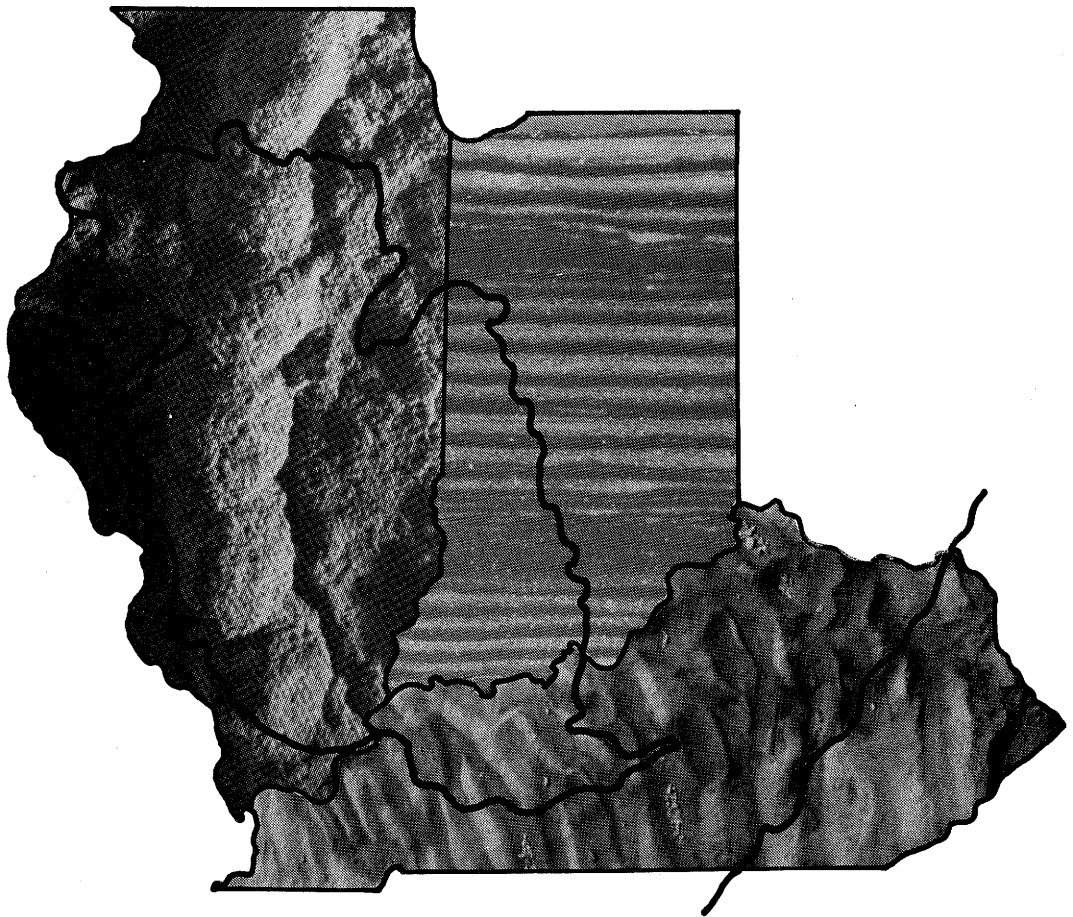


IBS 1

GEOLOGY OF THE LOWER PENNSYLVANIAN IN KENTUCKY, INDIANA, AND ILLINOIS

**JAMES C. COBB, COORDINATOR
KENTUCKY GEOLOGICAL SURVEY**



ILLINOIS BASIN STUDIES 1

published by
ILLINOIS BASIN CONSORTIUM
Kentucky Geological Survey
Indiana Geological Survey
Illinois State Geological Survey

1989

GEOLOGY OF THE LOWER PENNSYLVANIAN IN KENTUCKY, INDIANA, AND ILLINOIS

**James C. Cobb, Coordinator
Kentucky Geological Survey**

ILLINOIS BASIN STUDIES 1

**Published by
ILLINOIS BASIN CONSORTIUM
Kentucky Geological Survey
Indiana Geological Survey
Illinois State Geological Survey**

COVER ILLUSTRATION: Each state is filled in with a photograph from a paper about that state. Kentucky: ripple fan (Greb and Chesnut, p. 8); Indiana: siltstone and claystone tidal couplets (Kvale and Archer, p. 41); Illinois: trace fossil *Eiona* sp. (Devera, p. 68).

1989

CONTENTS

	Page
Preface	1
Acknowledgments	1
Introduction	2
Geology of Lower Pennsylvanian Strata Along the Western Outcrop Belt of the Eastern Kentucky Coal Field	3
Stephen F. Greb and Donald R. Chesnut, Jr., Kentucky Geological Survey	
Development of the Mississippian–Pennsylvanian Unconformity in Indiana	27
John B. Droste and Stanley J. Keller, Indiana Geological Survey	
Tectonic Implications of Regional Correlation and Formatting of the Pennsylvanian Mansfield Formation and Equivalents in the Illinois Basin	28
Lloyd G. Furer, Indiana Geological Survey	
Recognition of Tidal Processes in Mudstone–Dominated Sediments, Lower Pennsylvanian, Indiana	29
Erik P. Kvale, Indiana Geological Survey; Allen W. Archer, AzTEL, Indiana University Department of Geology	
Seasonal and Yearly Cycles Within Tidally Laminated Sediments: An Example from the Pennsylvanian of Indiana, U.S.A.	45
Allen W. Archer, AzTEL, Indiana University Department of Geology; Erik P. Kvale, Indiana Geological Survey	
Ichnofossil Assemblages and Associated Lithofacies of the Lower Pennsylvanian (Caseyville and Tradewater Formations), Southern Illinois	57
Joseph A. Devera, Illinois State Geological Survey	
The Caseyville Formation (Morrowan) of the Illinois Basin: Regional Setting and Local Relationships	84
W. John Nelson, Illinois State Geological Survey	
Core Workshop: Sedimentological Analysis and Depositional Environments of the Lower Pennsylvanian Caseyville Formation, Southern Illinois	96
C. Pius Weibel, Illinois State Geological Survey	

PREFACE

In 1989, the Illinois State Geological Survey, the Indiana Geological Survey, and the Kentucky Geological Survey formed the Illinois Basin Consortium to promote basinwide cooperation in geology, geochemistry, geophysics, and geotechnical and petroleum engineering. This agreement recognizes that the Illinois Basin, which extends into all three of the states, is an area of common interest. The participating Surveys have agreed that better understanding of the Illinois Basin is needed to ensure wise decisions regarding the use and development of the Basin's wealth of energy, mineral, and water resources.

The scope of cooperation between the three state geological surveys was set forth in a Memorandum of Understanding consisting of eight articles. Article 6 of this Memorandum encourages the publication of cooperative studies and provides for the establishment of a joint series. Other cooperative projects between the three Surveys are already underway, and findings will be published in the new series, *Illinois Basin Studies*. This collection of papers on the Lower Pennsylvanian is the first publication of the Illinois Basin Consortium.

ACKNOWLEDGMENTS

This guidebook would not have been possible without the close cooperation between the Kentucky, Indiana, and Illinois Geological Surveys. Particular thanks are due to the chiefs of these surveys, Don Haney (Kentucky), Norm Hester (Indiana), and Morris Leighton (Illinois), for encouraging this interstate effort.

Many thanks are due to the editorial staff of the Kentucky Geological Survey for editing and preparing this guidebook. Particular thanks go to Meg Smath, who supervised the publication process. Thanks also go to Bob Holladay and Roger Potts (KGS) for photographic services.

INTRODUCTION

The purpose of this guidebook is to present the results of recent research on the geology of Lower Pennsylvanian rocks in the Illinois and Central Appalachian Basins. This guidebook was prepared for the Geological Society of America Coal Geology Division field trip for the 1989 Annual Meeting in St. Louis. The preparation of this field trip and guidebook was a cooperative effort of the Kentucky, Illinois, and Indiana Geological Surveys. This guidebook reflects the great interest in the origin of Lower Pennsylvanian strata represented by the Lee and Caseyville Formations of the Central Appalachian and Illinois Basins.

There are two distinct parts to this field trip. Part one is a field excursion that explores the sedimentology of several outstanding exposures of Lower Pennsylvanian rocks on the western side of the Central Appalachian Basin. The exposures of Lower Pennsylvanian sandstones in the Central Appalachian Basin offer an exciting opportunity to observe a wide variety of sedimentary sequences, including bay fill, tidal estuary, sand flats, mouth bar, fluvial channels, mass flows, and peat swamps.

Part two is a field conference on the Illinois Basin. Many of the best exposures of Pennsylvanian rocks in the Illinois Basin have been well covered by previous field trips. The long travel times between new exposures of interest were considered unacceptable for this 3-day field trip. Therefore, new geological findings from outcrops and cores from the Illinois Basin will be brought to the field trip participants in the form of a field conference. Historic New Harmony, Indiana, which was the center of geologic research in North America in the middle of the last century, will be the backdrop for the second part of the trip. In the Illinois Basin the role of marine depositional processes in the Lower Pennsylvanian has been a major focus of research, both in Illinois and in Indiana. New and exciting findings will be discussed, including the recognition of tidal depositional processes and a greater degree of marine influence than was previously recognized. Moreover, core and trace-fossil workshops will be presented.

We hope the combination of field and conference formats will give to all the trip participants the best possible geologic experience.

James C. Cobb
Field Trip Coordinator

GEOLOGY OF LOWER PENNSYLVANIAN STRATA ALONG THE WESTERN OUTCROP BELT OF THE EASTERN KENTUCKY COAL FIELD

Stephen F. Greb and Donald R. Chesnut, Jr.
Kentucky Geological Survey
Lexington, Kentucky

INTRODUCTION

The lower part of the Pennsylvanian section of southeastern Kentucky has been the subject of intense debate. Much of the reason for conflicting interpretations of the depositional sequence is the diverse character of the facies exhibited in the section. The sequence of rocks from the Rockcastle Sandstone to the Corbin Sandstone will be examined in two different areas to highlight the diversity of facies.

STOP 1—LAUREL RIVER DAM SPILLWAY AND SPILLWAY CREEK

A recently examined exposure of Pennsylvanian sandstones in southeastern Kentucky offers a unique opportunity for both educational and scientific study. Ancient sedimentary bedforms can be examined in three dimensions in broad expanses of bedding-plane surfaces at the Laurel River Dam Spillway.

The spillway is adjacent to the Laurel River Dam in southeastern Kentucky (Fig. 1). The dam and spillway are located on the Laurel-Whitley County line in the Sawyer 7½-minute quadrangle. The spillway is on the Whitley County side of Laurel River at latitude 36°57'30" and longitude 84°16'00" (Carter coordinate location 12-F-63, 3200 FSL, 700 FEL). A creek that cuts through the spillway exposure can be followed 0.6 kilometer to the Laurel River.

Stratigraphy

The rocks exposed at the spillway and spillway creek belong to two formations of Pennsylvanian age: the Lee and Breathitt (Fig. 2). Regionally, the Lee Formation consists of a series of "clean" (greater than 90 percent) quartzose sandstones that occur as lenses (approximately 70 kilometers wide) within the Breathitt Formation (Chesnut, 1988). The Pine Creek(?) and Rockcastle Sandstones (Fig. 2)

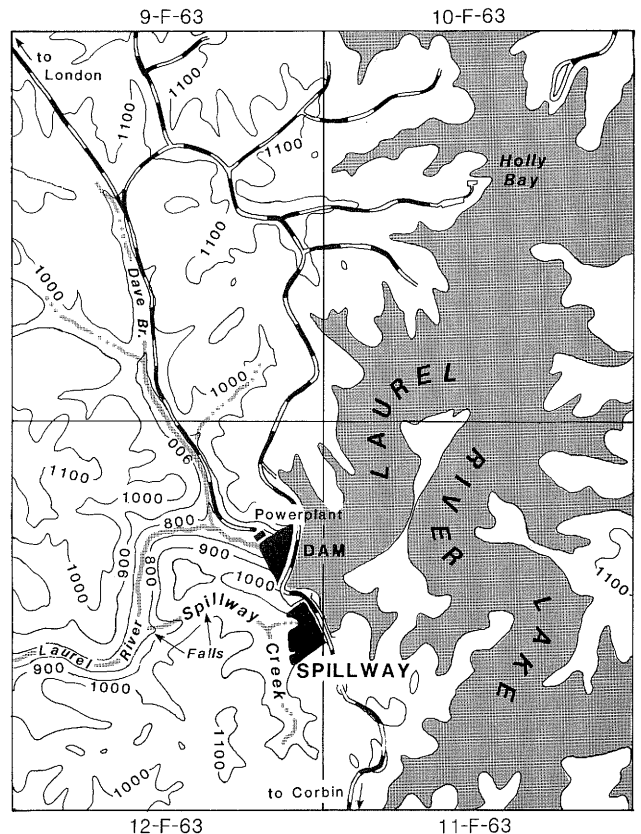


Figure 1. Location of the spillway and creek superimposed on state Carter coordinate grid (each grid is 4,800 feet x 6,000 feet).

are examples of Lee sandstones. These two units are considered parts of the Bee Rock Sandstone Member of the Lee Formation.

The Breathitt Formation is a heterogeneous unit composed of shales, siltstones, "dirty" sandstones, and coal. Most of the coal resources of eastern Kentucky occur in the Breathitt Formation. The Coal Cliff

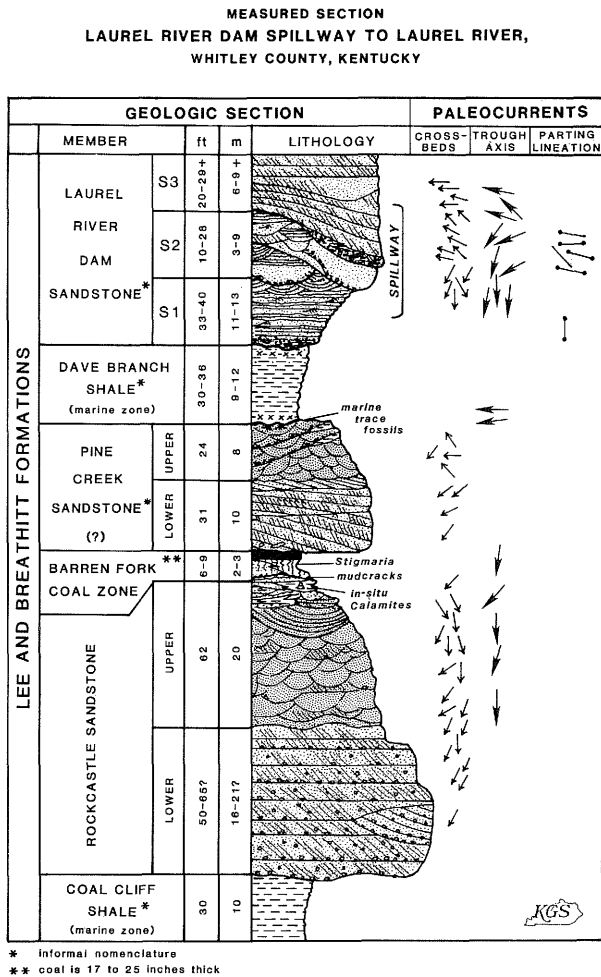


Figure 2. Geologic column for the spillway and creek.

shale, Dave Branch shale, and Laurel River Dam sandstone (Fig. 2) are all considered part of the Breathitt Formation.

The Bee Rock Sandstone of the Lee Formation is considered to be Early Pennsylvanian in age (Chesnut, 1988). The units overlying the Bee Rock are early Middle Pennsylvanian in age (Appalachian Basin terminology, Englund and others, 1979).

Spillway Creek Exposures

The spillway creek is a natural creek with bedrock exposures highlighting a section from the Rockcastle Sandstone up to the Laurel River Dam sandstone (Fig. 2). Two waterfalls occur along the creek (Fig.

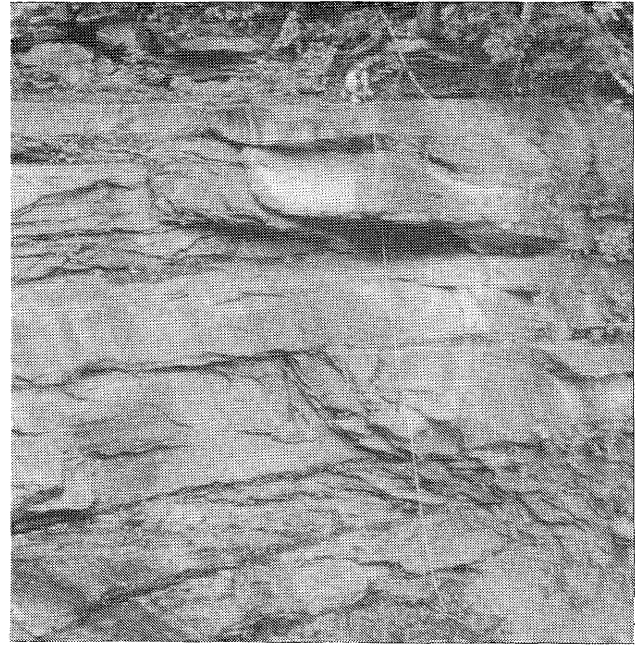


Figure 3. The Rockcastle Sandstone where the spillway creek enters the Laurel River.

1). Caution should be exercised near the waterfalls because the adjacent rocks are very slippery. Climbing is discouraged unless a rope or ladder is provided.

Rockcastle Sandstone

The Rockcastle Sandstone occurs as bluffs along the Laurel River (Fig. 3). The sandstone is 36 to 41 meters thick and consists of a lower pebbly facies (16 to 21 m) and an upper non-pebbly facies (20 m). The lower pebbly facies is medium to coarse grained, and dominated by planar-tabular and planar-wedge crossbedding with southern paleocurrents (Fig. 2). Quartz pebbles are scattered throughout the facies but are most common along coset bounding planes and foreset avalanche faces.

The upper, non-pebbly facies is transitional with the lower pebbly facies. The sandstone is fine to medium grained, with trough crossbedding becoming more common up-section (Fig. 2). Crest lines of foreset avalanche faces show marked curvature. Overturned crossbeds are common. A giant set of cross strata with shallow-dipping foresets occurs

near the top of the unit (Fig. 4). The top of the Rockcastle Sandstone is marked by a series of abandoned trough crossbeds oriented unimodally to the south with mudcracks on surfaces lateral to the

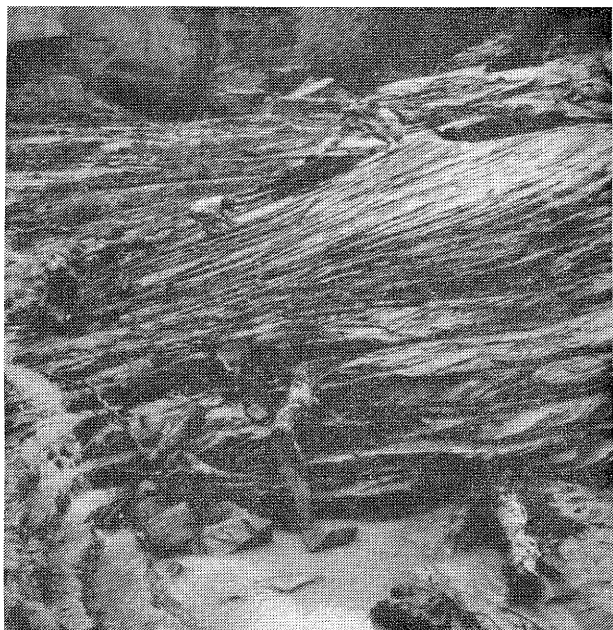


Figure 4. Large macroform in the upper Rockcastle Sandstone, Spillway Creek.

troughs. One of the troughs is filled with black shale containing in-situ *Calamites* (Fig. 5). A reptile trackway with tail drag was discovered in mudcracked sandstone at the top of the Rockcastle Sandstone about 23 kilometers southwest of this locality (Fig. 6).

Barren Fork Coal

The Rockcastle Sandstone is overlain by 2 meters of underclay and a 1-meter-thick coal called the

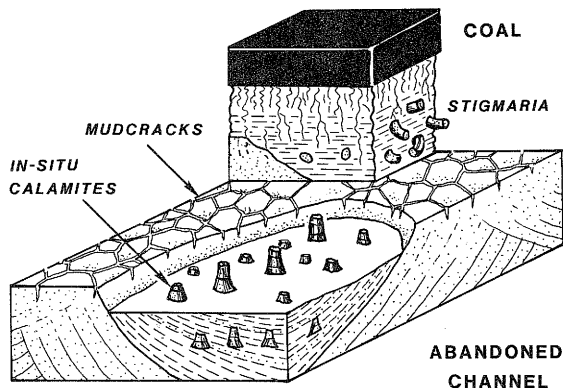


Figure 5. Upper surface of the Rockcastle Sandstone, Spillway Creek.

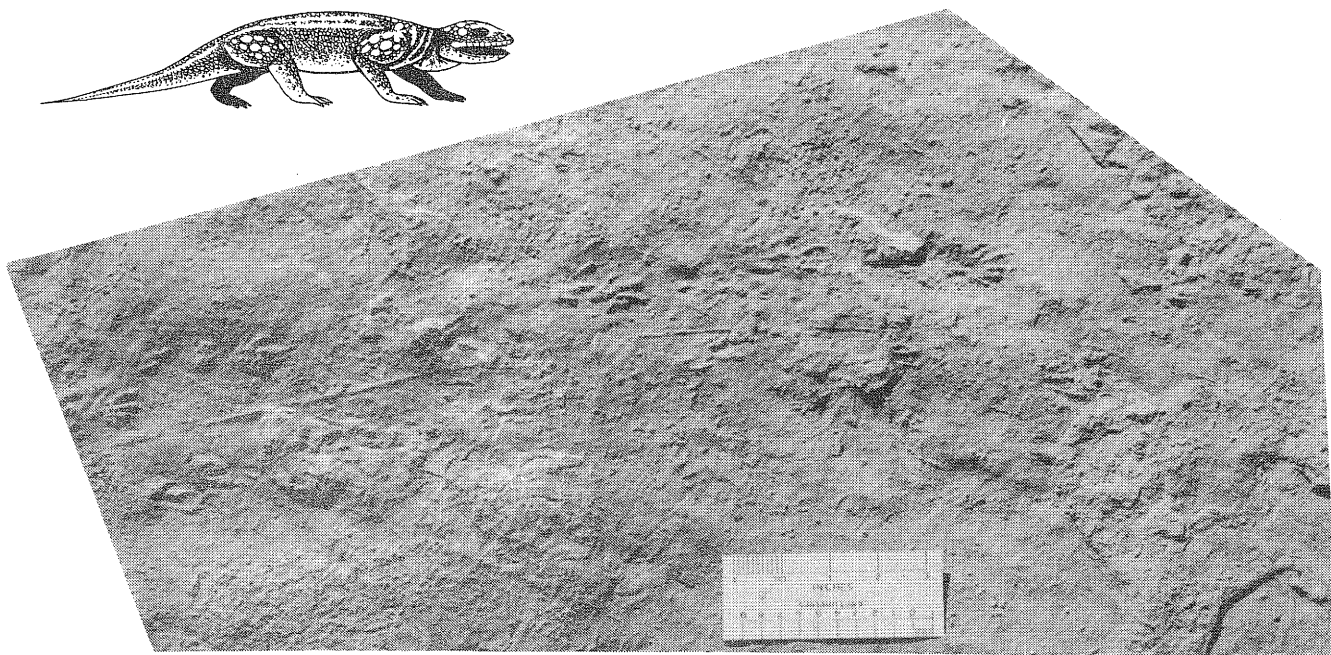


Figure 6. Reptile trackway from the upper surface of the Rockcastle Sandstone in McCreary County. This trackway may be the oldest evidence of reptilian life in the world.

Barren Fork coal (Fig. 2). *Stigmaria*, the fossilized roots of lycopod trees, are preserved on the top of the coal. This coal has been strip and drift mined in this and adjacent counties.

Sandstone 1 (Pine Creek Sandstone?)

The second thick sandstone in this section is informally correlated to the Pine Creek sandstone of Chesnut (1988). This sandstone also consists of a lower and upper facies (Fig. 2). The lower sandstone is 10 meters thick, medium grained, thin to medium bedded, with planar crossbedding dipping to the south and southwest. Two accretionary packets of shallow-dipping, planar-crossbedded (epsilon type) sandstone occur in the lower sandstone.

The upper sandstone consists of a series of channel-form packages dominated by trough crossbedding and structureless sandstone above scour surfaces, with planar crossbedding and current-ripple laminations more common vertically. Channels show fining-upward characteristics. Like the underlying Rockcastle Sandstone, the upper surface of the Pine Creek(?) sandstone is characterized by abandoned troughs. However, the sandstone contains no mudcracks. Also, it is overlain by a black shale rather than a coal (Fig. 7).

Dave Branch Shale

The Pine Creek(?) sandstone is overlain by 9 to 12 meters of black shale informally named the Dave Branch marine zone (Chesnut, 1988). The shale appears to fill abandoned troughs in the top of the sandstone, and is characterized by a surface of high-abundance, low-diversity trace fossils (*Zoophycos* and *Rhizocorallium*; Fig. 8) and a thin

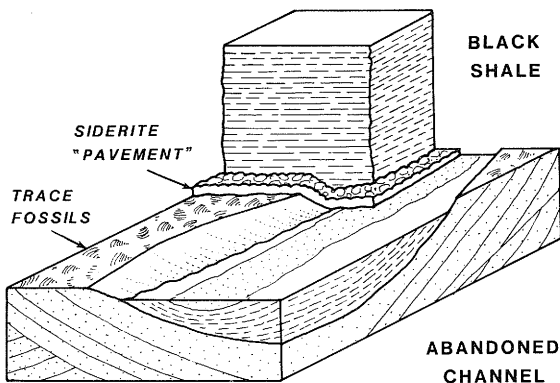


Figure 7. Upper surface of the Pine Creek(?) sandstone, Spillway Creek.

siderite pavement (Fig. 7). The shale is considered the base of a coarsening-upward sequence that is capped by three distinct sandstone facies.

Laurel River Dam Spillway Sandstones

The bedding-plane exposures of the spillway were analyzed by laying out 50-foot grids across the entire exposure. Each 50-foot grid was subdivided into 10-foot grids. In each 10-foot grid the sedimentary structures were mapped and described (Fig. 9).

Mapping of the sandstones at the spillway indicated three distinct lithofacies. A block diagram of the spillway shows their gross geometries (Fig. 10).



Figure 8. *Zoophycos* trace fossil, upper surface of the Pine Creek(?) sandstone, Spillway Creek.

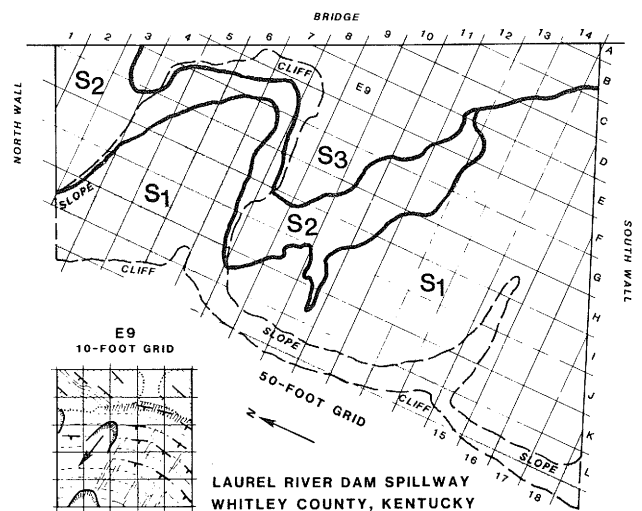


Figure 9. Map of spillway showing the distribution of three facies (S1, S2, S3) and general topography (stipple pattern is slope, white is essentially flat lying).

The lower sandstone is designated facies S1. It consists of silt to very fine-grained sandstone. Facies S1 is largely sheet form and can be traced across the spillway. The middle sandstone is designated facies S2. It consists of silt to fine-grained sandstone. Facies S2 consists of multiple, irregularly distributed channels and lateral sheet-form deposits. The upper sandstone is designated facies S3. It is fine- to medium-grained sandstone. Facies S3 occupies an apparent channel that is 115 meters wide.

Facies S1

Facies S1 is 11 to 13 meters thick. The basal contact with the underlying black shale is sharp (although thin lenses of S1-like siltstone occur in the upper meter of shale), with abundant plant debris in the lower meter of sandstone. The lower 6 meters of this facies are dominated by thin-bedded, very fine-grained sandstones and siltstones. These beds are arranged in micro-coarsening-upward and micro-thickening-upward intervals. Each interval is 15 to 40 centimeters thick and consists of wavy to non-parallel (approaching flaser) laminations in siltstone and very fine-grained sandstone, passing upwards into discontinuous, even- to wavy-parallel, laminated to thin-bedded sandstone. Asymmetric current ripples are the dominant sedimentary structures (Fig. 11a), although thin cosets of planar and trough

crossbedding are also common. Paleocurrents are to the south, although there is considerable spread in measurements. In rare cases, ripples are oriented down the stoss sides of small-scale crossbeds.

The upper 5 to 7 meters are dominated by trough crossbeds (Fig. 11b). Troughs are up to 6 meters across, 16 meters in length, and less than a meter in thickness. The troughs are obliquely filled and often have well-developed ripple fans preserved in scours on lee foresets (Fig. 11c). Reactivation surfaces are common. Orientation of trough axes is unimodal to the south, whereas ripple fans and current ripples on adjacent sheet-sands exhibit western paleocurrent directions (Fig. 12).

Facies S2

Facies S1 is truncated by facies S2. Rounded shale pebbles (many of which are "sideritized") and pebble imprints characterize the scour surface (Scsh, Fig. 10). Facies S2 consists of structureless fine-grained sandstone lenses (up to 30 meters in width) encapsulated by sheet-form, even- to wavy-parallel, thin-bedded to laminated siltstone and very fine-grained sandstones. Sheetform sandstones are dominated by upper-flow-regime structures such as parting lineations and washed-out ripples (Fig. 11d). A well-preserved clay plug occurs near the top of

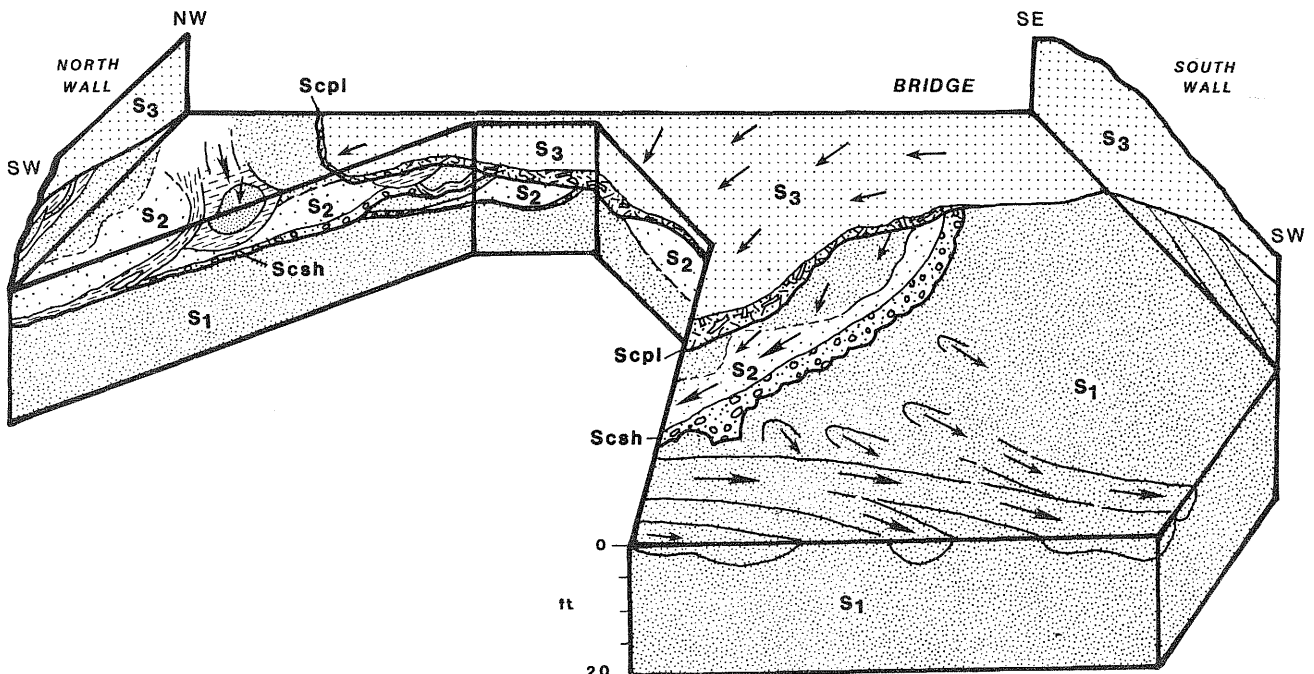


Figure 10. Block diagram of spillway showing geometry of the three sandstone facies (no horizontal scale).

