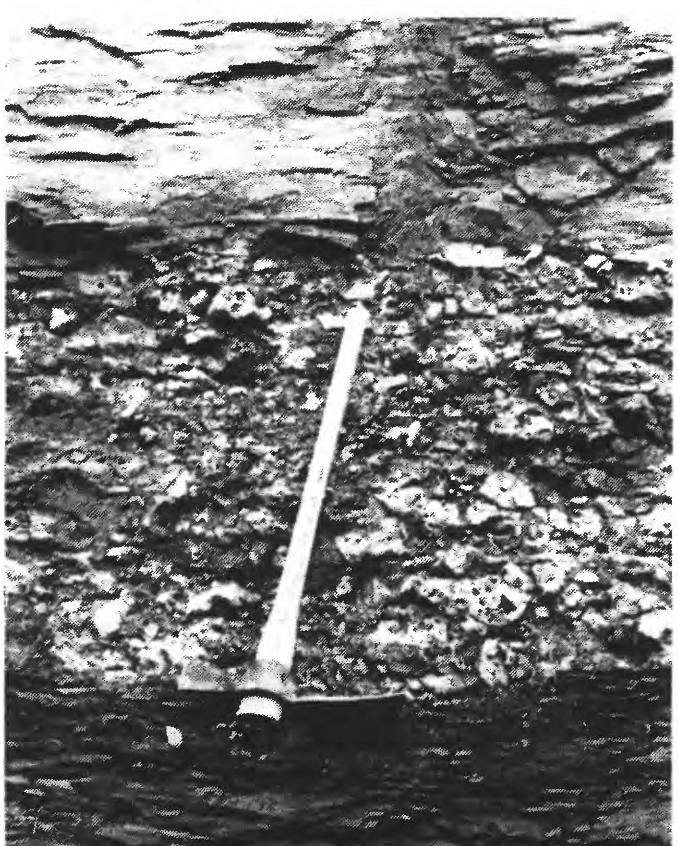

FIGURE 5.1. (A) Channel at base of the Pennsylvanian on Kentucky AA Highway 0.5 km (0.3 mi) west of Kentucky Route 7. Channel incised into siltstone of the Borden Formation (Early Mississippian) is filled with fluvial deposits. (B) Detail of basal conglomerate, composed of reworked Borden siltstone and silicified limestone of the Slade Formation.

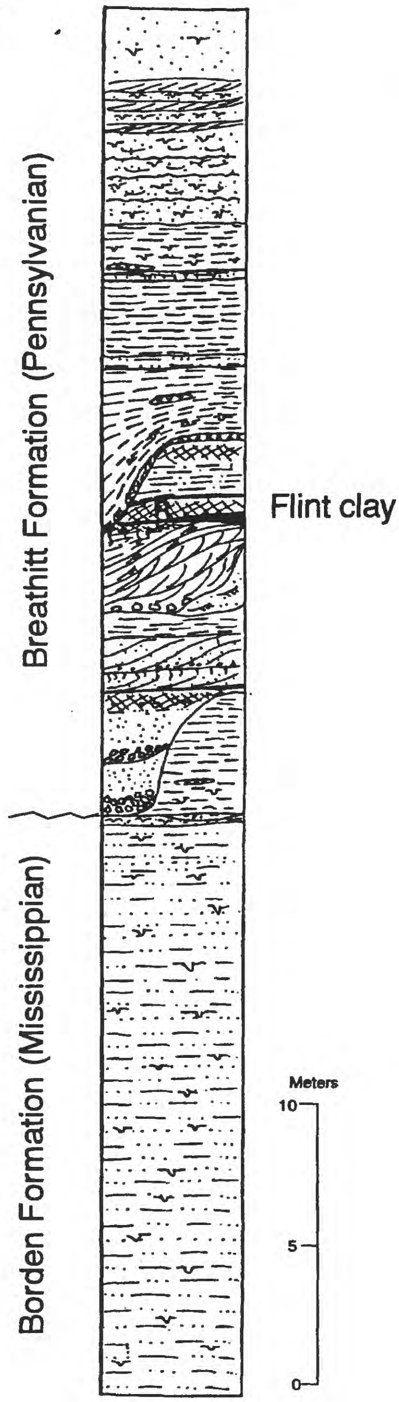

FIGURE 5.2. Composite stratigraphic column for Stop 5 showing the channel- and valley-fill deposits above the Mississippian-Pennsylvanian unconformity. Section is measured at eastern end of roadcut on north side of Kentucky AA Highway about 0.5 km (0.3 mi) west of Kentucky Route 7, Greenup County. See text for lithologic details.

dark-gray shale sequence overlies the flint clay. A burrowed siderite bed occurs at the base of this dark-gray shale and discontinuous siderite layers and lenses are locally present. At the west end of the cut, the lower 2-3 m (7-10 ft) contains large-scale lateral-accretion bedding with rhythmic lamination. The trace fossil *Teichichnus* is common in the lower 1-2 m (3-7 ft) and *Phycodes* is common in a highly bioturbated sandy shale near the top of the shale. The shale is thin bedded to fissile and apparently faunally barren. The trace fossil assemblage is suggestive of a restricted marginal marine setting. Conditions stressful to marine fauna may have been the result of brackish or fluctuating salinity, limited oxygen, and/or turbidity. These factors suggest deposition in an estuarine channel.

The outcrop is capped by about 7 m (23 ft) of thin-bedded, very fine grained sandstone and shale. Bioturbation is extensive, including *Asterosoma, Rosselia,* and *Teichichnus* among others. Wavy and flaser beds with carbonaceous shale partings are abundant. Isolated sets of medium-scale (15-20 cm (6-8 in.)) tabular planar cross-stratification alternate with thoroughly burrowed sandstone near the top of the sequence and suggest an estuarine sand flat depositional setting.

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STOP 6: BASAL PENNSYLVANIAN STRATA, KENTUCKY AA HIGHWAY 5.5 KM (3.4 MI) WEST OF KENTUCKY ROUTE 7

by

Ronald L. Martino and Charles L. Rice

New roadcuts have exposed about 60 m (197 ft) of strata from the Borden Formation and lower Breathitt Formation. The greenish-gray siltstone facies of the Borden is comparable to that seen in the Logan Formation at Stop 1 (Jackson, Ohio). Sparse burrowing and hummocky cross-stratification evident in the siltstone layers attest to intermittent, storm-induced high-energy conditions along a wave-dominated delta front setting; similar conditions have been previously described in the Cowbell Member of the Borden Formation (Chaplin, 1980). The Cowbell siltstones are overlain by 1-3 m (3-10 ft) of red and green shale contains spiriferid brachiopods. These beds may be an erosional remnant of the Nada Member that caps the Borden Formation.

A large, red-bed, channel- or valley-fill sequence more than 10 m (33 ft) thick and about 800 m (2,600 ft) wide truncates the Borden Formation exposed along the highway (Fig. 6.1). The predominant lithology within the channel and valley fill is maroon mudstone. Some reddening of the siltstones of the Cowbell Member immediately below the erosional contact is also present, particularly at the northwestern end of the roadcut. The basal 1-3 m (3-10 ft) and the central portion of the mudstone channel fill contain angular to subangular clasts of Cowbell siltstone, as well as silicified fossiliferous (fenestellid bryozoans, brachiopods) limestone that may have been derived from the St. Louis Limestone Member of the Slade Formation.

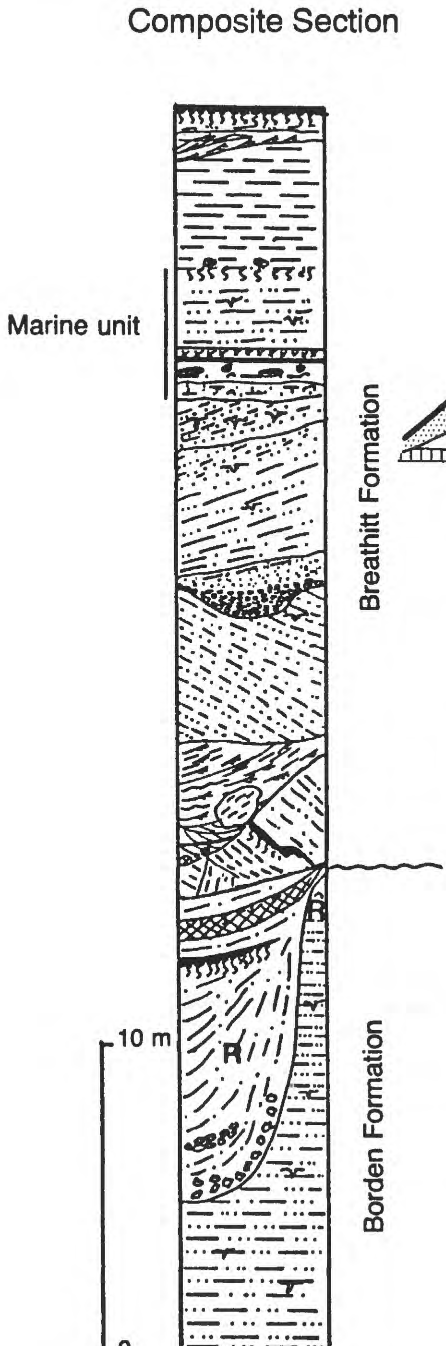
Chert rubble at the base of the Breathitt Formation has been reported from nearby quadrangles (Brushart quadrangle, Denny, 1964; Greenup and Ironton quadrangles, Dobrovolny et al., 1966). As much as 27.4 m (90 ft) of relief was reported along the unconformity at the base of the Breathitt Formation east of this stop in the Greenup and Ironton quadrangles. Further to the south along I-64, Ettensohn (1981) described limestone breccia of the St. Louis Member of the Slade Formation occurring at the base of the Breathitt as well as beneath disconformities within the Slade Formation.

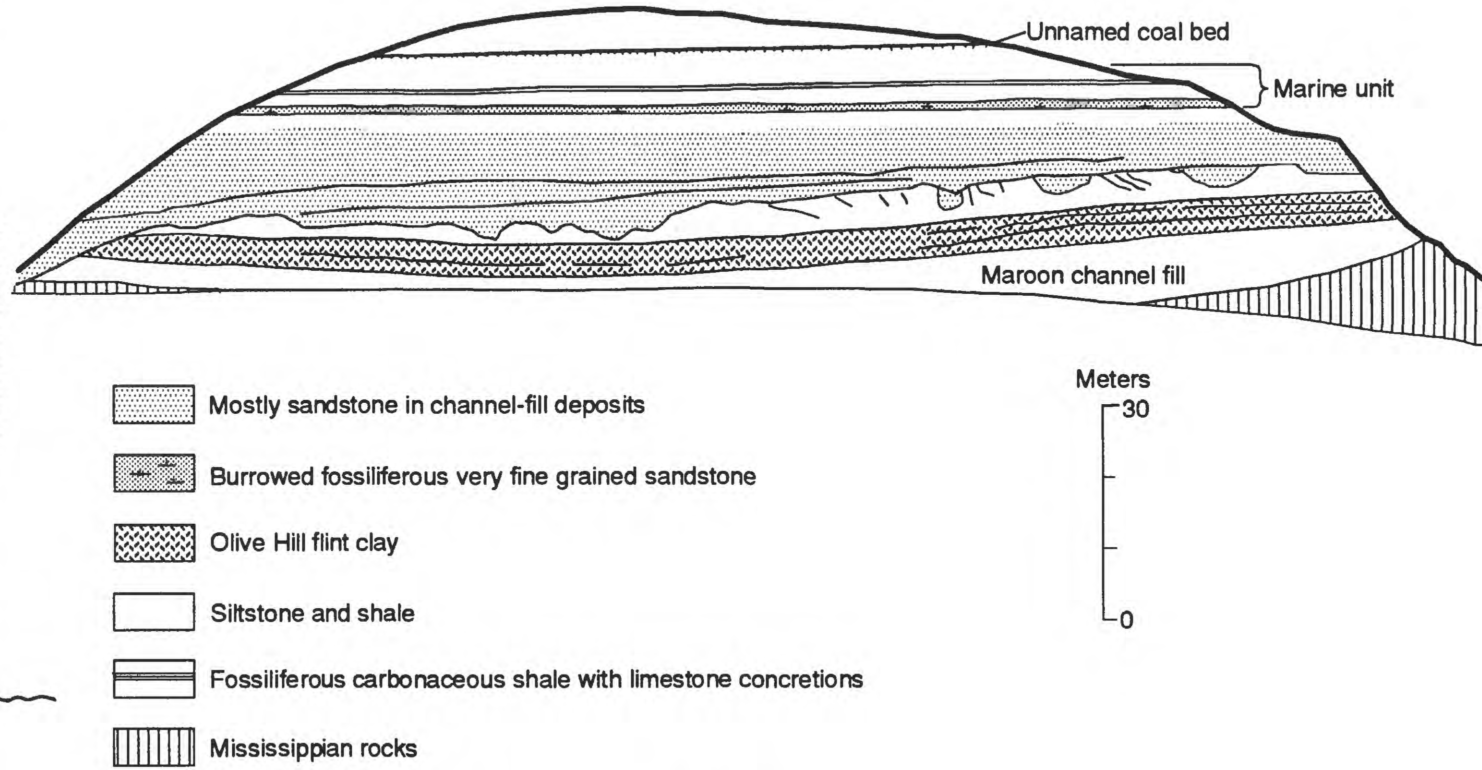
The fabric of the breccias at this stop involves mud-supported and clast-supported textures suggesting slumping or other mass-wasting processes. A limited amount of flowing water (if any) was involved during deposition.

The upper portions of the red mudstone channel fill contain intensely rooted gray mudstone seat earth overlain by bony coal as much as 15 cm (6 in.) thick (possibly latest Early Pennsylvanian age). This carbonaceous interval is restricted to the center of the channel fill and may correspond to a local, poorly drained paleotopographic low. The uppermost part of the channel fill is occupied by the Olive Hill flint clay bed. The flint clay occurs as two beds, which together have a maximum thickness of about 3 m (10 ft). The lower portion is pisolitic, and the upper part is extremely fine grained with bioturbation (root casts?) in the upper 10-20 cm (4-8 in.). The flint clay is capped by a variety of lithologies; in the center of the channel fill, it is conformably overlain by dark-gray, carbonaceous shale.

The 3- to 5-m-thick (10- to 16-ft-thick) sequence of dark-gray shale, coal, and flint clay above the Olive Hill flint clay is distinguished by contorted bedding and slump structures. The base of this disturbed sequence is erosional, with local relief of several meters; it truncates the Olive Hill clay bed and underlying channel-fill mudstone and breccia at the east end of the highway cut (near the southwest corner of intersection). Channel undercutting and bank destabilization are likely to have caused the slumping.

STOP 6





R in Composite Section, maroon channel fill

FIGURE 6.1. Diagrams showing the relations of basal Pennsylvanian strata in a roadcut on Kentucky AA Highway near the Howland Lookout Tower, Portsmouth 7 1/2-minute quadrangle, Greenup County, Kentucky. Lithologic description of detailed column is in text.

The contorted interval is overlain by about 15 m (50 ft) of vertically stacked, tidal, channel-fill sequences. In the basal part, quartz arenite with boulder-sized slump blocks can be seen along the road leading south of the AA highway. Along the south side of the highway, this unit has lateral accretion features (8- to 10-m-thick (26- to 33-ft-thick) set of epsilon cross-strata). Small- to medium-scale trough cross-stratification predominates in the lower 1-2 m (3-7 ft) of medium-grained sandstone whereas thin-bedded, parallel-laminated, very fine grained sandstone with carbonaceous shale partings occurs in the middle and upper portions. These sandstone and shale sequences regularly alternate and are interpreted as tidal bedding formed in tidal creek or estuarine channels. A quartz pebble conglomerate forms a lag at the base of one of the channel fills near the middle of the interval. Burrowing is sparse in the lower part but increases upward and is accompanied by increasing mud content. Bedding (lateral accretion deposits) dips as much as 13°. The uppermost portion of this interval is highly burrowed and contains the trace fossils *Teichichnus*, *Asterosoma*, *Planolites*, and anemone resting burrows (*Conostichus*).