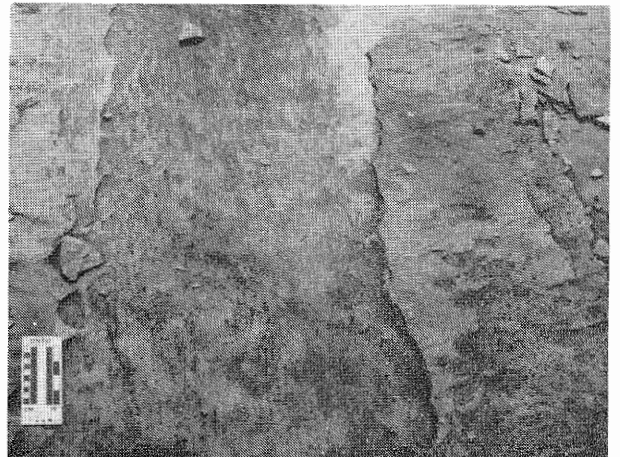
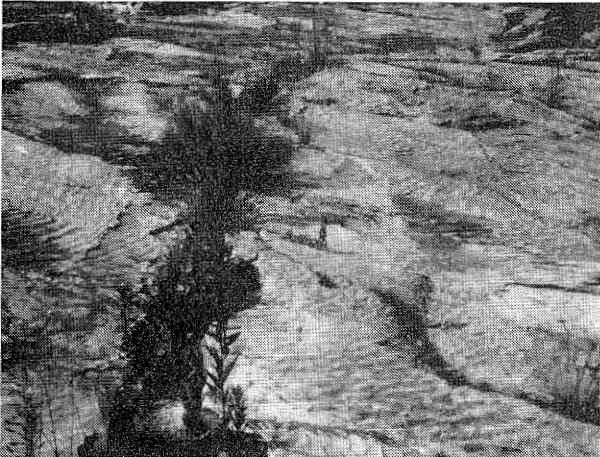
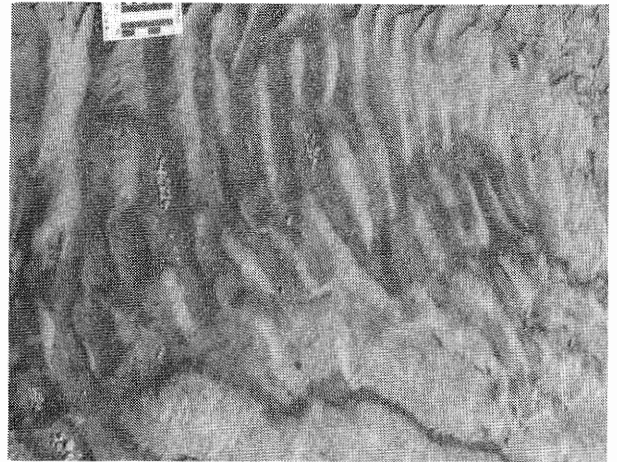
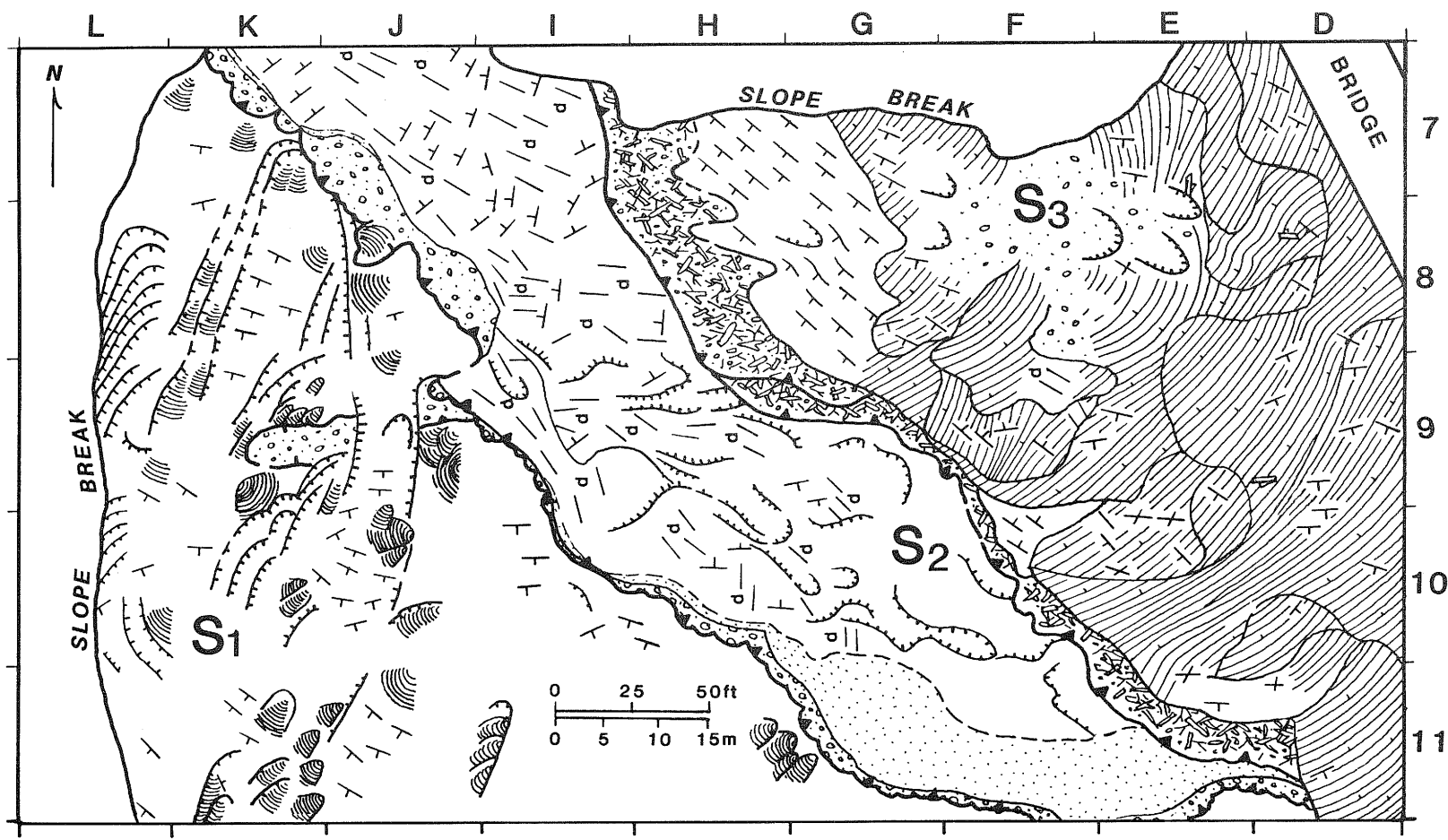












Figure 11. Photographs of the spillway: (a) linguoid (nearly rib and furrow) ripples, facies S1, (b) parallel troughs with superimposed ripple fans, facies S1, (c) ripple fan, facies S1, (d) parting lineations and washed-out ripples, facies S2, (e) clay plug (arrow), facies S2, (f) planar crossbeds, facies S3.



- | | | | |
|---|--|---|-------------------------|
|  | PLANAR CROSSBEDS, FORESET STRIKE AND DIP |  | STRUCTURELESS SANDSTONE |
|  | TROUGH CROSSBEDS, FORESET STRIKE AND DIP |  | PLANT-DEBRIS LAG |
|  | CURRENT RIPPLE STRIKE AND DIP |  | SHALE-PEBBLE LAG |
|  | INTERFERENCE RIPPLE STRIKES |  | PRIMARY SCOUR SURFACE |
|  | PARTING LINEATION STRIKE |  | RIPPLE FANS |

**LAUREL RIVER DAM
SPILLWAY (SOUTH)**

Figure 12. Detailed map of southern part of the spillway showing distribution and orientation of sedimentary structures.

the unit (Fig. 11e). Paleocurrent indicators trend to the southwest (Fig. 12).

Facies S3

Facies S2 is truncated by facies S3. Facies S3 is distinctly channelform (Fig. 10). The basal scour is characterized by a plant-debris lag that can be traced across much of the channel. The sandstone is fine to medium grained and dominated by planar crossbedding (Fig. 11f). Paleocurrent direction indicators trend to the west (Fig. 12). Planar crossbeds are separated by tabular (even-parallel), set-bounding surfaces exhibiting shale-pebble lags (Fig. 13). Foresets often exhibit parting lineations (Fig. 13). Low-amplitude, straight-crested ripples (at an oblique angle to crossbeds) also are preserved along set-bounding surfaces. Interference ripples occur along bounding surfaces of wedge-planar crossbeds along the southern margin of the channel (Fig. 12).

Interpretations

The origin of the Lee Formation is a topic of much controversy. Barrier bars, tidal channels, marine straits, and fluvial environments have been suggested (Ferm and others, 1971; Bement, 1976; Rice, 1984; Chesnut, 1988). Subsurface studies show that the sandstone lenses of the Lee are belt-shaped bodies of sandstone (Chesnut, 1988). These sandbelts, about 70 kilometers (50 miles) wide, are oriented to the southwest. Crossbed analysis also indicates an average paleocurrent flow to the southwest.

The Rockcastle Sandstone exhibits a scoured base and fining-upward grain sizes. Recent studies

suggest fluvial (tributary and distributary) origins for these sandstones (summarized in Chesnut, 1988). The unimodal paleocurrents, coarse grain size, abundant pebbles, and dominance of planar and trough stratification suggest that the Rockcastle rivers may have been low-sinuosity streams (Smith, 1970; Miall, 1978; Rust, 1978; Galloway and Hobday, 1983). Bedding architecture at the Laurel River exposure is similar to features interpreted as crossbedded simple bars (Allen, 1983) or transverse bars (Smith, 1970). A giant crossbed set near the top of the unit (Fig. 4) is only partially exposed, but undoubtedly represents part of a larger macroform. It may be part of a compound bar that had a relatively straight crest line, similar to bars described by Allen (1983). Avulsion of the Rockcastle rivers from this area, disconnection from a tectonic source area, a eustatic rise in sea level, or some combination of the three, resulted in abandonment and exposure of the channels (mudcracks) and the subsequent accumulation of a peat swamp (Barren Fork coal).

The Pine Creek(?) sandstone represents renewed detrital influx into the area. The sandstone is finer grained and has a different sequence of sedimentary structures than the Rockcastle. At least two lateral accretions of bar macroforms are indicated by the scale of shallow-dipping accretion surfaces in the lower part of the sandstone. Rather than braided or anastomosing streams, the Pine Creek in this area may represent distributary deposition. The vertical sequence is similar to other Carboniferous sandstones described as distributary channel bodies (Cobb and others, 1981; Chesnut and others, 1986; Fielding, 1986).

Abandonment of the channels is indicated by the trace fossils and siderite at the contact between the Pine Creek(?) sandstone and Dave Branch shale. The shales are black, organic rich, and barren of fossils (except for the trace fossils at the base) and were probably deposited in a brackish-water inland sea. Shallow, anoxic conditions may be indicated by the high-abundance/low-diversity traces (Ekdale and Mason, 1988). Estuarine conditions are inferred as the underlying channels were flooded by the sea.

Because the lateral relationships of the Laurel River Dam Spillway sandstones are not well understood, interpretations of the depositional history are still tentative. In general, the coarsening-upward section at the spillway suggests a deltaic origin.

Facies S1, with its lower flow regime structures and sheet-form deposition, suggests the accretion of a sand flat into a brackish bay. Similar vertical

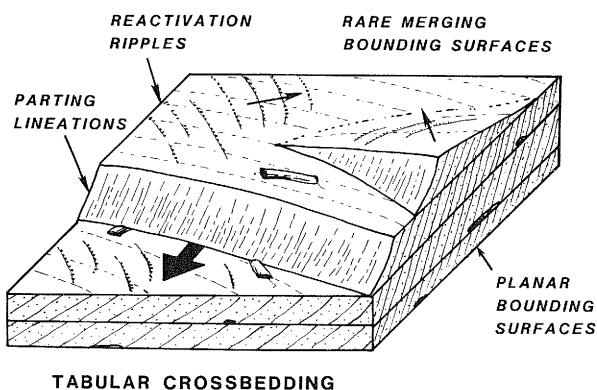


Figure 13. Block diagram of typical sedimentary structures in facies S3.

sequences have been interpreted as mouth-bar deposits (Farquharson, 1982). The micro-coarsening-up and micro-thickening-up intervals record periodic fluctuations in flow power, and suggest shallow-water deposition. The vertical change in facies S1, from ripple- to dune-field sedimentation, may record a shift from distal to proximal positions on the sand flat. Obliquely filled troughs and ripple fans in the upper part of facies S1 indicate that stream flow was separated obliquely to the face of migrating dunes (Allen, 1984). Ripple fans can occur in many environments, but many modern examples are recorded in tidally influenced estuaries (Knight and Dalrymple, 1975; Allen, 1984). Scattered reactivation surfaces, flaser laminations, and ripples that appear to migrate down the stoss sides of megaripples or small dunes may indicate microtidal reworking of the deposits (Reineck and Singh, 1980). But the fact that many of these features can be attributed to changes in flood stage, and interaction of bedforms, as well as reversals in flow direction (McCabe and Jones, 1977; Allen, 1984), coupled with the lack of bioturbation, the lack of recordable cyclicity (Kvale and Archer, this volume), unimodal paleocurrent indicators, and asymmetric bedforms, imply that facies S1 was fluviially dominated.

Facies S2, with its upper-flow-regime structures and multiple channels, suggests multiple flooding events: possibly minor crevasse channels or distal feeder channels (Elliot, 1974; Fielding, 1986) with southwestern orientations. The small scale and structureless nature of these sand bodies suggest "event" channels rather than "maintained" channels. Abandonment of some channels is indicated by the clay plugs at the top of the unit.

Finally, facies S3 may record the avulsion of a minor distributary channel with a slightly more western orientation, similar to the avulsions of minor distributaries on modern deltas (Elliot, 1974; Saxena, 1976). Tabular crossbedding may indicate the migration of sand waves (Harms and others, 1975). Exposed foreset traces indicate sand waves were arcuate and continuous across the channel. Multiple fluctuations in flow stage within the channel are indicated by the sequences of planar crossbeds (dune field/lower-flow regime) to sharp bounding planes and parting lineations (flat bed/upper-flow regime), to ripples (ripple field/lower-flow regime).

STOP 2—BILLOWS ROADCUTS, LAUREL AND PULASKI COUNTIES

The spillway section highlighted the sequence of rocks from the Rockcastle Sandstone to the Laurel River Dam Spillway sandstone (stratigraphically beneath the Corbin Sandstone). The same stratigraphic interval is exposed along Kentucky Highway 80 in the Billows Quadrangle (Hatch, 1963). The Billows roadcuts are exposed for about 10 kilometers on either side of the Rockcastle River in Laurel and Pulaski Counties (Fig. 14).

Westward from London, the Corbin Sandstone forms a flat, upland plain. The Corbin is the pink, trough-crossbedded sandstone in the small roadcuts west of the London exit. As Highway 80 nears the Rockcastle River, the section beneath the Corbin is exposed and the topography becomes more dissected.

The Corbin is underlain by a black shale, which in turn is underlain by a unit informally called the Hazel Patch sandstone (Chesnut, 1988). The Hazel Patch is also underlain by a black shale (Fig. 14). Sequences of black shale and quartzose sandstones are common beneath the Corbin. The Hazel Patch and underlying shale are at the same position beneath the Corbin as the Laurel River Dam Spillway sandstone and Dave Branch shale. However, the total thickness of the interval between the Rockcastle and Corbin Sandstones differs between the two localities. Rather than stratigraphic equivalence of sandstone "layers" and shale "layers," there is probably significant lateral and vertical facies distribution. More work is needed to work out correlations between the two areas. Hence, lithologic units between the Rockcastle and Corbin are designated numerically (Fig. 14).

Hazel Patch Cuts

Sandstone Zone 3—Hazel Patch Sandstone

The third sandstone above the Rockcastle Sandstone in the Billows area (SS3) is tentatively correlated to the Hazel Patch sandstone (Figs. 14–15). The sandstone is bounded above and below by black shale. The basal contact is sharp, with abundant fossilized logs. The lower 25 feet (7 meters) of the Hazel Patch is fine grained and contains planar- and trough-crossbedded sandstones interbedded with ripple-laminated sandstones that grade into shal-

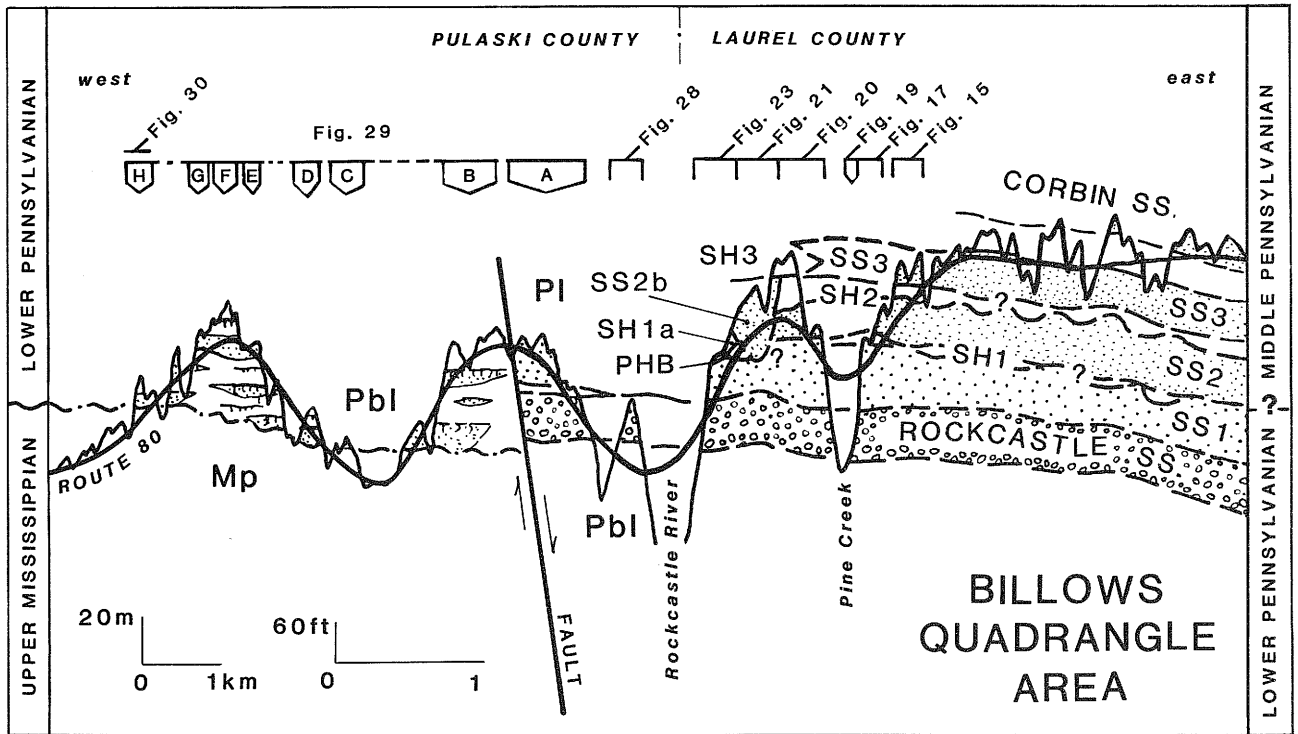


Figure 14. Cross section along Kentucky Highway 80 near the Rockcastle River, showing geologic units and location of sections discussed in this field guide.

low-dipping (2 to 5°), accretionary sandstones in the western cut (Fig. 15). The upper 50 feet also exhibit cosets of accretionary bedding. Accretion surfaces dip to the west. Trough crossbeds show southwestern orientations (220 to 255°), although rare northern dips (357 to 5°) were also noted.

The shallow-dipping accretion surfaces suggest westward migration of large macroforms such as fluvial bars or mouth bars (Reineck and Singh, 1980; Galloway and Hobday, 1983). The position of the sandstone above a black shale suggests shoreline conditions, possibly favoring a mouth-bar (or series of small mouth bars) interpretation. Also, tentative correlation of the Hazel Patch with shale zone 3 on the Sideroad cut (Fig. 16) suggests rapid lateral facies change into brackish or marine shales, which supports a mouth-bar environment of deposition.

Shale Zone 2a

The black shale beneath the Hazel Patch sandstone is 10 to 25 feet (7 meters) thick and fills two channel-form scours (Fig. 17). The scours are underlain by a leached zone. Small-scale slumping and deformation are common immediately beneath

the scour surface. The scours are overlain by black shales and siltstones. Siltstones are ripple and flat laminated and exhibit crude rhythmic bedding. *Skolithos* and *Zoophycos* trace fossils are common. The laminated siltstones thin along the edges of the easternmost scour and thicken into the scour. The siltstone is overlain by two 8- to 12-inch siderite bands that contain rare articulate brachiopods.

Black shales are deposited in low-energy, often anaerobic conditions not often associated with scour formation. They are commonly associated with bay-fill sequences in Carboniferous rocks (Elliott, 1974; Cobb and others, 1981; Amig, 1988; Chesnut, 1988). The scours were probably cut by small channels and then abandoned before shale deposition. Subaerial exposure prior to channelization is indicated by the leached zone and deformation below the scour. The abundant trace fossils and brachiopods suggest marine and brackish-water conditions. The rhythmically bedded siltstones may be similar to tidal deposits described by Kvale and Archer (this volume). In general, these black-shale-filled channels with siltstones probably indicate estuarine sedimentation.

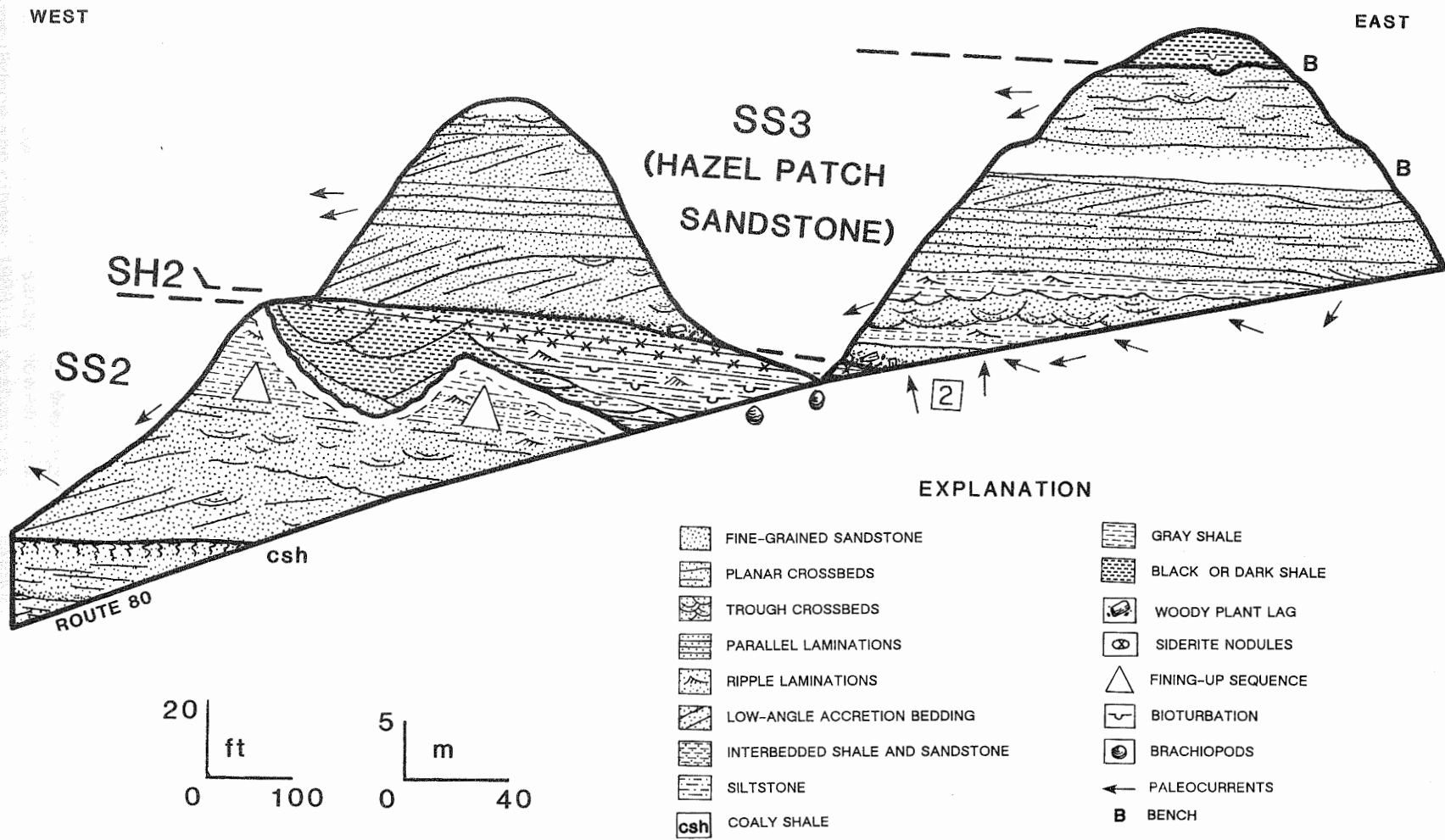


Figure 15. Hazel Patch roadcut section at mile marker 2. Sections along north side of the road.

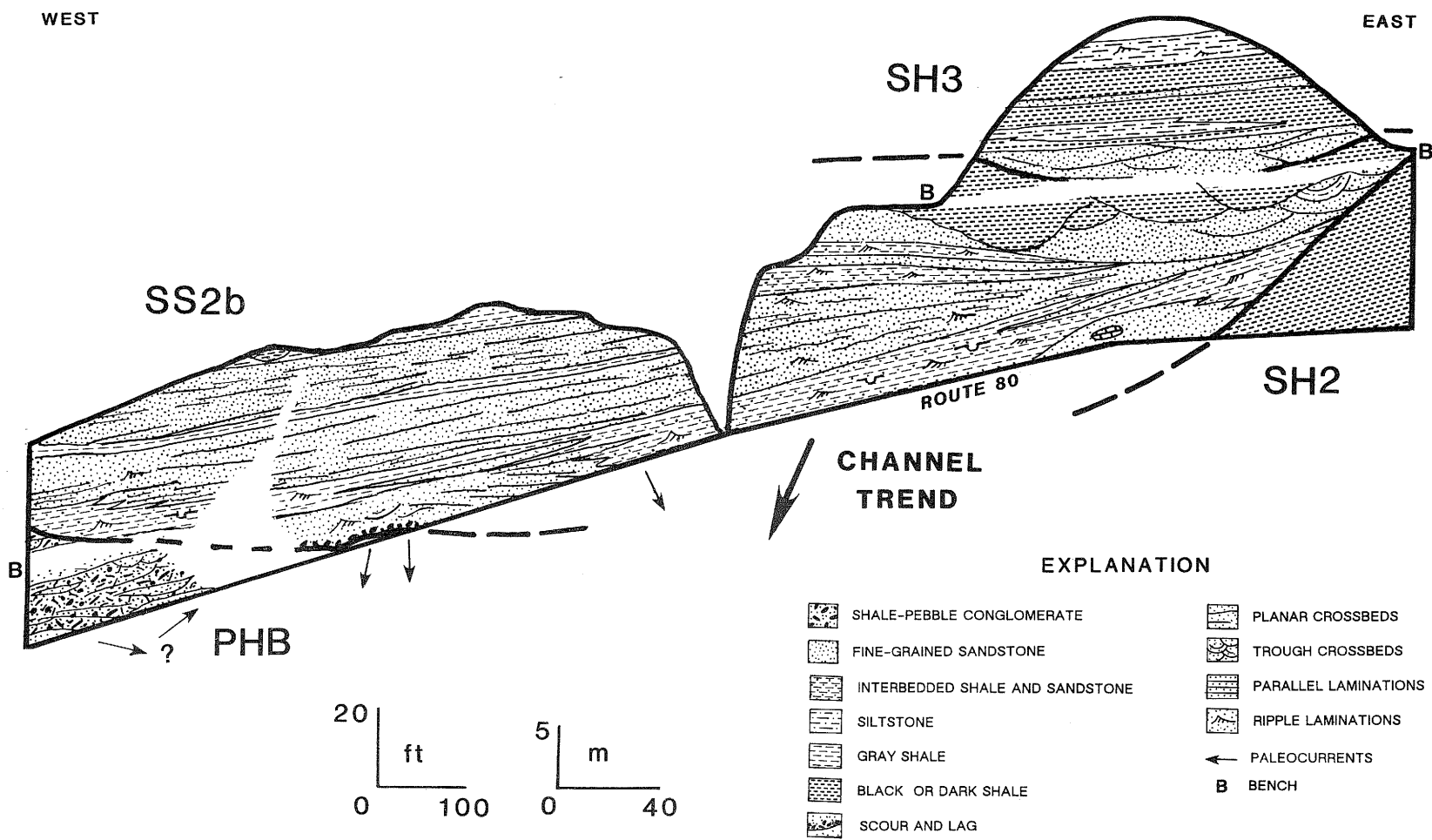


Figure 16. Sideroad roadcut sections (continuous with Figures 20 and 22). North side of road.

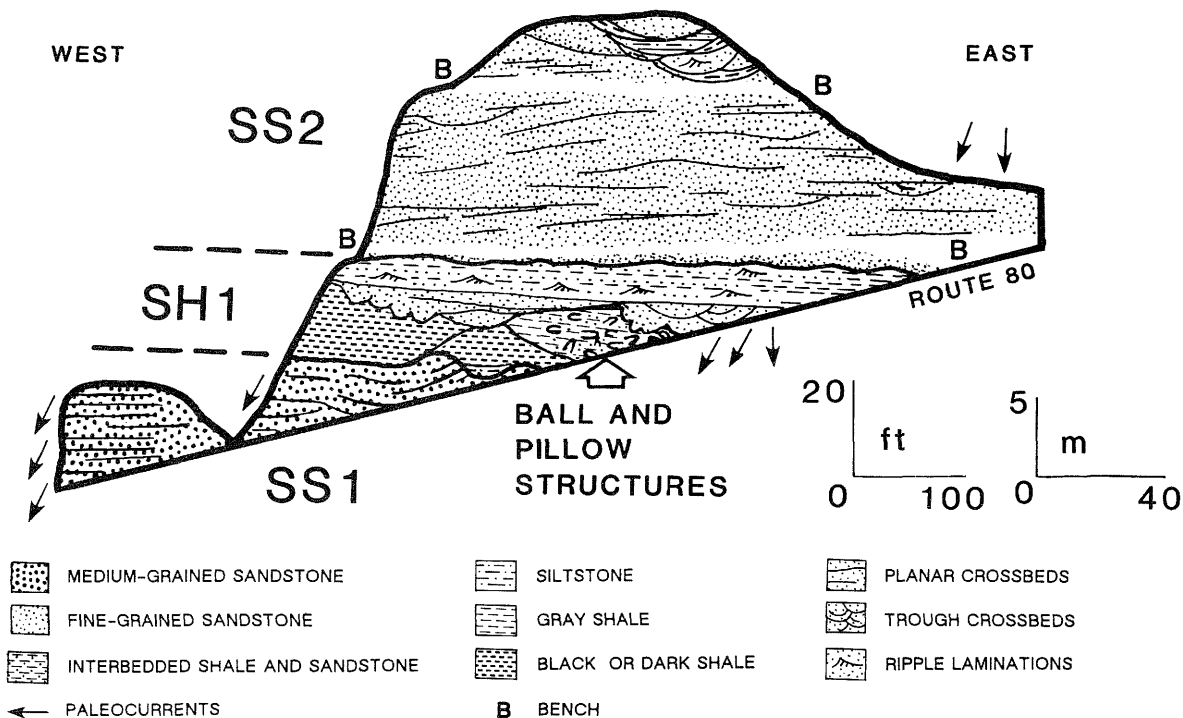


Figure 17. Pine Creek East roadcut section. Sections along north side of the road.

Sandstone Zone 2

The sandstone beneath shale 2 is the second sandstone above the Rockcastle Sandstone. The sandstone is fine to medium grained and multistroy. The middle and upper sandstones are exposed in the Hazel Patch cuts (Fig. 15). The upper sandstone is 58 feet (18 meters) thick, thick to medium bedded, exhibits shallow-dipping accretion surfaces and trough crossbedding, and in the upper 18 feet (6 m) fines upward into ripple-laminated sandstone and shale.

The upper and middle sandstones are separated by a thin, discontinuous coal. The coal is rooted into the middle sandstone. The middle sandstone is 25 feet (8 meters) thick, trough crossbedded, with westward and southwestward accretion surfaces. It contains two sandstones separated by a channel-form scour. Paleocurrents above and below the scour are similar, between 185 and 245°.

The fining-upward character of the sandstone suggests fluvial channel conditions. Multiple scours suggest channel switching. The thin, discontinuous coal may represent plant colonization of a channel bar, which is common in sandy, low-sinuosity streams (Bridge and others, 1986) or peat accumu-

lation in an abandoned channel. The thick fining-upward interval in the upper sandstone may also reflect increasingly stronger influence from bay waters in which the overlying black shales were deposited.

Pine Creek East Cut Sandstone Zone 2

The lower part of sandstone 2 is 33 feet (10 meters) thick and is exposed in the Pine Creek East cut (Figs. 14, 17). The sandstone is fine to medium grained, thin to thick bedded, and exhibits trough and planar crossbedding with both continuous and discontinuous, wavy-parallel, set-bounding surfaces. Paleocurrents are south-southwest from 180 to 220°. The upper part of this cut (apparently the middle part of the sandstone) contains a series of small, fine-grained sandstone channels interbedded with thin, gray to black shales exhibiting lenticular bedding.

Shale Zone 1a

The first black shale above the Rockcastle Sandstone east of Pine Creek is 20 feet (6 meters) thick. Shale 1a occurs above a series of channel-form scours (Fig. 17). The westernmost scour is overlain

by black shale. The easternmost scour is overlain by black shale and gray shales that contain curious, isoclinally folded, saucer-shaped and deformed; sandstone ball-and-pillow structures (Fig. 18). Folding in the pillows shows no preferred orientation. Both shaly fills are truncated by a sandstone exhibiting dramatic load structures. This sandstone fines upward into ripple-laminated siltstones and sandstones that interfinger with gray shale on the eastern end of the cut.

Black shales of zone 1a are similar to shale zone 2 and are also interpreted as estuarine deposits. The ball-and-pillow structures represent disarticulation or "foundering" of original thin, flat-bedded sandstones and siltstones (Potter and Pettijohn, 1977). The ball-and-pillow structures were not formed by slumping because the pillows do not show a preferred orientation of overturning or folding (Anketell and others, 1970). The pillows (and load structures immediately above) may represent dewatering and density instability of liquidized sand and mud layers (Sorauf, 1965; Anketell and others, 1970; Potter and Pettijohn, 1977). Instability may have been caused by the application of a shock to the unconsolidated sediments (Kuenen, 1958).