The stacked tidal channel interval is overlain by a 3.5-m-thick (1.51-ft-thick) marine unit (see Fig. 6.2, following paper by Bennington). The base is marked by a calcareous, muddy, thoroughly burrowed, very fine grained sandstone containing marine invertebrates (horn coral, gastropods). The sand is transgressive and is overlain by sandy shale, with biomicritic limestone, carbonaceous shale, and siderite. Crinoid plates and columns are common in the limestone nodules and the carbonaceous shale contains planispiral gastropods. The upper portion of the marine shale unit coarsens into burrowed siltstone.

The marine unit is capped by rooted, sandy, sideritic mudstone and carbonaceous shale with plant fossils. The shale is truncated by cross-stratified channel sandstone as much as 1.1 m (3.6 ft) thick that fines upward into light-gray seat earth and coal.

A comparison of this stop with Stop 5 about 5 km (3 mi) to the east raises some interesting points. Both exposures show channel- and valley-fill deposits, the lower 10 m (33 ft) of which are capped by flint clay beds. The red color so pervasive at this stop (Stop 6) may be the result of minimal reworking of paleosols that slumped into the paleovalley. Here there is an abundance of mud-supported breccias and pedogenic features, whereas at Stop 5 there is evidence of through-flowing drainage in alluvial channels for much of the time and intermittent deactivation and swamp development. The 15- to 18-m-thick (50- to 60-ft-thick) interval above the Olive Hill flint clay is an estuarine channel complex at both locations. The open marine unit and coal at the top of the section at Stop 6 were not observed at Stop 5, probably owing to truncation by erosion.

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PRELIMINARY ANALYSIS OF A MARINE INTERVAL NEAR THE HOWLAND LOOKOUT TOWER ON KENTUCKY AA HIGHWAY

by

J. Bret Bennington

General Description

Breathitt Formation marine intervals are generally characterized by a relatively thin, fossiliferous, transgressive base, overlain by a thick, coarsening-upward, regressive top (Chesnut 1981; Bennington 1991a, 1991b). Accordingly, the paleontology and lithology of the marine interval about 16 m (53 ft) above the Olive Hill flint clay near the Howland Lookout Tower on Kentucky AA Highway records a marginal-marine to marine transition: a transgressive lower interval and a regressive upper interval, culminating in a marine to nonmarine transition (Fig. 6.2). The base of the marine interval is placed at the first appearance of fossils of stenohaline marine organisms (crinoid columnals, brachiopods) in a thin, burrowed, muddy sandstone occurring above a muddy sandstone lacking in marine fossils. The thin sandstone at the base of the marine interval grades upward into a dark-grey, muddy, very fine grained, slightly calcareous, bioturbated sandstone with more abundant marine fossils (Fig. 6.2). Overlying the fossiliferous, very fine grained sandstone is an interval of very fissile, moderately silty, dark-grey to black shale. That shale appears to contain abundant carbonaceous material and may be canneloid. It is slaty in appearance, and can be split into large, thin sheets. Fossils are common on some bedding surfaces (Figs. 6.3, 6.4). Additionally, large coalified wood fragments are present.

The fissile, black shale grades upward into a thin sequence of unfossiliferous, medium- to dark-grey, silty clay shale capped by an irregular bed of siderite. Above the siderite is a relatively thick sequence of dark-grey siltstones with thin-bedded to very fine grained sandstone. The first conclusive evidence of non-marine deposition is provided by a thicker sand bed with abundant root structures.

Depositional Environments

Lithologies not pictured but below the marginal marine burrowed sandstone in Figure 6.2 show rhythmic bedding and trace fossils similar to those generally interpreted to result from deposition in estuarine tidal channels (Martino and Sanderson, in press). Rhythmic bedding disappears upsection, yielding to a mix of fine sand and mud, perhaps due to the colonization of the substrate by burrowing organisms. The appearance of stenohaline marine organisms appears to record a change from estuarine conditions to more open marine shoreline conditions. The transition upsection to very fine grained sandstones with a more abundant marine fauna indicates transgression and continued deepening to a nearshore shallow marine habitat. This fauna contains many of the same genera seen at the base of other marine units in the Breathitt Formation. Crinoid columnals, the large gastropod *Worthenia*, and the small rugose coral *Lophophyllidium* predominate. Brachiopods, pelecypods, and other macrofossil groups are less abundant. Although somewhat sparse relative to basal layers in other Breathitt marine intervals, this fauna does not appear to be impoverished or in any way indicative of unusually stressful environmental conditions. Organisms generally associated with normal marine conditions, such as echinoids, corals, and bryozoans, are present. Furthermore, many specimens appear to have attained an adult size comparable to that seen in other marine intervals. The fact that 7 kg (16 lbs) of rock yielded only 29 macrofossil specimens (not counting crinoid columnals) from 10 genera is probably due to a dilution of available shelly material by relatively high rates of sedimentation, rather than to any impoverishment of the fauna.

The trend toward decreasing sediment size

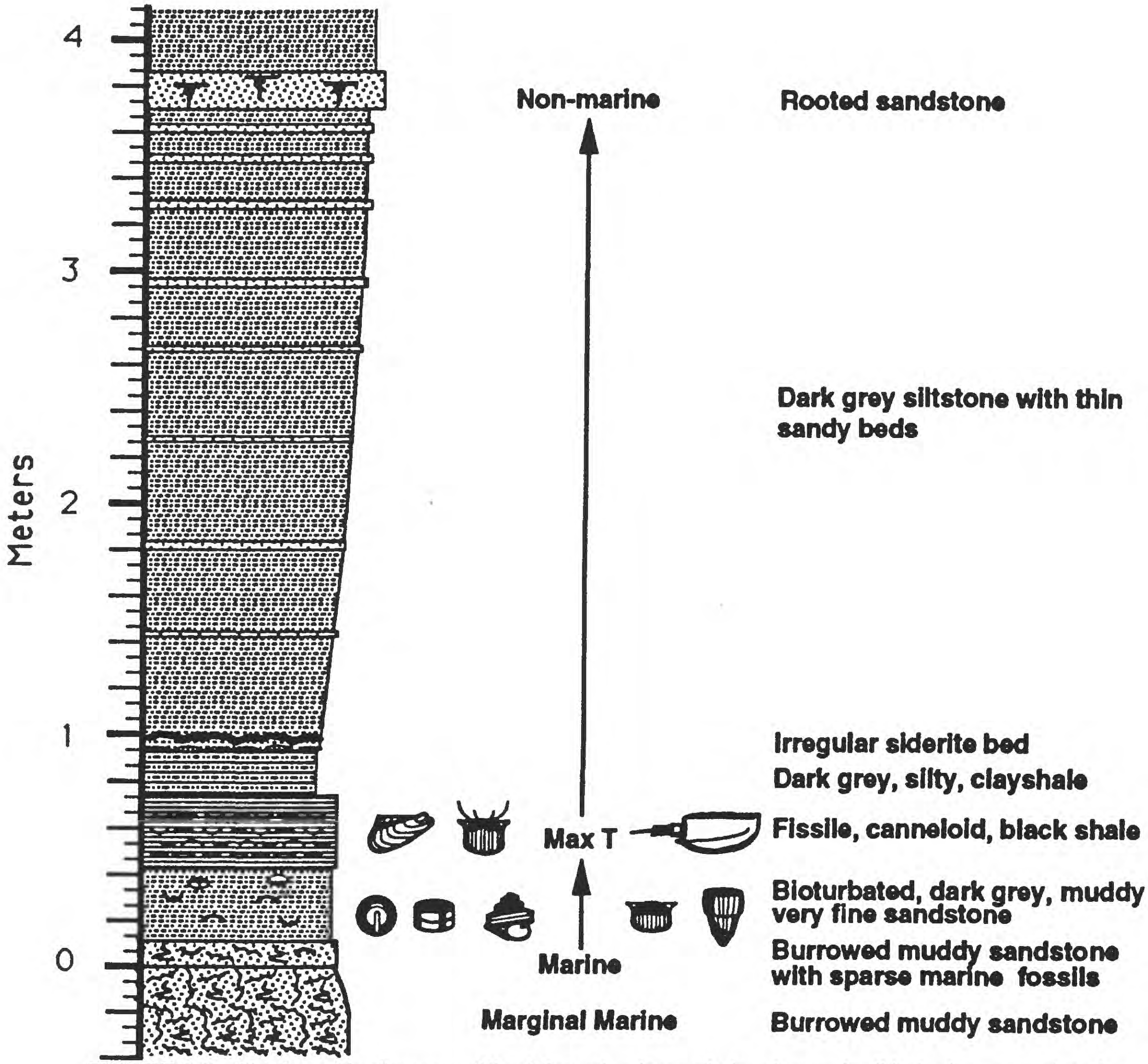


FIGURE 6.2. Stratigraphic diagram of the AA marine interval showing major lithologies, associated fossils, and the interpreted sequence of depositional environments. For names of fossil species, see Figure 6.3. Diagram shows the vertical changes of environment from marginal marine to maximum transgression (Max T) to non-marine.

and apparent transgression appears to culminate in the fissile black shale interval. Lithologies similar to this are uncommon, but are known from elsewhere in the Breathitt Formation, both from the Magoffin marine interval (Bennington, 1991a) and from a marine unit mapped and described by Coskren and Hoge (1978) and later identified as the Betsie Shale (Cobb et al., 1981). Although some elements of the black shale fauna are also known from elsewhere in the Pennsylvanian, this particular assemblage (Fig. 6.3), consisting predominantly of an undescribed species of the brachiopod *Linoproductus*, the thin-shelled pelecypod *Posidonia fracta*, and common spines and carapaces of the phyllocarid crustacean *Dithyrocaris* (Fig. 6.4), has not yet been reported.

Some general observations can be made on the paleoenvironmental significance of the black shale lithology and fauna. The sediments were almost certainly anoxic. No evidence of infaunal life is apparent in these fissile black shales. Bioturbation is absent; the shale can be evenly split to thicknesses of several millimeters. Microfossils such as ostracods, microgastropods, foraminifers, and tiny echinoderm skeletal elements, present in most fossiliferous sediments in the Breathitt

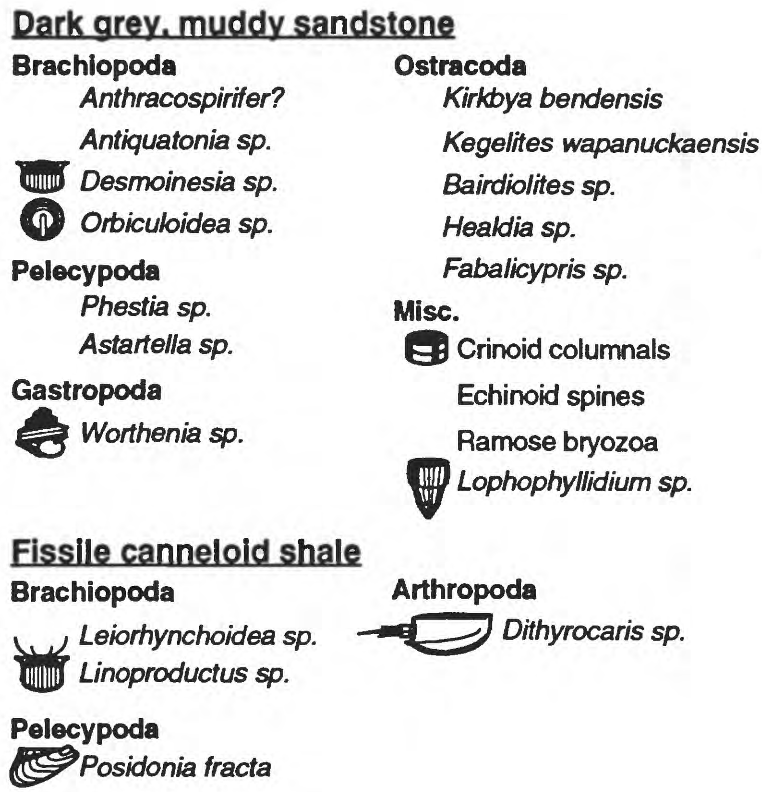
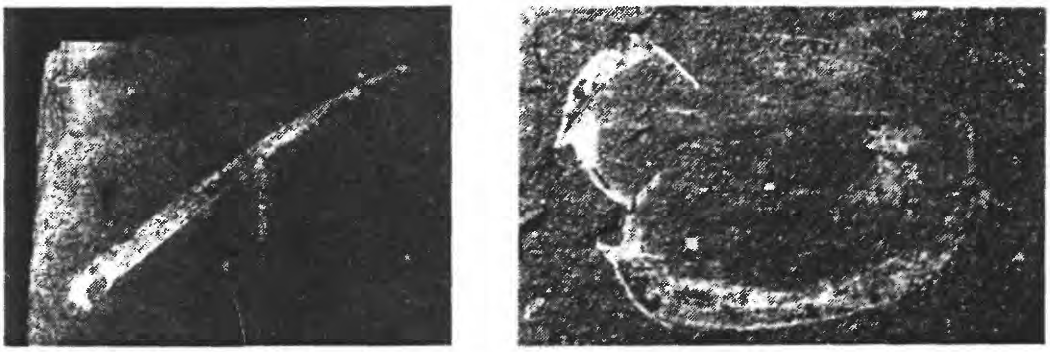


FIGURE 6.3. Diagram showing all fossils identified from the AA marine unit, arranged by associated facies. Fossils identified with symbols are relatively common in outcrop and are considered to be characteristic of that facies.

Formation, are absent from the fissile black shales. That the water column overlying the sediment was at least partially aerobic is suggested by the presence of *Linoproductus*, a semi-infaunal brachiopod, and *Posidonia*, a thin-shelled bivalve that probably rested on the sediment surface (*Posidonia* lacks evidence of a byssus for attachment). *Dithyrocaris*, a phyllocarid crustacean, may have been pelagic, living in oxygenated waters above the sediment surface. However, it has also been suggested that *Dithyrocaris* was epibenthic (Rolfe, 1969).

Several lines of evidence support a relatively deep water interpretation for the depositional environment of the black shale, marking it as the stratigraphic position of maximum transgression: (1) The fissile shale is finer grained than the sandy beds below and the siltstones with sandy beds above. It appears to lie in the middle of a single transgressive to regressive sediment package. (2) The sediment composing the fissile black shale appears to have been deposited below storm wave base. The thin shale laminations and the fact that the delicate and easily disarticulated phyllocarid crustaceans are preserved relatively intact, many with only minor displacement of their skeletal elements, suggest that the bottom was disturbed only by low velocity currents. (3) Similar lithologies from elsewhere in the Pennsylvanian have been interpreted to have been deposited in relatively deep-water. *Posidonia*-rich, fissile black shales have been described in the Magoffin marine interval, lying above a transgressive base with a diverse marine fauna (Bennington, 1991b). This interval is thin,



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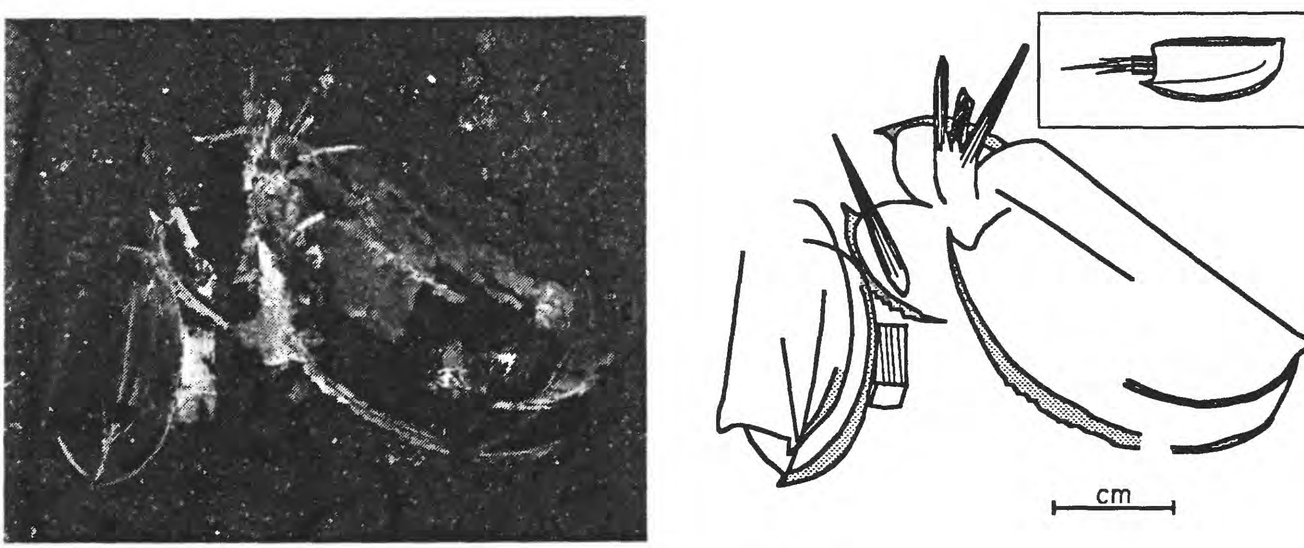

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2 3 4

FIGURE 6.4. Photographs of fossils from the fissile black shale facies of the AA marine interval. 1) *Dithyrocaris* sp., a phyllocarid crustacean: (a) large furcal ramus of telson [X1.5]; (b) bivalved carrapace showing pronounced postero-ventral spines [X3]. (c,d) Group of three specimens preserved together, see also Figure 6.3. Note large individual with overlapping carapace valves and well-perserved three-spined telson. Inset shows life arrangement of articulated carapace, abdomen, and telson. 2) *eiorhynchoidea* sp. pedicle valve [X2}. 3) *Linoprpductus* sp. hinge line with well-preserved spines and internal mold of pedicle valve [X2.5]. 4) *Posidonia fracta* (Meek) right valve [X2].

homogeneous, and geographically widespread, suggesting deposition in uniform, deep water conditions. Another Pennsylvanian fissile black shale containing abundant phyllocarids is the Mecca Shale of Indiana. This unit was originally interpreted to be the product of shallow-water deposition beneath an algal "flotant" (Zangerl and Richardson, 1963). Recent work, however, has tended toward a reinterpretation of this and other Pennsylvanian black shales as products of deep-water deposition (Heckel, 1977; Boardman et al., 1984). Heckel (1980) has suggested that oxygen-poor bottom conditions developed in epicontinental seas during times of maximum transgression due to the formation of a thermocline in poorly circulated deep basins. An anoxic bottom and dysaerobic overlying water column in the depositional environment of the fissile black shale could have resulted from such a thermocline, in combination with a high concentration of organic matter accumulating due to low rates of clastic input and decaying to exhaust the available oxygen in the sediments.

Above the fissile black shale in the AA marine interval, the lithology changes to a medium- to dark-grey, silty clay shale with no apparent macrofauna, capped by a massive bed of siderite. This facies records the beginning of regression or an increase in the rate of clastic deposition. Because siderite formation is inhibited by the presence of marine sulfate (Baird et al., 1986), the appearance of siderite suggests the end of stable stenohaline conditions, perhaps due to influxes of fresh water from terrestrial runoff. I have seen siderite beds similar to the one here at several localities of the Magoffin marine interval at the transition to persistently unfossiliferous conditions. Above the siderite are dark-grey siltstones and tabular sandstone beds showing an increasing rate of deposition of coarse clastic material. Conclusive evidence of nonmarine deposition is first provided by a rooted sandstone, which marks the top of the AA marine interval.

Stratigraphic Position and Correlation

The AA marine unit occurs in stratigraphic proximity to the underlying Mississippian-Pennsylvanian unconformity; it is probably Morrowan in age. However, because the Breathitt Formation thins greatly in northern Kentucky, it is difficult to reliably determine age from stratigraphic position in the section. Two ostracod species that have been recovered from the basal muddy sandstone of the AA marine interval are identified as *Kirkbyia bendensis* (Harlton) and *Kegelites wapanuckaensis* (Harlton). Christopher (1990), in a study of ostracods from the Appalachian basin, described these two species only from the Kendrick Shale Member of the Breathitt Formation; they appear in no younger marine units. Unfortunately, Christopher (1990) did not examine any material older than the Kendrick, so these ostracods suggest only an upper limit on the age of the AA marine interval. However, I have collected samples of a fissile black shale from a marine unit identified as the Betsie Shale Member of the Breathitt Formation (Cobb et al., 1981) exposed along the Moun-tain Parkway in the Campton quadrangle. This shale is similar in lithology and fauna (although not identical) to the fissile black shale of the AA marine interval. The fossiliferous shale in the Betsie Shale Member is black, fissile, and slaty, but it is also very calcareous. The dominant faunal element is the brachiopod *Leiorhynchoidea*, which occurs with rare *Linoproductus* of the same species seen in the AA marine interval. Are these two fissile black shales similar facies of the same unit? Three points argue for a tentative correlation of the AA marine interval with the Betsie Shale Member: (1) They have similar stratigraphic positions. The Betsie Shale is a widespread marine sequence occurring in the lower part of the Breathitt Formation, particularly in northeastern Kentucky (Rice et al., 1987, Fig. 8). (2) In a survey of all reported fossil occur-rences in the Breathitt Formation (Chesnut, 1991), *Leiorhynchoidea* is reported only from the Betsie Shale Member. (3) In their descrip-tion of the geologic section exposed in the Campton quadrangle, Coskren and Hoge

(1978) reported a second fossiliferous facies associated with the fissile black shale of the Betsie: a calcareous siltstone containing a well-preserved marine fauna with productid brachiopods, gastropods, pelecypods, horn corals, and crinoids. This facies may be equivalent to the basal fossiliferous sandstones seen in the AA marine interval.

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STOP 7: BASAL ALLEGHENY GROUP, SOUTHERN OHIO
(Roadcut on U.S. Highway 52, 1 km (0.6 mi) south of Ironton, Ohio)

by

Charles L. Rice

The roadcut at Stop 7 exposes much of the lower part of the Allegheny Group as it is defined in Ohio. In Ohio, the base of the Allegheny is placed at the top of the Homewood sandstone or the base of the Newland or No. 4 coal bed. The Newland coal bed commonly is mistakenly correlated with the Brookville coal bed of western Pennsylvania. Rice et al. (1979) and Douglass (1987) have correlated the newly named Obryan limestone (see Fig. 7.1) (called the Vanport limestone by Phalen (1912) and generally by most subsequent workers) with the Columbiana limestone of central and northern Ohio. Type section for the Obryan is across the Ohio River in Kentucky (Rice et al., in press). Regional implications of correlating the Obryan with the Columbiana include (1) the coal bed below the Obryan is the Lower Kittanning, and (2) the No. 5 and No. 6 coal beds (as shown on Figure 7.1) are, respectively, equivalent to the Middle and Upper Kittanning coal beds of northern Ohio and western Pennsylvania.

Figure 7.1 is modified from Ferm et al. (1971, Fig. 5), who with Webb (1963) and Whaley (1969) made extensive stratigraphic studies of the sedimentology and depositional environments of the lithologic sequence between the Newland coal and the Obryan limestone in southern Ohio and northeastern Kentucky. Ferm et al. (1971, p. 9) identified this sequence as "an excellent example of a distributary-mouth bar sand and its levees as well as adjoining bay and crevasse-splay deposits." Thus, silty shales with phosphatic brachiopods lie directly on the Newland coal bed and represent a marginal marine depositional environment, which extended locally above the distributary-mouth bar sand at the southern (left-hand) end of the roadcut. The levees (above the road sign, Fig. 7.1) "sealed off the adjoining bays from further detrital influx" to permit burrowing of the top sand bar and deposition of the overlying clay shale with marine to brackish-water fossils. Overlying those deposits are thin coal beds, rooted claystones, and sequences of crevasse-splay deposits that extend upward to within a couple of meters of the Obryan limestone. Most of the remaining strata extending to the Obryan and strata above the Obryan to the No. 5 coal bed are rooted claystone and some thin coal beds. Locally this entire sequence makes up the Lawrence clay bed, particularly where the Obryan limestone pinches out as it does in the roadcut and locally in this region. A flint clay bed, perhaps 15 cm (6 in.) thick, occurs just below the No. 5 coal bed; the overlying No. 5 coal bed has been fired, making lithologic determinations and measurements difficult near the position of the coal bed. The massive, channel-fill, crossbedded sandstones in the upper part of the roadcut locally cut through and replace the No. 5 coal bed and in places even cut below the Obryan limestone.

The formal division of the Pennsylvanian rocks in this area into Pottsville and Allegheny Formations or Groups seems hardly justified on the basis of field studies. Nothing distinguishes these sequences of strata from one another: both contain the same kinds and successions of similarly colored lithologies--coal

STOP 7

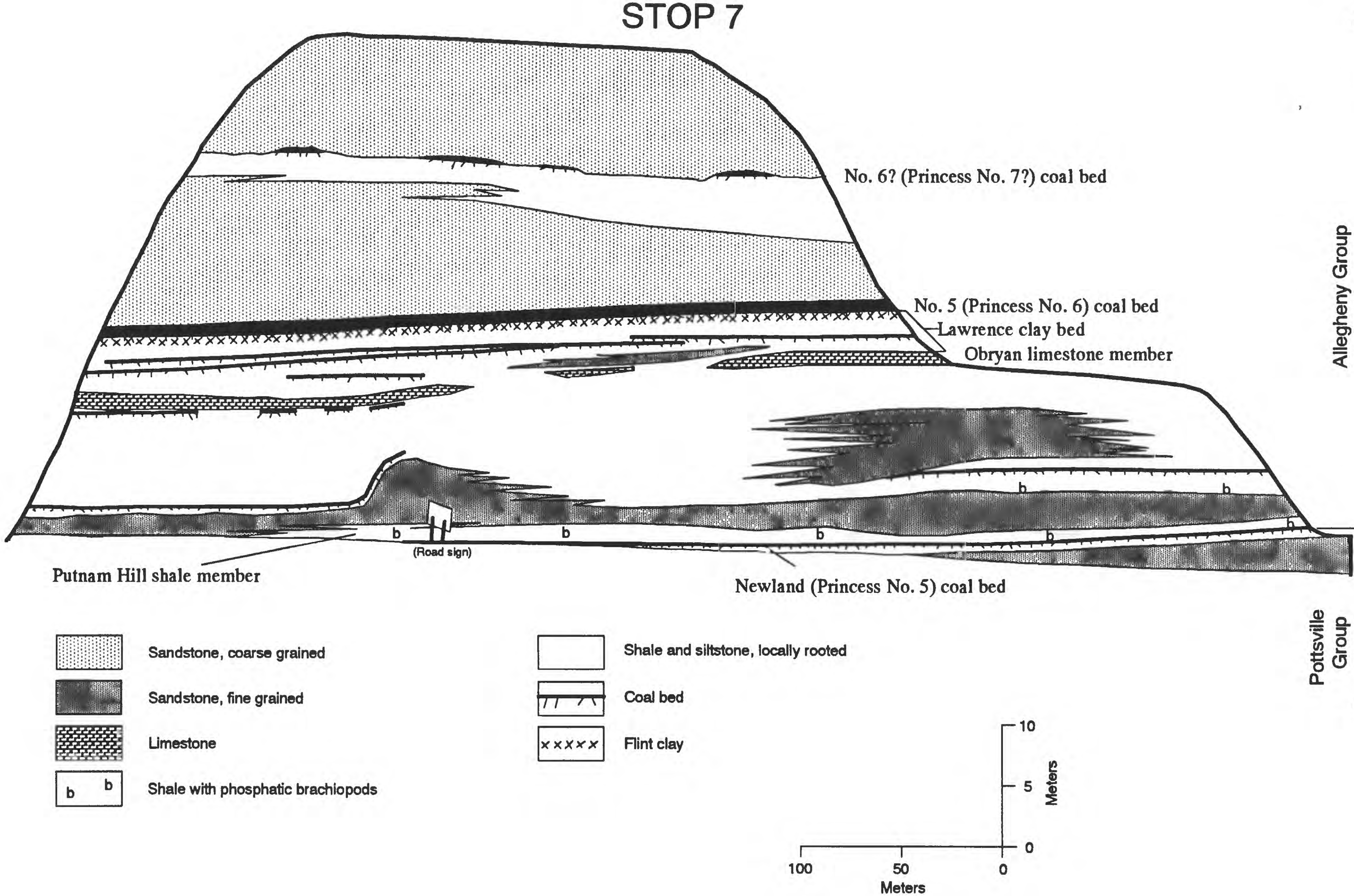

FIGURE 7.1. Diagram showing stratigraphic relations of basal Allegheny rocks on east side of U.S. Highway 52 about 1 km (0.6 mi) south of entrance ramp at Ironton, Ohio. Diagram modified from Ferm et al. (1971, Fig. 5). The correlative names of coal beds (Princess Nos. 5, 6, and 7?) used in Kentucky are shown in parenthesis for reference purposes.

beds, marine units, and thin and thick sequences of shale and sandstone. The bounding units, whether the Homewood sandstone or the so-called Brookville coal bed, generally have been misidentified and miscorrelated from their type sections and do not represent recognizable or mappable units in this area. Even in northern Ohio, State geologists now identify all strata below the Vanport limestone as "Pottsville/Allegheny, undivided" for lack of definitive stratigraphic control. These facts suggest that the two "units" be replaced by a single unit, such as the Breathitt Formation in Kentucky, which has come to include in this area all the strata between the eroded top of the Mississippian and the base of the Conemaugh Formation.

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STOP 8: BASAL "ALLEGHENY" STRATA, NORTHEASTERN KENTUCKY (Roadcut at west exit ramp of U.S. Highway 60 onto I-64, near Coalton, Kentucky)

by
Charles L. Rice

The roadcut at Stop 8 contains the type section of the Kilgore Flint Member of the Breathitt Formation exposed along the base of the cut (see Fig. 8.1). Figure 8.1 is modified from Ferm et al. (1971, Fig. 9) and illustrates essentially the same stratigraphic interval as that of Stop 7, south of Ironton, Ohio. At Stop 6 the Obryan Limestone Member of the Breathitt Formation is only a thin silty shale containing rare calcareous brachiopods; it is separated from the Kilgore Flint Member by a few meters of mostly rooted claystone containing the Princess Nos. 5A and 5B coal beds. The Hitchins clay bed (equivalent to the Lawrence clay bed of Ohio) is 3 m (10 ft) or more thick just below the Princess No. 6 coal bed at the top of the exposure. The Hitchins clay bed contains at least two flint clay beds, one as much as 30 cm (12 in.) thick at the eastern end of the outcrop where it is both overlain and underlain by thin coal beds. Conversely, at the western end of the outcrop, only one flint clay bed a few centimeters thick can be found in the Hitchins. The Hitchins clay bed also contains a deeply weathered argillaceous sandstone at its base at the western end of the roadcut. According to Carlson (1965), the Princess No. 7 coal bed (the No. 6 coal bed of Ohio) has been strip mined in much of this area and is approximately 12 m (39 ft) above the Princess No. 6 coal bed exposed at the top of the roadcut. However, the No. 7 coal bed is not visible from the road at Stop 6.

Factors controlling the silicification of the Kilgore Flint Member and associated strata are important in understanding the distribution of these deposits and have critical stratigraphic implications. Knauth and Epstein (1976) showed that many cherts associated with marine deposits have a major meteoric-water component, and Knauth (1979) concluded that silicification of coastal sediments can occur as a consequence of mixing meteoric and marine waters where shoreline sediments prograde over lagoonal or other offshore deposits. Cavaroc and Ferm (1968) also suggested that siliceous spiculites are shoreline indicators in deltaic sequences in several Allegheny marine units, including the Kilgore Flint Member.