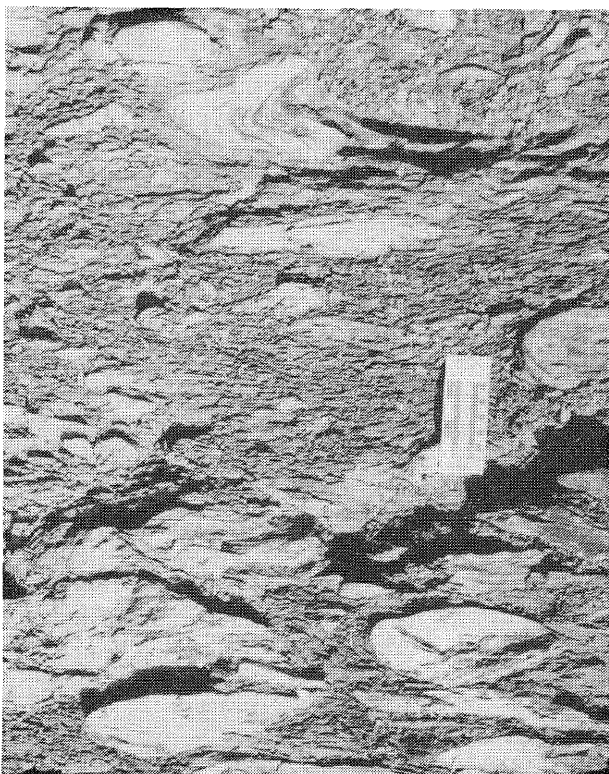


Figure 18. Photograph of ball-and-pillow structures.

These ball-and-pillow structures occur at approximately the same stratigraphic horizon in another area south of the Highway 80 roadcuts, but are rare in other parts of the coal field. Both localities are in the vicinity of a fault along the Rockcastle River. An earthquake-produced shock is a possible explanation for the structures. This theory is discussed in the section on the Poison Honey beds.

Sandstone Zone 1—Pine Creek Sandstone

The first sandstone above the Rockcastle Sandstone is called the Pine Creek sandstone by Chesnut (1988). The sandstone is medium grained, moderately to well sorted, quartzitic, medium to thick bedded, and dominated by planar crossbedding with even-, wavy-, and curved-parallel set-bounding surfaces. Paleocurrent directions are oriented unimodally to the southwest from 185 to 225°. A sandstone block just below road level has northwestern paleocurrents from 270 to 340°, but it may not be in place. The Pine Creek sandstone is 80 feet (25 meters) thick along Pine Creek, but only the upper 25 feet (7 meters) is exposed above road level (Fig. 19).

The Pine Creek sandstone is interpreted as a fluvial, low-sinuosity (possibly sandy braided) channel system (Amig, 1988; Chesnut, 1988). The regional "sand-belt shape," large width-to-depth ratio, scour base, unimodal paleocurrents, dominance of planar (often tabular) crossbedding, and lack of lateral suspension deposits are typical of sandy, low-sinuosity streams (Smith, 1970; Miall, 1978; Rust, 1978; Bridge and others, 1986).

Rockcastle Sandstone

The Rockcastle Sandstone is exposed below road level in the Pine Creek Valley (Figs. 14, 19). The sandstone is medium grained, very thick to medium bedded, planar crossbedded, with even-parallel set-bounding surfaces and abundant quartz pebbles. Paleocurrent directions are to the west and northwest. The Rockcastle is exposed at road level in the Rockcastle River east cut.

The Rockcastle Sandstone occurs in a belt approximately 50 miles (70 kilometers) wide, and striking to the southwest. It has been interpreted as part of a beach-barrier system by Ferm and others (1971), fluvial braided streams by Rice (1984) and Chesnut (1988), and as a delta front/transition zone/braided stream complex by Amig (1988). The bedding architecture at this stop supports a low-sinuosity fluvial, perhaps braided, interpretation, as discussed for the Spillway creek section.

Pine Creek West Cuts

Sandstone Zone 1—Pine Creek Sandstone

The cliffs that line the valleys are formed from the combined thickness of Rockcastle Sandstone, Pine Creek Sandstone (sandstone 1), and sandstone 2. The Pine Creek sandstone exhibits similar facies on either side of the Pine Creek Bridge (Figs. 16, 19–20) with southwest-oriented planar crossbedding (210 to 250°).

Shale Zone 1a

The first shale zone above the Rockcastle is truncated in the Pine Creek West cut (Fig. 20). While the shaly interval was 20 feet (6 meters) thick to the east, it is less than 3 feet (1 meter) thick at this site.

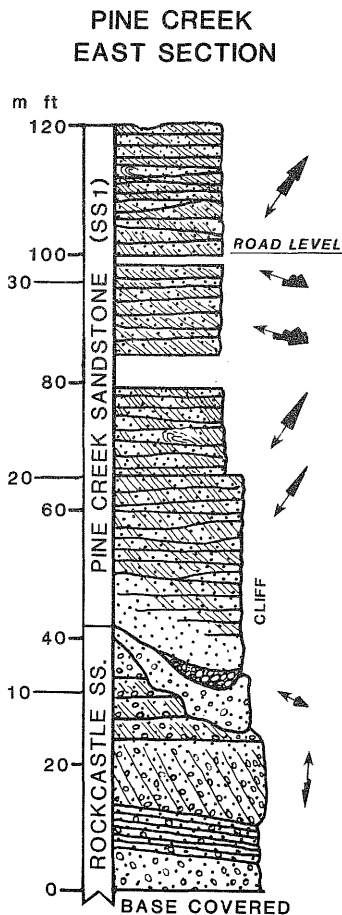


Figure 19. Vertical section through Pine Creek valley.

Sandstone Zone 2a

The second sandstone above the Rockcastle Sandstone west of Pine Creek is 60 feet (19 meters) thick, fine to medium grained, exhibits trough and planar crossbedding with paleocurrents between 190 and 230°, and fines upward into ripple-laminated sandstone and gray shale (Fig. 20) similar to the upper part of sandstone 2 east of Pine Creek (Fig. 17). Crossbed set-bounding surfaces are wavy to curved parallel, in contrast to even-parallel surfaces in the upper part of the Pine Creek sandstone. The fining-upward interval is truncated by a sharp-based sandstone that exhibits trough and planar crossbedding and small-scale scours with laminated sandstone fills. This upper sandstone thickens to 20 feet (6 meters) west of a small slump (Fig. 20).

Overall, sandstone zone 2a is thinner west of Pine Creek, and the coal is missing (Fig. 14). Also, the sandstone does not have the multistory appearance that it has west of Pine Creek. Stratigraphic correlations and depositional interpretations are problematic because the beds have not been traced in three dimensions. Either the fining-up sandstone here is laterally equivalent to the lower and middle sandstones of the Pine Creek East cut and the upper sandstone of the Pine Creek East cut is laterally equivalent to shale 1b here, or the fining-upward sequences in both cuts are equivalent, and the lower and middle sandstone of the Pine Creek East cuts are missing west of Pine Creek.

Shale Zone 1b

Sandstone 2a is overlain by a much thicker black shale sequence west of Pine Creek than to the east (Figs. 17, 20). The shale is 22 to 52 feet (7 to 15 meters) thick in the Pine Creek West cuts, and thickens to the west. Several scour surfaces, each steeply dipping to the northwest, are noted in the shale. Shale 1b is overlain by a rooted coal 10 to 25 centimeters thick. This coal is partially hidden by talus on the first bench. It cannot be traced westward into the Sideroad cut (Fig. 16), and appears to be stratigraphically higher than the coal in sandstone zone 2 of the Hazel Patch cut. This coal indicates that the upper part of the shale zone was at least slightly above sea level in order for marsh development and peat accumulation to have occurred.

Shale Zone 1c

The coal is overlain by a sequence of dark shales and sandstones, each having scoured bases. The sandstones are fine grained, massive to thin bedded, and exhibit ripple and flat laminations (Fig. 20).

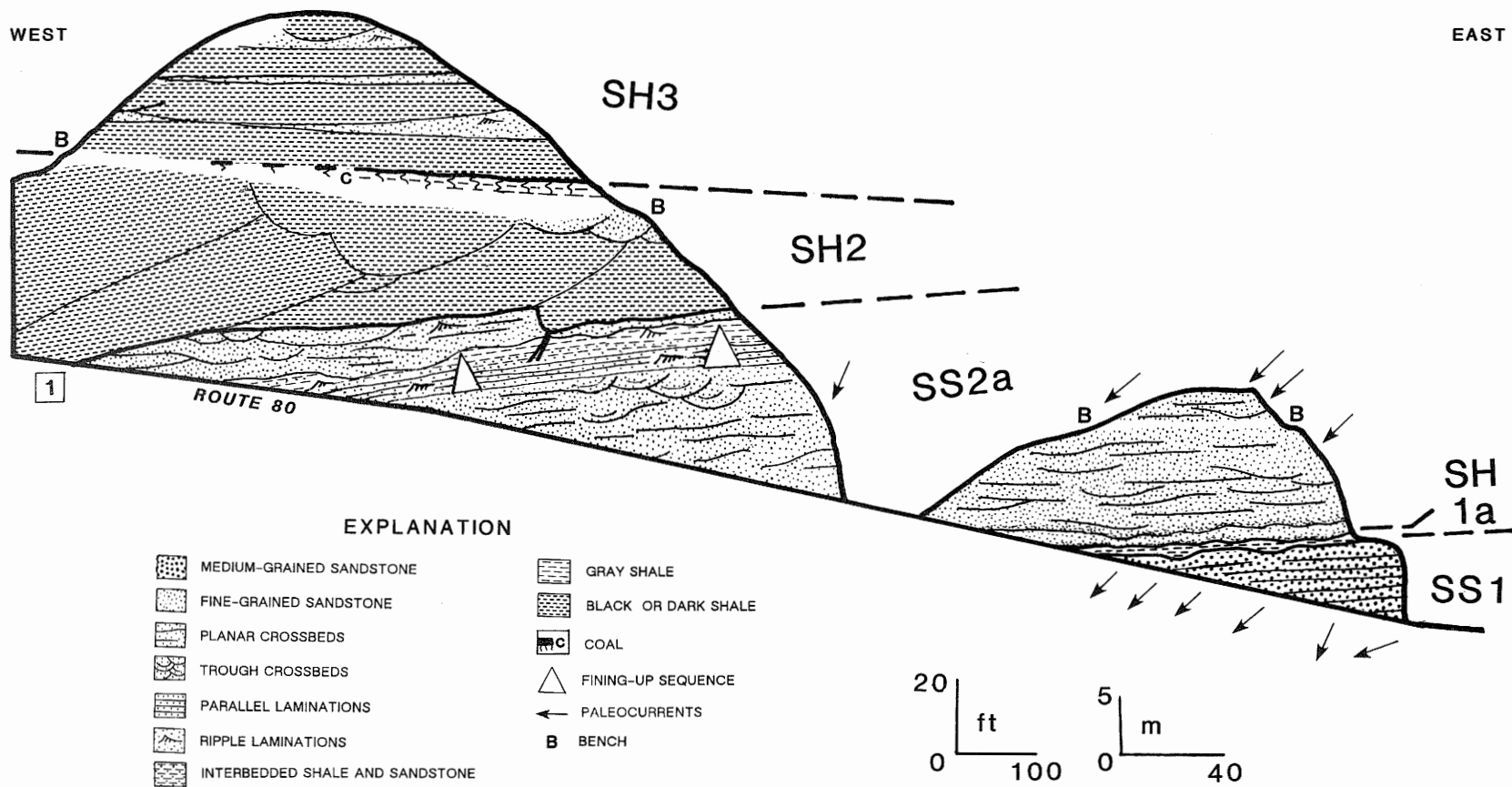


Figure 20. Pine Creek West roadcut section, from Pine Creek to mile marker 1. North side of road.

Shale zone 1c is stratigraphically equivalent to the Hazel Patch sandstone (Figs. 14–15). Sandstones in the interval may represent distal parts of the Hazel Patch mouth bars that are truncated and reworked by estuarine processes; the shales represent estuarine and bay-fill deposition.

Sideroad Cuts

Sandstone Zone 2b

The westernmost, northwest-dipping scour surface in shale zone 1b of the Pine Creek West cuts contains stacked sets of thin- to medium-bedded, fine- to very fine-grained sandstone interbedded with gray shale and silty shale (Figs. 16, 21). The western side of the scour is exposed 0.35 mile (0.56 kilometer) to the west in the Rockcastle River East cuts (Fig. 22). The entire channel strikes southwest. Each of the sandstones thickens toward the center of the channel and tapers along the margins of the scour in the Sideroad cut. The sandstones exhibit small-scale crossbedding, flat laminations, and flaser and lenticular bedding. Interbedded siltstones and gray shales are ripple laminated. Vertical burrows are uncommon. A carbonate(?) concretion occurs near road level in a fine-grained sandstone (Fig. 16).

The large channelform comprising both the shale 1b and sandstone 2b zones is oriented to the southwest. The parallel-dipping scour surfaces indicate a lateral migration of the channel to the west. Curiously, the first channel margins are composed completely of black shale, while only the final fill contains sandstones. The size of the channel indicates that it may have been a major distributary (Fielding, 1986).

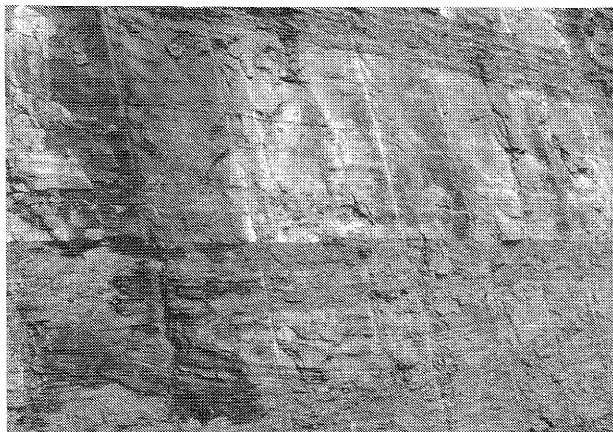


Figure 21. Laminated fine-grained sandstone, facies SS2b, Sideroad roadcut.

It is probably part of the same channel system that deposited the thicker section of sandstone zone 2 east of Pine Creek. Amig (1988) interpreted this zone as delta-front deposits similar to deposits on shoal-water deltas (Coleman, 1976; Vos, 1977). The channel-form nature of the zone is not typical of sloping delta-front deposits, but perhaps a shaly delta-front sequence was deposited in an abandoned or back-filled distributary. The black shales, rare burrows, and carbonate(?) concretion indicate brackish-water influences during deposition.

Sandstone Zone 3b

The coal separating shale zone 1b from shale zone 1c in the cut to the east (Fig. 20) is missing in the Sideroad cut (Fig. 16). In its place is a series of thin sandstone lenses overlain by a ripple-laminated siltstone. Both the sandstones and siltstone interfinger laterally with surrounding dark shales. The remaining section to the top of the hill is similar to the Pine Creek West exposures except for a slight increase in laminated siltstone near the top of the hill.

Rockcastle River East Cuts

Sandstone Zone 2b

The western edge of the large channel described in the Sideroad cuts at this horizon is exposed here (Fig. 22). The channel fill is the same as described for the eastern channel exposure. The basal scour contains a lag of siderite pebbles and shale clasts. The channel is capped by black shale. Exposures of the shale lateral to the channel contain pyrite nodules. Fine-grained, sheet sandstones interbedded or capping the black shales contain high-abundance, low-diversity trace fossils (vertical and horizontal), which attests to at least brackish-water influences.

Poison Honey Beds

Between sandstone zone 2b and the Pine Creek sandstone is an unusual series of matrix-supported conglomerates that are unlike any of the facies recorded elsewhere at this stratigraphic interval (Fig. 22). The Poison Honey beds have a fine-grained sandstone matrix with abundant transported shale clasts and siderite nodules (Fig. 23). The fabric of the clasts forms rough bedding features in the unit that can be divided into: (1) matrix-supported, shale-pebble sandstones with massive and crude, planar layering dipping to the east (Fig. 23), (2) small-scale channels or troughs filled with matrix-supported shale-pebble sandstones or "clean"

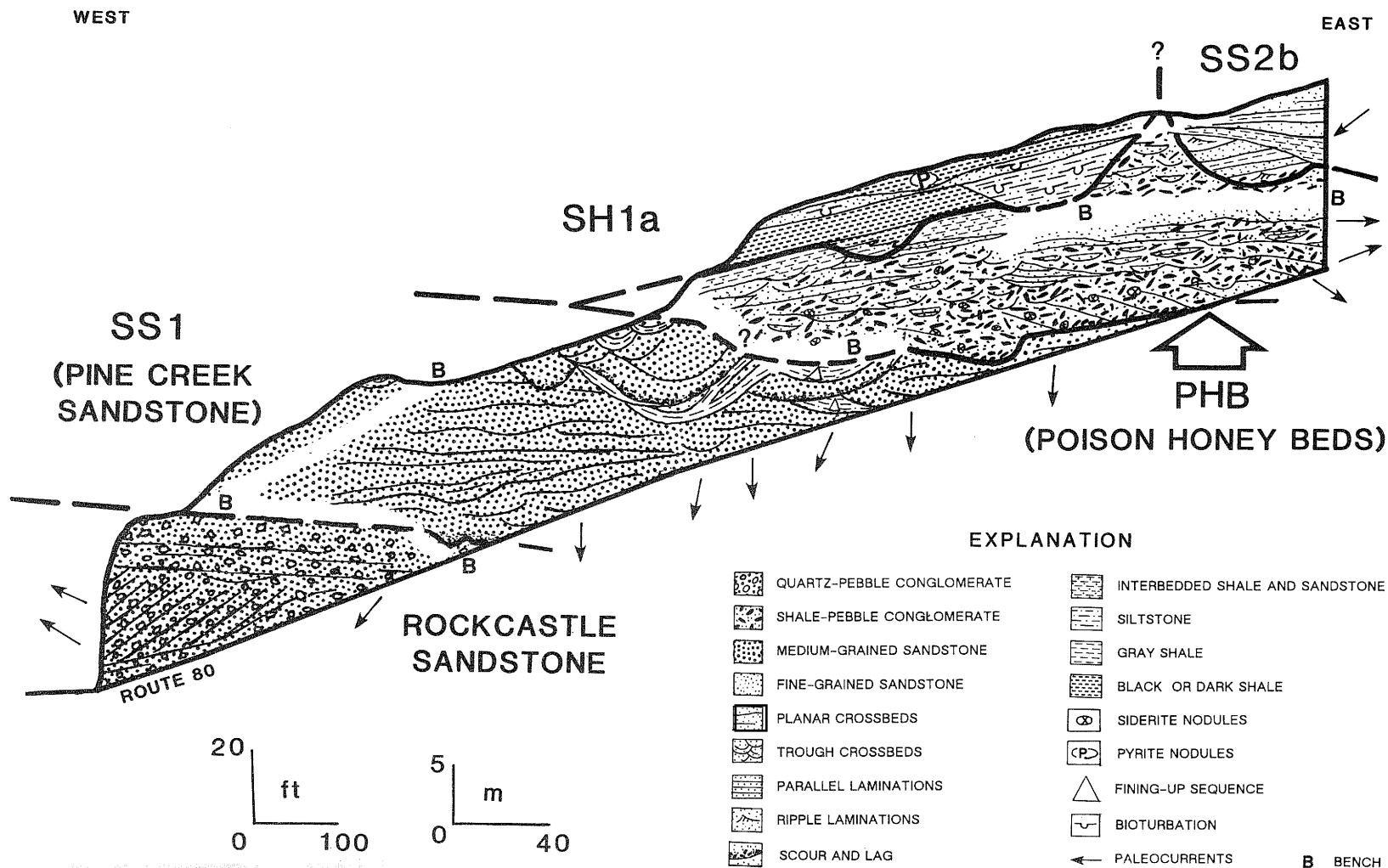


Figure 22. Rockcastle River East roadcut section. North side of road.

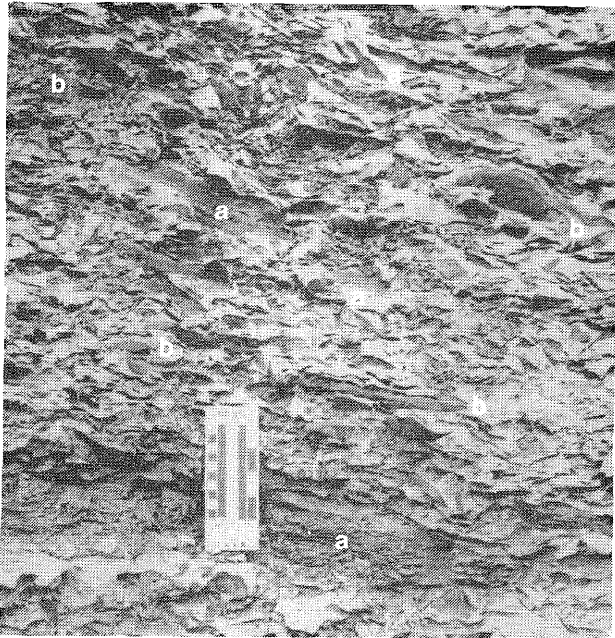


Figure 23. Poison Honey beds. Imbricated, detrital shale (a) and siderite (b) create a crude layering.

sandstone with multiple orientations (Fig. 24), and (3) thin, "clean" sandstone sheets and lenses with massive or flat laminations defined by concentrations of transported shale chips (Fig. 25). Several sequences of matrix-supported conglomerate, cut by small channels and overlain by "clean" sheet sands, are preserved.

The Poison Honey beds are interpreted to represent mass-flow deposits that accreted eastward at

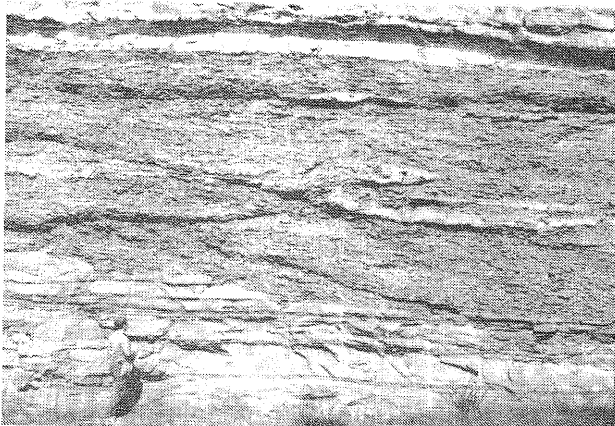


Figure 24. Photograph of Poison Honey beds shows small-scale channeling with both diamictite and sandstone fill.

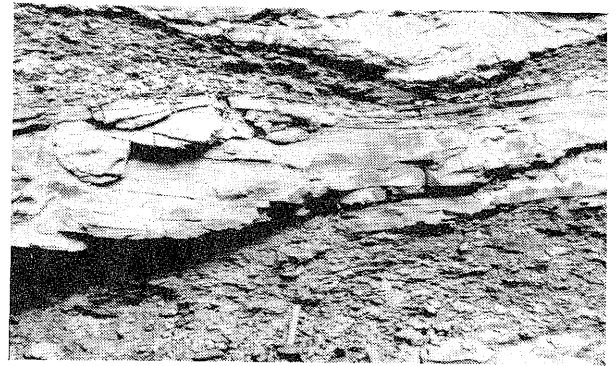


Figure 25. Photograph of Poison Honey beds shows laminated sandstone from south side of the road.

right angles to the flow represented in the underlying and overlying sandstones (Fig. 26). The crude layering of this deposit (in contrast to typical, massive "plug" debris flows) may have resulted from multiple flow surges defined by large scour surfaces and truncated sheet sands. Mass flows often contain a facies mosaic of different rheologic flow conditions (Middleton and Southard, 1977; Postma, 1986). Several types of mass flows may exist within the Poison Honey beds, including debris flows, grain flows, turbidity currents, and stream flows.

One possibility for the formation of the flow is that it was deposited from a fault scarp just west of the present Rockcastle River. Stratigraphic and gravity anomalies indicate a normal fault (down to the east) parallel to the present Rockcastle River (Fig. 14). Fault-controlled sedimentation is suggested by: (1) the abundant siderite clasts, which are rare in the underlying Pine Creek sandstone or Rockcastle Sandstone but abundant in the Breathitt-type shale on the upthrown fault block, (2) the abundant shale clasts, indicating short transport distance, (3) the eastward accretion surfaces at right angles to the fault and corresponding to the downthrown side of the fault, in contrast to southwestern paleocurrents in surrounding units, and (4) the coincidence of the unit to the fault (no other matrix-supported conglomerates have been reported in the Eastern Kentucky Coal Field). Fault control is also suggested by deformed beds such as the pillow structures in the Pine Creek East cut and in other areas at the same stratigraphic horizon on the downthrown side of the fault.

Pine Creek Sandstone

The Pine Creek sandstone (SS1) is exposed in the western part of the Rockcastle River East cut (Fig. 22). The sandstone is 60 feet (18 meters) thick and

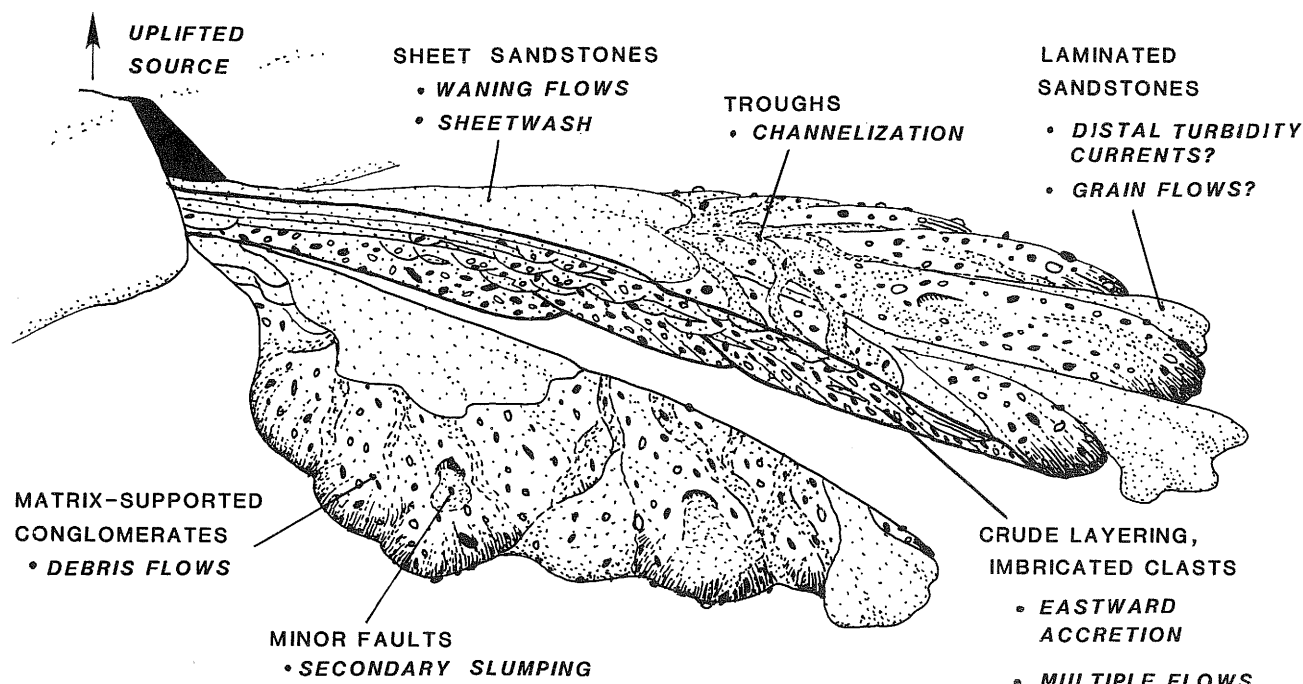


Figure 26. Mass flow model for the Poison Honey beds.

can be divided into an upper and lower unit. The lower part of the sandstone is medium grained and exhibits planar and trough crossbedding similar to the facies at the Pine Creek East and West cuts. Paleocurrents are to the south between 175 and 220° . The upper part consists of a series of cross-cutting sandstone and shale lenses. Most of these channel-form sandstones are trough crossbedded with paleocurrents to the southwest; they fine upward into gray shales. Again, the overall bedding architecture implies fluvial, low-sinuosity deposition.

Rockcastle Sandstone

The Pine Creek sandstone truncates the Rockcastle Sandstone (Fig. 22), and possibly the Barren Fork coal (which is absent here but has been drift mined 0.5 kilometer to the south). The sandstone is medium grained, poorly sorted, very thick to medium bedded, and quartzose with abundant well-rounded quartz pebbles throughout. At the Rockcastle River a wedge-tabular macroform is preserved (Fig. 27). The giant crossbed set consists of quartz-pebble conglomerates with steeply dipping foresets 6.2 meters high. Climbing ripples are preserved on foresets. The coset is more than 50 meters wide and pinches out to the east and south over flat bottom sets and west-dipping, low-angle accretion deposits. Paleocurrent directions indicate that

the foresets migrated in a west to northwest direction (270 to 325°).

Several large, tabular foresets are exposed at this stop. Each of them appears to have advanced over the slope of the immediately underlying accretion deposits, thus forming a series of slightly offset northwest- and southwest-migrating bedforms. Unlike the Rockcastle at the spillway stop, only the pebbly facies is preserved along Highway 80 (although the possibility exists that one of the three sandstone units above the Rockcastle is equivalent to the non-pebbly portion of the Rockcastle at the spillway). Also, the pebbly facies appears thicker and contains

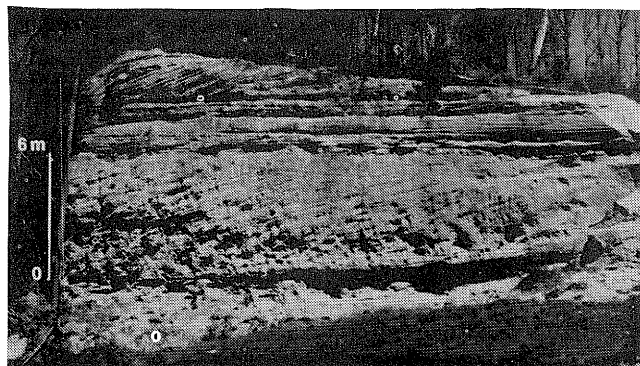


Figure 27. Giant crossbed set in the Rockcastle Sandstone.

much larger bedforms. If the bedforms occurred in fluvial, braided streams, then the rivers must have been very large and deep to accommodate a 6.2-meter bedform. Another possibility is that the bedforms represent the accretion of a minor braid delta (Amig, 1988) or Gilbert-type delta into a local bay. Accretionary sandstone bedding is well developed in the lower part of the Rockcastle Sandstone in the Rockcastle West cut (Fig. 28).

The Lee sandstones cannot be traced west of the fault (Figs. 14, 29). The crop line may represent modern erosion or it may represent nondeposition west of the fault. Perhaps subsidence on the eastern margin of the fault led to deeper channeling of Rockcastle rivers, or created a small lake or bay that the Rockcastle braided streams emptied into.

Rockcastle River to Price Valley Roadcuts

West of the Rockcastle River the base of the Rockcastle Sandstone Member is exposed (Fig. 28). It is sharp, with a well-developed lag. Beneath the Rockcastle Sandstone is the Lower Tongue of the Breathitt Formation. The Breathitt consists of interbedded shales, coals, siltstones, and thin, "dirty" sandstones. The fault west of the Rockcastle River is downthrown to the east so only the Breathitt section below the Rockcastle is exposed to the west (Fig. 29). Detailed descriptions of these Breathitt roadcuts are not included in this field guide except for a shallow, fine-grained channel fill at Price Valley, which is typical of these Breathitt exposures (Fig. 30). The abundance of dark shales and bioturbated

siltstones in these roadcuts indicates marine- and brackish-water deposition, probably in crevasse-splay, bay-fill, and estuarine environments.

Price Valley Roadcut

This stop highlights the contact between the Mississippian and Pennsylvanian section in the Eastern Kentucky Coal Field. A mid-Carboniferous regional unconformity has been documented by Chesnut (1988). The unconformity is Early Pennsylvanian in age, although it has been incorrectly referred to as the Mississippian-Pennsylvanian (systemic) unconformity because earliest Pennsylvanian rocks have been removed across much of the Central Appalachian Basin, and Pennsylvanian rocks overlie Mississippian rocks, as at this locality. Most of the Late Mississippian Pennington Group and Early Pennsylvanian Pocahontas Formation and Middlesboro Sandstones are absent at this stop.

In the Billows Quadrangle, the systemic contact is placed beneath a thin coal rooted along a shallow scour (Fig. 30). The coal is partially eroded by a fining-upward, thin-bedded, fine-grained sandstone interbedded with a dark shale containing a high abundance and low diversity of horizontal trace fossils. Because the leach zone follows the plane of the scour and not the underlying bedding planes, it is disconformable with the underlying variegated shales.

The leached zone is inferred to represent sub-aerial exposure of the underlying Late Mississippian Paragon (Pennington) Formation and soil formation in an abandoned channel, followed by peat-swamp

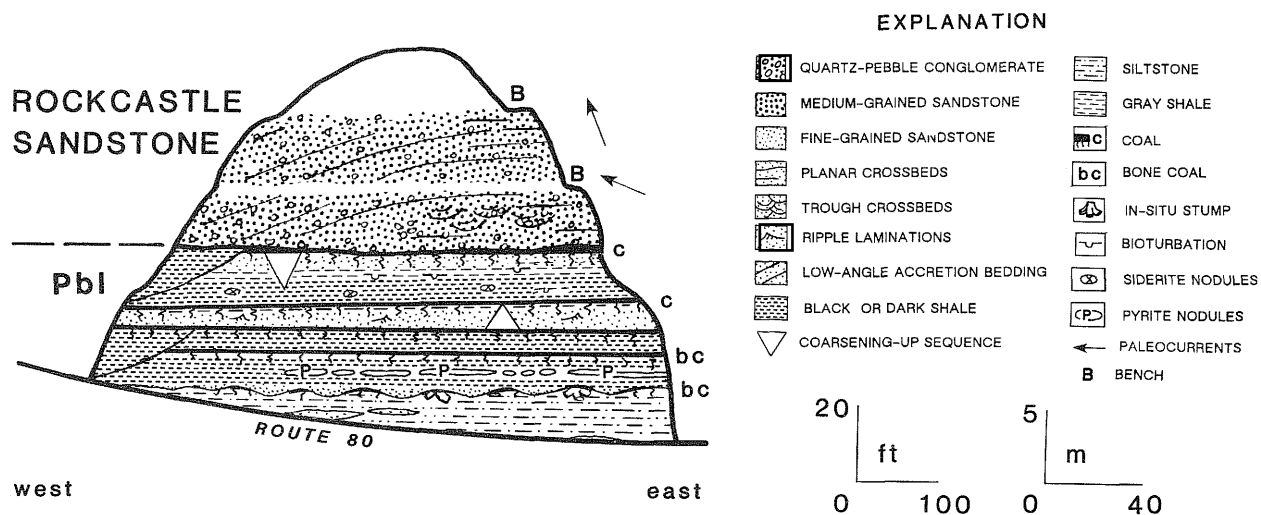


Figure 28. Rockcastle West roadcut section. North side of road.

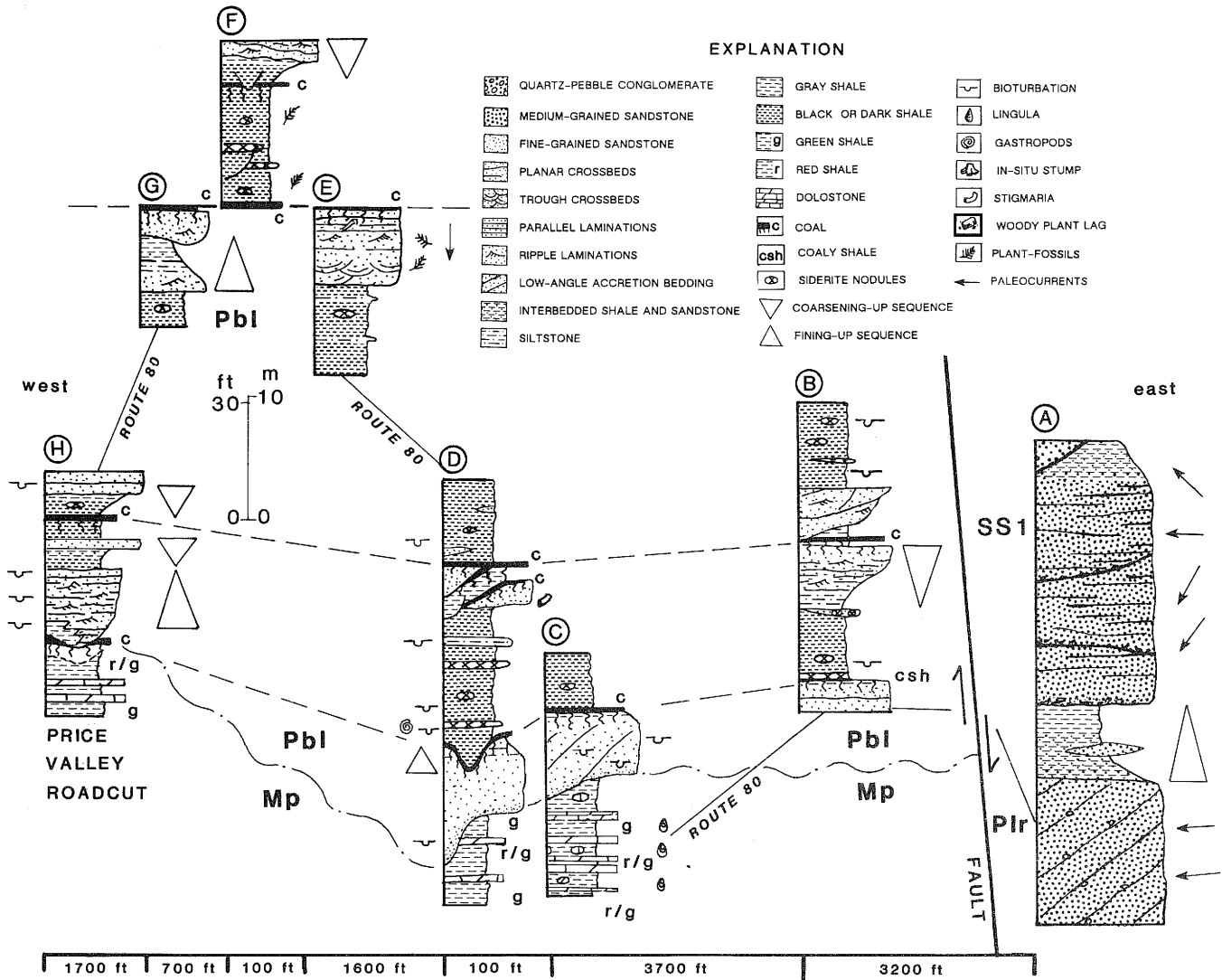


Figure 29. Vertical sections between the Rockcastle River and Price Valley, north side of the road. Note the abrupt change in facies across the fault.

development and subsequent Breathitt Formation channeling. Thin, abandoned-channel-fill coals accompanied by thin-bedded sandstones and dark-gray shales are common in this part of the section and indicate deposition in marine- and brackish-water-influenced marshes and swamps.

In contrast to this Pennsylvanian paleosol, the nodular dolostone layer (in some places exhibiting columnar peds) in the underlying red and green variegated shales of the Paragon Formation represents possible Mississippian exposure of tidal-flat environments. Multiple exposures of these units in this area are probably because of the area's proximity to the Cincinnati Arch.

REFERENCES CITED

Allen, J. R. L., 1983, Studies in fluvial sedimentation: Bars, bar-complexes, and sandstone sheets (low-sinuosity braided streams) in the brownstones (L. Devonian), *Welsh borders: Sedimentary Geology*, v. 33, p. 237-293.

Allen, J. R. L., 1984, Sedimentary structures—Their character and physical basis: Elsevier, *Developments in sedimentology*, v. 30, 663 p.

Amig, B. C., 1988, Lithofacies and paleoenvironments, Lower Pennsylvanian rocks, Kentucky State Highway 80 near the Rockcastle River: Lexington, University of Kentucky, M.S. Thesis, 98 p.

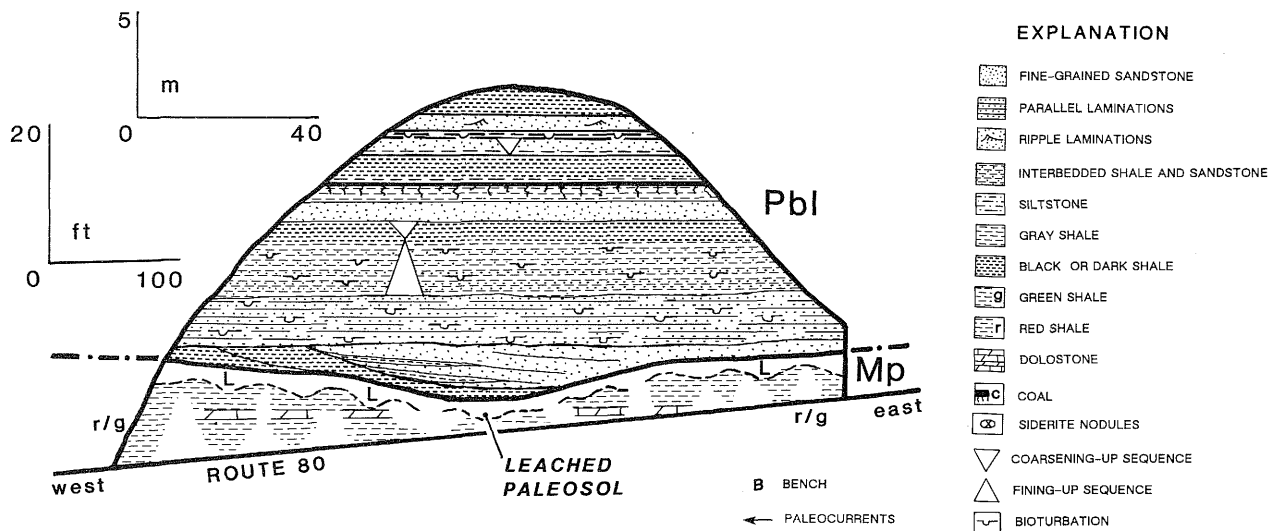


Figure 30. Price Valley roadcut section. "L" indicates the area of leached paleosol beneath the channel.

Anketell, J. M., Cegla, J., and Dzulyński, S., 1970, On the deformational structures in systems with reversed density gradients: *Rocznik Polskiego Towarzystwa Geologiczne*, v. 40, p. 1-30.

Bement, W. O., 1976, Sedimentological aspects of middle Carboniferous sandstones on the Cumberland Overthrust Sheet: Cincinnati, University of Cincinnati, Ph.D. Dissertation, 181 p.

Bridge, J. S., Smith, N. D., Trent, F., Gabel, S. L., and Bernstein, P., 1986, Sedimentology and morphology of a low-sinuosity river: Calamus River, Nebraska Sand Hills: *Sedimentology*, v. 33, p. 851-870.

Cant, D. J., and Walker, R. G., 1978, Fluvial processes and facies sequences in the sandy braided South Saskatchewan River, Canada: *Sedimentology*, v. 25, p. 625-648.

Chesnut, D. R., Jr., 1988, Stratigraphic analysis of the Carboniferous rocks of the Central Appalachian Basin: Lexington, University of Kentucky, Ph.D. Dissertation, 296 p.

Chesnut, D. R., Jr., Cobb, J. C., and Kiefer, J. D., 1986, "Four Corners"—A three-dimensional panorama of stratigraphy and depositional structures of the Breathitt Formation (Pennsylvanian), Hazard, Kentucky: *Geological Society of America Centennial Field Guide, Southeastern Section*, p. 47-50.

Cobb, J. C., Chesnut, D. R., Hester, N. C., and Hower, J. C., 1981, Coal and coal-bearing rocks of eastern Kentucky (Guidebook and roadlog for

Coal Division of Geological Society of America Field Trip No. 14), *Annual Geological Society of America Coal Division Field Trip: Kentucky Geological Survey*, ser. 11, 169 p.

Coleman, J. M., 1976, Deltas: Processes of deposition and models for exploration: Champaign, Illinois, Continuing Education Publication, 102 p.

Elliot, T., 1974, Interdistributary bay sequences and their genesis: *Sedimentology*, v. 21, p. 611-622.

Ekdale, A. A., and Mason, T. R., 1988, Characteristic trace-fossil associations in oxygen-poor sedimentary environments: *Geology*, v. 16, p. 720-723.

Englund, K. J., Arndt, H. H., and Henry, T. W., eds., 1979, Proposed Pennsylvanian stratotype, Virginia and West Virginia: *American Geological Institute Guidebook Series*, no. 1, 136 p.

Farquharson, G. W., 1982, Lacustrine deltas in a Mesozoic alluvial sequence from Camp Hill, Antarctica: *International Association of Sedimentologists*, p. 717-725.

Ferm, J. C., Horne, J. C., Swinchatt, J. P., and Whaley, P. W., 1971, Carboniferous depositional environments in northeastern Kentucky (Roadlog for Geological Society of Kentucky 1971 Field Excursion): *Kentucky Geological Survey*, ser. 10, 30 p.

Fielding, C. R., 1986, Fluvial channel and overbank deposits from the Westphalian of the Durham coalfield, NE England: *Sedimentology*, v. 33, p. 119-140.

- Galloway, W. E., and Hobday, D. K., 1983, Terrigenous clastic depositional systems—Applications to petroleum, coal, and uranium exploration: New York, Springer-Verlag, 423 p.
- Harms, J. C., Southard, D. R., Spearing, D. R., and Walker, R. G., 1975, Depositional environments as interpreted from primary sedimentary structures and stratification sequences: Society of Economic Mineralogists and Paleontologists Short Course 2, 161 p.
- Hatch, N. L., Jr., 1963, Geology of the Billows Quadrangle: U. S. Geological Survey Geologic Quadrangle Map GQ-228.
- Knight, R. J., and Dalrymple, R. A., 1975, Intertidal sediments from the south shore of Cobequid Bay, Bay of Fundy, Nova Scotia, Canada, *in* Ginsburg, R. N., ed., Tidal deposits: New York, Springer, p. 47-55.
- Kuenen, P. H., 1958, Experiments in geology: Transactions of the Geological Society of Glasgow, v. 23, p. 1-28.
- McCabe, P. J., and Jones, C. M., 1977, Formation of reactivation surfaces within superimposed deltas and bedforms: *Journal of Sedimentary Petrology*, v. 47, no. 2, p. 707-715.
- Miall, A. D., 1978, Lithofacies types and vertical profile models in braided river deposits—A summary, *in* Miall, A. D., ed., *Fluvial sedimentology*: Canadian Society of Petroleum Geologists, Memoir 5, p. 597-605.
- Middleton, G. V., and Southard, J. B., 1977, Mechanics of sediment movement: Society of Economic Paleontologists and Mineralogists, Short Course Notes 3, 242 p.
- Postma, G., 1986, Classification for sediment gravity-flow deposits based on flow conditions during sedimentation: *Geology*, v. 14, p. 291-294.
- Potter, P. E., and Pettijohn, F. J., 1977, Paleocurrents and basin analysis: New York, Springer-Verlag, 425 p.
- Reineck, H. E., and Singh, I. B., 1980, Depositional sedimentary environments: New York, Springer-Verlag, 549 p.
- Rice, C. L., 1984, Sandstone units of the Lee Formation and related strata in eastern Kentucky: U.S. Geological Survey Professional Paper 1151-G, 53 p.
- Rust, B. R., 1978, Depositional models for braided alluvium, *in* Miall, A. D., ed., *Fluvial sedimentology*: Canadian Society of Petroleum Geologists Memoir 5, p. 605-627.
- Saxena, R. S., 1976, Modern Mississippi delta—Depositional environments and processes: American Association of Petroleum Geologists field trip guidebook, New Orleans, Louisiana, 125 p.
- Smith, N. D., 1970, The braided stream depositional environment: Comparison of the Platte River with some Silurian clastic rocks, north-central Appalachians: *Geological Society of America Bulletin*, v. 81, p. 2993-3014.
- Sorauf, J. E., 1965, Flow rolls of Upper Devonian rocks of south-central New York state: *Journal of Sedimentary Petrology*, v. 35, p. 535-563.
- Vos, R. G., 1977, Sedimentology of an Upper Paleozoic river, wave and tide influenced delta system in southern Morocco: *Journal of Sedimentary Petrology*, v. 47, p. 1242-1260.

DEVELOPMENT OF THE MISSISSIPPIAN-PENNSYLVANIAN UNCONFORMITY IN INDIANA

**John B. Droste and Stanley J. Keller
Indiana Geological Survey
Bloomington, Indiana**

ABSTRACT*

In very Early Pennsylvanian time the place now called Indiana was the locus of subaerial erosion. About 8,000 square miles of this landscape is preserved in western Indiana beneath the rocks of the Pennsylvanian System. Data from 20,000 wells provide the evidence to reconstruct this surface and to describe its geomorphology.

Six ancient physiographic regions that show clear relationships of landform to outcropping Mississippian bedrock have been identified. From north to south, a distinctive topography is associated with

each of the ancient outcrop areas of (1) the Borden Group, (2) the Sanders and Blue River Groups, (3) the West Baden Group, (4) the Stephensport Group, (5) the Tar Springs Formation through the Menard Limestone, and (6) the Palestine Sandstone through the Grove Church Shale.

In northern Indiana the Mississippian-Pennsylvanian unconformity may represent as much as 8 million years of erosion. In southern Indiana that same unconformity may represent less than 3 million years of erosion.

*Abstract from Indiana Geological Survey Occasional Paper 55.

TECTONIC IMPLICATIONS OF REGIONAL CORRELATION AND FORMATING OF THE PENNSYLVANIAN MANSFIELD FORMATION AND EQUIVALENTS IN THE ILLINOIS BASIN

**Lloyd C. Furer
Indiana Geological Survey
Bloomington, Indiana**

ABSTRACT

Several intervals within the Mansfield Formation produce hydrocarbons, and different names have been applied to individual reservoirs. The time-stratigraphic relationships between these reservoirs and the formations and members described in outcrop in the tri-state area are poorly understood.

A format method of correlation of the Mansfield from its type section in Parke County, Indiana, to the thickest equivalent rocks in southern Illinois permits subdivision of these Morrowan rocks into lower, middle, and upper stratigraphic formats.

Significant regional variations of the thickness of the lower zone appear to be related to paleo-highlands bordering the Illinois Basin during Morrowan time. Northward and eastward thinning of the Mansfield in Indiana is probably related to onlap of the basal Pennsylvanian sediments onto paleotopographic highs, possibly ancestral to the Kankakee

and Cincinnati Arches. Thinning of this section also occurs in southwestern Kentucky across the Rough Creek Fault Zone and southward in Hopkins and Christian Counties onto the northwestern edge of the Nashville Dome. In Illinois, thinning of the Lower Pennsylvanian occurs across the ancestral LaSalle Arch. Abrupt thinning also occurs westward in southern Illinois to the eastern edge of the Mississippi River Arch, but southward through Saline County, Illinois, the basal Pennsylvanian thickens onto the northern edge of the Cottage Grove Fault Zone, where it was truncated by post-Pennsylvanian erosion.

These isopach relationships indicate that the Illinois Basin in Morrowan time was surrounded by tectonically elevated paleotopographic highs to the east, north, and west, but was open to a shallow sea to the southwest, in the vicinity of the Reelfoot Basin.

RECOGNITION OF TIDAL PROCESSES IN MUDSTONE-DOMINATED SEDIMENTS, LOWER PENNSYLVANIAN, INDIANA

Erik P. Kvale
Indiana Geological Survey
Bloomington, Indiana

Allen W. Archer
AzTEL
Department of Geology, Indiana University
Bloomington, Indiana

INTRODUCTION

Tidal deposits have not, until recently, been generally recognized in the Pennsylvanian of the Illinois Basin. This is in part because of the influential work of Shaw (1964). He argued that tidal currents could not operate in inland cratonic basins because tidal friction would so dampen tidal currents that they would become too weak to transport sediments. In addition, the occurrence of coals (especially those that contain less than 1 percent sulfur), the presence of rooted horizons, the abundance of plant fossils, and the general absence of marine megafossils within much of the Pennsylvanian siliciclastic sequence were taken to imply that the depositional settings were dominantly upper delta plain in origin. Lower delta plain and interdistributary bay deposits were recognized mainly by the presence of marine-to brackish-water body fossils or limestones.

The intent of this paper is to demonstrate how tidal processes can be interpreted from rocks of Pennsylvanian age in the Illinois Basin. The two tidally influenced intervals to be discussed in detail are the so-called Hindostan Whetstone beds of the Mansfield Formation and the lower part of the Brazil Formation between the Lower Block Coal Member and the Upper Block Coal Member (Fig. 1).

The two sequences discussed in detail are Morrowan to Atokan in age, commonly contain abundant plant fossils, including upright trees, are typically mudstone dominated (silt- and clay-sized particles), are formed in a tropical environment, and lack the more obvious bidirectional current indicators or large-scale tidal-bundle sequences described by researchers from other tidal regimes. In addition, except for isolated, low-diversity occurrences, characteristically marine trace fossils are generally ab-

sent. The best evidence of tidal influence within these rocks is the rhythmic bedding of small-scale primary sedimentary structures characteristic of the mudstones and interbedded sandstones and mudstones; this rhythmicity can be related to monthly cycles of tidal-current fluctuation. Such cycles may be the best evidence of tidal influence

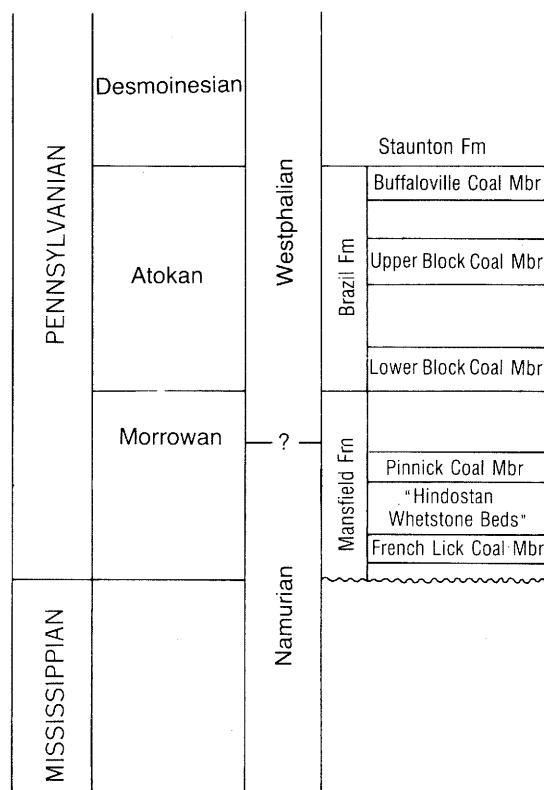


Figure 1. Stratigraphy of units discussed. From Shaver and others (1985).

within inland muddy environments of perhaps limited tidal range.

HINDOSTAN WHETSTONE BEDS

The Hindostan Whetstone beds are an informal unit in the Mansfield Formation (Shaver and others, 1985) that is exposed in Orange County, Indiana (Fig. 2). The whetstone beds are discussed in greater detail by Kvale and others (1989) and Archer and Kvale (1989). Briefly, the whetstone sequence consists of about 10 meters of siltstone intercalated with claystone. Planar and laterally continuous laminations of siltstone occur throughout the lower 6 meters of the whetstone sequence; upper parts of the whetstone sequence consist largely of small-scale trough cross stratification and discontinuous planar laminations.

General Background

The information in this report is based on field and subsurface investigations in three quarries in Orange County (Dishman, Old Braxton, and Hopper Quarries; Fig. 2). To study laminae sequences, two cores 5 centimeters in diameter were drilled 6 meters apart at the Dishman Quarry, and an additional core was provided by AMAX Coal Company, Indianapolis, Indiana, from the same area. A flat surface was created on each core through the whetstone interval by grinding with a belt sander; the flat sur-



Figure 2. Location of whetstone quarries investigated.

faces were then stained red with food coloring to enhance the laminations.

Sedimentology

Planar-Laminated Siltstones

The laminae range from about 0.5 millimeter to slightly more than 1 centimeter in thickness. The laminae are commonly conspicuously paired into couplets consisting of a thicker, or dominant, lamina and a thinner, or subordinate, lamina (Fig. 3). Commonly, the laminae are separated by very thin (thickness of microns to millimeter scale) but later-

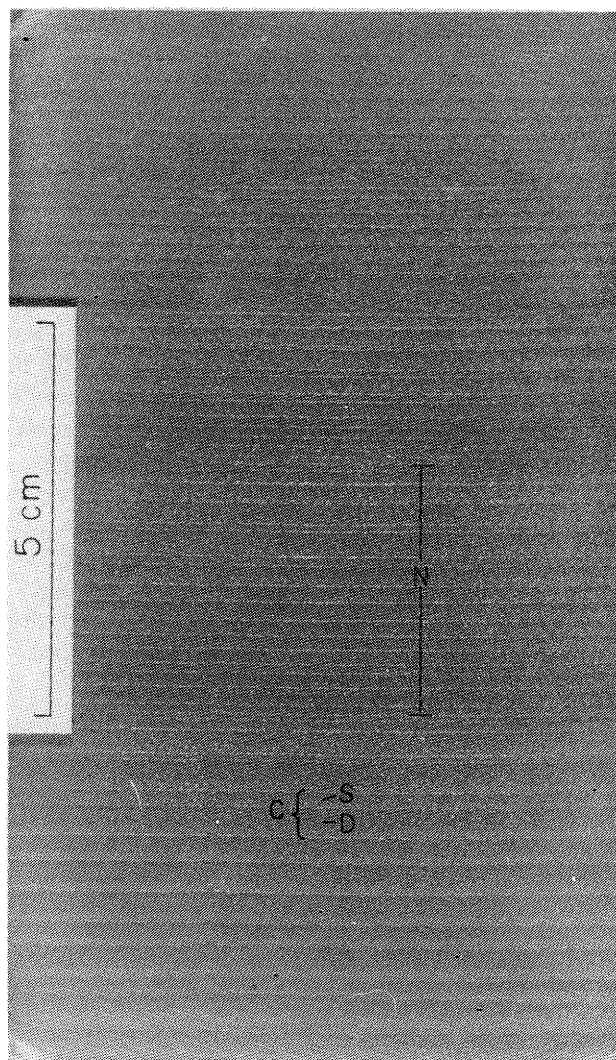


Figure 3. Sequence of laminae within a slab of the planar-laminated siltstone facies, illustrating couplet (C) relationship of subordinate (S), or thinner, laminae, and dominant (D), or thicker, laminae. N delineates a tidal cycle of a half lunar month. Block collected at Hopper Quarry.

ally continuous clay drapes. Thin-section analyses reveal that individual laminae were deposited by bottom-hugging density flows (Archer and Kvale, 1989). Laminae that were developed within pith casts of horizontally oriented lycopod stems also support this interpretation. Erosive contacts between successive laminae are rarely present in the lower 6 meters of the laminated sequence but become more common upward in conjunction with the occurrence of small-scale trough cross stratification. In addition, a number of sedimentological structures indicate periodic emergence during deposition of the whetstone sediments; these include runzel marks, drain features, and millimeter ripples with flattened crests (Fig. 4).

Thickness measurements of the laminae in the whetstones indicate cyclical thickening and thinning (Fig. 5). When sequential laminae are numbered and then plotted against their thicknesses in a histogram, a consistent sinusoidal curve exhibiting a periodicity of 30 or fewer siltstone laminations is formed. This periodicity is interpreted as representing a semidiurnal to mixed tidal cycle of a half lunar month. Similar curves have been generated from classic large-scale tidal bedform features (tidal bundles) of Holocene, Cretaceous, and Jurassic deposits from the United States and Europe (Visser, 1980; Allen, 1981; Homewood and Allen, 1981; Uhlir and others, 1988). Thickness variability within these examples is attributed to neap-to-spring tidal fluctuations in current velocities that occur during a lunar synodic month. A more detailed explanation of this process is presented elsewhere in this guidebook (Archer and Kvale). The lower 6.9 meters of the whetstone beds appear to represent 6 years of nearly continuously generated laminae in an intertidal to subtidal setting.

Complexly Rippled Siltstones

In places, laminae in several horizons can be traced laterally into climbing oscillatory ripples. These structures are variable three-dimensional bedforms, are slightly coarser grained (very fine-grained sandstone), and are nearly symmetric, with ripple indices of 7 to 7.5. The couplet relationship of dominant and subordinate laminae is preserved within the ripple form (Fig. 6a). A detailed study of a set of climbing ripples shows that at the ripple crests the thicker, dominant laminae are separated from the thinner, subordinate laminae by very thin, discontinuous wedges of reverse-dipping foresets; this indicates current reversal (Fig. 6b). It is unlikely that these smaller scale foresets are the result of backflow in the sense of Boersma and others (1968), be-

cause they occur on the crests of the larger scale ripples rather than within the troughs, where reverse-flow eddies would be most likely.

The complex ripples in the whetstones are an example of a very small tidal-bundle sequence generated by a dominant flow, followed by a weak current reversal, and in turn succeeded by a secondary (subordinate) flow in the same direction as the dominant flow. Because clay drapes are not preserved within the ripple sequence, either stillstand events did not result in deposition of significant amounts of suspended materials, or the drape was removed by the next flow event.

Tidal Regime

Two flow events (a strong, dominant event followed by a weaker, subordinate event) in the same direction strongly suggest a semidiurnal or a twice-daily tidal regime. But the fact that a "couplet" of dominant and subordinate laminae does not always occur suggests that at times the tides may have been diurnal or once daily. Therefore, the whetstone system as a whole may best be considered as a mixed tidal regime.

Archer and Kvale (1989) considered the whetstone laminae to be flood dominant, in part because an inland depositional setting is indicated by the upright trees within the whetstone beds and by the coals immediately above and below the beds. The evidence of subaerial exposure from the penecontemporaneous structures indicates that the whetstones were at least periodically intertidal.

Similarly laminated siltstones, also interpreted to be of tidal origin, have been described in Illinois from the Frances Creek Shale (Desmoinesian), which directly overlies the Colchester Coal (Baird and others, 1986), and from the Precambrian Elatina Formation of Australia (Sonett and others, 1988; Williams, 1989). Other examples exist in the Fountain Formation (Pennsylvanian) of Colorado and the Caseyville (Pennsylvanian) of Iowa (Archer and Kvale, 1989; unpublished data).

Paleontology

Bedding-plane views of the laminated siltstone are possible on the discarded blocks of siltstone from the mining operations. These surfaces reveal a variety of trace fossils; the most common forms are *Plangtichnus eraticus*, *Treptichnus bifurcus*, and *Haplotichnus indianensis* (Archer and Maples, 1984). Although about 20 ichnogenera occur (Archer and Maples, 1984; Maples and Archer, 1987; Archer, unpublished data) and are common in places, there is virtually no bioturbation of the thin

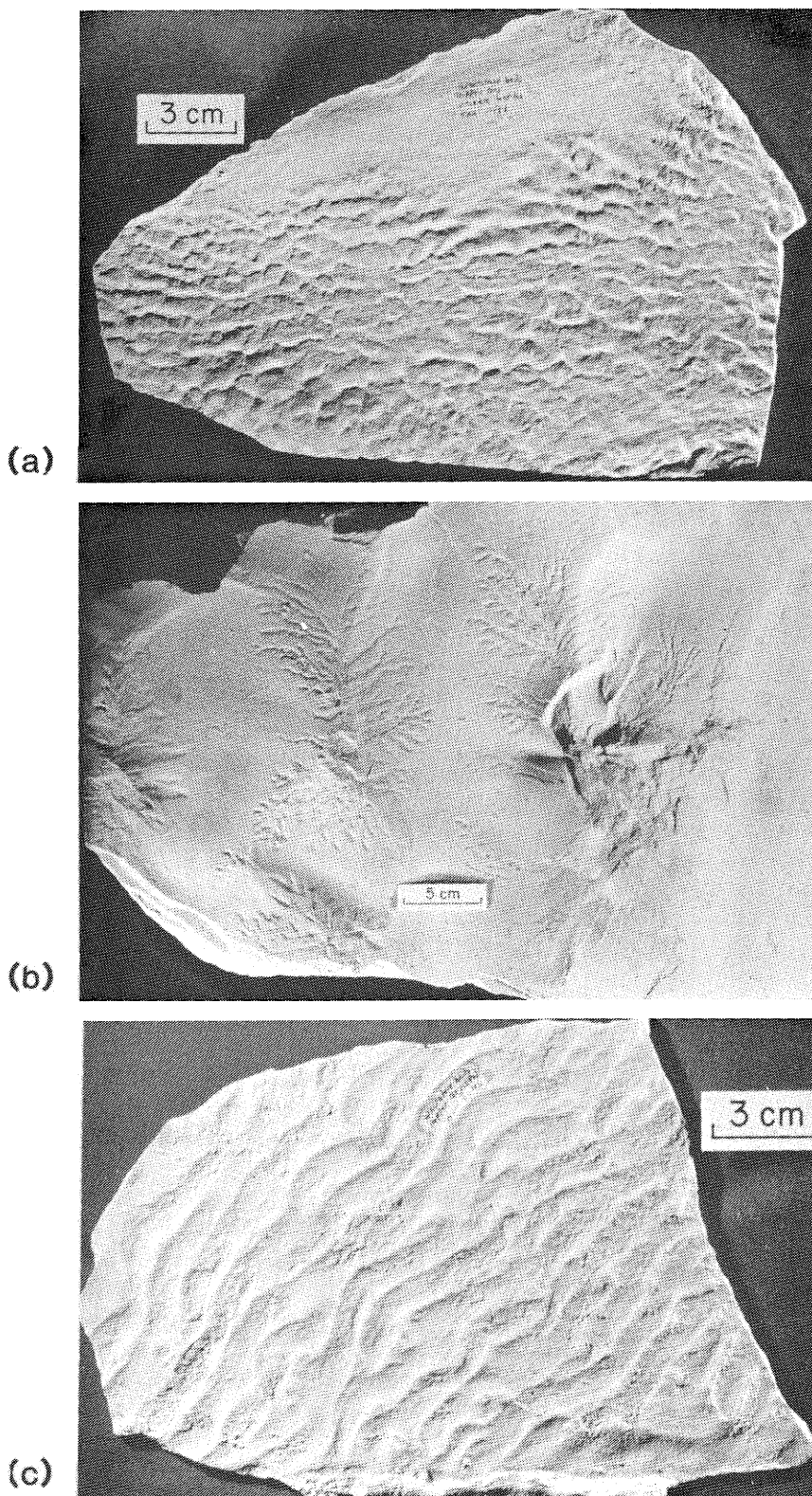


Figure 4. Bedding-plane views of oriented blocks of whetstones illustrating examples of: (a) runzel marks, (b) bifurcating rill marks with flow away from the center of silt volcanoes formed by dewatering or degassing of the sediment, and (c) millimeter ripples with flattened crests. All of these structures are useful indicators of periodic subaerial exposure of the whetstone beds.