The cherts of the Kilgore Flint Member and equivalent horizons in Kentucky (such as the Flint Ridge Flint of Morse, 1931) are spicular and contain a variety of marine fossils. The Kilgore Flint Member crops out in an area of only about 40 km^2 (15 mi^2) in northeastern Kentucky. Locally, it grades laterally to a thin silty shale that contains brackish-water fossils such as occur in the correlative shale unit found above the Newland coal bed at Stop 7 in Ohio. The Kilgore is associated with some silicification of the underlying coal bed in Kentucky and Ohio, for example, the uppermost bench of the Princess No. 5 coal bed at the eastern end of this roadcut. In northeastern Kentucky, a broad thin zone of silicified siltstone containing plant fossils locally occurs at or just below the horizon of the Kilgore Flint Member (see Carlson, 1971). Whereas the limited extent of the member and its lateral brackish-water facies indicates deposition in nearshore environments or relatively small embayments, the wide extent of silicification of the Princess No. 5 coal bed and related siltstones in Kentucky suggests an interaction of silica-rich ground water with coastal sediments saturated with marine water prior to lithification. The correlative Flint Ridge Flint of Morse (1931), originally a limestone as much as 9 m (30 ft) thick, is mostly chert at

STOP 8

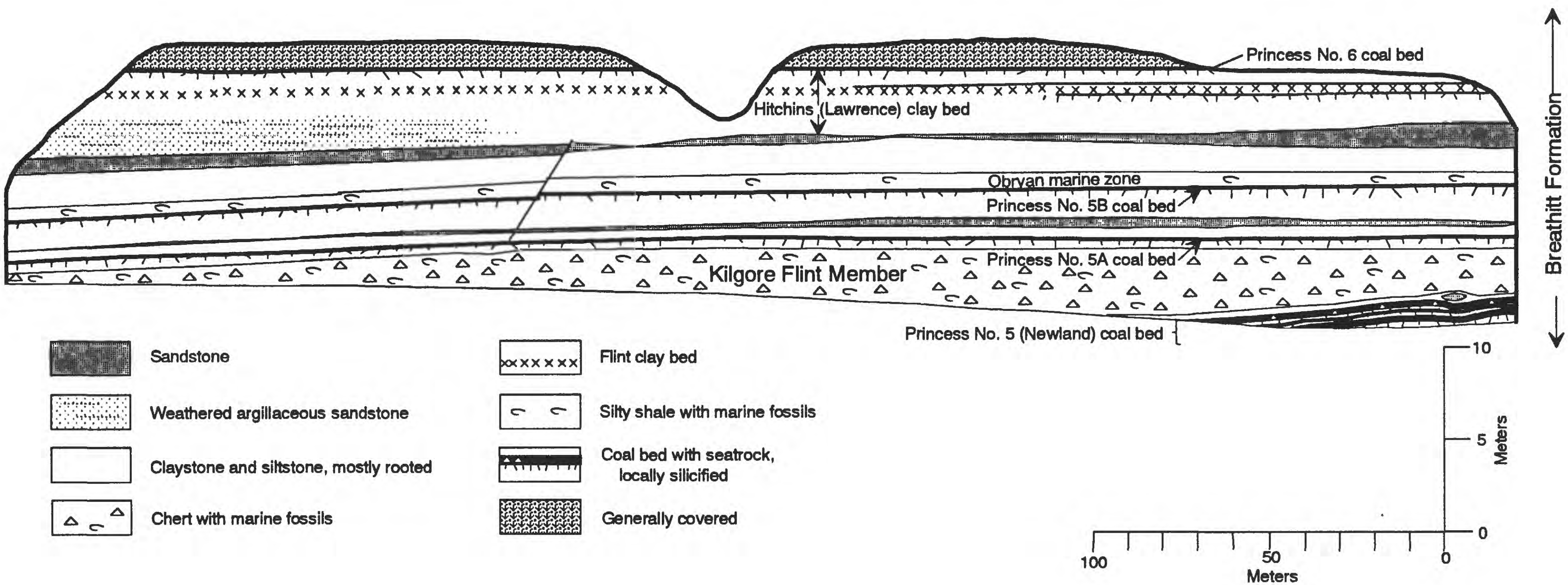

FIGURE 8.1. Diagram showing lithologic relations in Allegheny-equivalent strata at the type section of the Kilgore Flint Member of the Breathitt Formation. Roadcut is on the exit ramp of the intersection of U.S. Highway 60 and I-64 in Kentucky., and represents the basal part of the Allegheny Group as viewed at Stop 7 in southern Ohio. The Kilgore Flint Member is the equivalent of the Putnam Hill marine shale or limestone of Ohio (Webb, 1963). Figure is modified from Ferm et al. (1971, Fig. 9). Coal bed nomenclature between Kentucky and Ohio is confusing: the Princess No. 6 of Kentucky is the No. 5 coal bed of Ohio; the Princess 5B of Kentucky is probably the No. 4A coal bed of Ohio; and the Princess No. 5 of Kentucky is, as previously indicated (Fig. 4.1), the Newland or No. 4 coal bed of Ohio. Here, at Stop 9, the Obryan Limestone Member of the Breathitt Formation is only a thin silty shale that contains marine fossils above the Princess No. 5B coal bed.

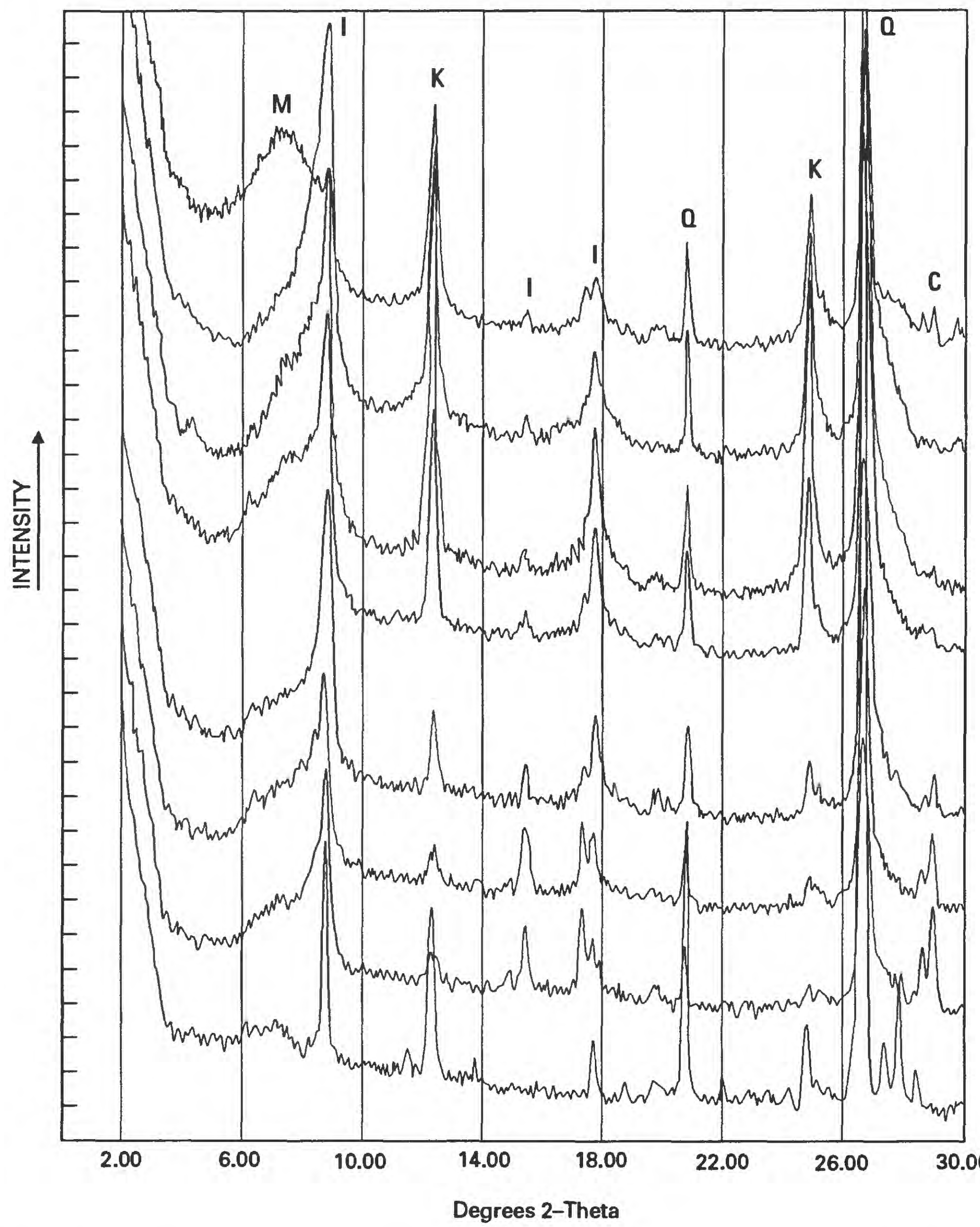

FIGURE 8.2. X-ray diffraction traces of seven untreated clay channel samples from the 86-cm-thick (2.8-ft-thick) interval between the Kilgore Flint Member of the Breathitt Formation and the overlying Princess No. 5A coal bed at the type locality of the Kilgore. M = mixed-layer clay, I = illite, K = kaolinite, Q = quartz, and C = calcite. The ratio (K+M)/I decreases downward suggesting clay interval is a paleosol. Lowest trace is the clay component of 1.3 cm (0.5 in.) of chert from the top of the Kilgore Flint Member. (Data compilation by J.W. Hosterman in 1990.)

the top and is silicified downward along fractures, indicating that the alteration was a late-stage feature of deposition (Hinrichs, 1978). In order to determine if any discernible mineralogical relation exists between the Kilgore Flint Member and overlying strata, seven evenly-spaced samples (vertically) were collected at this roadcut from the 86-cm-thick (2.8-ft-thick) sequence between the top of the Kilgore and the base of the overlying Prin-cess No. 5A coal bed. Figure 8.2 shows the X-ray diffraction traces of the untreated samples and indicates that the (kaolinite+mixed-layer clay)/illite ratio decreases downward from the coal to the top of the Kilgore, suggesting that the unit is a paleosol. The sharp boundary between the base of the clay unit and the underlying chert indicates that, if the clay unit was originally part of the underlying marine unit, all evidence, including spicules and calcareous fossils has been removed by leaching, probably during soil formation.

Disaggregated samples of a flint clay from the Hitchins clay yielded euhedral igneous mineral grains, such as beta-form quartz, zircon, apatite, biotite, and a highly twinned plagioclase feldspar. The presence of these crystals suggests that the deposit is an altered volcanic ash fall. Similar beds of flint clay occur in strata above and below the Princess No. 6 coal bed in Kentucky and its correlatives in Ohio, and locally are found as partings in the coal beds. These beds, commonly called tonsteins, indicate active volcanism during this part of the Pennsylvanian, probably along the eastern margins of the craton. About 25 percent of the quartz grains of these samples consist of low temperature detrital or polycrystalline quartz. These detrital grains and the discontinuous nature of the flint clay beds suggest that the volcanic ash was partially reworked before final deposition.

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STOP 9: GREGORYVILLE EXPOSURE ON, I-64 IN KENTUCKY--AN EXAMINATION OF TWOMIDDLE CARBONIFEROUS DEPOSITIONAL MODELS

by
Donald R. Chesnut, Jr., Stephen F. Greb, Cortland Eble,
and Charles L. Rice

Introduction

This paper about the Gregoryville exposure at Stop 9 discusses (1) how different interpretations of depositional environments of individual outcrops have led to very different models for the Appalachian basin as a whole; (2) the role that sea-level changes have had in the deposition of the coal-bearing rocks; (3) the development of the mid-Carboniferous unconformity and subsequent onlap of mid-Pennsylvanian strata to the northwestern margin of the basin, and (4) the formation of the Olive Hill flint clay. The roadcut is on the north side of Interstate 64 (I-64) at mile-marker 166 about 6.4 km (4 mi) east of the Olive Hill (161) exit (Grahn 7.5-minute Quadrangle, Carter Coordinate 3-V-79, 4100 FSL X 600 FEL).

Outcrop description

The rocks exposed above road level in the I-64 roadcut belong to the Breathitt Formation and are probably of Middle Pennsylvanian age. Of the four thin coal beds exposed in the roadcut (Fig. 9.1), labeled in ascending order as A, B, C, and D, only C, the Bruin coal bed, is continuous enough in this area to have been mapped. Samples of coals A (38 cm (15 in.) thick) and C (Bruin coal bed, 41 cm (16 in.) thick) were collected for palynological analyses by Cortland Eble; the analyses confirmed an age assignment of Middle Pennsylvanian. Specifically, the coals occur somewhere just below the base of the Betsie Shale Member of the Breathitt Formation and up to and including the Upper Elkhorn No. 3 coal zone. The Fire Clay coal bed, locally mined in this area, occurs about 52 m (170 ft) above the Bruin coal and has been mapped near the top of the hill above the roadcut. The Fire Clay coal is probably the best regional stratigraphic marker bed in the Middle Pennsylvanian of the Appalachian basin because of its distinctive tonstein (flint clay) parting. The tonstein, an altered volcanic ash fall, has been isotopically dated at about 311 Ma and, on the basis of megafossils, its stratigraphic position has been projected to the uppermost part of the Trace Creek Member of the Atoka Formation of the midcontinent region (Rice et al., 1990).

In the underpass exposure, below I-64 road level, at the eastern side of the roadcut (Fig. 9.1), a thin Pennsylvanian sandstone (containing abundant clay and quartz pebbles) overlies a heavily weathered soil profile (pedogenic flint clay) developed on shales and sandstones of the Paragon Formation (Late Mississippian). The mid-Carboniferous regional unconformity is placed at the soil profile (Fig. 9.1). The strata of the Gregoryville section have been divided into five members for purposes of discussion (Fig. 9.1). Although the shales of the three lowest members, 1, 2, and 3, contain marine or brackish body or trace fossils, the units are not distinctive enough to have been traced or mapped in this part of northeastern Kentucky. Spore data from coals A, B, and C do not preclude either shale member 1 or 3 from being equivalent to the Betsie Shale Member. The Betsie Shale, of marine or brackish-water origin, is the most widespread marker unit in the Pennsylvanian of the Appalachian basin. Bennington (this volume) has identified the brachiopod *Leiorhynchoidea* at Stop 6 in a marine shale at approximately the same stratigraphic level as that of member 3 (Fig. 9.1); previously, *Leiorhynchoidea* had been identified only in the Betsie Shale Member. The upper part of shale member 1 (Fig. 9.1) contains abundant small *Lingula*. The canneloid black shale ("bone") at the base of member 3 contains abundant specimens of the brackish-water pelecypod *Anthraconaia*.

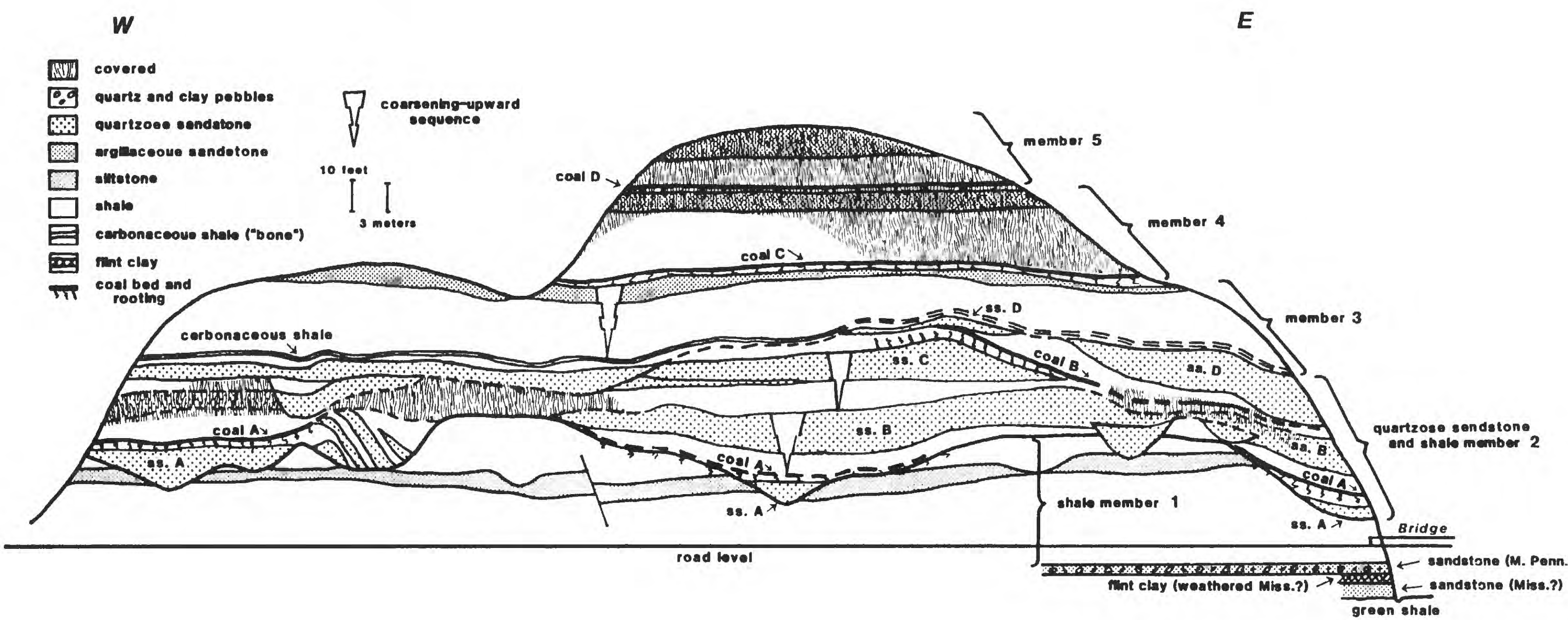

FIGURE 9.1. Diagram of the roadcut at Gregoryville (Stop 9) on the north side of I-64 at mile 166. Drawing is based on field measurements and photographic montages; section above coal C, now largely covered, is based on information in Ferm et al. (1971, Fig. 10). Elevation at road level is about 210 m (690 ft) at the eastern end and about 218 m (715 ft) at the western end. Flint clay at the base of theeastern end of the roadcut is truncated at top by a thin Pennsylvnaian sandstone and only the lower part of what is considered to be the Olive Hill flint clay is preserved. However, Englund (1976) mapped an outcrop of the Olive Hill clay bed only 210 m (700 ft) southeast of this area. No horizontal scale is implied.

This black shale, identified as 'coal' in Ferm et al. (1971), is overlain by shale and sandstones containing the trace fossils *Lockeia*, *Neonereites*, and *Planolites*.

Member 2 is composed of thin channel-form or tabular quartzose sandstone bodies that alternate with shales and coal beds (see lower part of roadcut, Fig. 9.1). Several of these sandstone and shale beds contain marine or brackish-water trace fossils including *Bifasciculus*?, *Biformites*?, *Chondrites*, *Cochlichnus*, *Lockeia*, *Neonereites*, *Planolites*, and *Rusophycus*? The sandstones are dominantly ripple laminated and show evidence of bimodal paleocurrents. Sandstone D at the eastern end of the cut exhibits soft-sediment deformation and trough crossbeds, and contains coal spars (transported coaly material), and numerous plant fossils including a vertical Calamites limb. Typical of coastal "bay"-fill or prodelta deposits, members 3, 4, and 5 consist of coarsening-upward sequences, which are commonly capped by seat rock and coal beds (Fig. 9.1).

Tectonic Setting

The Gregoryville outcrop is in a part of the Appalachian basin that, during the middle and late parts of the Carboniferous, was a tectonic high on the northern rim of the Rome trough basement structure, and near the crest of the north-trending Waverly Arch. In the Late Mississippian and Early Pennsylvanian, a broad shallow topographic basin developed in northwestern Pennsylvania and Ohio that was separated from the main Appalachian basin by a drainage divide. This drainage divide was formed by a low northeast-oriented cuesta or series of Mississippian hills (Wanless, 1975; Rice, 1984), and Gregoryville lay near its crest. In the Early Pennsylvanian, the two basins, one to the northwest and the other to the southeast, were slowly filled with fluvial and paralic deposits until the old drainage divide was overwhelmed by terrestrial sediments being shed from the growing Appalachian orogen. The first sediments to cover the divide in this area are represented by the Olive Hill (Sciotoville in Ohio) flint clay and the overlying Anthony coal bed of latest Early or earliest Middle Pennsylvanian age. Part of the Olive Hill flint clay is preserved at the Gregoryville site and is discussed in a section below; the Anthony coal bed, however, is not preserved at Gregoryville.

Controversial Interpretations

This roadcut was originally described by Ferm et al. (1971) to illustrate the Lee-Newman[Slade]-Barrier-Shoreline model of Horne et al. (1971). Those authors, not having the benefit of Englund's (1976) geologic map of the area, misidentified the upper beds in the roadcut as the Tom Cooper coal, Kendrick Shale, and Fire Clay coal, all of which occur higher up the hill. The Fire Clay coal, identified by its tonstein (flint clay parting of volcanic origin) occurs at an elevation of 280 m (920 ft), approximately 36.6 m (120 ft) above the coal identified as Fire Clay by Ferm et al. (1971). Ferm et al. (1971) interpreted the strata above the quartzose sandstones (members 3, 4, 5; Fig. 9.1) to be "lower delta plain" facies composed of bay-type coarsening-upward sequences, delta-front/distributary-bar sands, seat rock, and coals. The lower part of the roadcut (members 1 and 2) was interpreted to be "back-barrier" facies including bay-type coarsening-upward sequences (largely the shales), barrier overwash and tidal inlet deposits (quartzose sandstones), seat rock, and coals. These "back-barrier" deposits were correlated with "barrier" sandstones at two localities about 10 km (6 mi) west (Ferm et al., 1971, p. 16-21). One of these barrier sandstones (their stop 8) is the Carter Caves Sandstone of the Paragon Formation, the other (their stop 9) is a local sandstone lens occurring in the Slade Formation. Both of these sandstones are Late Mississippian in age and occur below the mid-Carboniferous regional unconformity (Dever, 1980; Ettensohn, 1980; Chesnut, 1988) and, therefore, cannot be laterally equivalent to the Pennsylvanian quartzose sandstones at the Gregoryville locality.

Quartzose Sandstones

The presence of quartz pebbles in the

sandstone directly overlying the mid-Carboniferous unconformity suggests correlation with the quartzose sandstones of the Corbin Sandstone Member of the Lee Formation. Breathitt Formation sandstones are generally lacking in quartz pebbles (Rice, 1984). The Gregoryville locality is only 2.4 km (1.5 mi) northwest from the mapped pinchout of the Lee Formation (Englund, 1976). This pinchout marks the edge of the Corbin Sandstone, a Lee sandstone belt which averages about 56 km (35 mi) in width, and is oriented northeast across the western part of the central Appalachian basin (Rice, 1984; Chesnut, 1988, in press). Sedimentological studies of the Corbin and other Lee sandstone members do not support a beach-barrier-island interpre-tation. Rather, the Lee sandstone units occur in broad belts that are interpreted to represent fluvial trunk transport systems situated between a mid-Carboniferous forebulge to the west and the Breathitt clastic wedge to the southeast (Chesnut, 1988). A compilation of crossbed directions indicate that sediment dispersal during the mid-Carboniferous was dominantly to the southwest, *parallel* to the orientation of the sandstone belts (listed in Chesnut, 1988; see Rice (1984) for Corbin Sandstone crossbed dips); such an orientation of current structures is more typical of fluvial rather than beach-barrier systems. Vertical and lateral profiles, well-developed pebble lags, bedding architecture, thinning-upward bedding, and general blocky to fining-upward grain-size trends (rather than coarsening -upward) also are more typical of fluvial than beach-barrier systems (Walker, 1984; Miall, 1985; Reineck and Singh, 1986). This com-bination of sedimentological criteria has been used by several authors to reinterpret Lee sandstone deposits as fluvial deposits in many parts of the basin (BeMent, 1976; Hester, 1977; Rice, 1984; Greb and Chesnut, 1989; Wizevich, 1991). Marine indicators that might be used to support barrier-bar deposition do not occur throughout the major Lee sandstone bodies as would be expected in a foreshore-to-beach transition (McCubbin, 1982; Moslow, 1983; Reineck and Singh, 1986). Rather, marine indicators such as bioturbation, her-ringbone stratification, and megaripple-style cross stratification, if they occur at all, are mostly restricted to the uppermost part of the major sandstone members of the Lee Formation, where they may record estuarine reworking of fluvial sandstones (Greb and Chesnut, 1989). As the Mississippian Carter Caves Sandstone, the sandstone in the Slade Formation to the west, and the Pennsylvanian Corbin Sandstone to the south are all not interpreted as Pennsylvanian-age barrier sandstones, the interpretation of back-barrier facies for the strata (members 1 and 2) in the lower part of this stop is not supported. However, the thin channel-fill facies of member 2 may represent deposition in tidal creeks (Ferm et al., 1971). The channel-form cross section, bimodal paleocurrents, and marine trace fossils are common in modern tidal creeks (Walker, 1984; Reineck and Singh, 1986). The shallow tidal channels may have formed in conjunction with marine reworking and redistribution of nearby fluvial sands of the Lee Formation (such as the Corbin Sandstone) during a period of rising sea level, or they may represent tidal channel deposits developed along the channel-coastal margin and may be, in part, laterally equivalent to the larger channel sandstone deposits of the Lee Formation.

Upper Part of the Section

Horne et al. (1971) characterized the strata in the upper half of this stop (members 3, 4, and 5; Fig. 9.1) as lower delta plain facies. This interpretation was based on the use of the Mississippi delta as a modern analog for the coal-bearing rocks of the central Appalachian basin. Thus, the lower part of the Breathitt Formation, with abundant marine strata, was equated with the lower delta plain environments, whereas the upper Breathitt, dominated by fluvial sands, was the upper delta plain. The vertical shift in the rock record from lower to upper delta plain was attributed to increasing development of the Alleghenian orogeny and subsequent progradation of deltaic environments to the west. The alternation of coal beds, shales, and sandstones observed throughout the basin (and seen at this stop) was thought to be caused by autocyclic mechanisms such as delta switching. Therefore, according to the model, the lateral distribution of individual strata would be restricted to delta-lobe-size areas. Hence, in the broadest sense, the Mississippi delta model does not support extensive correlation of any stratigraphic unit. However, detailed geologic mapping of coal-bearing strata in the Appalachian basin has demonstrated: (1) the regional occurrence and distribution of tonsteins (volcanic ash falls) and (2) the regional continuity of coal beds in deep and surface mines. Additionally, regional subsurface mapping of specific units and marine beds utilizing thousands of logs of subsurface cores and oil and gas wells, demonstrates that the major coal beds and marine strata are widespread and may extend across the central Appalachian basin with only local interruptions. The alternation of extensive sequences of coal beds, marine strata, and fluvial sandstones across such a wide area suggests deposition on a broad coastal plain that was traversed by small shallow streams and that was subject to repeated transgressions. Also, at present, there is no thick, low-ash and low-sulfur peat forming in the Mississippi delta that could ever form an economical coal deposit (McCabe, 1984).

Sequences such as those illustrated by this site (Fig. 9.1) are typical of transitional coastal lowland and alluvial plains to shallow-marine shelves similar to those of coastal Indonesia (Cobb et al., 1989). The repeated transition from fluvial to marine conditions in the Breathitt Formation, such as seen at this stop, is interpreted to result from fluctuating Pennsylvanian sea level, which, in the Appalachian basin, generally has been attributed to a combination of regional-tectonic and glacio-eustatic control (Chesnut, 1989).

Regional Unconformity and Pennsylvanian Onlap

The Lee-Newman[Slade]-Barrier-Shoreline model of Horne et al. (1971) is a detailed example of the widely referenced (see Galloway and Hobday, 1983, Figs. 12-35) central Appalachian basin model of Ferm and Cavaroc (1969). Whereas the basin model is based largely on subsurface data, the Lee-Newman model is based on interpretations of outcrops along I-64 in northeastern Kentucky including this roadcut. The Lee-Newman model suggested that the facies relations between Mississippian and Pennsylvanian strata are such that marine offshore (Mississippian) rocks are interpreted to be laterally equivalent to shoreface and terrestrial (Pennsylvanian) rocks. This model was put forward as an alternative to the "tabular-erosional" model of earlier mappers and compilers of Carboniferous geology in northeastern Kentucky (see Fig. 1, Horne et al., 1974), in which the discontinuity of tabular units was ascribed to either intra-formational erosion or erosion at the base of the Pennsylvanian. One of the important elements of the Horne et al. (1974) thesis was that the exposures along the newly constructed I-64 allowed stratigraphic analyses of the Carbon-ferous section "with a degree of detail previously unattainable" illustrating stratigraphic relations not previously recognized. However, later stratigraphic analyses by many workers (see, for example, Dever, 1973, 1980; Ettensohn, 1980; Chesnut, 1988) reaffirmed the validity of the "tabular-erosional" model and the classical time-stratigraphic separation and superposition of the Mississippian and Pennsylvanian rocks. The two models are schematically reproduced in Figure 9.2.

The Lee-Newman[Slade]-Barrier-Shoreline model essentially maintained that no unconformity exists between Mississippian and Pennsylvanian sequences and instead that they are in facies relation with each other (Fig. 9.2B). The marine strata of the Mississippian were interpreted to be laterally equivalent to the deltaic-alluvial coal-bearing deposits of the Pennsylvanian Breathitt Formation. The quartzose sandstones of the Lee Formation were interpreted as beach or barrier bar deposits that were transitional between the marine Mississippian carbonates and terrestrial

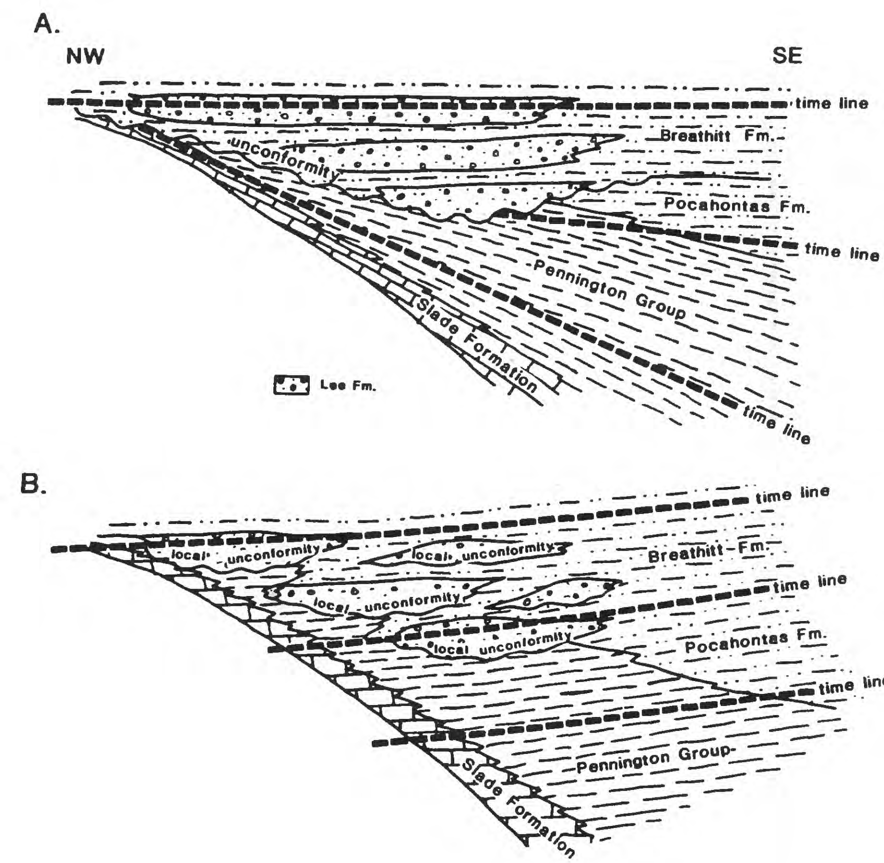

FIGURE 9.2. Schematic diagram illustrating basin models for the Carboniferous rocks of the central Appalachian basin (from Chesnut, 1988). A) Schematic diagram for the Tabular-Erosion model. At a regional scale, lithologic units tend to be wedge shaped. B) Schematic diagram for the Lee-Newman[Slade]-Barrier-Shoreline model.