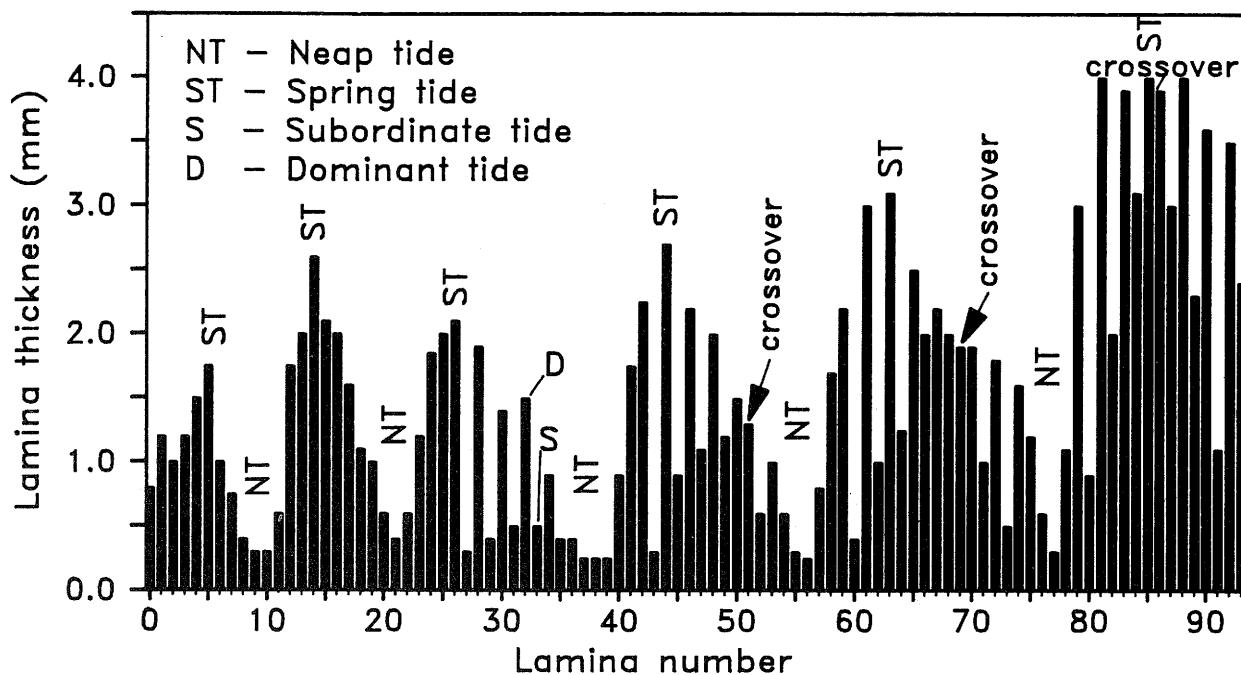


Figure 5. Systematic thickness variations of whetstone laminae in the block depicted in Figure 3. The crossover refers to the point at which dominant siltstone becomes about equal in thickness to subordinate siltstone. *Modified from Kvale and others (1989).*

laminae; however, dewatering structures may disrupt laminae.

Plant fossils found in the whetstones are principally lycophytes, including well-preserved trunks (*Lepidodendron*), cones (*Lepidostrobus*), and leaves (*Lepidopholius*). Lycopod trunks as much as 50 centimeters in diameter and 2.5 to 5.5 meters in height have been preserved in an upright position (Fig. 7). They appear to be rooted in a coal that directly underlies the whetstones. Other significant fossils include two well-preserved insect wings discovered in a whetstone quarry in the late 1800's (Smith, 1871; Scudder, 1885) and an amphibian trackway (N. G. Lane, Indiana University, 1988, personal commun.). In addition, Carl Rexroad (Indiana Geological Survey, 1988, written commun.) has recovered the conodonts *Streptognathodus* and *Cavusgnathus* found in intercalated claystones collected from whetstones in the Hopper Quarry.

LOWER PART OF THE BRAZIL FORMATION

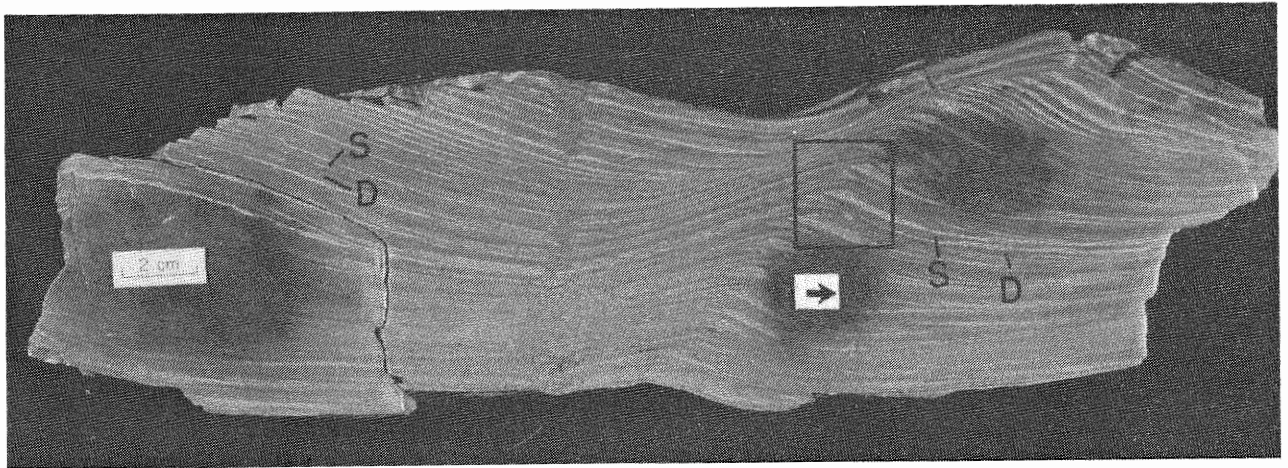
This section discusses the lower part of the Brazil Formation that extends from the Lower Block Coal

Member to the Upper Block Coal Member (Fig. 1). The interval averages about 8 meters in thickness within the study area. The block coals are among Indiana's lowest in sulfur and ash, and are of considerable economic importance.

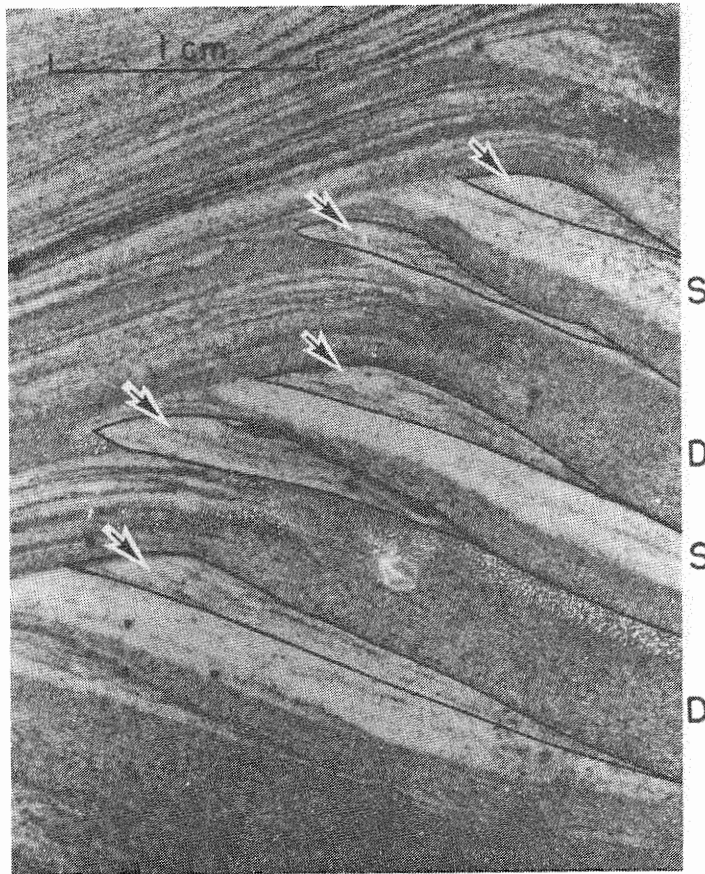
The dominant primary sedimentary structures between the Upper and Lower Block coals are rhythmically alternating sandstones and mudstones that can be classified as flaser, wavy, and lenticular bedding (Reineck and Wunderlich, 1968). Such structures have been recognized as important components of subtidal and intertidal deposits (e.g., Reineck and Wunderlich, 1968; Clifton, 1982).

General Background

The information in this section was derived principally from five open-pit strip mines in Daviess and Clay Counties (Fig. 8). The Lower Block coal averages slightly less than 1 meter in thickness within these mines, and the Upper Block coal averages 60 centimeters. Multiple sections were measured within the Little Sandy pit (Fig. 8) and were combined into a composite section of an active mine wall. The re-



(a)



(b)

Figure 6. (a) Polished slab of climbing oscillatory ripples. The dominant flow direction is indicated by the large arrow. Note that dominant (D) and subordinate (S) couplets are preserved in the bedform. The laminae are disrupted by a dewatering or degassing event. (b) An enlargement of the rectangular area outlined in (a) shows discontinuous wedges of reverse-dipping foresets (small arrows) that separate the dominant from the subordinate laminae. The wedges are formed by reversing tidal currents.



Figure 7. Upright tree preserved in a whetstone quarry. The tree likely extends downward to a coal that underlies the whetstone bed, a distance of 3 to 4 meters beneath the base of the tree.

sults of this investigation are documented more fully in Kvale and Archer (in press).

Sedimentology

The interval between the coals can be divided lithologically into a mudstone-dominant lithofacies (greater than 50 percent mudstone) and a sandstone dominant lithofacies (less than 50 percent mudstone). The former lithofacies generally occurs at the base and the top of the sequence and is dominated by laminated mudstones lacking sand and by lenticular- and wavy-bedded sandstones and mudstones. The latter lithofacies generally occurs in the center to the upper part of the sequence and is dominated by wavy- and flaser-bedded sandstones and shales. In the Little Sandy pit, associated with the sandstone-dominant lithofacies, are broad (tens of meters) and shallow (less than 3 meters thick)

channel-fill deposits. Overall, the sequence coarsens upward above the Lower Block coal from mudstone to sandstone and then fines upward into mudstone beneath the Upper Block coal (Fig. 9).

Of particular interest in this interval are the pronounced centimeter-to-decimeter-scale cycles of thickness variability of mudstone laminations within the laminated mudstones and of sandstone-mudstone couplets of the lenticular- to wavy-bedded units (Fig. 10). Each cycle shows a gradual increase in thickness of successive mudstone laminae within the laminated mudstones or of sandstone layers within successive sandstone-mudstone couplets and then a gradual decrease in thickness. A zone of sandstone (or mudstone laminae) thickness minima separates each zone of sandstone (or mudstone laminae) thickness maxima. Such cycles can be

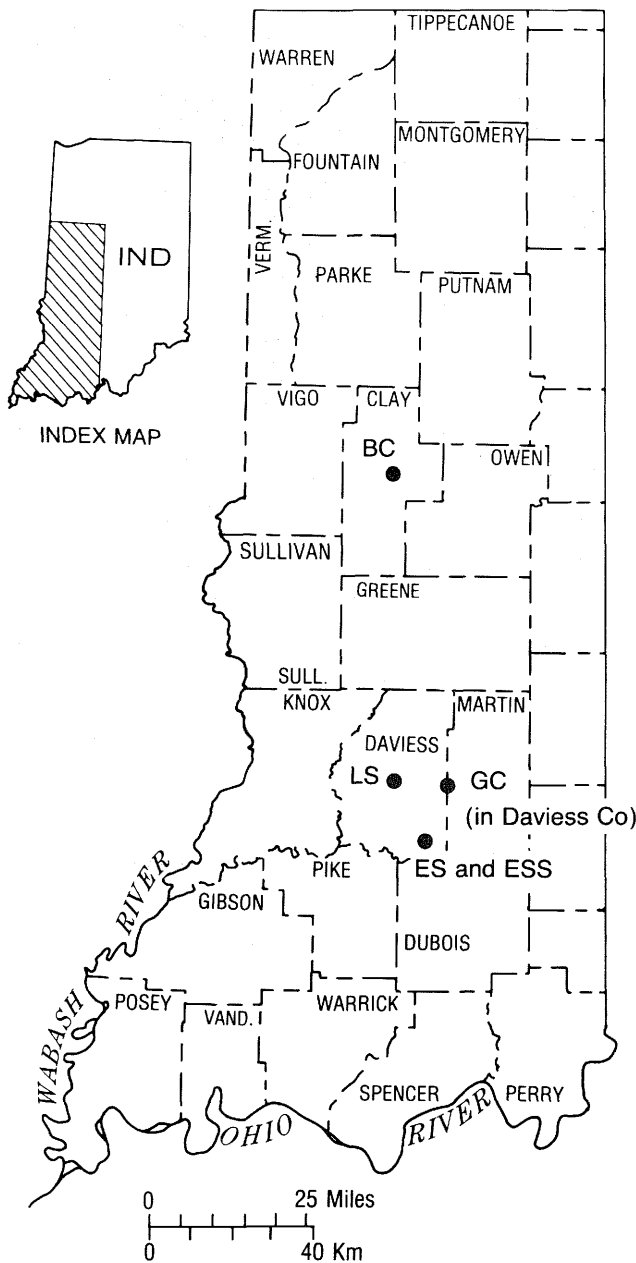


Figure 8. Map of southwestern Indiana showing the location of the coal mines investigated. BC—Brazil Coal and Clay Mine (NW $\frac{1}{4}$ NW $\frac{1}{4}$ Sec. 30, T. 11 N., R. 6 W.), ES—Energy Supply, North Pit Venturi Mine (SW $\frac{1}{4}$ NE $\frac{1}{4}$ NW $\frac{1}{4}$, Sec. 19, T. 2 N., R. 5 W.), ESS—Energy Supply, South Pit (N $\frac{1}{2}$ SW $\frac{1}{4}$ SW $\frac{1}{4}$, Sec. 30, T. 2 N., R. 5 W.), GC—Green Construction Co. Mine (NE $\frac{1}{4}$ NW $\frac{1}{4}$, Sec. 32, T. 3 N., R. 5 W.), LS—Little Sandy No. 1 Pit (S $\frac{1}{2}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$, Sec. 24, T. 3 N., R. 6 W.).

equated to neap-spring tidal-current fluctuations and provide most compelling evidence of tidal influence within this coal-bearing sequence.

Mudstone-Dominant Lithofacies

Kvale and Archer (in press) grouped the primary sedimentary structures within this lithofacies into three types: (1) parallel-laminated mudstones, (2) parallel-laminated sandstone and mudstone couplets, and (3) rippled sandstones and mudstone couplets. In a very general sense, the occurrence of these types is a function of stratigraphic position above the Lower Block coal.

Parallel-Laminated Mudstones (Type 1)

This type of bedding is best developed immediately above the Lower Block coal. Millimeter-scale or finer scale laminae first appear within a few centimeters (usually less than 5 centimeters) above the upper surface of the coal. At the lowest level, pronounced cycles of thin laminae (minima) grading to thicker laminae (maxima) and finally back into thin laminae (minima) occur in a vertical distance of 5 millimeters or less. The distance between laminae minima increases to 30 millimeters within a distance of 50 centimeters above the coal (Fig. 11a). These laminae are not apparent in outcrop but are prominent on polished blocks. Polished slabs of mudstone show an upward-fining of siltstone to claystone within each lamination; this is an indication of waning flow. Contacts between laminae are sharp and regular, although some soft-sediment deformation is present. Both asymmetric and symmetric cycles occur as laminae thicknesses vary rhythmically with periodicities of 13 or less (Fig. 11b).

This bedding type is usually very well preserved immediately above the Lower Block coal but not so below the Upper Block coal. In color and mineralogy the mudstone that occurs immediately beneath the Upper Block coal is similar to the laminated mudstone that occurs above the Lower Block coal. But rooting associated with the upper coal penetrates at least a meter and has destroyed any primary sedimentary structures that might have been associated with these mudstones.

Parallel-Laminated Sandstone and Mudstone Couplets (Type 2)

This type of bedding is usually present between type 1 and type 3 and is transitional with both. The couplets consist of very fine-grained sandstone stringers that are flat, generally laterally continuous, and interlayered with mudstone. Where they are not continuous laterally, the sandstone stringers resemble the incipient ripple forms that Reineck and Wun-

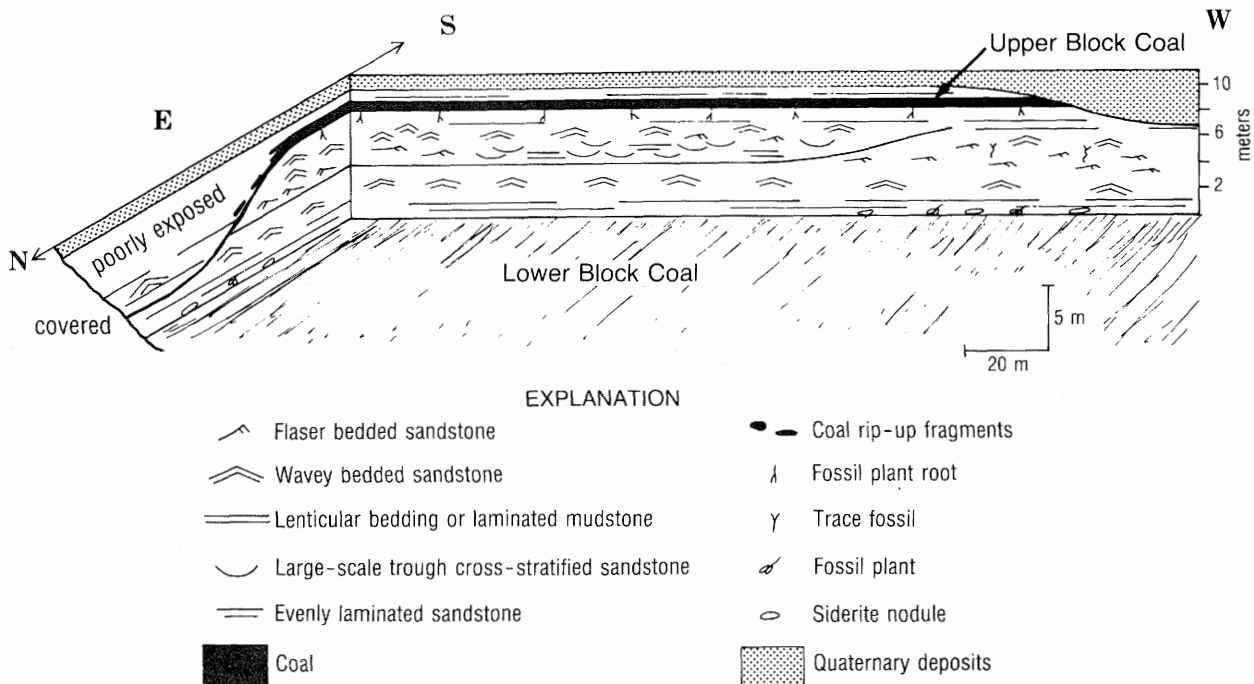


Figure 9. Block diagram of the Little Sandy No. 1 mine-wall reconstruction.

derlich (1968) termed "lenticular bedding" and Klein (1977) referred to as "pinstripe lamination."

The mudstone laminae generally fall into two categories: claystone-rich and siltstone-rich. The former is interpreted to have been deposited from suspension, whereas the latter, because of its coarser grain size and greater thickness, is interpreted to have been deposited from bedload sediment. The siltstone laminae range in thickness from less than 1 millimeter to as much as 8 millimeters, and have sharp upper and lower contacts. The associated sandstone laminae rarely exceed 1.5 millimeters (Fig. 12). Within the claystone-sandstone couplets, the claystone laminae are more uniform in thickness (usually 1 to 2 millimeters thick) and have sharp upper boundaries and more transitional lower boundaries with the underlying sand laminae. The associated sandstone laminae range from a few grains in thickness to 3 millimeters (Figs. 10 and 13a). The sandstones within both categories appear well sorted, quartz rich, and generally massive, but faint internal horizontal laminations of coal fragments are sometimes present in some sandstones. Small load structures are common. The siltstone member is dark, sandy, and poorly sorted and contains abundant sand- and silt-sized coal fragments with minor amounts of silt- to sand-sized quartz grains. Over-

all, each siltstone lamina fines upward to a claystone just beneath the next sandstone lamina; this is an indication of waning flow.

As with type 1 bedding, there are pervasive cycles of thickness variability within type-2 bedding (Fig. 13b). Each cycle exhibits a gradual increase in the thickness of sandstone laminae to a maxima and then a gradual decrease to a sandstone minima. The maximum number of clean sandstone laminae between sandstone minima is 13. Distances between sandstone minima vary from 7 millimeters to 30 millimeters.

Rippled Sandstone and Mudstone Couplets (Type 3)

This bedding type is transitional with type-2 bedding and reflects an increase in flow velocity and sand supply probably associated with deepening water. It is also the most common, the most easily observed in outcrop, and perhaps the most variable of the bedding types. The sandstone layers range from 1 to 35 millimeters in thickness, and the mudstone layers range from 2 to 10 millimeters in thickness. Both may be laterally continuous for many meters. In particularly clean high-wall exposures, individual sandstone layers can be traced laterally for tens of meters. The limiting factor is commonly the

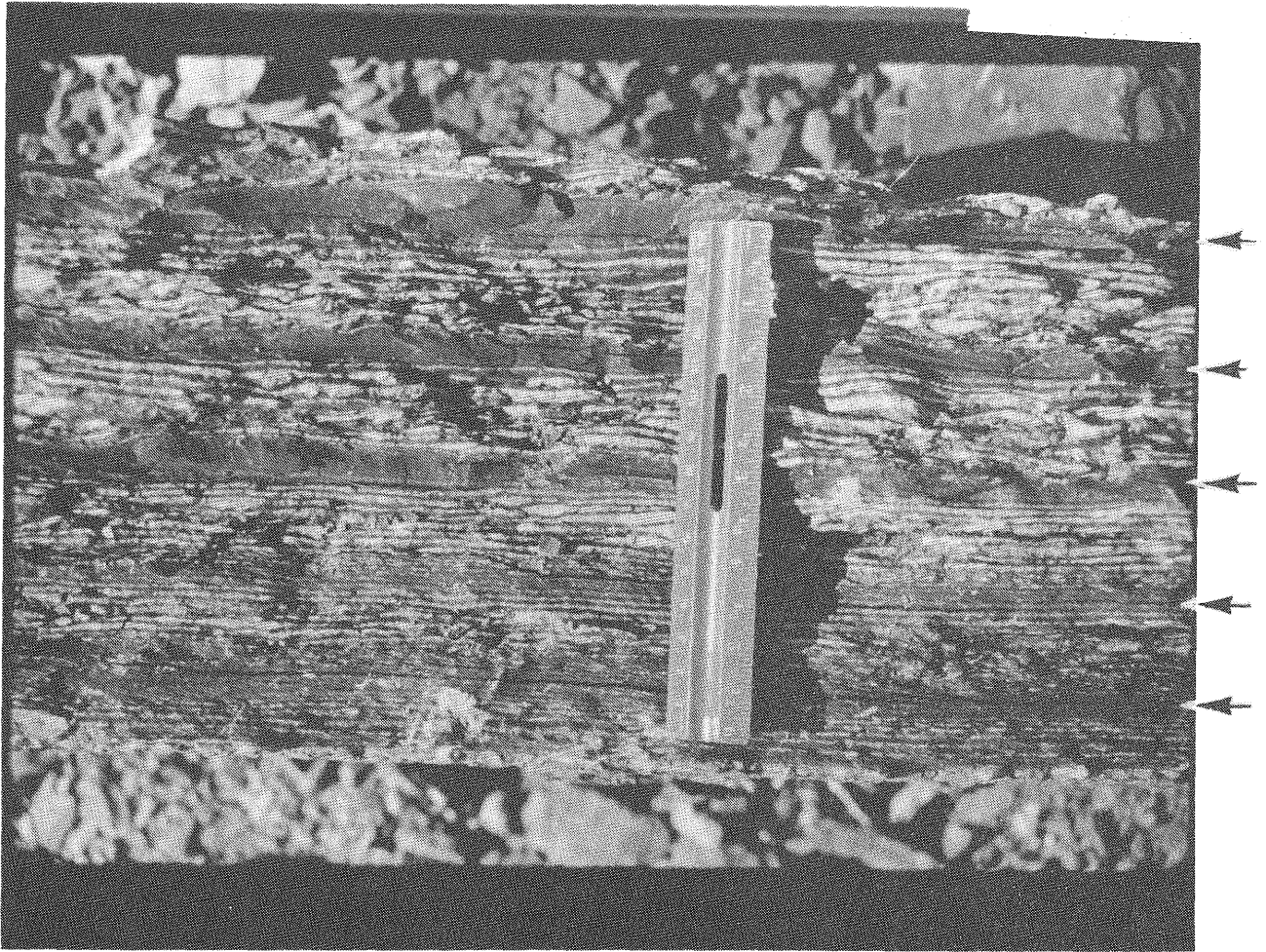


Figure 10. Cross-sectional view of sandstone-mudstone couplets. The arrows point to the sandstone minima. The top of the photograph is stratigraphic up.

safety of the mine wall or rock falls that prevent further observation.

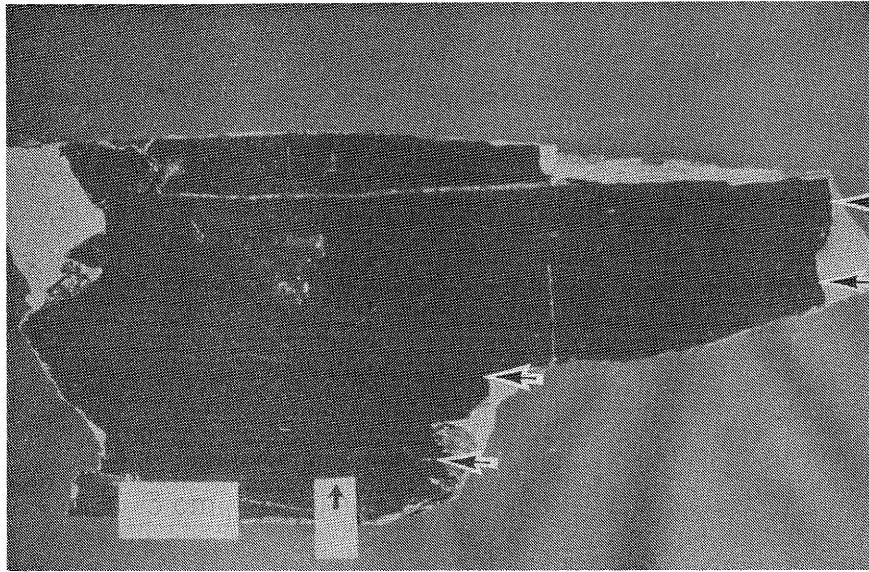
The sandstones are ripple laminated and are composed of relatively clean, fine-grained to very fine-grained, quartz-rich sands (Fig. 14). Ripple laminations are accentuated by dark coal fragments. The type-3 mudstone layers are siltstone dominated and have sharp contacts with the overlying and underlying sandstones. Like the type-2 siltstone-dominated layers, the type-3 mudstones are composed of predominantly dark, silt- to sand-sized coal fragments with minor amounts of quartz. The siltstone layers grade vertically to claystones a fraction of a millimeter thick just beneath the overlying sandstone layer. The loading of overlying sandstone into the underlying mudstone is locally intense, and well-

developed enterolithic structures of sandstone in mudstone are preserved in many places. This bedding type is transitional with the sandstone-siltstone couplet of type 2.

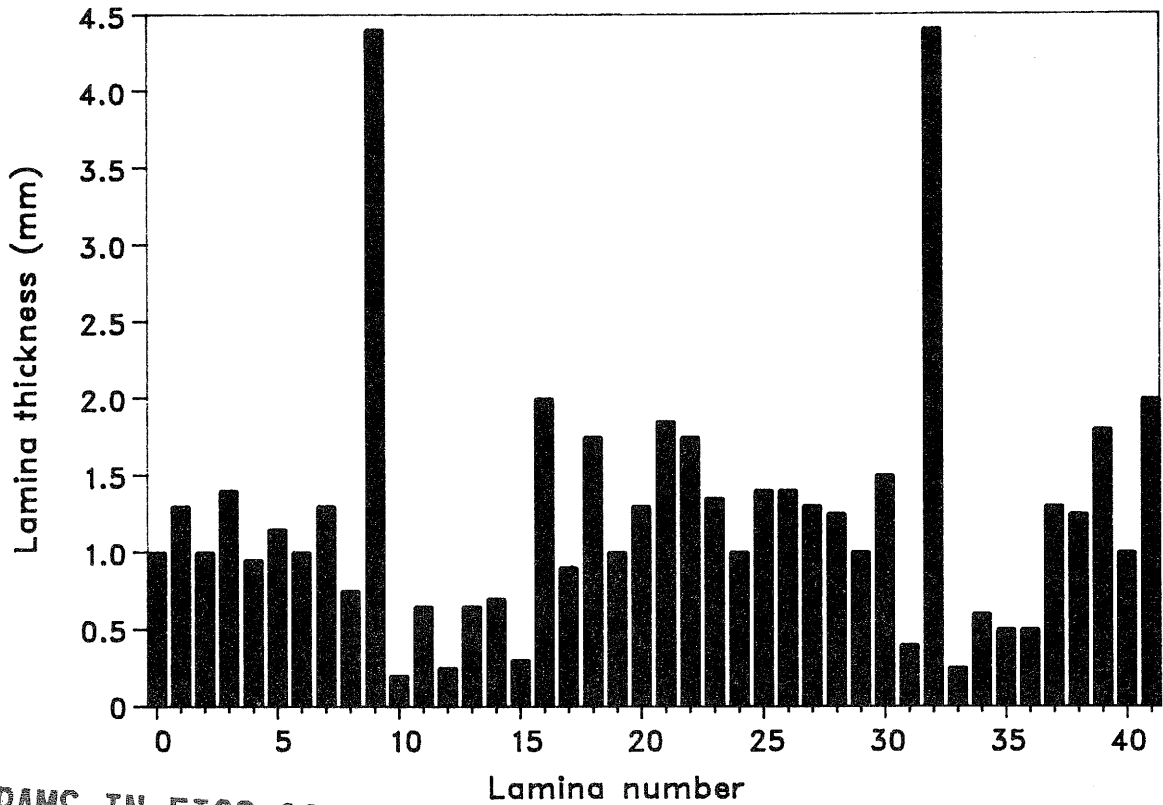
The type-3 structures, like those of types 1 and 2, also exhibit general cycles of sandstone maxima and minima (Fig. 15). These are not as clearly developed, in part because of the erosive bases of some ripple sets. Ranges in thickness between sandstone minima measured in the field are 11 to 52 centimeters. The overall trend is for the thickness between sandstone minima to increase with grain size.

Sandstone-Dominated Lithofacies

This lithofacies occurs at about the midpoint between the Upper and Lower Block coals. This loca-



(a)



(b)

HISTOGRAMS IN FIGS 11 & 13
INADVERTENTLY SWITCHED

Figure 11. (a) Parallel-laminated mudstone (type 1). Note the laminae minima (small arrows) that separate the laminae maxima. Load structures occur at the base of the thickest laminae. The large arrow points to stratigraphic up. (b) The histogram plot of lamina number versus lamina thickness is measured from the block pictured in (a). The peaks can be related to spring tides and the troughs can be related to neap tides.

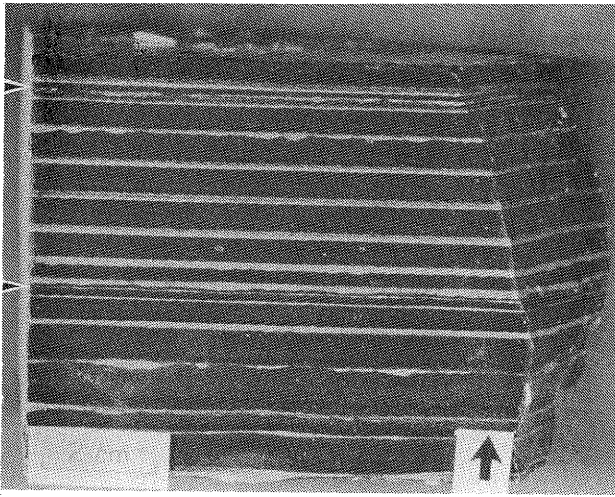


Figure 12. Parallel-laminated sandstone and siltstone couplet (type 2). The couplet was generated by two separate flow events, one flow (flood-tide) deposited clean, quartz-rich sand, and the second flow (ebbtide) deposited organic-rich silts derived from reworked peat fields. The small arrows point to the laminae minima (neap deposits).

tion makes the sandstone-dominated lithofacies the most difficult to study because of its position in the high walls. This lithofacies is dominated by flaser to wavy bedding and contains the only channel-fill sequences. The channels range from a few meters to tens of meters in width and from 30 centimeters to 4 meters in thickness. The exact dimensions are difficult to ascertain because the nature of the mining limits most outcrops to two-dimensional views. The small-scale channels are either symmetric or asymmetric, are scour based, and filled with wedge-shaped, massive sands separated by wavy-bedded sandstones and shales. But the largest scale structures are found within the large channels. The general fill sequence of one of these channels is shown in Figure 9. The well-developed primary current lineations (PCL) preserved on bedding-plane surfaces indicate that the horizontally stratified units were deposited in upper plane bed conditions. Individual sets of large-scale trough cross stratification are less than 30 centimeters thick, and some of the foresets are draped with clay (Fig. 16). Because the large channels are inaccessible, little is known regarding the paleocurrent trends of these channels.

Like the patterns observed in the whetstones, the regular patterns of cyclic thickness variability that have been observed within the Brazil interval are

best explained in terms of neap-spring tidal fluctuations in current velocities that occur during a lunar month. The mudstone-dominant lithofacies within the lower part of the Brazil may have been deposited within a diurnal system based on laminae counts that usually number less than 13. As it is likely, however, that not every tide during a monthly cycle produced a lamination, a diurnal tidal interpretation is not certain.