Breathitt deposits. Based on this model, time lines crossed the Mississippian-Pennsylvanian boundary (Fig. 9.2B). The previous biostratigraphic framework separating the two systems was regarded as incorrect. Subsequently, the stratigraphic relations between the Mississippian and Pennsylvanian units in northastern Kentucky were shown to be unconformable based primarily on reexamination of the I-64 roadcuts (Dever, 1980; Ettensohn, 1980). Stratigraphic studies, based on basin-wide cross sections, indicate that the mid-Carboniferous regional unconformity (commonly called the Mississippian/Pennsylvanian" unconformity) reflects progressive truncation of underlying units toward the northwest margin of the basin and progressive overlap by younger Pennsylvanian units in the same direction (Fig. 9.2A) (Chesnut, 1988, in press). At the center of the Appalachian basin in parts of Virginia and southern West Virginia, erosional truncation may be absent. Here at Gregoryville near the northwest margin of the basin, most of the Paragon Formation and younger Mississipian strata as well as strata coeval with the Pocahontas Formation (Early Pennsylvanian) of Virginia and West Virginia are absent, perhaps due to erosional truncation during formation of the unconformity and subsequent exposure. (Rice does not believe that continuous deposition has been demonstrated across the Mississippian-Pennsylvanian systemic boundary in Virginia or West Virginia or that any strata equivalent in age to the

Pocahontas Formation, earliest Pennsylvanian, were ever deposited in this part of the Appalachian basin. In fact, Rice and Schwietering (1988) suggested that the exposed Mississippian rocks of this area contributed detritus southeastward into the Appalachian foreland basin in earliest Pennsylvanian time.)

At this stop, the mid-Carboniferous unconformity is marked by a paleosol at the top of the eroded Paragon Formation (uppermost Mississippian) (Fig. 9.1). Following the initial development of the unconformity, Pennsylvanian strata progressively onlapped the exposed surface toward the northwest margin of the Appalachian basin. The unconformity continued to develop throughout the Late Mississippian and the Early and Middle Pennsylvanian. The oldest Pennsylvanian strata deposited in this area were sediments derived from the local landscape, which may have included fire clays from weathered limestone or pebbly bands from Mississippian sandstones. The first onlapping strata to reach this area were part of the Breathitt or Lee Formations (here, late Early or early Middle Pennsylvanian) derived from the Appalachians in part.

Olive Hill Flint Clay

As previously discussed, the Gregoryville area was a tectonic and topographic high during the Carboniferous. The systemic boundary between Mississippian and Pennsylvanian rocks in this area is an unconformity of low topographic relief developed on Mississippian strata as old as the Borden Formation (Tournaisian, Early Mississippian) and as young as the Paragon (Pennington) Formation (Namurian A, Late Mississippian). In the Gregoryville area, in topographic lows of the unconformity, the basal Pennsylvanian rocks commonly are the Olive Hill flint clay bed (probably of latest Early Pennsylvanian age) (Ettensohn and Dever, 1979). The Olive Hill clay bed and its equivalent, the Sciotoville clay bed of southern Ohio, occur in discontinuous deposits as much as 8 m (26 ft) thick in a narrow belt 16-32 km (10-20 mi) wide, which extends from I-64 about 50 km (30 mi) southwestward and 160 km (100 mi) northeastward near and along the Cumberland Escarpment at the western edge of the Appalachian basin. Generally, north and south of Gregoryville, the flint clay bed is developed on Pennsylvanian strata and is as much as 30 m (100 ft) above the base of the Pennsylvanian northeast of Jackson, Ohio. In the Gregoryville area, the clay bed appears to have formed by pedogenic alteration of Mississippian strata and their weathering products (Smyth, 1984). However, only the lower part of the Olive Hill clay, which commonly shows features of penecontemporaneous erosion, is preserved at the base of a thin pebbly sandstone about 3 m (10 ft) below I-64 road level at the eastern end of the Gregoryville outcrop.

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STOP 10: ESTUARINE TIDAL RHYTHMITES, LOWER BREATHITT FORMATION (PENNSYLVANIAN), EASTERN KENTUCKY

by
Ronald L. Martino and Dewey D. Sanderson

Introduction

Roadcuts at Stop 10, I-64 milemarker 148.6, expose dark-gray sideritic shales, burrowed sideritic sandstones, and thin coals that are interpreted to be coastal bay, estuarine, and swamp facies similar to those seen at several previous stops. Not only are the facies very similar, but so is the stratigraphic position; the base of the section at the southwest end of the roadcut at locality 2 is about 20 m (65 ft) higher than the level of the Olive Hill clay mined 0.6 km (0.4 mi) south of the highway (Philley et al., 1975). The primary focus of this stop is a 15- to 23-m-thick (50- to 75-ft-thick) rhythmic channel fill or scour fill that displays tidally generated features including flaser and wavy current ripple bedding, bipolar paleocurrents, and cyclic thickening and thinning of mud-draped sandstone layers. A high-diversity trace-fossil assemblage is also present. Statistical analyses of variations in sand layer thickness have been used to identify a hierarchy of cycles that are interpreted to be the result of daily, fortnightly (spring-neap), monthly (lunar perigee-apogee), and 6-month seasonal (solstitial-equinoctial) variations in tidal range and associated hydraulic conditions.

Sedimentary Facies

Facies Relations

The facies present at five localities along a 2.4-km (1.5-mi), cross section trending northeast along I-64 are shown in Figures 10.1 and 10.2. This field trip stop corresponds to locality 2 in these figures.

Black Shale Lithofacies

The black shale lithofacies is as much as 7.5 m (25 ft) thick in outcrop and consists of dark-gray to black, fissile, thin-bedded to laminated clay shale to silty shale. Lenticular current-rippled sandstone is rarely present.

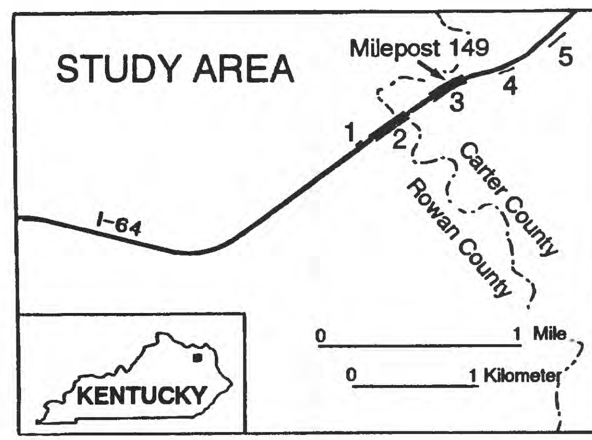

FIGURE 10.1. Location map showing 5 outcrop localities along Interstate 64 in eastern Kentucky near the Rowan-Carter County line.

Planolites and *Conostichus* are also present locally. Plant fragments are common and *Lingula* has also been reported (Short, 1979).

The shale unit fills a channel (or valley) that unconformably overlies Mississippian strata (Ettensohn, 1981). At locality 1, the shale unit is overlain by a sandy seat earth with abundant root traces. The seat earth is apparently truncated further northeast by a scour surface at the base of the rhythmic heterolithic facies.

Rhythmic Heterolithic Lithofacies

The rhythmic heterolithic lithofacies is well exposed at locality 2 (this field trip stop) and locality 3 (Fig. 10.1). A thin coal and seat earth cap the unit and occur at approximately the same elevation at localities 2 and 3 (as indicated by altimeter), whereas the basal contact deepens at least 7.5 m (25 ft) toward the northeast (Fig. 10.2). The sharp, erosional, sloping basal contact and horizontal top of the heterolithic facies reflects a wedgelike geometry that may represent partial preservation of a broad channel fill as much as 23 m

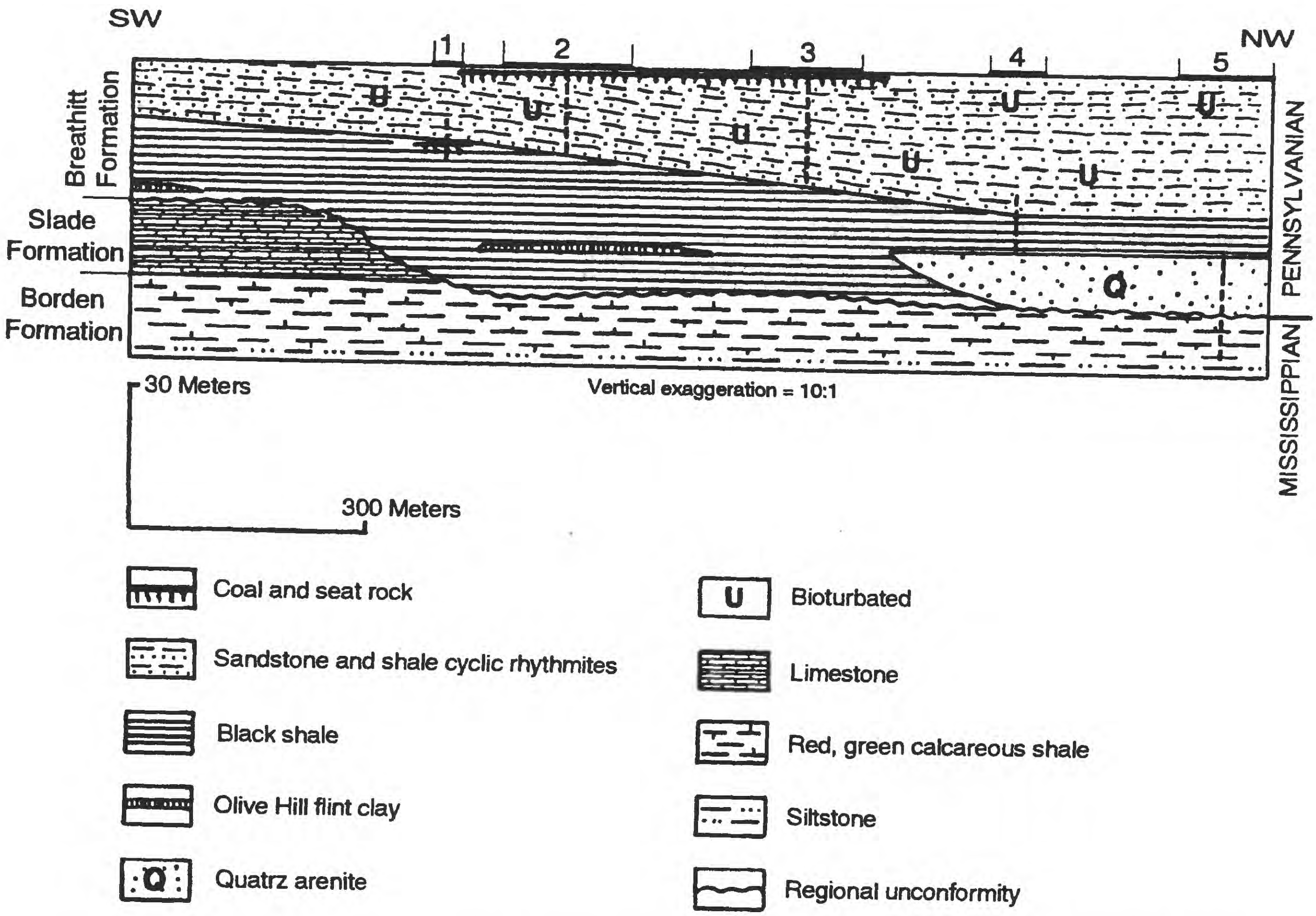

FIGURE 10.2. Schematic stratigraphic cross section along I-64 showing relations of quartz arenite, black shale, and heterolithic lithofacies of the Breathitt Formation above the regional Mississippian-Pennsylvanian unconformity. Figure is based on outcrop data from this study and data from the Soldier 7.5-min. geologic quadrangle map of Philley et al. (1975). The vertical extent of outcrops at localities 1 through5 (Fig. 10.1) is shown with vertical dashed lines. Lateral extent is indicated with tick marks that bracket each locality number. Breathitt strata above the rhythmic heterolithic facies are omitted. Figure is modified from Martino and Sanderson (in press).

(75 ft) thick. Broad channels or scours filled with bioturbated heterolithic facies are commonly incised into black shales of the lower Breathitt Formation in eastern Kentucky (Horne 1979; Greb and Chesnut, 1992). Channel depths as much as 24 m (78 ft) and widths of over 1 km (0.6 mi) have been reported. The heterolithic lithofacies consists of thinly interbedded to interlaminated, light-gray, fine-grained to very fine grained sandstone, siltstone, and minor amounts of shale. The sandstones are silty and quartzose but noticeably less mature than the quartz arenite body at the northeast end of the roadcut. Soft rock fragments and mica flakes make up about 10-15 percent of the framework grains. Shale partings are abundant and contain coarse mica and abundant carbonaceous detritus. Siderite commonly occurs as nodules and very thin beds.

Light-gray, sand-dominated intervals alternate with thinner, darker, and more organi-matter-rich sand and mud intervals (Fig. 10.3). Both the sand-dominated and sand-mud intervals are horizontally persistent for hundreds of meters across both outcrops 2 and 3. In addi-

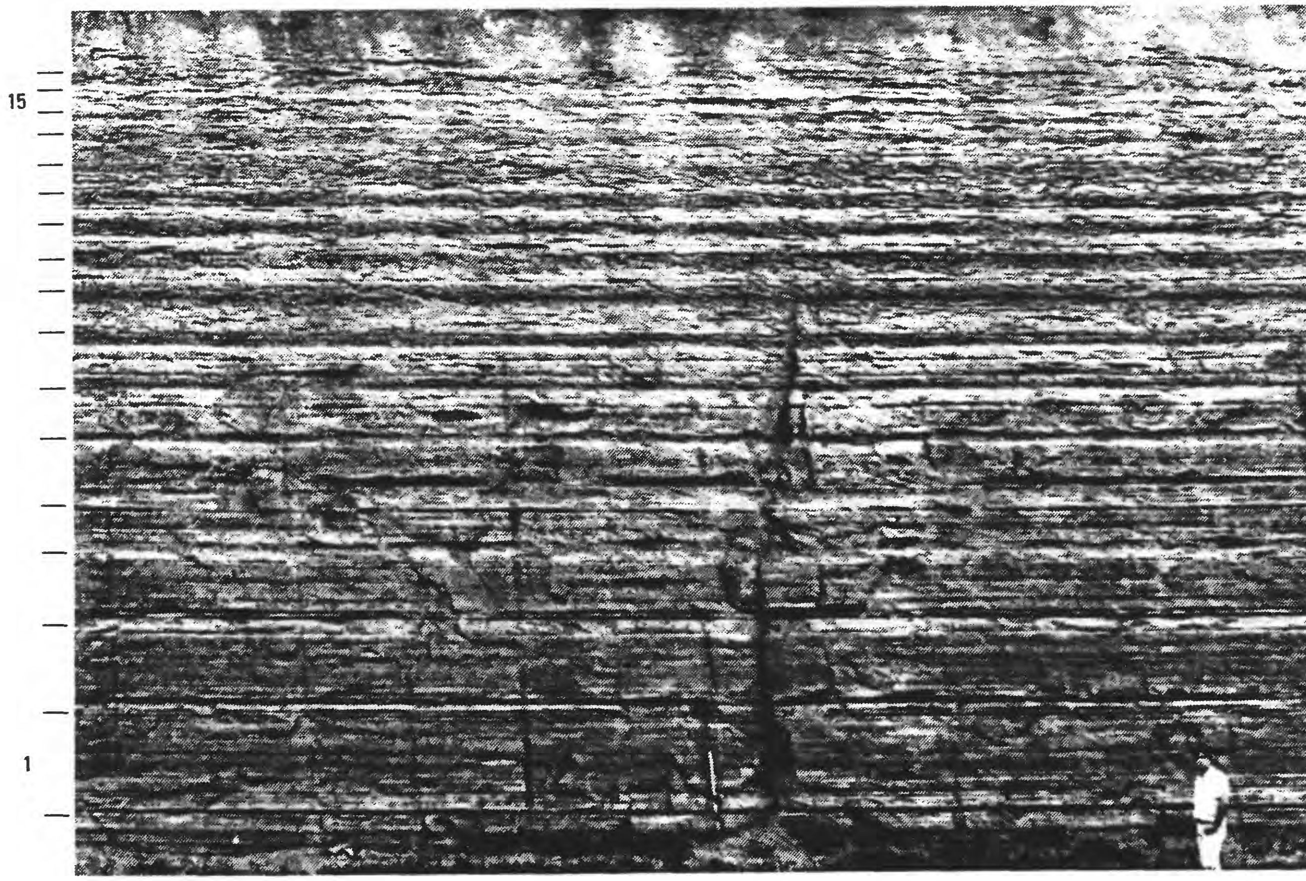

FIGURE 10.3. Outcrop at locality 2 (Fig. 10.1) with light-dark packets that repeat and thin vertically. Color banding is distinct in the upper half of the exposure, where light-gray intervals represent muddier, more carboniferous strata. In the lower half of the outcrop, the muddy, heterolithic intervals are recessed, and the sand-dominated intervals are distinguishable in this view. The midpoints of the muddy, heterolithic intervals are marked with tick marks at left margin. The rhythmic sequence is capped by a thin coal and seat earth which are shown at the top of the photo. Staff at base (center) of outcrop is 1.5 m (4.9 ft). Figure is modified from Martino and Sanderson, in press.

tion, the thickness of both light and dark intervals systematically decreases upward (Fig. 10.4), and the sand is finer grained in the upper portion (very fine) than at the base (fine).