Paleontology

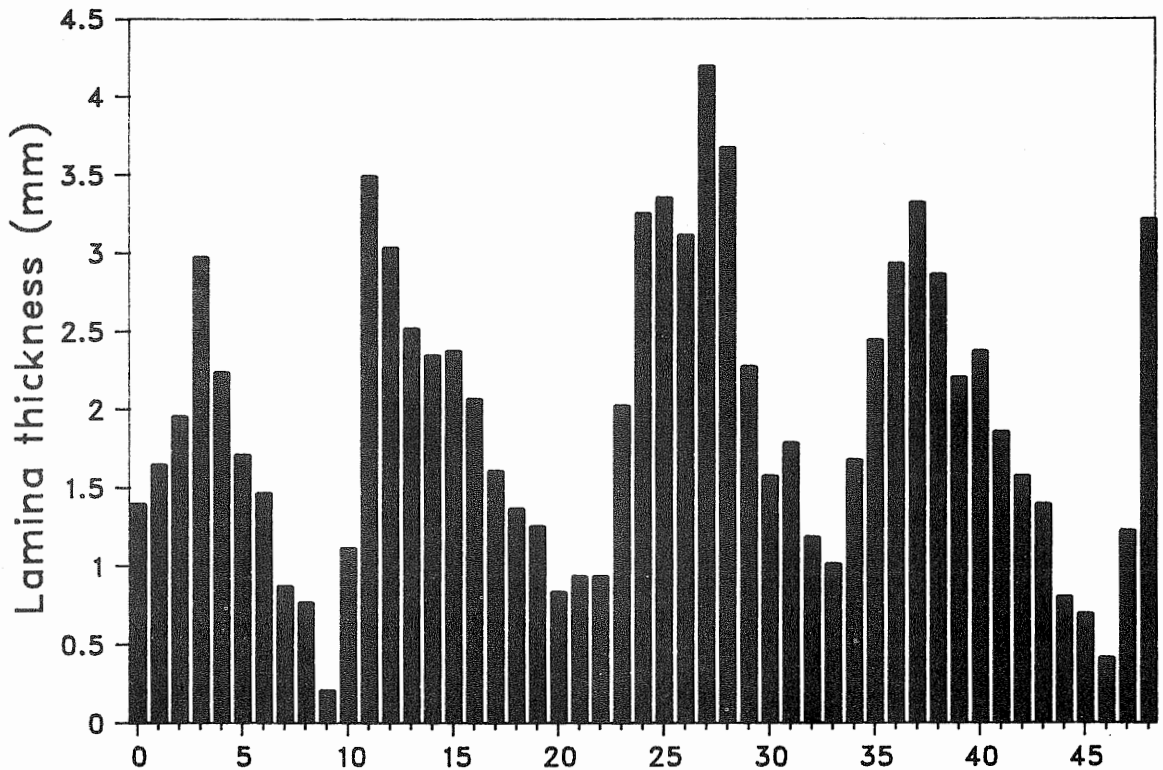
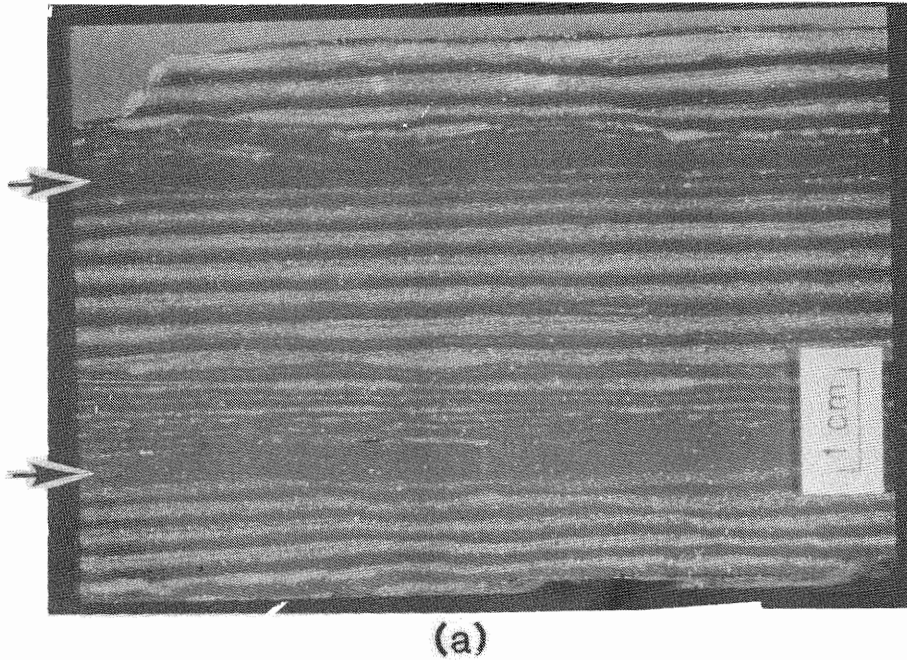
The only megafossils found by the authors within this interval were plant fossils. The largest accumulations are in the clay mudstones immediately above the Lower Block Coal Member. The flora varies spatially in taxonomic composition and includes several species of pteridosperms, *Calamites*, and in places, *Lepidodendron wortheni* (William DiMichele, 1989, Smithsonian Institution, personal comm.). At some locations the plant remains are preserved within siderite nodules and are typically confined to strata immediately above the Lower Block coal.

Upright tree stumps or stems of lycopods and *Calamites* have been reported in shales immediately above the Lower Block coal in some mines (John Nelson, 1988, Illinois State Geological Survey, personal comm.). In one mine an in-situ *Lepidodendron* was uncovered that nearly spanned the distance between the Upper Block coal and the Lower Block coal (about 8 meters; Dennis Brown, 1988, Energy Supply, Inc., personal comm.). This particular tree was branched at the top. Such preservation indicates that the trees were buried very quickly (on the order of decades rather than centuries).

Biogenic structures have not been recognized within the parallel-laminated mudstone. Thin, bioturbated zones containing *Chondrites*, *Planolites*, and *Locheia* are present but are not common within the facies that are more sand rich.

ACKNOWLEDGMENTS

Support for this research has come from the Indiana Geological Survey and an Indiana University Dean of Faculties Multidisciplinary Ventures Research Grant. We thank B. DiMichele, G. Fraser, N. Hester, B. Keith, J. Nelson, and T. Thompson for helpful discussions and comments. We appreciate the professional drafting and photography services provided to us by the Indiana Geological Survey sections under the direction of B. Hill and R. Hill. We also gratefully acknowledge the coal and whetstone companies that granted us access to their mines.



HISTOGRAMS IN FIGS 11 & 13 INADVERTENTLY SWITCHED

(b)

Figure 13. (a) Parallel-laminated sandstone and claystone couplets (type 2). The arrows point to the sandstone minima zones that formed during periods of neap tides when the tidal currents were too weak to transport sand. The top of the photograph is stratigraphic up. (b) The laminae thickness variability is measured from the block pictured in (a). The tallest bars correspond to multiple clay depositional events when the sands were not being deposited.

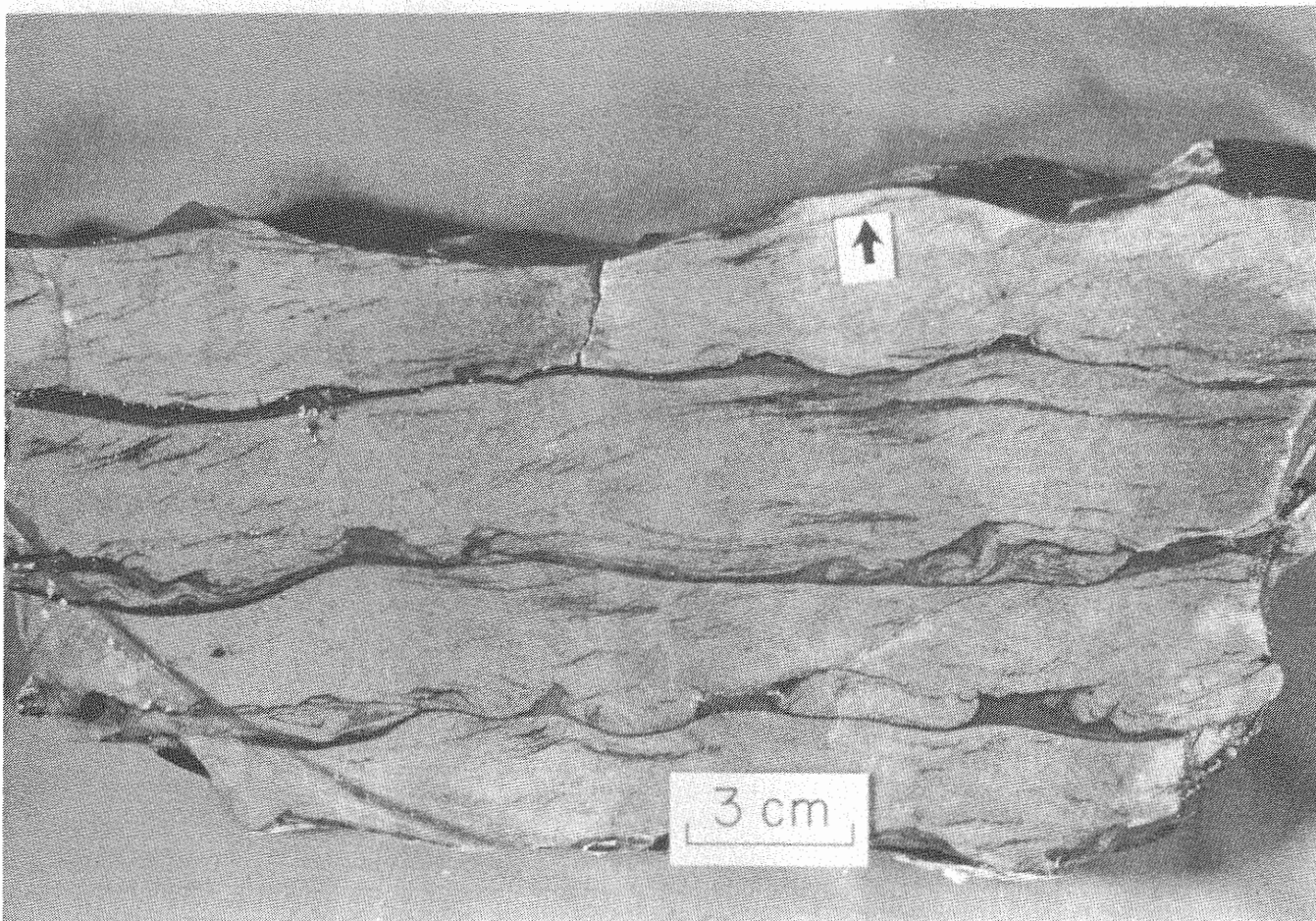


Figure 14. Rippled sandstone and mudstone couplets (type 3). Note the enterolithic structures caused by loading of the sands into the muds.

REFERENCES CITED

- Allen, J. R. L., 1981, Lower Cretaceous tides revealed by crossbedding with mud drapes: *Nature*, v. 289, p. 579–581.
- Archer, A. W., and Kvale, E. P., 1989, Rhythmically laminated sandstones within the Glen Eyrie "Member" of the Fountain Formation, near Manitou Springs, Colorado, in Suttner, L. J., ed., *A guide to field study of Pennsylvanian alluvial-fan and coarse-grained delta deposits near Manitou Springs, Gateway, and McCoy, Colorado: Guidebook for field trip conducted for BP Exploration, Inc.*, p. 15–19.
- Archer, A. W., and Maples, C. G., 1984, Trace-fossil distribution across a marine-to-nonmarine gradient in the Pennsylvanian of southwestern Indiana: *Journal of Paleontology*, v. 58, p. 448–466.
- Baird, G. C., Sroka, S. D., Shabica, C. W., and Kuecher, G. J., 1986, Taphonomy of Middle Pennsylvanian Mazon Creek area fossil localities, northeast Illinois: Significance of exceptional fossil preservation in syngenetic concretions: *Palaaios*, v. 1, p. 271–285.
- Boersma, J. R., Van de Meene, E. A., and Tjalsma, R. C., 1968, Intricated cross-stratification due to interaction of a megaripple with its lee-side system of backflow ripples (upper pointbar deposits, lower Rhine): *Sedimentology*, v. 11, p. 147–162.
- Clifton, H. E., 1982, Estuarine deposits, in Scholle, P. A., and Spearing, D., eds., *Sandstone depositional environments: American Association of Petroleum Geologists Memoir 31*, p. 179–189.
- Homewood, P., and Allen, P., 1981, Wave-, tide-, and current-controlled sandbodies of Miocene Molasse, western Switzerland: *American Association of Petroleum Geologists Bulletin*, v. 65, p. 115–128.

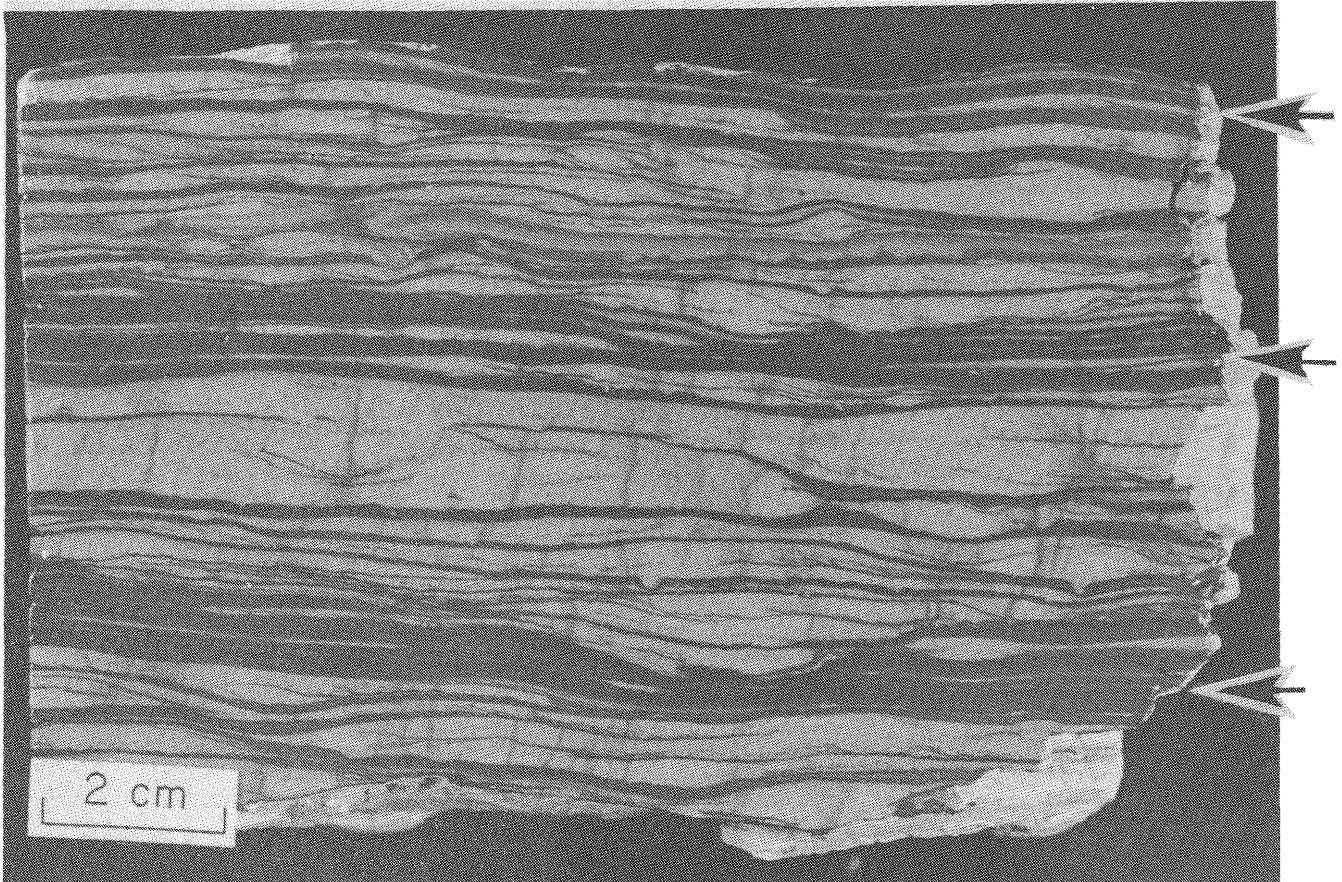


Figure 15. Rippled sandstone and mudstone couplets (type 3). Note the sandstone minima (arrows).

- tion of *Petroleum Geologists Bulletin*, v. 65, p. 2534–2545.
- Klein, G. de V., 1977, A sedimentary model for determining paleotidal range: *Geological Society of America Bulletin*, v. 82, p. 2585–2592.
- Kvale, E. P., and Archer, A. W., in press, Low-sulfur coal and associated tidal deposits, Brazil Formation (upper Carboniferous), Indiana: *Journal of Sedimentary Petrology*.
- Kvale, E. P., Archer, A. W., and Johnson, H. R., 1989, Daily, monthly, and yearly tidal cycles within laminated siltstones (Mansfield Formation: Pennsylvanian) of Indiana: *Geology*, v. 17, p. 365–368.
- Maples, C. G., and Archer, A. W., 1987, Redescription of Early Pennsylvanian trace-fossil holotypes from the nonmarine Hindostan Whetstone beds of Indiana: *Journal of Paleontology*, v. 61, p. 890–897.
- Reineck, H., and Wunderlich, F., 1968, Classification and origin of flaser and lenticular bedding: *Sedimentology*, v. 11, p. 99–104.
- Scudder, S. H., 1885, *Dictyonera* and the allied insects of the Carboniferous Epoch: *Proceedings, American Academy of Science (new series)*, v. 20, p. 167–173.
- Shaver, R. H., and others, 1985, Midwestern basin and arches region: Tulsa, American Association of Petroleum Geologists, *Correlation of Stratigraphic Units of North America Chart*.
- Shaw, A. B., 1964, *Time in stratigraphy*: New York, McGraw-Hill, 365 p.
- Smith, S. I., 1871, Notice of a fossil insect from the Carboniferous Formation of Indiana: *American Journal of Science (ser. 3)*, v. 1, p. 44–46.
- Sonett, C. P., Finney, S. A., and Williams, C. R., 1988, The lunar orbit in the late Precambrian and



Figure 16. Channel sandstone exhibiting large-scale trough cross stratification with clay-draped foresets (arrows).

the Elatina sandstone laminae: *Nature*, v. 335, p. 806–808.

Uhlir, D. M., Akers, A., and Vondra, C. F., 1988, Tidal inlet sequence, Sundance Formation (Upper Jurassic), north-central Wyoming: *Sedimentology*, v. 35, p. 739–752.

Visser, R., 1980, Neap-spring cycles reflected in Holocene subtidal large-scale bedform deposits: A preliminary note: *Geology*, v. 8, p. 543–546.

Williams, G. E., 1989, Late Precambrian tidal rhythmites in south Australia and the history of the earth's rotation: *Journal of the Geological Society of London*, v. 146, p. 97–111.

SEASONAL AND YEARLY CYCLES WITHIN TIDALLY LAMINATED SEDIMENTS: AN EXAMPLE FROM THE PENNSYLVANIAN OF INDIANA, U.S.A.

Allen W. Archer

AzTEL

**Department of Geology, Indiana University
Bloomington, Indiana**

Erik P. Kvale

**Indiana Geological Survey
Bloomington, Indiana**

ABSTRACT

Within the Mansfield Formation (Pennsylvanian) of Indiana there exist plane-laminated tidal rhythmites formed in inland tidal settings. These deposits are significant because of their association with coals and because previous interpretations invoked fresh-water deposition. In addition, although the strata do not contain marine macroinvertebrates, they contain tidally influenced cycles of deposition that are some of the most complete described from the rock record.

Four orders of tidal cycles and a fifth-order nontidal cycle are preserved within these rocks. The three smallest order tidal cycles were produced by semidiurnal tides, tropical-equatorial tides, and neap-spring tides. The two larger-order cycles consist of solstitial-equinoctial tidal cycles related to the earth's orbit and axial tilt, and yearly cycles related to nontidal, climatic parameters.

Vertical continuity of the cycles indicates that sedimentation rates of approximately 1 meter/year were attained during deposition of these laminated sediments. Conversely, based upon an average formation thickness and estimated formation duration of 15 million years, the average rate of preserved accumulation for the Mansfield Formation was about 6 meters/million years. Thus, long-term rates, which reflect rates at which sediments are preserved, are many orders of magnitude less than measurable short-term rates at which sediments are deposited.

INTRODUCTION

Geologic setting, stratigraphy, and sedimentology of the Hindostan Whetstone Beds (Mansfield Formation) are described by Kvale and others (1989) and Kvale and Archer (this guidebook). Field and subsurface investigations were conducted in or near three whetstone quarries in Orange County, Indiana. The most continuous record of laminated siltstone was obtained from two 5-centimeter-diameter cores drilled at the Dishman Quarry in Orange County, Indiana. These cores were drilled approximately 6 meters apart so that detailed core-to-core comparisons could be made. Additional core was provided by Amax Coal Company of Indianapolis, Indiana. Cores were hydrostatically extruded from the coring tube into plastic troughs. These troughs were then filled with plaster so that the vertical integrity of the cores could be maintained. Cores were cut and polished using a belt sander, and the whetstone portions were stained with red food coloring to enhance the laminations.

Detailed measurements of lamination thicknesses were made using photographic enlargements in conjunction with binocular microscopic examination. Using these techniques, the thicknesses of more than 2,000 vertically stacked laminations were measured. In addition, measurements were made of the spacing between successive zones of closely spaced laminations, which indicate the periodicity of the neap-spring cycles (see Fig. 1). Although short gaps in the sequence were encountered, principally

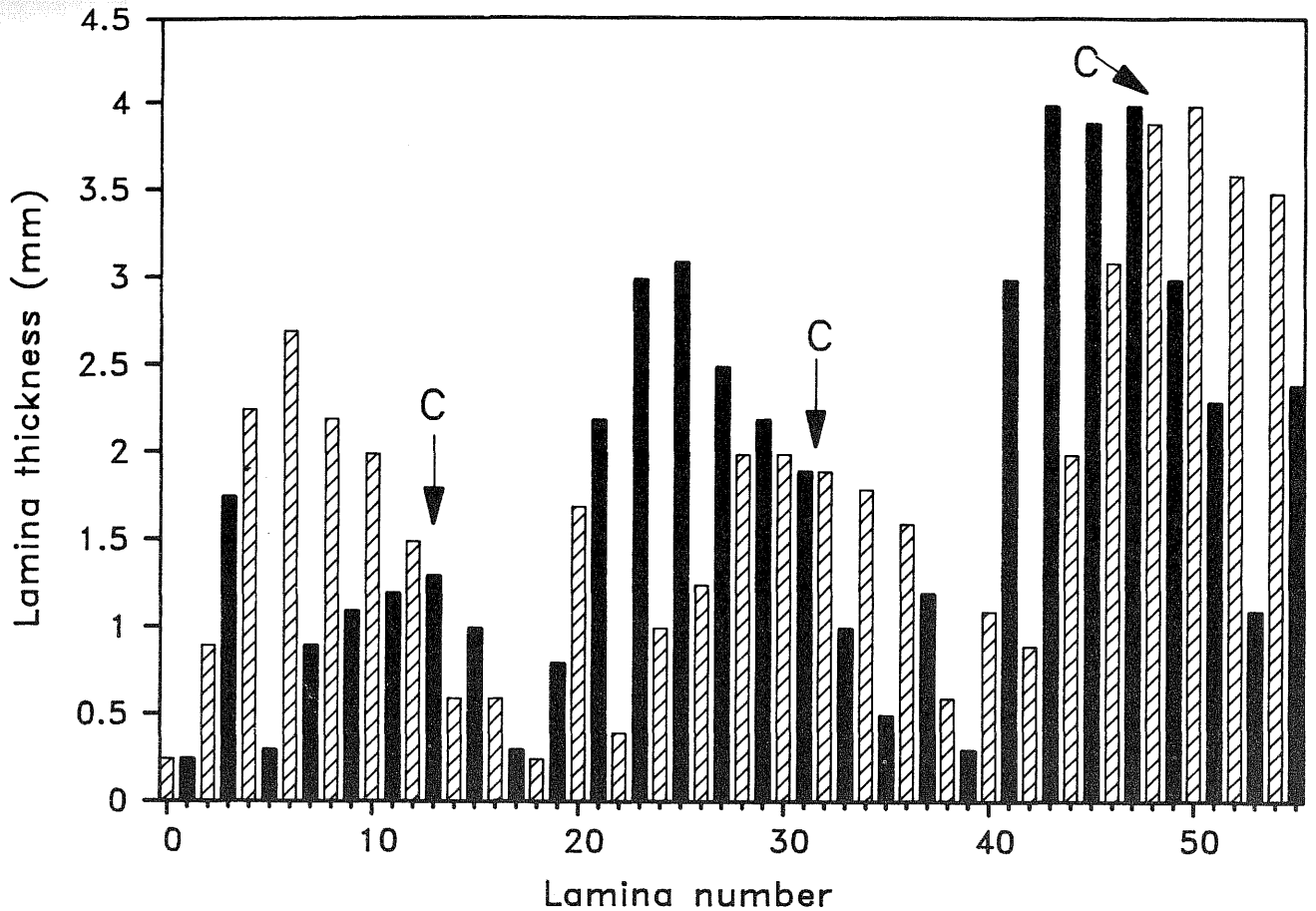


Figure 1. Thickness variability of dominant and subordinate laminae from section of Hindostan whetstone. Two orders of cycles are evident, including thickness inequality within laminae pairs, or couplets (related to semidiurnal tides) and systematic variation in laminae thicknesses (related to lunar orbit). In addition, subordinate and dominant lamina become approximately equal at "crossovers" (C), which are related to lunar declination.

owing to soft-sediment deformation, this data set consists of essentially a continuous series of sequential measurements.

Similarly laminated, slightly younger Pennsylvanian siltstones occur in Illinois and have been interpreted as tidal deposits (Kuecher, 1983; Baird and others, 1984, 1986). Similar Precambrian examples, originally described as exhibiting yearly varves and reflecting sunspot cycles (Williams, 1981; Williams and Sonett, 1985), have been recently redescribed as tidal deposits (Sonett and others, 1988; Williams, in press).

HIERARCHY OF CYCLES

As will be discussed, five levels of cycles are present: (1) semidiurnal tidal laminae, (2) neap-spring tidal cycles, (3) tropical-equatorial tidal cycles, (4) seasonal variability in tidal patterns, and (5) yearly

cycles related to sea-level variation. When a continuous series of laminations is plotted as a histogram, with bar heights indicating lamina thickness, systematic variations in thicknesses are evident (Fig. 1). Such diagrams exhibit the strong couplet relationship of alternating thick-thin pairs. These couplets represent the smallest scale, or first-order, pattern and are related to the effects produced by the earth's daily rotation in relation to the gravitational effects of the moon and sun (Fig. 2). A tidal bulge forms within the oceans and sweeps around the earth with a periodicity of slightly more than 12 hours. Thus, this bulge has a twice daily, or semidiurnal, effect on the earth's oceans. Because of the axial tilt of the earth, the two components of semidiurnal tides are unequal for nonequatorial latitudes. This inequality, or "semidiurnal inequality," is

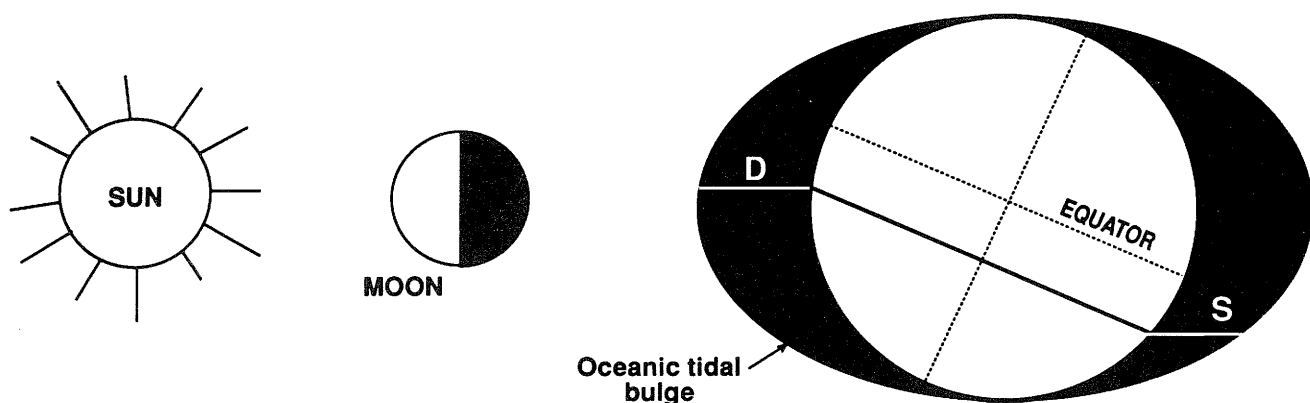


Figure 2. Tidal bulge (not to scale) as produced on the earth by the gravitational effects of the moon and sun and resultant semidiurnal (twice daily) tidal inequality that occurs in southern latitudes. During 1 day, a higher high, or dominant (D), tide and a lower high, or subordinate (S), tide are produced.

also affected by other astronomical factors, as will be discussed.

Neap-spring tidal cycles constitute the second-order patterns observed within the Hindostan whetstones. Such cycles are manifested by a systematic change in laminae thicknesses. Harmonic analyses of the continuous series of laminations indicate the strongest periodicities consist of about 26 laminae; this periodicity is best explained as having occurred in an area that experienced mixed to semidiurnal tides. These neap-spring cycles are related to the periodicity of the lunar orbit. The earth, moon, and sun are aligned whenever the moon is either in a new or full phase (Fig. 3). During these times the gravitational effects of the moon and sun are combined, and the highest, or spring, tides occur. Conversely, during the half-moon phases the secondary gravitational effects of the sun tend to contradict the lunar effects; thus, the lowest, or neap, tides occur. Neap-spring cycles occur every 14.75 days, and two such cycles occur during one lunar orbit (lunar month).

Third-order patterns are related to the moon's declination (Fig. 4), which is the angle of the lunar orbit to the earth's equatorial plane. The time required for the moon to change declination from 0 (over the earth's equator) to the maximum of 28° (over the tropics) and then back to 0 is 13.66 days. During the time when the moon crosses the equator, or "crossover," the semidiurnal inequality is minimized. Thus, the two semidiurnal tides formed during a crossover are approximately equal in height;

conversely, when the moon is at its maximum declination, the semidiurnal inequality is maximized (Fig. 4). Because this period is less than the interval between spring tides (14.75 days) described above, these crossovers will occur about 1 day earlier within each successive neap-spring cycle. Such patterns in modern tidal settings (Fig. 5) can be readily compared to those observed within the Pennsylvanian whetstones (Fig. 1).

The yearly cycle of seasons on the earth is related to earth's axial tilt of 23.5° (Fig. 6). Fourth-order tidal patterns can be specifically related to solstitial and equinoctial tides. In modern environments (Fairbridge, 1966) tidal ranges are maximized during the solstices (June and December); this is also the time of maximal semidiurnal inequality (height inequality of the dominant and subordinate tides) of the tides (Fig. 6). An opposite effect occurs during the equinoxes (March and September) when the semidiurnal inequality is at a minimum and tidal ranges are closer to the yearly average. In other words, during the equinoxes dominant tides are approximately equal to the subordinate tides (Fig. 6).

Such systematic variations in semidiurnal tidal heights would be manifested as systematic variations within the thickness inequality of the dominant and subordinate members of a couplet. When the difference between dominant and subordinate thicknesses is low within spring-tidal events, the couplets are generally thin (Fig. 7a). Conversely, within the thickest couplets, the difference between dominant and subordinate thicknesses is greater (Fig. 7b).

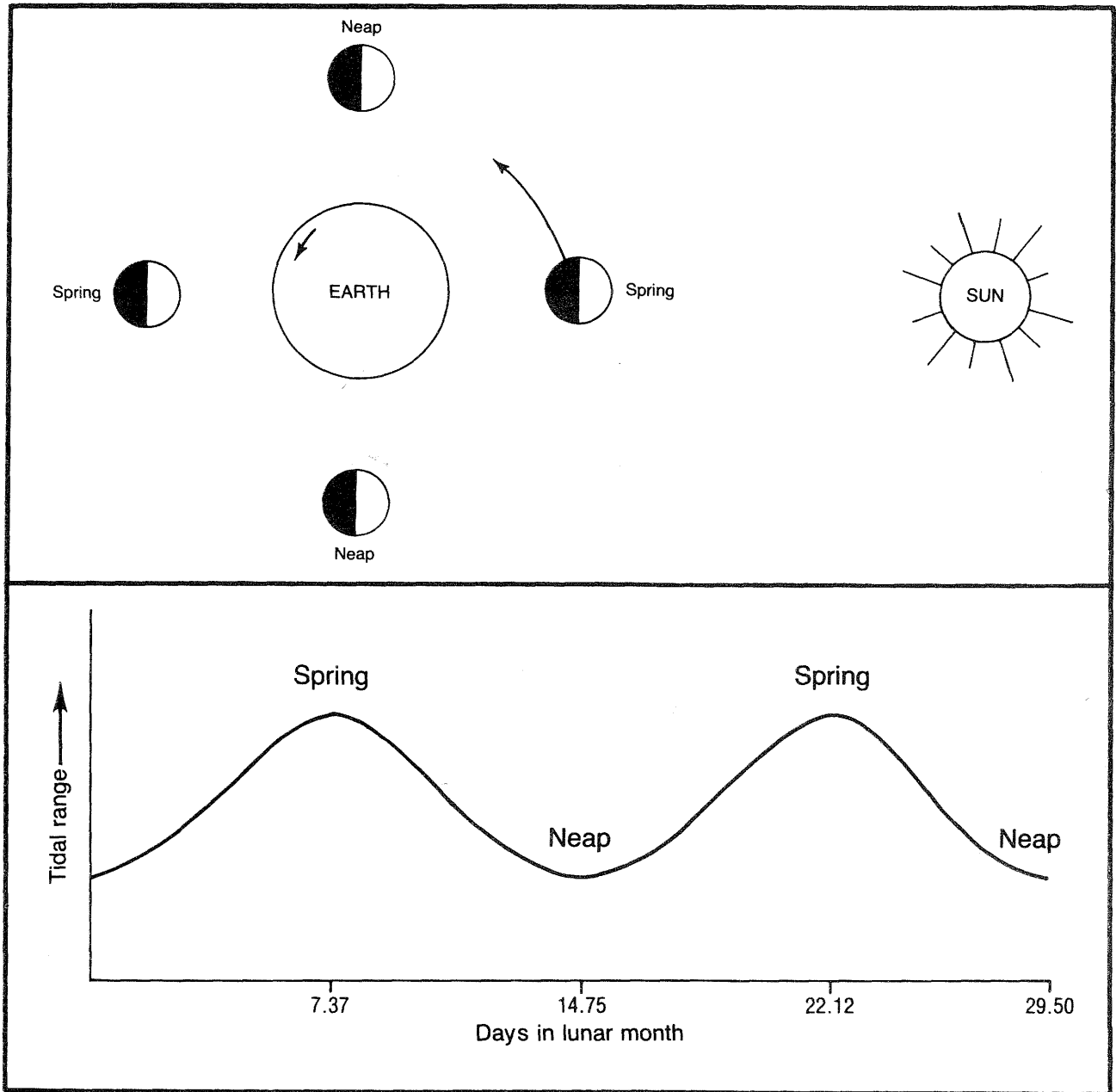


Figure 3. Lunar orbit (upper) and resultant monthly tidal variation (lower); neap tides are times of lowest monthly tides and spring tides are highest monthly tides.

The interpretation of these fourth-order cycles can be best explained together with the fifth, and largest, order of cycles.

Fifth-order cycles are apparent when a number of neap-spring-neap cycle thicknesses are plotted. It is expressed by a systematic increase and decrease in maximal neap-spring cycle thicknesses; the periodicity of these variations is on the order of hundreds of laminae (Fig. 8). As will be discussed, this

largest order cycle probably represents a yearly periodicity.

The examples presented in the discussion on variations of dominant-subordinate thicknesses (fourth order) can be systematically related to the largest cycle (fifth order). As delineated in Figure 8, the positions where the subordinate-dominant thickness inequality (fourth-order cycles) are at the greatest and at the least (Fig. 7) are related to specific por-

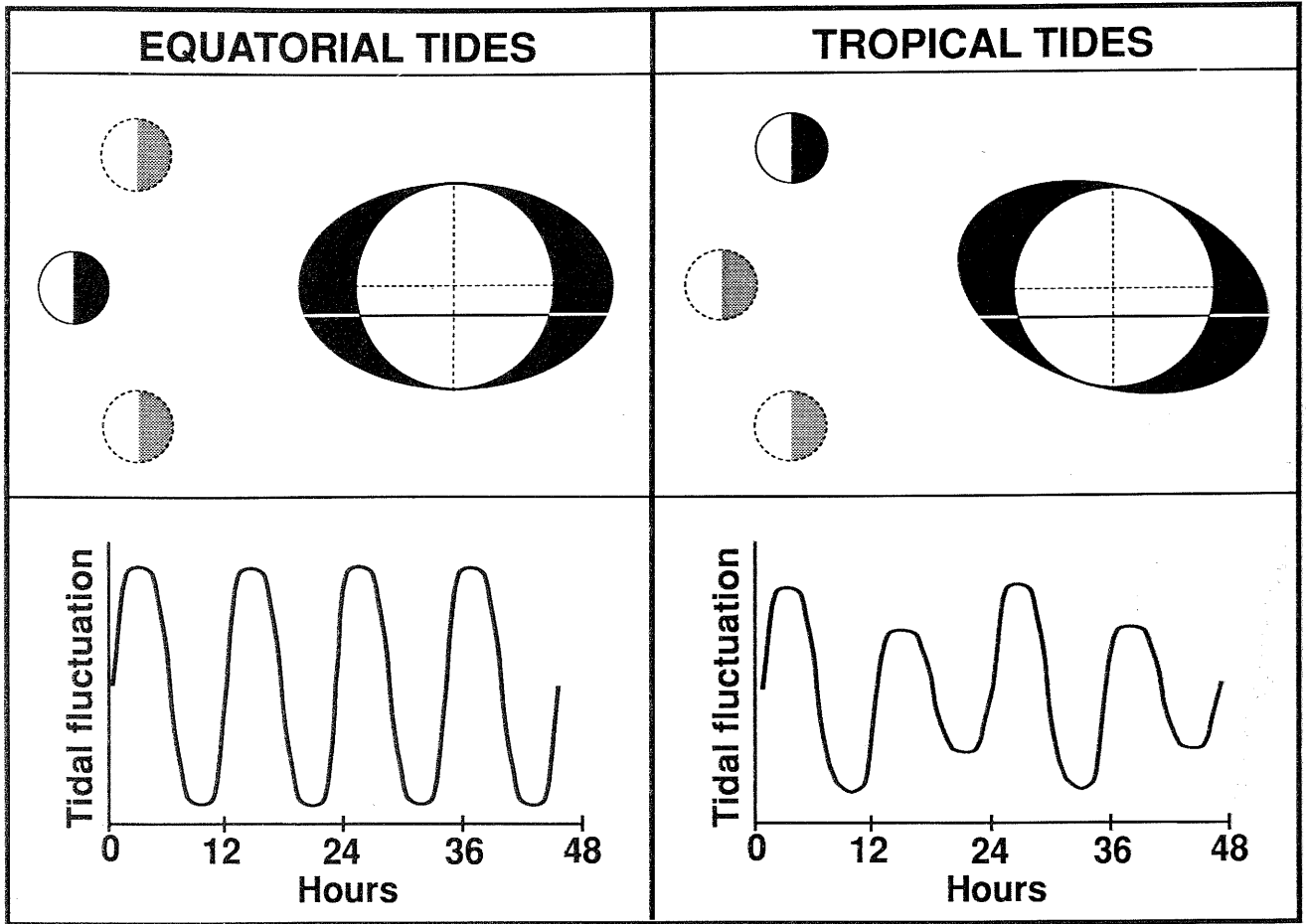


Figure 4. Effects of lunar declination upon tidal patterns. When the moon is over the equator (upper left), semidiurnal tidal inequality is minimized, resulting in near equality of tides (lower left). Conversely, when the moon is at its maximum declination of 28° (upper right), inequality is maximized and one higher and one lower tide results (lower right).

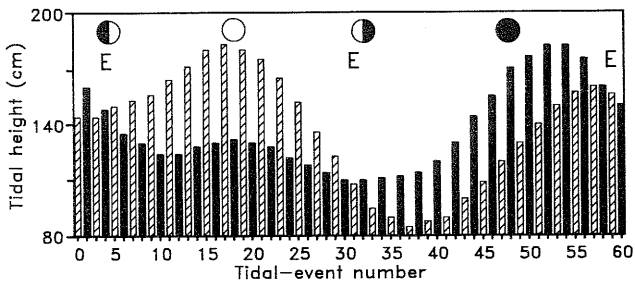


Figure 5. Tidal patterns from Boston, Massachusetts, for January 1963 (from Harris, 1981) illustrating equality of tides, or a "crossover," that occurs when the moon crosses the equator (E). At that time, the semidiurnal tidal inequality is minimized.

tions of the large-scale cycle. The positions are best explained by an analysis of modern tidal data.

As a modern analog for seasonality in tides, we have examined the predicted tides for a number of environmental settings. Tidal periodicities at Kolaka, Sulawesi, seem to offer a useful comparison because: (1) the low latitudinal setting is similar to that hypothesized for our study area during the Pennsylvanian (Scotese and others, 1979; Roy and Morris, 1979), (2) the tropical setting is similar to currently evolving thought on modern analogs for Pennsylvanian coal-forming peat deposition in the Illinois and Appalachian Basins, and (3) the strongest harmonics of the Kolaka tides are about 26 high tides per neap-spring-neap cycle, and this mixed, predominantly semidiurnal pattern closely matches the

26.1-laminae-per-neap-spring-neap cycle observed within the whetstones. As discussed previously, tidal ranges are maximized during the solstices (June and December); this is also the time of maximal semidiurnal inequality of the tides (Fig. 9b). An opposite effect occurs during the equinoxes (March and September) when the semidiurnal inequality is at a minimum and ranges are closer to a yearly average. In other words, during the equinoxes dominant tides are approximately equal to subordinate tides (Fig. 9a). It is apparent that areas where the subordinate-dominant thicknesses are nearly equal within the whetstones (fourth-order cycles; Fig. 7a) are similar to equinoctial tidal patterns that can be observed at Kolaka (Fig. 9a). In addition, where subordinate-dominant thicknesses are markedly different within the whetstones (Fig. 7b), such patterns are very much like tidal patterns produced during the solstices at Kolaka (Fig. 9b).

The fifth-order cycles can be related to yearly variations in sea level. Yearly sea-level variations also occur across much of the earth (see Fig. 10).

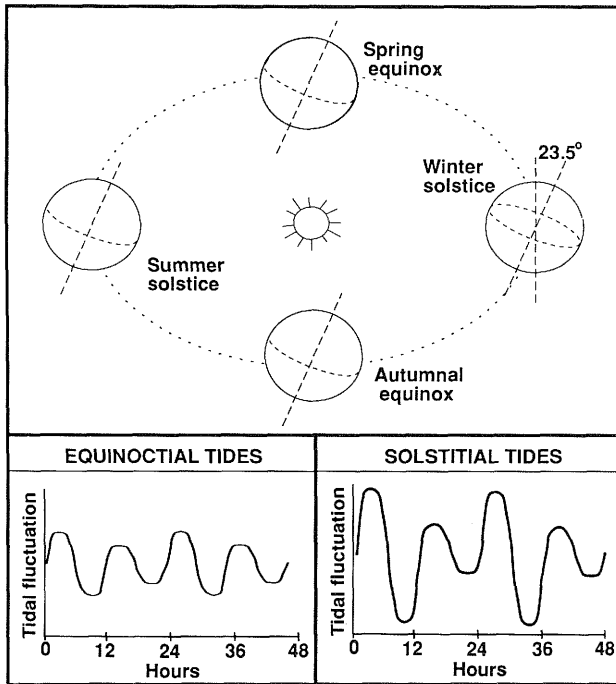


Figure 6. Because the effects of the earth's axial tilt are maximized during the solstices, maximum semidiurnal tidal variability occurs as well as highest tides at these times (lower left). Conversely, during the equinoxes, semidiurnal tidal inequality is at a minimum and tidal range is generally reduced (lower right).

Direct astronomical effects are in part responsible for yearly sea-level change; however, the fluctuation has been more directly equated to seasonally varying parameters such as temperature, salinity, and air pressure (see Fairbridge, 1966, p. 478). Thus, tidal patterns in such areas will exhibit yearly fluctuations in tidal heights related to nontidally forced parameters superimposed upon all the previously discussed, smaller scale patterns.

To statistically test the repetition of these large-scale patterns, harmonic analysis was performed on the neap-spring thickness data. When accumulated thickness is used as an independent variable, there are several periods of significance. Of greatest statistical significance are periods of 93 centimeters and a secondary period of 50 centimeters. The larger period corresponds to the thickness of a yearly cycle and indicates that nearly 1 meter of vertically accreted laminae were deposited during this time period. The secondary period reflects the equinoctial-solstitial variations in dominant-subordinate laminae thicknesses.

DISCUSSION

The occurrence of over 100 successive neap-spring cycles within the whetstones indicate that little to no significant storm activity was preserved during the deposition of the laminae. Although continuous series of laminations within the disturbed zones ("DZ" of Fig. 8) could not be measured, couplets within these highly convoluted zones were apparent. Thus, these zones are apparently the result of post-depositional soft-sediment deformation and probably are related to localized dewatering or degassing and are not the result of random high-energy events such as storms. The lack of evidence of storm deposits is consistent with an inferred inland depositional setting, which would have protected the deposits from such effects.

Estimates of deposition rates of about 1 meter/year within these tidally influenced environments is based upon thicknesses of semidiurnally emplaced laminae, occurrence and thickness of neap-spring-neap cycles, and the interpretation that the largest scale pattern is yearly. This high rate is supported by other observations, such as the occurrence of upright lycopod trunks (see Kvale and others, 1989). Other studies of similar marine-influenced coal-bearing Pennsylvanian strata have likewise suggested that very high rates of sedimentation were

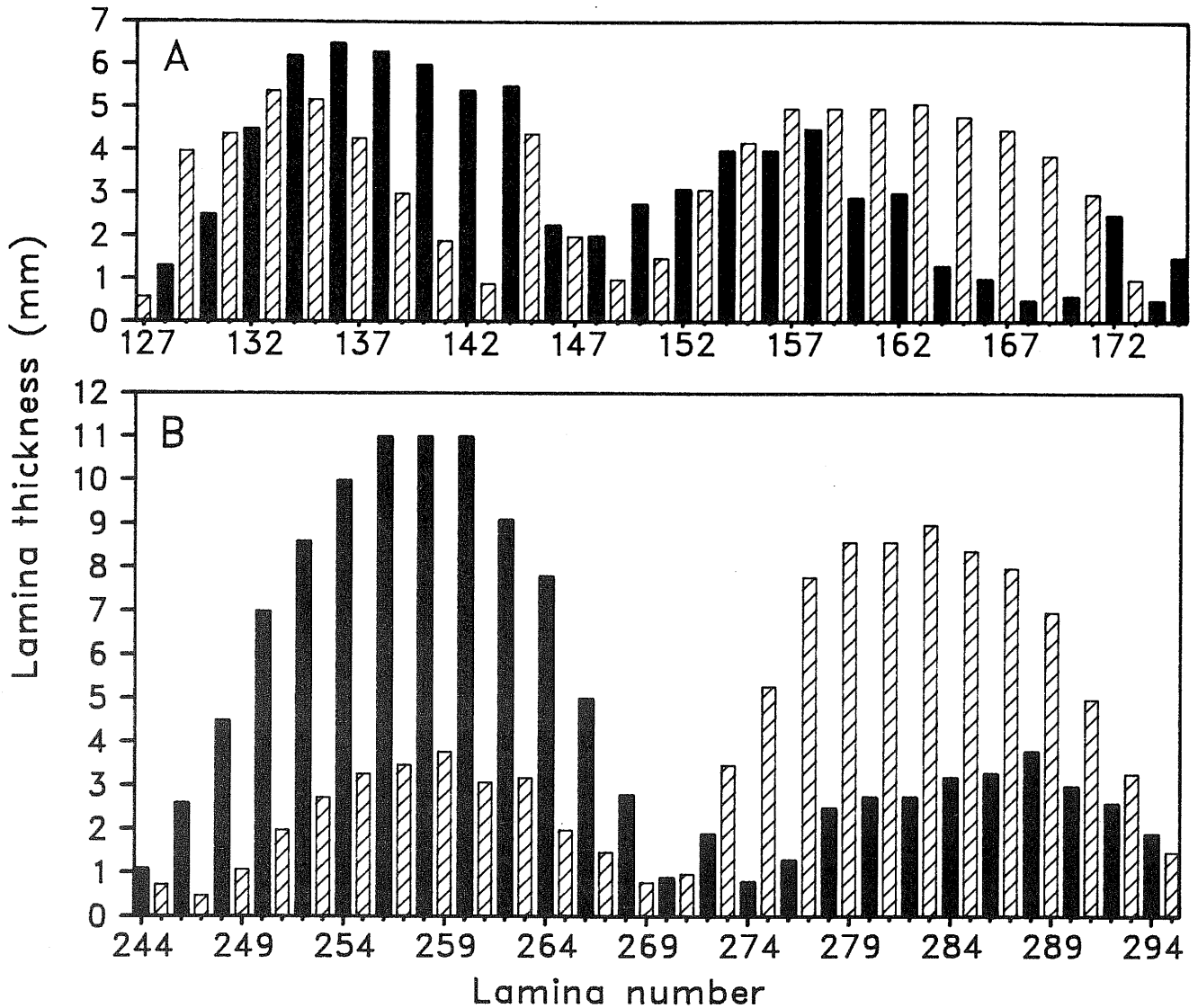


Figure 7. Fourth-order patterns observed within core data. Upper diagram (A) illustrates thinner (less than 7 mm) laminations with reduced difference between subordinate and dominant laminae. Lower diagram (B) illustrates thicker laminae (as much as 11 mm) interspersed with thin subordinate laminae. These patterns are interpreted to represent equinoctial and solstitial tides, respectively; their relation to larger scale patterns is shown in Figure 8.

possible (Zangerl and Richardson, 1963; Kuecher, 1983; Baird and others, 1984, 1986).

Finally, the nearly continuous semidiurnal deposition of laminae for several successive years bears greatly on the concept of "stratigraphic completeness" (Sadler, 1981; Sadler and Dingus, 1982; Anders and others, 1987). Not only has a detailed, multi-yearly record of nearly continuous diurnal and semidiurnal sedimentation events been preserved, but also extremely high rates (approximately 1 me-

ter/year) of sedimentation have been documented, although it appears that such rates were achieved only locally and may be related to peat compaction (Kvale and Archer, 1988). The occurrence of such rates of sedimentation indicate one of the difficulties of delineation and correlation of longer term (10,000 to 100,000 years) cycles on either the local or regional scale, such as has been advocated by some workers (see Busch and Rollins, 1984; Goodwin and Anderson, 1985; Busch and others, 1988). Thus, it

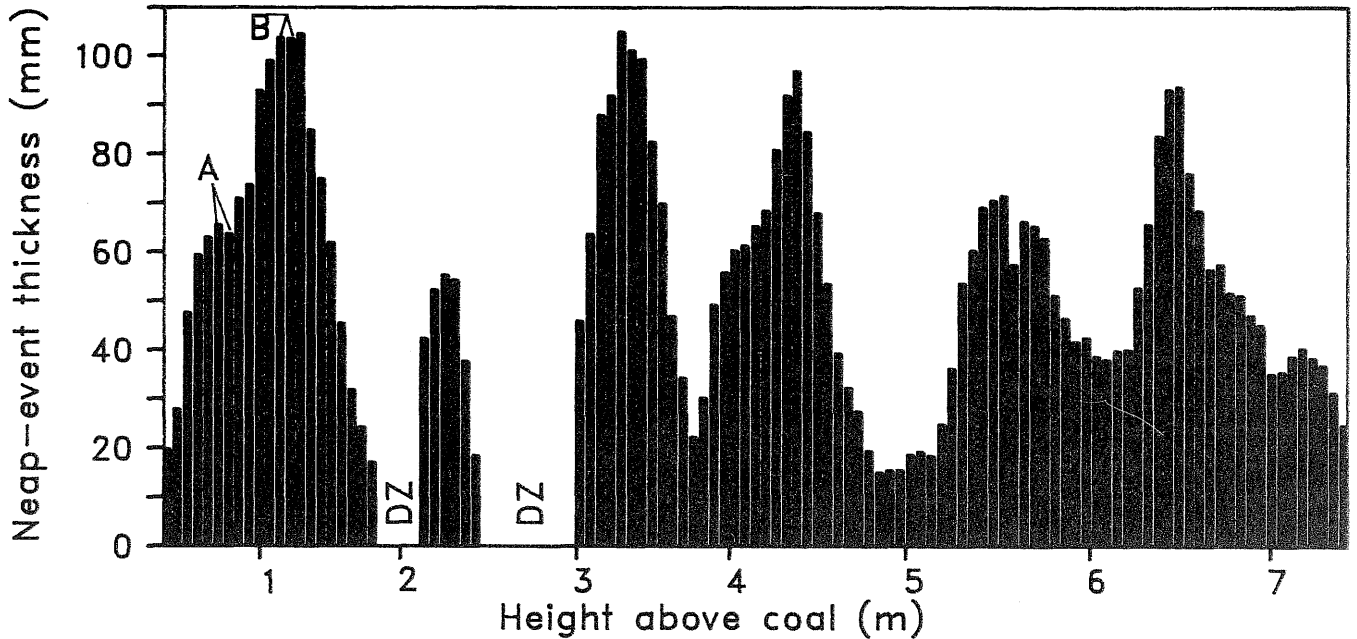


Figure 8. Systematic thickness variations in neap-zone spacings within the whetstone, as measured above the underlying coal. These measurements are based upon the distance between two zones of closely spaced laminae. Six large-scale cycles are evident; the second fifth-order pattern contains two disturbed zones (DZ) containing highly convoluted laminae.

is quite clear that such studies require a full understanding of the depositional environments of the units involved. Rates of deposition of the whetstone interval, when 6 meters of silt was deposited in approximately 6 years, are also difficult to reconcile with total thickness of about 90 meters and total time of about 15 million years for the Mansfield Formation within the study area (Shaver and others, 1986). Such a comparison suggests that short-term episodes of rapid sedimentation punctuated by long periods of nondeposition or erosion may well characterize the Pennsylvanian rock record in southwestern Indiana (see Dott, 1983).

Comparison of two techniques to estimate the length of time represented by 1 meter of section is illustrated in Figure 11. Based upon recognition of fine-scale tidal cycles, 1 meter of siltstone could have been deposited within 1 year; conversely, based upon the total formational thickness of the Mansfield (about 90 meters, based on Shaver and others, 1986) and formational time of 15 million years, then the average rate of Mansfield sedimentation was about 6 meters per million years, or about 1 meter per 160,000 years. Thus, at least in these localized tidal deposits, dividing formational thick-

ness by formational time can yield depositional rates that are many orders of magnitude too slow (Archer and Kvale, 1988).

CONCLUSIONS

The various levels of patterns strongly support a tidal interpretation for the whetstone deposits, despite the general lack of marine macroinvertebrates. Analysis of the patterns also support an interpretation that invokes rates of sedimentation of approximately 1 meter/year. The degree of preservation of the laminations is in part owing to lack of erosive events, elevated rates of sedimentation, and the general absence of bioturbating organisms. Thus, within this relatively unusual environment of deposition, a very complete record of various patterns of tidal cyclicity has been preserved, including not only daily laminae and neap-spring cycles, but also seasonal and yearly cycles. Thus, in such strata, stratigraphic completeness is very high for periods of time that are exceedingly small in a geological sense.

REFERENCES CITED

- Anders, M. H., Krueger, S. W., and Sadler, P. M., 1987, A new look at sedimentation rates and the

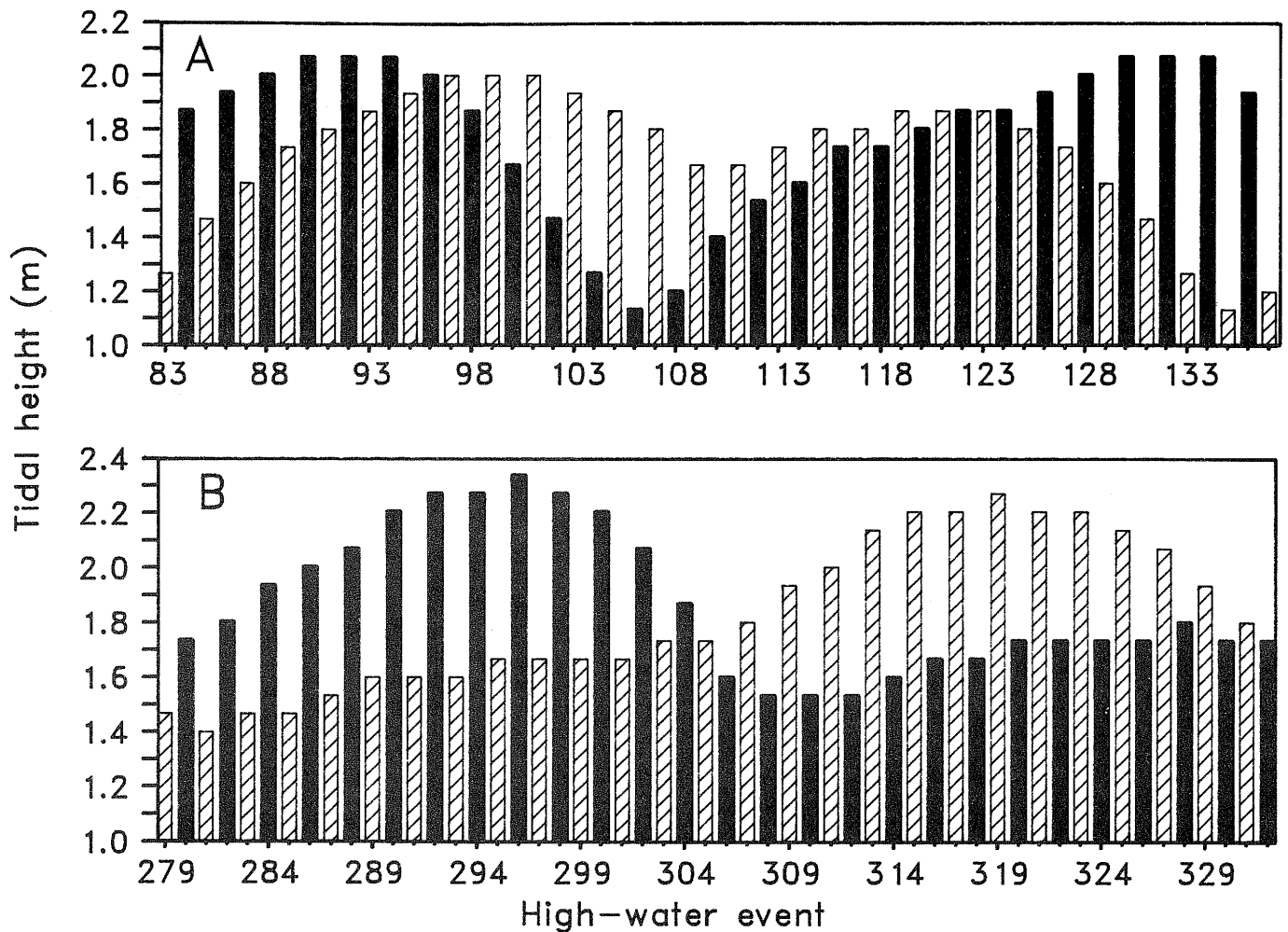


Figure 9. Selected portion of 1988 predicted high tides at Kolaka, Sulawesi (from NOAA, 1988). Seasonal effects on tides are maximized during the solstices when maximum semidiurnal tidal variability as well as highest tides occur (B—June 15 through July 15). Conversely, during the equinoxes, semidiurnal tidal inequality is at a minimum and tidal range is reduced (A—March 15 through April 15).

completeness of the stratigraphic record: *Journal of Geology*, v. 95, p. 1–14.

Archer, A. W., and Kvale, E. P., 1988, Ultimate resolution of transgressive–regressive stratigraphic units: A theoretical discussion based upon the Carboniferous of the Illinois Basin [abs.]: *Geological Society of America Abstracts with Programs*, v. 20, p. 327–328.

Baird, G. C., Shabica, C. W., Anderson, J. L., and Richardson, E. S., Jr., 1984, Biota of a Pennsylvanian muddy coast: Habitats within the Mazonian Delta Complex, northeast Illinois: *Journal of Paleontology*, v. 59, p. 253–281.

Baird, G. C., Sroka, S. D., Shabica, C. W., and Kuecher, G., 1986, Taphonomy of Middle Penn-

sylvanian Mazon Creek area fossil localities, northeast Illinois: Significance of exceptional fossil preservation in syngenetic concretions: *Palaios*, v. 1, p. 271–285.

Busch, R. M., and Rollins, H. B., 1984, Correlation of Carboniferous strata using a hierarchy of transgressive–regressive units: *Geology*, v. 12, p. 471–474.

Busch, R. M., Bogina, M. A., and Clark, M. H., 1988, Preliminary report on the genetic stratigraphy of the Hamilton, Kansas, fossil localities—Deer Creek fifth-order T–R unit: *Hamilton Quarry Guidebook*, Kansas Geological Survey.

Dott, R. H., Jr., 1983, 1982 SEPM presidential address: Episodic sedimentation—How normal is av-

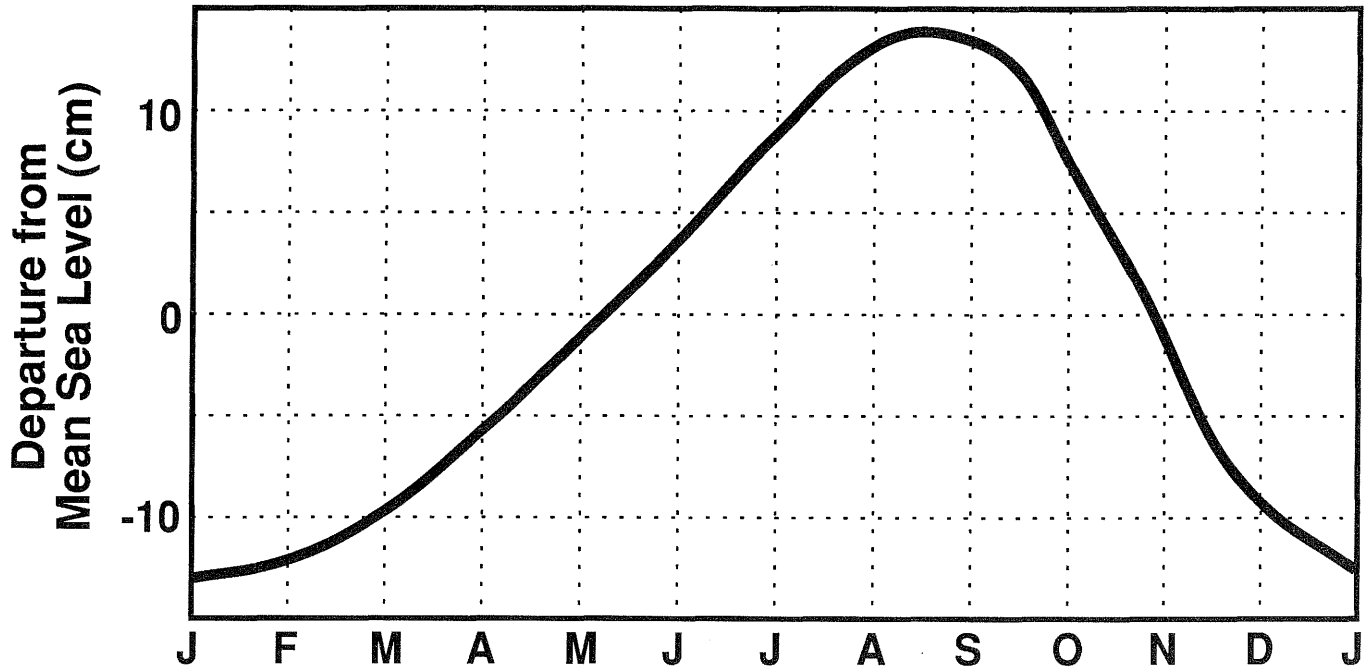


Figure 10. Yearly variation in sea-level for Taiwan (*modified from* Fairbridge, 1966); the variation is largely owing to climatic factors such as water temperature and air pressure.

erage? How rare is rare? Does it matter: *Journal of Sedimentary Petrology*, v. 53, p. 5–23.

Fairbridge, R. W., 1966, *The encyclopedia of oceanography*: New York, Van Nostrand Reinhold Company.

Goodwin, P. W., and Anderson, P. W., 1985, Punctuated aggradational cycles—A general hypothesis of episodic stratigraphic accumulation: *Journal of Geology*, v. 93, p. 515–533.

Harris, D. L., 1981, *Tides and tidal datums in the United States*: U.S. Army Corps of Engineers Coastal Engineering Research Center, Special Report 7.

Kuecher, J. G., 1983, *Rhythmic sedimentation and stratigraphy of the Middle Pennsylvanian Francis Creek Shale near Braidwood, Illinois*: Northeastern Illinois University, M.S. thesis.

Kvale, E. K., and Archer, A. W., 1988, The association of rhythmic tidalites and coals in the Illinois Basin [abs.]: *Geological Society of America Abstracts with Programs*, v. 20.

Kvale, E. K., Archer, A. W., and Johnson, H. R., 1989, Daily, monthly, and yearly tidal cycles

within laminated siltstones (Mansfield Formation: Pennsylvanian) of Indiana: *Geology*, v. 17, p. 365–368.

NOAA (National Oceanic and Atmospheric Administration), 1988, *Tide tables, 1988, high and low water predictions, central and western Pacific Ocean and Indian Ocean*: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service.

Roy, J. L., and Morris, W. A., 1979, Paleomagnetic results from the Carboniferous of North America; development of a chronostratigraphic marker horizon for Canadian east coast Carboniferous strata, *in* Belt, E. S., and MacQueen, R. W., eds., *Ninth International Congress on Carboniferous Stratigraphy and Geology guidebook*: Carbondale, Illinois, Southern Illinois University Press, p. 23–35.

Sadler, P. M., 1981, Sediment accumulation rates and the completeness of stratigraphic sections: *Journal of Geology*, v. 89, p. 569–584.