Current ripple cross-lamination is common, particularly in the sand-dominated intervals. A compilation of paleocurrent data shows a bipolar (northeast-southwest) flow pattern (Fig. 10.5). Ripple bedding is common and includes mainly flaser varieties with subordinate wavy and rare lenticular current ripple types. Rare, medium-scale, scour-fill trough cross-stratification occurs near the base of the heterolithic facies at locality 3.

Bioturbation is extensive and exhibits an overall upward increase within the heterolithic facies. It is also more intense within the darker, more thinly layered sand and mud intervals than in the sand-dominated intervals.

Individual sand layers appear to be grouped into thick and thin bundles, which alternate in outcrop. A hierarchy of cycles of thickening and thinning is present, which is discussed further in the section on tidal cycles.

Interpretation of Depositional Environments

Black Shale Lithofacies

The black shale lithofacies contains evi-

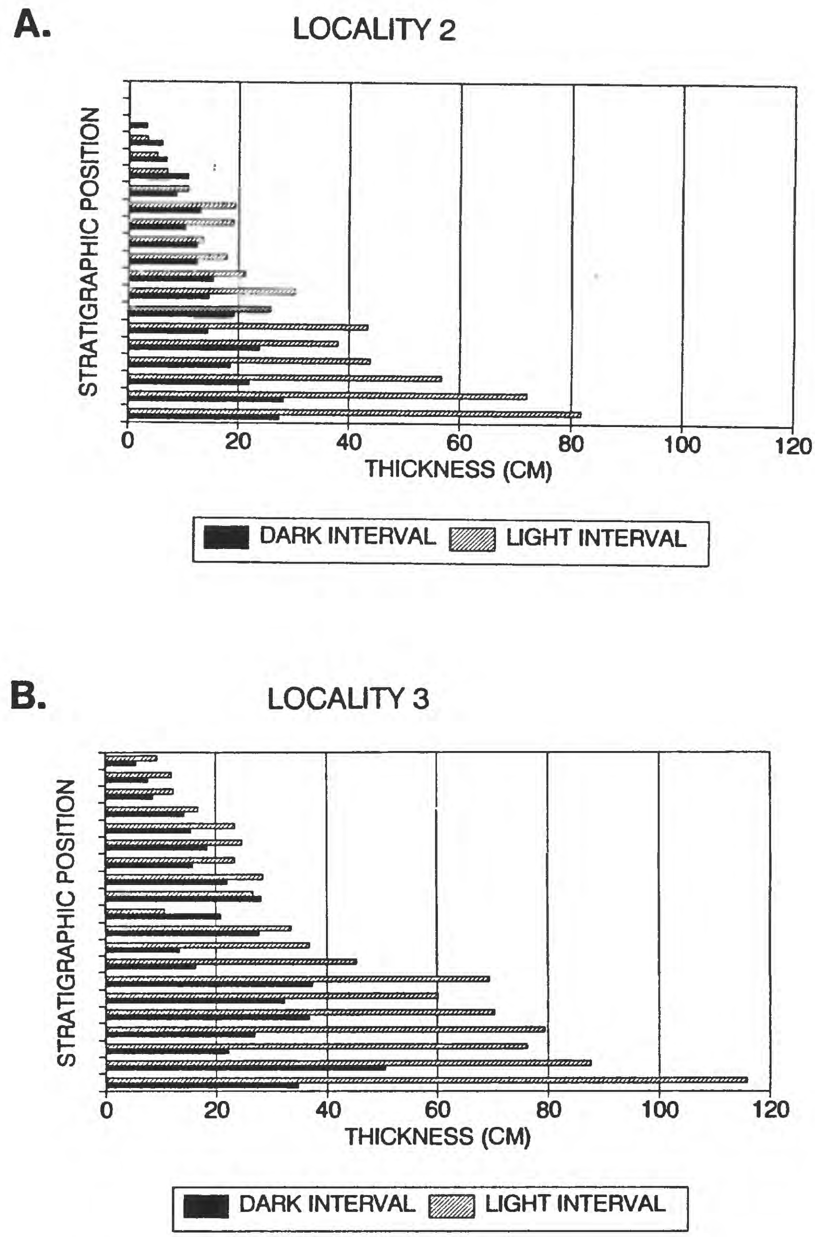

FIGURE 10.4. Graph showing vertical decrease in light-dark packet thickness within the rhythmic heterolithic facies. Dark intervals contain a greater proportion of mud while light intervals are sand dominated. Figure is from Martino and Sanderson, (in press).

dence suggesting deposition in a tidally influenced coastal setting. The occurrence of *Lingula* and *Conostichus* (anemone resting/dwelling burrow) indicates that salinity was brackish to marine. The abundance of plant detritus is consistent with nearshore deposition in a coastal embayment such as a lagoon (a restricted bay of the open ocean) or an estuary (a bay with freshwater runoff and regular tidal influence; Davis, 1983). The predominance of laminated, clay-sized sediment indicates that deposition from suspension prevailed. The fissility and dark-gray to black color and the paucity of body and trace fossils suggest that for much of the time, the environment may have been inhospitable for benthos due to limited oxygen and/or fluctuating salinity. The root-traced seat rock that locally caps the black shale lithofacies indicates that bay filling ultimately led to the development of a

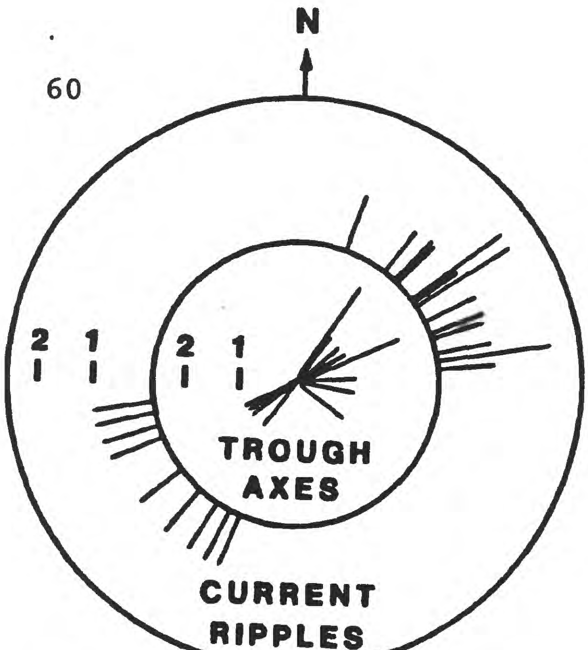

FIGURE 10.5. Spoke diagram showing paleocurrent data. Flow directions are based on ripple cross-lamination trough axes (13) and current ripple crests (26) from the heterolithic lithofacies at localities 2 and 3 (see Fig. 10.1 for locations). A bipolar pattern is developed with southwest (offshore) and northeast (onshore) modes. Figure is from Martino and Sanderson, (in press).

coastal swamp.

Heterolithic Lithofacies

The base of this facies is marked by a broad scour surface. Evidence for tide-dominated deposition during infilling of the scoured area includes (1) the close spatial and temporal association of current-generated sedimentary structures indicating a bipolar, onshore-offshore (northeast-southwest) flow; (2) the presence of flaser, wavy, and lenticular ripple bedding indicating the repeated alter-nation of weak traction transport and depo-sition from suspension; and (3) the occurrence of thick and thin bundles of mud-draped sand layers that alternate cyclically. These features and the facies relations of the heterolithic unit are comparable to those described from inshore tidal sequences (Clifton, 1982; Frey and Howard, 1986; Terwindt, 1988). The lateral continuity of bedding, the paucity of large-scale crossbedding or scour surfaces, and the abundance of burrowing make an active channel-fill origin unlikely.

Marine influence is suggested by the abundance and diversity of trace fossils. Studies of modern estuaries along the coast of Georgia indicate that bioturbation is abundant only in the lowermost reaches (Howard and Frey, 1975). The relatively high trace-fossil diversity, along with the presence of ichnogenera that are characteristically found in marine facies (examples including *Zoophycos*, *Olivellites*, *Teichichnus*), suggests that normal or near-normal marine salinity prevailed for much of the time during deposition of the heterolithic facies. The sporadic occurrence of bedded siderite may reflect sudden influx of iron-rich freshwater into more saline waters (Ferm, 1957; Woodland and Stenstrom, 1979).

The trace-fossil assemblage in the heterolithic lithofacies is dominated by the burrows of intrastratal deposit feeders (annelids: *Teichichnus*, *Asterosoma*, *Planolites*, *Chondrites*, *Scalarituba*, *Zoophycos*; gastropods: *Curvolithus*; ? arthropods: *Olivellites*; for examples, see Fig. 10.6). Subordinate burrows include resting or dwelling structures of sea anemones (*Conostichus*, *Bergauria*) and filter-feeding annelids (*Arenicolites*). This variety of ichnofacies reflects generally low energy conditions, an abundance of both sus-pended and detrital food, resource partitioning, and high preservation potential (Ekdale et al., 1984).

Bioturbated, heterolithic channel or scour fills with ripple bedding, bimodal paleocurrents, cyclic rhythmites, and similar trace fossils have been reported from other Breathitt exposures in southeastern Kentucky (Greb and Chesnut, 1992). Short (1979) interpreted the heterolithic facies in outcrops of this study as an inter-deltaic bay fill. This interpretation bears some resemblance to the estuarine environment developed here in the sense that both views involve deposition in a coastal embayment. However, Short (1979) did not recognize the dominance of tidal processes during sedimentation.

Tidal Cycles

A number of recent studies of Pennsylvanian marginal marine deposits have included spectral analysis of rhythmic bedding in tidal facies (Archer and Kvale, 1989; Kvale and

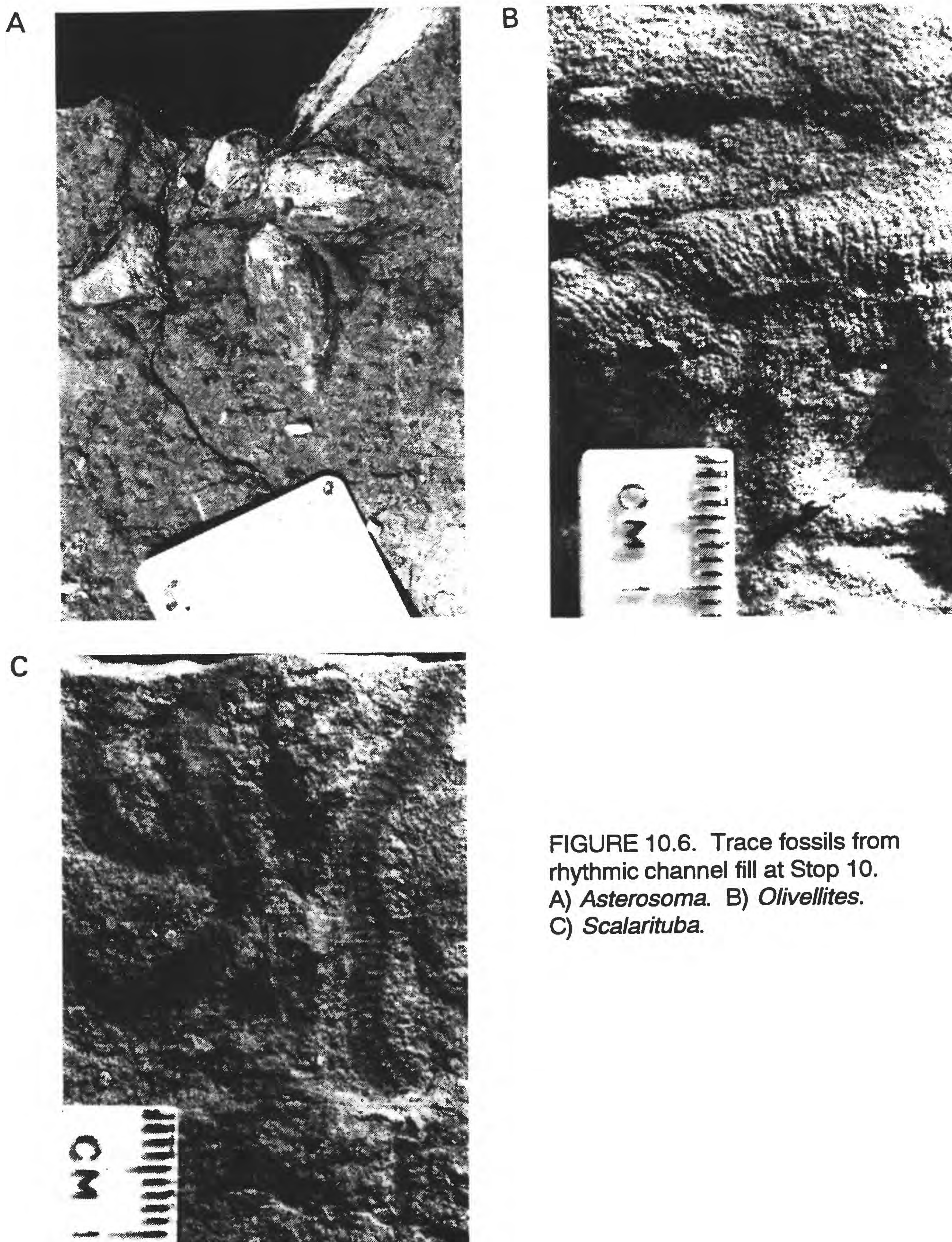

FIGURE 10.6. Trace fossils from rhythmic channel fill at Stop 10. A) *Asterosoma*. B) *Olivellites*. C) *Scalarituba*.

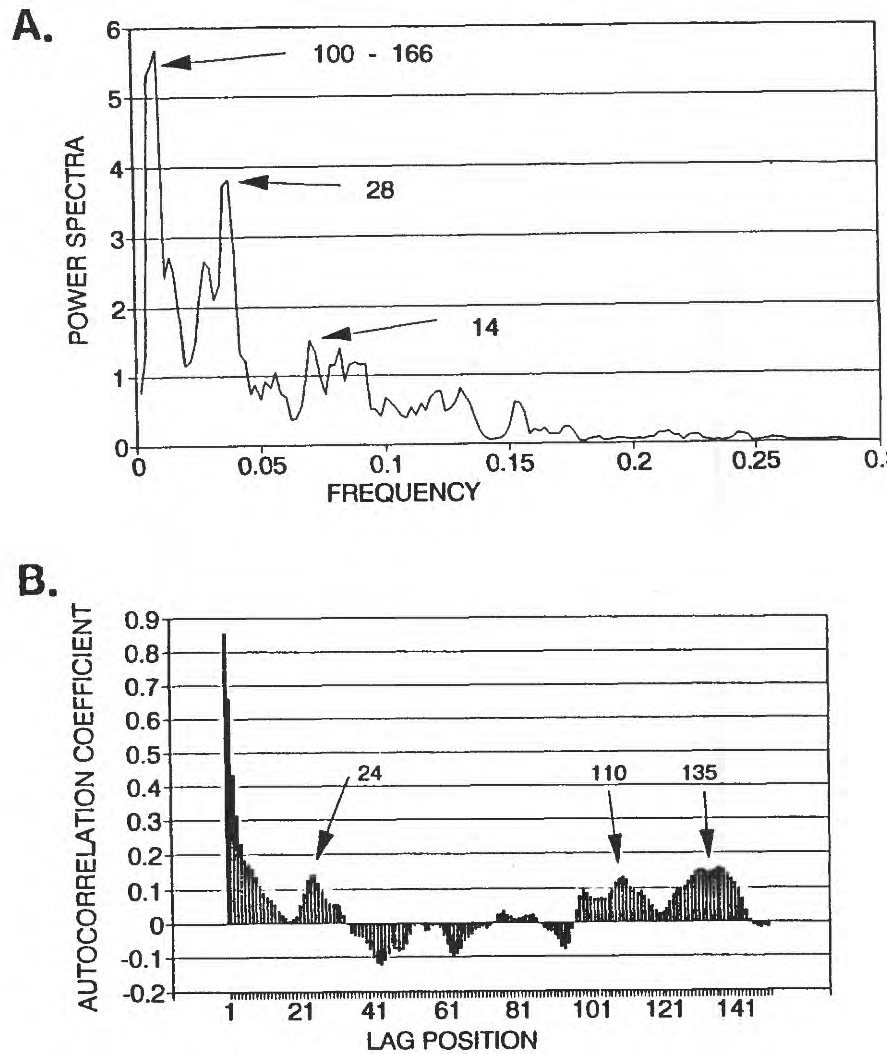

FIGURE 10.7. Statistical analyses of smoothed thickness data from locality 2. A) Power spectra analysis. B) Autocorrelation analysis. Figure is from Martino and Sanderson (in press).

Archer, 1989, 1990, 1991; Kvale et al., 1989; Keucher et al., 1990; Demko et al., 1991). We have used a similar approach to study rhythmic bedding exposed in these roadcuts.

Sand layer thickness in the heterolithic lithofacies was plotted on histograms with each layer being assigned a number based on its position in the sequence. Over 2,100 layers were recorded in situ: 1,182 at locality 2, and 931 at locality 3. The thickness data sets were smoothed and analyzed by Fourier and autocorrelation analyses to determine the presence or absence of cyclic patterns in sand layer thickness.

The results of these analyses indicate the presence of four orders of cycles embedded in the section at locality 2. There is a first-order cycle of about 2-3 layers, a second-order cycle of 11-14 layers, a third-order cycle of 24-35 layers, and a fourth-order cycle ranging from 100-166 layers (Fig. 10.7). The most plausible explanation for these cycles is that they reflect daily, fortnightly (spring-neap), monthly (lunar perigee-apogee), and seasonal (solstitial-equinoctial) variations in tidal range and associated current velocity. An idealized stratigraphic model portraying the longer cycles is shown in Figure 10.8. A smoothed data set from the lower portion of locality 2 showing interpreted tidal cycles is shown in Figure 10.9.

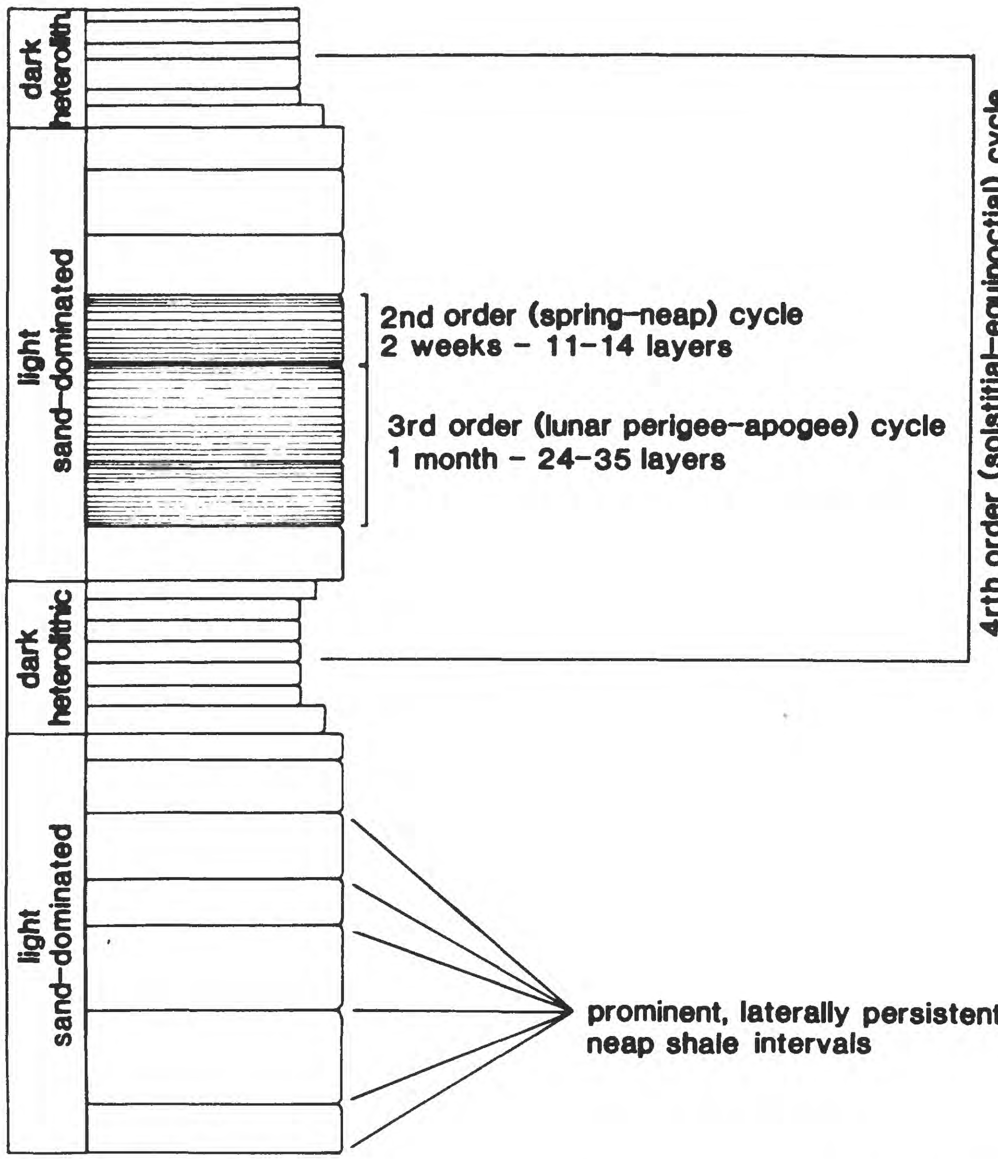

FIGURE 10.8. Idealized stratigraphic model for second-, third-, and fourth-order cycles at locality 2 (see Fig. 10.1 for location). Figure is from Martino and Sanderson (in press).

Prevailing hydraulic conditions generally resulted in the preservation of an average of one mud-draped sand layer per day, although during certain times it is likely that no sand deposition occurred for several days, and at other times that more than one layer of sand may have accumulated per day.

The first-order cycles of two to three layers and related thick- thin couplets that are locally preserved reflect tide-dominated sedimentation on a daily basis. The alternating thick-thin layering can be the result of semidiurnal or mixed tidal inequality (Archer and Kvale, 1989; Williams, 1991). They may also be the result of unequal flood and ebb events of a single tidal cycle. Our paleocurrent data indicate that both flood (NE) and ebb (SW) currents deposited sand at times during accumulation of the heterolithic lithofacies. There was no distinguishable pattern of ripple cross-laminated flood and ebb layers that could be used in conjunction with sand thickness cycles to de-

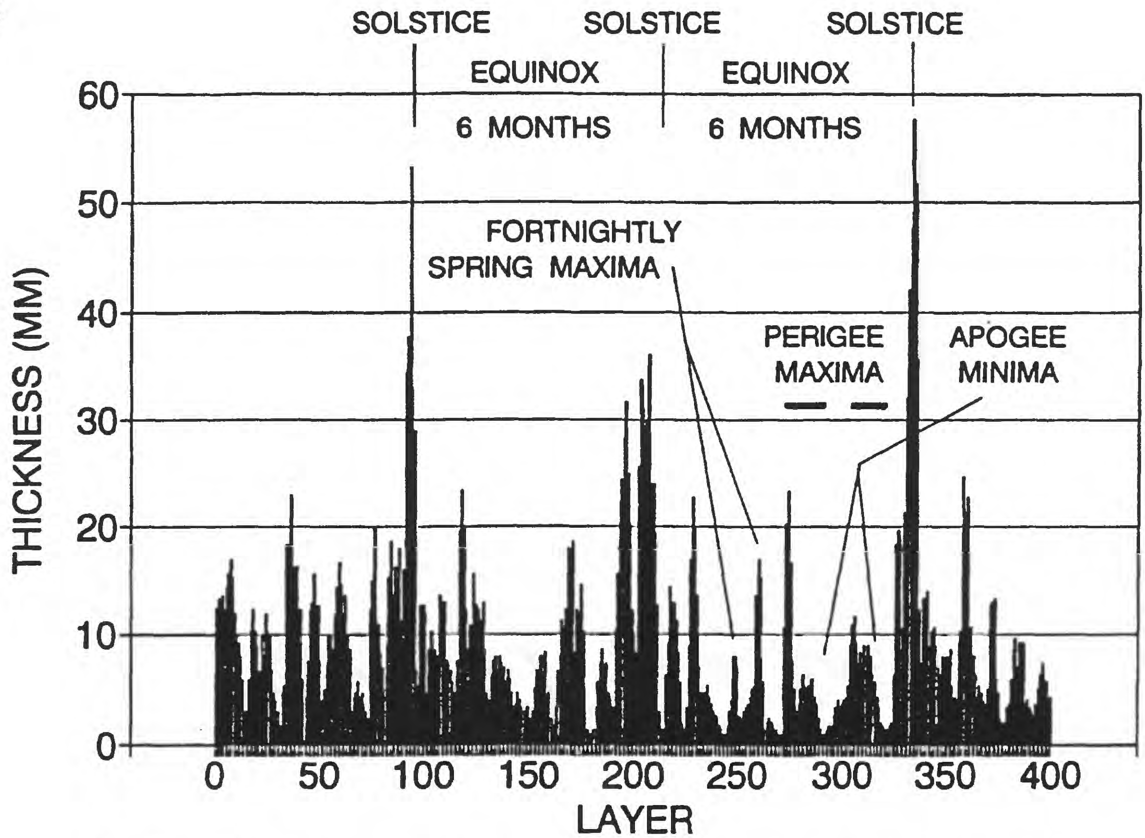

FIGURE 10.9. Histogram showing interpretation of second-, third-, and fourth-order tidal cycles from smoothed sand layer thickness data from the lower portion of the section at locality 2. Figure is from Martino and Sanderson (in press).

termine whether the system was diurnal, semidiurnal, or mixed.

Second-order cycles typically consist of 11-14 layers and reflect spring-neap variations in tidal range over approximately 14 days (Fig. 10.6). Third-order cycles typically contain 24-35 layers and reflect monthly variations in tidal range resulting from the ellipticity of the moon's orbit, with higher tides during lunar perigee and weaker tides during lunar apogee.

The longest period (fourth-order) cycles occur over a range of 100-166 layers and consist of about 150 layers. This fourth-order cycle corresponds to the light-dark packets that are so conspicuous in outcrop (Fig. 10.3). These large-scale cycles resulted from seasonal (6-month) variations in tidal range. During the summer and winter solstices (June and December), tidal range is maximized. During the spring and fall equinoxes (September and March), tidal range is reduced, and lower flow velocities result in thinner sand layers and higher preservation potential for mud drapes. Thus, the dark-gray, recessed intervals correspond to the equinoctial portions of the year.

The light-dark packets contain 12-14 prominent, laterally persistent, thin, shale-dominated intervals that correspond to neap intervals occurring over a 6-month period. They are broadly spaced during the solstices and more closely spaced during the equinoxes, reflecting faster and slower rates of seasonal deposition respectively. The occurrence of 12-14 second-order cycles between the midpoints of very recessed, gray, shaly intervals containing about 150 layers each is evident at locality 2 (Fig. 10.8). These numbers are consistent with a spring-neap interpretation for the second-order cycles.

Seasonal (6-month) cycles have also been identified within the Mansfield Formation

(Lower Pennsylvanian) of Indiana (Archer and Kvale, 1989) and the Pottsville Formation (Lower Pennsylvanian?) of Alabama (Demko et al., 1991). In the Mansfield Formation, silt laminae deposited during the dominant daily solstitial tides were twice as thick as those deposited during the equinoctial tides. Systematic variations in neap-spring cycle thickness were also identified and were based on the vertical spacing of neap zones as interpreted from core. This systematic variation is analogous to that observed for the 12-14 prominent neap shale partings that occur in light-dark seasonal packets of the Breathitt Formation. The occurrence of 12-14 of these partings per cycle suggests they are part of a seasonal pattern, whereas a higher number (about 20) per cycle in the Mansfield Formation led Archer and Kvale to interpret them as related to yearly cycles.

Our data indicate that many second-order cycles contain fewer mud-draped sand layers than would be anticipated based on deposition of one layer per day. We interpret these to be attenuated spring-neap cycles. Fewer sand layers per cycle may have resulted from amalgamation of sand layers by burrowing or erosion of interbedded mud drapes. Alternatively, during neap portions of the tidal cycle, currents may have been too weak to entrain and deposit sand.

The seasonal cycles also appear to be incomplete, probably for the same reasons. One would anticipate 180-190 sand layers per seasonal (6-month) cycle, if an average of one layer per day were typically deposited. Our statistical results indicate that 100-166 layers were deposited in a season. Notations from the field marking the centers of the dark heterolithic packets show that there are from 101-168 layers in a season at locality 2 (Fig. 10.9). The mean of seven seasons is 146 layers. On the basis of 12 layers per fortnightly cycle over a season (solstice to solstice), one would expect nearly 150 layers per season, a value in close agreement with the field average of 146 layers.

The seasonal interpretation of the light-dark packets indicates an average depositional rate of about 0.91 m/year (3 ft/year) at locality 2 and 1.32 m/year (4.53 ft/year) at locality 3. The systematic decrease in thickness of these packets upward (Fig. 10.4) indicates that the rate of sedimentation was initially faster and decreased over time. At locality 2, this rate ranged from 2.0 m/year (6.6 ft/year) at the base of the section to 0.2 m/year (0.7 ft/year) at the top of the section.

The decreasing rate of sediment accumulation is accompanied by an upward increase in the intensity of bioturbation. In an estuarine setting like that of the Salmon River-Coequid Bay, Bay of Fundy, Canada, these trends would be expected if there were a seaward shift in the estuarine system. Tidal flats along axial channels in the more headward portions of the estuary accumulate more rapidly and with relatively little bioturbation compared with those in the middle and lower portions of the estuary (Dalrymple et al., 1991).

Acknowledgements

This study was supported by a grant from the Petroleum Research Fund administered by the American Chemical Society to Martino. Helpful reviews were provided by I. Banerjee, D. Cant, and A. Archer.

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