Sadler, P. M., and Dingus, L. W., 1982, Expected completeness of sedimentary sections: Estimating a time-scale dependant, limiting factor in the

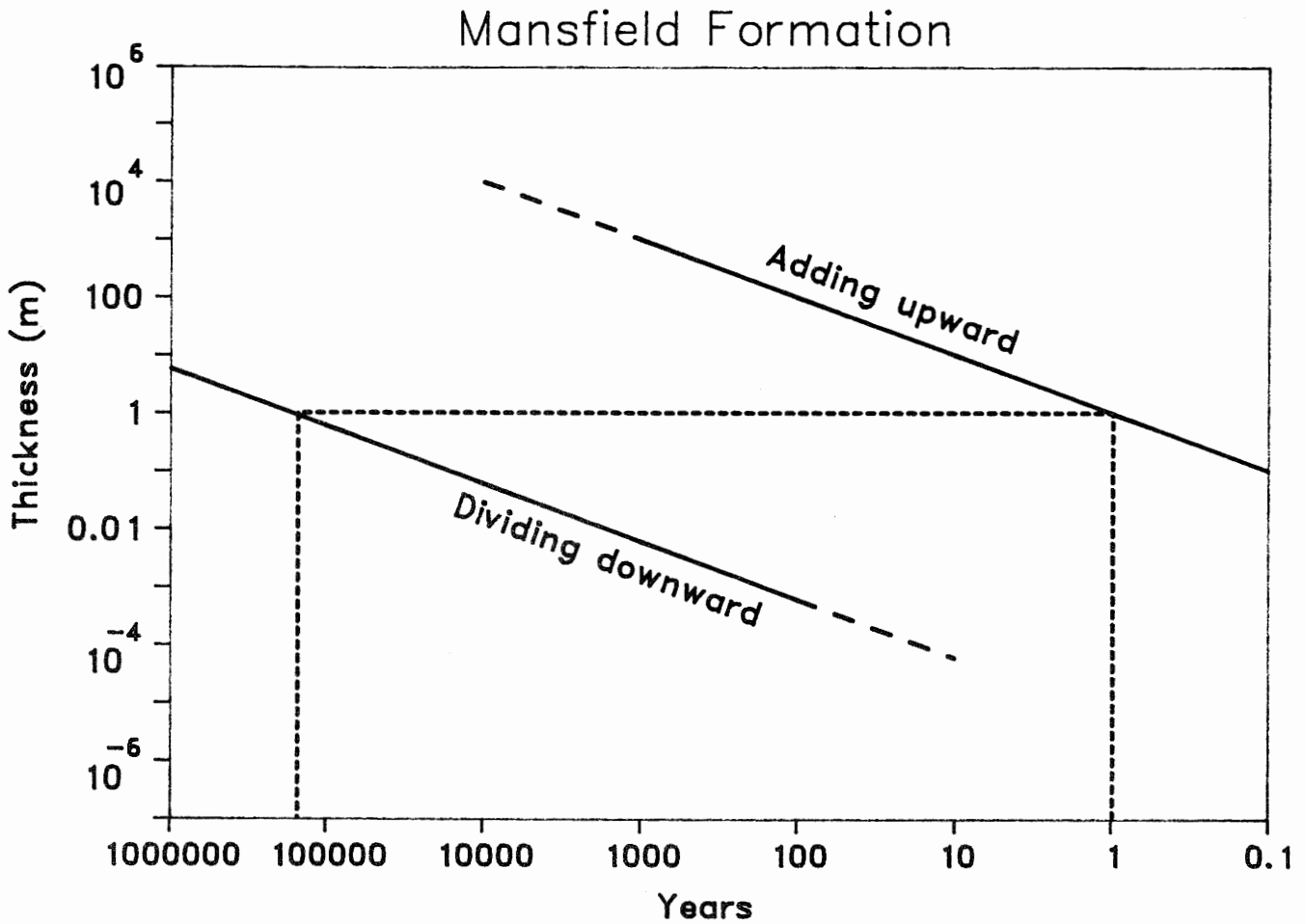


Figure 11. Differences in estimating lengths of time for deposition. Curves labeled “adding upward” illustrate rates of sedimentation based upon fine-scale analysis of daily, biweekly, and yearly tidal cycles. Conversely, line labeled “dividing downward” is based upon average rates computed by dividing entire time span of Mansfield Formation by total formational thickness. Tidal cycles illustrate that 1 meter of section could be produced within 1 year; conversely the dividing downward technique suggests over 100,000 years would be required.

resolution of the fossil record: Proceedings, Third North American Paleontological Convention, v. 2, p. 461-464.

Scotese, C. R., Bamback, R. K., Barton, C., Van Der Voo, R., and Ziegler, A. M., 1979, Paleozoic base maps: *Journal of Geology*, v. 87, p. 217-233.

Shaver, R. H., and 31 others, 1986, *Midwestern Basin and Arches*: Tulsa, American Association of Petroleum Geologists, Correlation of Stratigraphic Units of North America, Chart MBA.

Sonett, C. P., Finney, S. A., and Williams, C. R., 1988, The lunar orbit in the late Precambrian and

the Elatina sandstone laminae: *Nature*, v. 335, p. 806-808.

Williams, G. E., 1981, Sunspot periods in the Late Precambrian glacial climate and solar-planetary relations: *Nature*, v. 291, p. 624-628.

Williams, G. E., in press, Late Precambrian tidal rhythmites in south Australia and the history of the earth's rotation: *Journal, Geological Society of London*, v. 146.

Williams, G. E., and Sonett, C. P., 1985, Solar signature in sedimentary cycles from the late Precambrian Elatina Formation, Australia: *Nature*, v. 318, p. 523-527.

Zangerl, R., and Richardson, E. S., Jr., 1963, The paleoecological history of two Pennsylvanian black shales: Chicago Natural History Museum, Fieldiana Geology Memoir 4.

ICHNOFOSSIL ASSEMBLAGES AND ASSOCIATED LITHOFACIES OF THE LOWER PENNSYLVANIAN (CASEYVILLE AND TRADEWATER FORMATIONS), SOUTHERN ILLINOIS

Joseph A. Devera
Illinois State Geological Survey
Southern Illinois University, Department of Geology
Carbondale, Illinois

ABSTRACT

Within the southern portion of Illinois, Lower Pennsylvanian rocks contain a variety of ichnofossils. At some locations body fossils are found associated with these ichnofossils; however, most ichnofossils occur in facies that lack macroinvertebrate fossils.

A highly significant aspect of trace-fossil assemblages in Lower Pennsylvanian rocks of southern Illinois is that they indicate a greater degree of marine influence than was previously interpreted for these strata. Recent reevaluation of sedimentological, paleontological, geomorphic, and geophysical evidence indicates that the Caseyville and Tradewater Formations were dominated by brackish to normal marine conditions rather than fluvially dominated deltas.

Ten ichnofossil locations are discussed: Little Grassy Spillway, Old Town, Goreville I-57 Roadcut, Hayes Creek, Upper Bay Creek, Trigg Tower, Upper I-24 Roadcut, Ogden Branch, Zimmer Cemetery, and Tunnel Hill. Trace fossils found at these locations predominantly indicate brackish to normal marine origins. This interpretation is based on sedimentology, paleontology, and the geomorphologies of the associated lithologies.

INTRODUCTION

The discovery of hundreds of ichnofossils at numerous locations of Lower Pennsylvanian strata within the study area (Fig. 1) is one of the results of the ISGS-USGS COGEOMAP program in southern Illinois. From this large array of ichnofauna localities, 10 locations are discussed here. The stratigraphic intervals that were collected are shown in Figure 2.

Ichnofossils typically represent in-situ fossilized behavior, spatial relationships of the paleocommunity, and the integrated ethological connections between resting, feeding, and locomotory habits of the paleocommunity. Trace fossils can indicate rela-

tive sedimentation rate, and with the proper sedimentological constraints, the density of bioturbation varies inversely with rate of sediment influx. Another important aspect of trace fossils is that they are common in facies containing few or no macrofossils. Only a few localities with marine body fossils were found during the past 4 years of field mapping, whereas ichnofossil locations have exceeded 100. Preservation potential is poor for invertebrate body fossils in the Lower Pennsylvanian facies. The opposite is true for their lebensspuren.

Some cubichnia and repichnia traces have yielded detailed morphologies (Plate 1, a) of the producer organisms. The trace makers are rarely preserved because of their soft bodies, and the ichnofossils provide the only clue to the existence of entire families or even classes of organisms.

The idea that a single animal has multiple behavior patterns must be taken into account when compiling ichnofossil diversity for a specific assemblage (Fig. 3). Conversely, different species can also make similar traces because of similar behavior.

ICHNOFOSSIL LOCATIONS

Location 1: Little Grassy Spillway

A man-made rock cut exposing 11½ feet of a medium-gray to reddish-brown, hematite-stained quartz sandstone occurs below the Little Grassy Lake spillway on Little Grassy Creek. This rock interval yields an abundant and diverse ichnofauna dominated by the horizontal repichnion *Aulichnites parkerensis* and the looped and lateral working spreite builder *Zoophycos*. The floor of the box cut teems with fossil lebensspuren. Rare pelmatozoans, rugose corals, brachiopods, and gastropods are found in this exposure (Fraunfelter and others, 1973; Stanley, 1980).

Optimum times to observe the trace fossils at the spillway cut are late summer, fall, or when water levels permit. The spillway is located at the northeast-

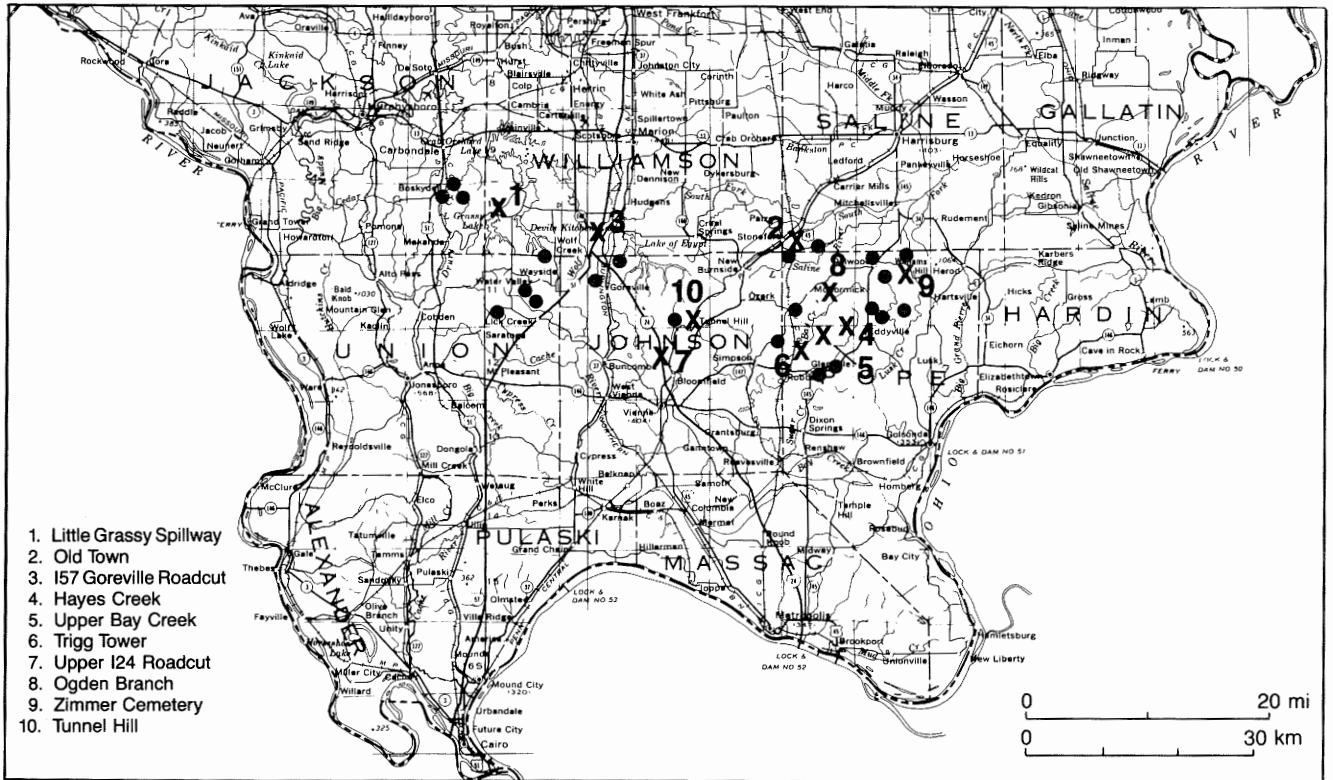


Figure 1. The sites of the 10 ichnofossil locations discussed in this paper are marked by x; dots mark other ichnofossil locations in both Pennsylvanian and Mississippian. Over 60 other locations (not shown) have been found in southern Illinois.

ern end of the lake in Section 18, T10S, R1E, Carbondale Quadrangle. The exact stratigraphic position of this exposure is not certain; it probably belongs in the lower middle part of the Tradewater Formation (middle Abbott), stratigraphically close to the "Boskeydell Marine Zone" (Lamar, 1925). Farther to the east, within the Creal Springs Quadrangle, conodonts were reported from about the same interval with a relative age near the Morrowan/Atokan boundary (Jacobson and others, 1983).

Two distinct ichnofossil assemblages occur in the Little Grassy spillway cut: the *Aulichnites* facies in the lower sandstone and the *Zoophycos* facies in the upper sandstone. The lower spillway assemblage is primarily composed of horizontal repichnia/pascichnia: *Aulichnites parkerensis*, *Cochlichnus auguineus*, *Eiona* sp., *Olivellites plummeri*, *Rhabdoglyphus*(?), *Sclarituba missouriensis*, *Scolicia* sp., *Torrowangea* sp., cf. *T. rosei*. To a lesser extent vertical fodinichnia-like *Chondrites* sp. and *Stelloglyphus* sp. are also found in the lower sandstone (Plates 1-4). *Aulichnites parkerensis* is commonly found in the lower sandstone unit looping and meandering over the rip-

ple-marked bedding planes as a convex epirelief. The abundance of horizontal ichnofossils, primary sedimentary structures such as spoon-shaped trough crossbeds filled with ripple marks and clay pebbles indicate episodic fluctuations between low and moderate sedimentation rates.

The upper thinner sandstone represents a different assemblage. This sandstone is typified by a high-density, low-diversity *Zoophycos* assemblage, with a few rare *Chondrites* sp., *Rhizocorallium* sp., and *Skolithos* sp. traces (Plate 4, c). The latter two ichnofossils listed are possibly related to the *Zoophycos* trace maker in the upper sandstone. The *Rhizocorallium* described at the spillway by Stanley (1980) was only a fragment of *Zoophycos* and not true *Rhizocorallium*. The *Skolithos* described by Fraunfelter (1973) is also thought to be the central tube of the *Zoophycos* trace and not a true *Skolithos*.

Body fossils are not common, but a few can be found in both sandstone units. Taphonomic evidence indicates that the lower sandstone was deposited in a moderately high-energy, shallow-water

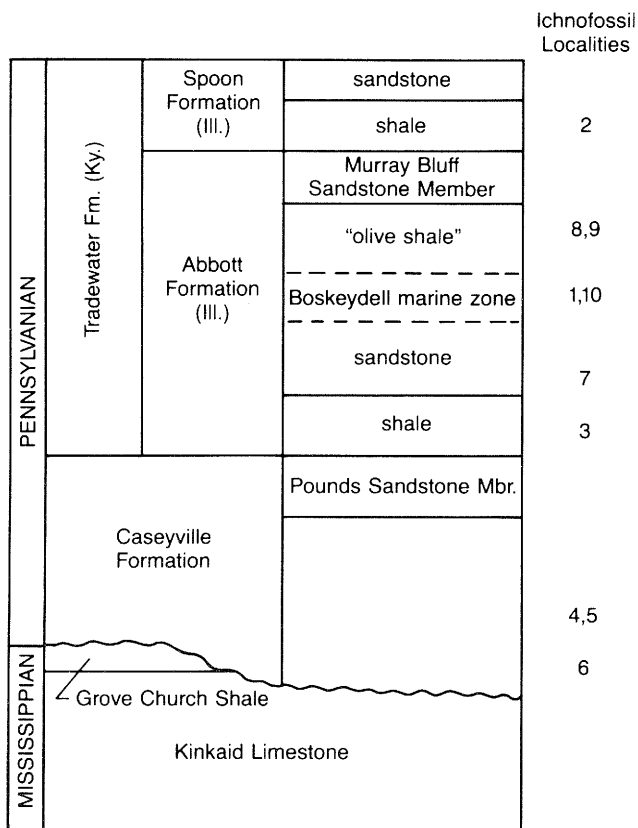


Figure 2. Stratigraphic chart and ichnofossil localities.

environment. Rugose corals show signs of abrasion

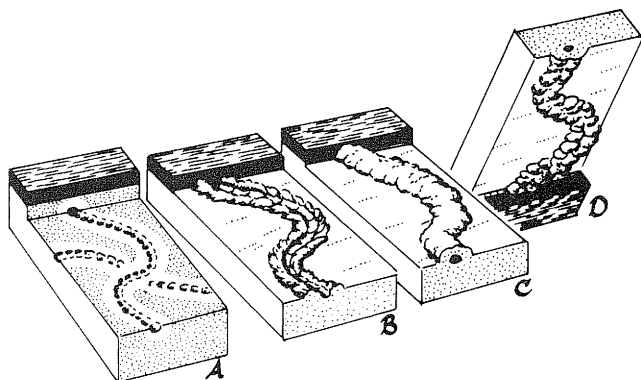


Figure 3. Burrows of (a) *Eiona*, (b) *Scarituba*, (c) *Neonereites*, (d) *Neonereites* having different preservational expressions because of slight difference in burrowing level. (A) is a cleavage relief, (b) and (c) are epireliefs, and (d) is a hyporelief. (Modified from Ekdale and others, 1984.)

and transportation. Pelmatozoan fragments are disarticulated. Poorly preserved brachiopods and gastropods also show signs of transportation over short distances.

Ethological diversity may not reflect faunal diversity. For instance, in the lower sandstone, the gastropods found may have been responsible for making the traces of *Aulichnites*, *Scolicia*, and *Olivellites*. These traces are usually found in close proximity to each other. They have the same width. Small morphological differences between these three ichnofossils were probably the result of differing rates of locomotion, feeding habits, or the thixotropic nature of the sediment. *Aulichnites parkerensis* was originally thought to have been produced by the peristaltic movement of a scavenging snail (Fenton and Fenton, 1937). *Scolicia* sp. was also considered a product of a prosobranch gastropod (Chamberlin, 1971). Fenton and Fenton (1937) suggested a gastropod origin for *Olivellites plummeri*.

Eiona sp. (string of beads) and *Scarituba missouriensis* may be different preservational expressions of the same trace at different levels of burrowing (Ekdale and others, 1984; see Fig. 2). Both of these ichnofossils are found in the lower sandstone.

Taking ethological diversity into account, the number of trace makers in the lower sandstone has possible dropped to five different taxa rather than eight.

The basal sandstone is composed of linguloid ripples. Larger (2 to 3 feet) spoon-shaped troughs, with current-modified oscillatory ripples within these troughs, may indicate that the sand was reworked from larger scale bed forms (personal commun., Erik Kvale). Periodic fluctuations between low and moderate sedimentation rates are reflected by two lines of evidence. The dominant horizontal nature of the bottom-dwelling epifauna and infauna supports periods of low-energy, quiet stages. The presence of clay pebbles, current-modified ripples, and lateral accretion surfaces supports higher energy periods.

The sedimentological, ichnological, and taphonomic evidence indicates that the lower sandstone was deposited in a shallow subtidal shelf environment. Reworked larger scaled bed forms, ripple crests, fluctuation in sedimentary rates and fluid flow energy, diversity of ichnofossils, and disarticulation and abrasion of the sparse invertebrate fauna all indicate a tidally affected environment. The *Aulichnites* assemblage best represents the *Cruziana* ichnofacies of Seilacher (1967) and Frey and Seilacher (1980), which occurs in shallow shelf settings. Di-

verse traces are also indicative of the *Cruziana* ichnofacies.

While the lower sandstone fits the environmental description of Frey and Seilacher's (1980) *Cruziana* ichnofacies, the upper sandstone, which is dominated by *Zoophycos*, does not fit the environmental description of their *Zoophycos* ichnofacies. It has been well established that the *Zoophycos* trace alone does not indicate a specific bathymetry. However, according to a recently proposed oxygen-controlled trace-fossil model, *Zoophycos* might reflect dysaerobic environments (Ekdale and Mason, 1988). The oxygen-controlled trace-fossil model would have more applicability to the organic-rich, paralic swamp and marine-influenced deltaic environments of the Illinois Basin than to the bathymetric-controlled ichnofacies of Seilacher (1964, 1967). If the oxygen-controlled model is correct, the trace fossils show a shift from aerobic conditions in the lower sandstone to a dysaerobic environment in the upper sandstone. The sedimentology supports this shift, from fluctuations in sedimentary rates and reworked ripple crests in the lower sandstone to carbonaceous plant debris, driftwood, and finer grained sandstone in the upper sandstone unit.

The lower sandstone might have been near or within a tidal inlet or tidal delta, while the upper sandstone possibly shows a shift to a more organic-rich, low-oxygen environment shoreward toward the lagoon on the flood shield of a tidal delta.

Location 2: Old Town

About ½ mile south of Old Town, Illinois, along the Illinois Central Railroad, there is a 60-foot, man-made cut exposing a shaly sequence of rocks in the basal part of the upper Tradewater Formation (at Abbott-Spoon contact) (Sec. 6, T11S, R5E, Stonefort Quadrangle). The lower part of this section is a fine- to medium-grained, thin-bedded sandstone that is a part of the massive Murray Bluff Sandstone to the east. The sandstone is light gray with yellow and orange to brown iron oxide stains. Numerous clasts and partings of gray to black shale are found, as well as small siderite nodules. The bedding is slightly lenticular, with ripple marks being faint.

Laterally equivalent to the upper part of the Murray Bluff Sandstone is the 60-foot-thick silty shale unit that conformably overlies the thin-bedded part of the lower Murray Bluff. This shale facies is dark gray and becomes an interbedded sandy shale at the top. This shale unit is covered by a rooted underclay with a bright-banded coal about 2 feet thick on top.

The silty shale sequence has a low-density, low-diversity ichnofauna dominated by the cone-shaped trace fossil *Conostichus broadheadi* (Plate 5, a-b). *Asterosoma* sp., *Teichichnus* sp., and *Gyrolithes* sp. are also present (Plates 6-7). *Asterosoma* sp. is composed of elongate oval structures that branch from a central point. Both radial and fan-shaped forms are found. *Teichichnus* sp. is a horizontal gutter-stacked burrow. A corkscrew appearance is the best way to describe *Gyrolithes* sp., which is also stacked. All of the traces show vertical stacking, indicating that the trace makers were constantly keeping up with a moderate sediment influx. In many cases *Conostichus* is stacked cone in cone. All of the ichnofossils are found as full reliefs in the silty shale facies.

Conostichus broadheadi usually has a small apical disc that can show duodecimal symmetry (Plate 5, b). It is strongly cone shaped, having well-developed longitudinal furrows. *C. stouti*, another species found in this interval, is elongate and subconical, and has a small apical disc and weak to moderately well-developed septation. Both of these species show duodecimal symmetry. The distinct septal ornamentation, longitudinal furrows, and cone-like shape are similar to modern actinarian sea anemones (Chamberlin, 1971).

Asterosoma sp. has elongate, bulbous, radiating arms that connect at a central plug. In the Illinois Basin, wherever one finds *Conostichus* one finds *Asterosoma*. Chamberlin (1971) also noted that *Asterosoma* is typically associated with *Conostichus* in the Ouachita region. This location has produced a few specimens with characteristics seen in both *Conostichus* and *Asterosoma* (Plate 7, c). The cone-shaped *Conostichus* sometimes will have an elongate, bulbous arm or two, which is the "*Asterosoma*" component.

Instead of the annelid affinity proposed by Chamberlin (1971) for *Asterosoma* sp., I believe it represents a different type of burrowing behavior of an actinarian sea anemone.

Teichichnus sp. is found here as straight or J-shaped, horizontal, infaunal fodinichnia (Plate 7, a) that was possibly produced by a polychaete. *Gyrolithes* sp. has a similar diameter and is closely associated with *Teichichnus* sp. Both ichnogenera are gutter stacked. The evidence suggests that the same trace maker was responsible for both of these preserved behavior patterns.

Therefore, it is thought that only three different species were present in this silty and muddy envi-

ronment: two different species of sea anemones and one species of polychaete worms.

The Murray Bluff Sandstone is a thick, lenticular sand body, as determined from detailed geologic mapping. I interpret it as a distributary-mouth bar because of its overall geometry, coarsening-upward sequence (from fine-grained, well-sorted sublithic arenite at the base to coarse-grained sand with quartz granules at the top), thick-bedded nature, and trough crossbedding. The massive and abundant large-scale crossbeds probably represent distributary channel development that was preserved near the top. The lower portion of the Murray Bluff is composed of sheet sands with scour and fill structures. Apparent paleocurrent directions are west-northwest. Many of the sheet sands appear to be massive, but they are actually composed of small-scale crossbeds and laminations typical of a high-energy flow regime. Murray Bluff, located in the northeastern corner of the Eddyville Quadrangle, is composed of a 150-foot-thick sandstone that has been observed from core. Three miles west, at the Old Town *Conostichus* assemblage, the Murray Bluff Sandstone drastically thins to about 50 feet and is composed of a thinly bedded facies.

The silty, shaly facies containing the Old Town *Conostichus* assemblage is interpreted as a marine-influenced interdistributary bay that was subsequently filled by deltaic progradation.

Location 3: I-57 Goreville Roadcut

A 1-mile-long roadcut on Interstate 57, south of the Goreville exit (E $\frac{1}{2}$, Sec. 24, T11S, R1E, Lick Creek Quadrangle), exposes a shaly interval sandwiched between two crossbedded sandstone units. The shaly middle portion is composed of a dark-gray, sandy, silty shale. This shale unit is part of the basal Tradewater Formation (basal Abbott). Moderately diverse and abundant ichnofossils are seen locally in this silty shale facies. Traces are usually found as convex hyporeliefs on the soles of very fine-grained sandstone interbeds within the shale.

The most abundant trace fossil found is an unnamed arthropod cubichnia that occurs parallel to the paleocurrent direction, perpendicular to ripple crests (Plate 8, a). Almond-shaped *Lockeia* sp., with the repichnia *Uchirites* sp., an unnamed repichnia, fecal pellets, and an unnamed trackway, are all found as convex hyporeliefs on the sole of the thin-bedded sheets of fine-grained sandstone. Seven different ichnofossils are found within the shale interval. However, only four individual trace makers are thought to be responsible for these seven traces.

The arthropod cubichnia are all evenly spaced and are thought to represent resting eumalacostracans (shrimp) (Plate 8, a). Most crustaceans are detritus feeders and scavenge. Modern eumalacostracans that show quasi-social behavior commonly space themselves equally on the shallow sea floor during their normal resting phase (personal commun., Dr. Frederick Schram). The orientation parallel to current would be the most stable resting position. This is established because the arthropod cubichnia are perpendicular to ripple crests. These shrimp(?) resting traces are related to the unnamed bilaterally symmetrical repichnia (Plate 8, e). A few of the crawling traces are connected to the shrimp(?) cubichnia. I believe that the knobby pellets (Plate 8, d) found on the same bedding plane as the cubichnia and repichnia are the fecal pellets of the shrimp(?).

The crawling trace *Uchirites* sp. was found to be connected to a *Lockeia* sp. cubichnia. Both of these traces were probably made by the locomotory and resting behaviors of the same bivalve (see Plate 8, b). It is uncertain what made the unnamed trackway (Plate 9, a), but whatever the trace maker was, its locomotion habits and width were quite different from those of the shrimp(?) or the bivalves. Another repichnia trace was recovered from this shale unit. It is a convex hyporelief of a trackway with longitudinal ridges that was most likely produced by a limulid (horseshoe crab). The ichnofossil is *Kouphichnium* sp. These types of traces are common in brackish to marine environments.

The overlying sandstone was affected by tidal currents (Kvale and Uhlir, 1988). Support for this interpretation is seen by coupled foresets and periodicity of the foreset thickness with paleocurrent direction to the west-southwest, whereas topset direction is northward, as seen by linguloid ripples.

The shale is thought to be laterally interbedded with the overlying sandstone away from the roadcut. Lenticular and sheet-like sand bodies are interbedded within the shale and are characterized by micro-cross laminations and current and wave ripples. Flaser bedding is common, and the dark-gray mudstone also shows linguloid ripples, load casts, flute casts, and ball-and-pillow structures.

This shale facies is interpreted as a tidally affected mud with an overlying tidally dominated sandstone. The moderate to low diversity of the fauna suggests a brackish-water environment; during low tide this muddy environment may have been cut off from normal marine conditions. The presence of limulid trackways also supports the brackish-water

interpretation. However, this muddy environment probably remained subaqueous at low tide, because no evidence of desiccation has been found in this unit.

Location 4: Hayes Creek

Within a northeast-trending tributary to Hayes Creek, 750 feet from the west line and 100 feet from the south line, Sec. 11, T12S, R5E, Glendale Quadrangle, there is a poorly exposed, thin-bedded sandstone that yields a moderately diverse ichnofauna. This sandstone occurs within the lower part of the Caseyville Formation.

Five different fossil lebensspuren were found: *Calycraterion* sp., *Aulichnites* sp., *Teichichnus* sp., *Cochlichnus auguineus*, and *Eiona* sp. (Plate 9). These traces represent five different trace makers. These trace fossils were found in a clean, well-sorted, fine-grained, thin- to medium-bedded quartz sandstone. *Aulichnites* is preserved as a convex epirelief, and is seen as meandering trails on the exposed bedding planes. *Teichichnus* sp., *Cochlichnus* sp., and *Eiona* sp. are preserved as full reliefs that are weathering out of the exposed sandstone beds. The most abundant ichnofossils present are the small conical-shaped *Calycraterion* that are preserved as convex hyporeliefs on the bases of the beds and concave epireliefs on the tops of the bedding planes.

The thin-bedded sandstone facies displays oscillatory ripples on the upper surfaces of the beds and has associated bioturbation. This facies is part of a much thicker sandstone package. Overall geometry shows a massive sand body filling a pre-Pennsylvanian paleochannel in this area. This paleochannel has been documented by detailed geologic mapping of the Glendale Quadrangle (Devera, in preparation). A large (3 to 4 miles wide) paleovalley has also been verified by drill holes in this area.

Cochlichnus auguineus was probably produced as sediment excretion from some infaunal detritus feeder that was worm like. Moussa (1970) suggested that this sinuous trace was made by a nematode. Observations along modern lakes have shown a similar sinuous trace produced by insect larvae (Metz, 1987). However, a sinuous concave epirelief is observed in the modern example. *Cochlichnus* is typically seen as a full relief ichnofossil. *Calycraterion* was interpreted to have been made by a small annelid (Karaszewski, 1971). *Eiona* was also thought to be produced by annelids or polychaetes.

The thin-bedded sandstone facies associated with the ichnofossils is considered to be marine. Ori-

nally, the sandstone was probably a fluvial deposit within the paleovalley, but was subsequently reworked by tidal processes. The fauna is moderately diverse and the primary sedimentary structures support a tidal brackish to marine setting.

Location 5: Upper Bay Creek

There is a low-diversity, moderate-density, vertical-tubed *Skolithos* assemblage on a ridge in Sec. 17, T12S, R53, NW $\frac{1}{4}$, NW $\frac{1}{4}$ in the Glendale Quadrangle. Stratigraphically, this assemblage is found in the lower Caseyville Formation. *Skolithos* sp. (Plate 10, a-d) occurs within a clean, poorly sorted orthoquartzite with quartz pebbles. The tubes are hematite-stained and are closely spaced with U-shaped tubes. Observation from the top of the bed shows holes arranged in couplets (Plate 10, d). These are the U-shaped burrows.

Trace makers that created the U-shaped and vertical tubes are dubious, but are considered here as marine polychaete filter feeders. The sandstone occurs between marine facies. The sandstone is clean and uniform with quartz pebbles. The upper and lower contacts are abrupt on gamma-ray and spontaneous-potential logs in nearby wells. This type of log signature indicates offshore bars. Therefore, the interpretation most consistent with the data indicates filter-feeding polychaete worms on a shallow shelf sand.

Location 6: Trigg Tower

One mile due east of Trigg Tower there is a south-flowing stream near the center of Sec. 12, T12S, R4E in the Glendale Quadrangle. Within this stream valley is a gray, silty shale with fine-grained quartz sandstone filling simple horizontal burrows in full relief. Septarian nodules also occur within the shale. Small plug-like ichnofossils filled with fine-grained sandstone and pyrite are also common. Some of the plug-shaped fossils have discs at the base showing duodecimal symmetry. One specimen collected was identified as *Conostichus stouti* (Plate 11, a). This shale is stratigraphically placed in the basal part of the Caseyville Formation. A poorly developed coal is found above the shale within the overlying massive sandstone. Stigmarian rootlets (Plate 11, c) are seen at the top of the shale and associated with local lenses of coal; other lenses of coal are rafted within the massive sandstone.

The ironstone or septarian nodules yielded numerous small gastropods. No detailed sedimentology has been done on these units. A core taken $\frac{1}{4}$ mile west of this location provides evidence that this shale was deposited on the paleo-uplands of a nearby paleochannel. The core (Gd no. 1) shows

that nearly 60 feet of Grove Church Shale (Mississippian) was drilled below this shale unit. The ichnofauna is sparse but strongly suggests marine deposits.

This shale facies is thought to be prodeltaic muds or a bayfill sequence; it coarsens upward into a silty, sandy deltaic sequence.

Location 7: Upper I-24 Roadcut

North of Vienna, Illinois, on Interstate 24, sandstone in the upper Caseyville Formation is exposed in a roadcut in the northeast corner of Sec. 8, T125, R3W, of the Vienna Quadrangle. Just above the Caseyville sandstone is a siltstone and rooted claystone that is dark gray with abundant carbonized plant material. Stigmarian roots are common in the claystone. A 2-foot coal identified as the Reynoldsburg Coal Bed overlies the claystone and siltstone beds. *Lepidodendron* sp. and *Sigillaria* sp. abound at the top of the coal bed; pyrite is common.

Above the coal is a 3-foot-thick, dark-brown siltstone facies containing muddy siltstone interbedded with fine-grained sandstones. Plant leaves and plant debris are common. Superimposed and conformable to the siltstone is a light-brown sandstone over 10 feet thick. Sheet sands and large-scale trough stratification are the primary sedimentary structures. Sandstone-filled cracks or desiccation cracks were observed near the top of this sandstone unit.

Lockeia fugichnia, cubichnia, and repichnia traces (Plate 12, d, c, e) were observed in and on the thin-to medium-bedded sheet sands. These sheet sands were deposited rapidly. Dewatering structures are commonly seen. The *Lockeia* escape burrow-resting trace relationship has been recognized in the Lower Pennsylvanian of Indiana by Archer and Maples (1984) and in coarsening-upward sequences in England of Namurian age by Eagar and others (1983).

High-angle escape structures with back-fill are common features of this upper sandstone unit, and occasionally the bottom of the bed yields a *Lockeia* resting trace. Trails of these bivalves are also observed along the bedding planes. No other trace fossils have been found in sheet sands.

The bivalves were initially crawling across the sandy substrate. This is recorded as foot and valve marks that are preserved as convex hyporeliefs on the sole of overlying beds and in some cases concave epireliefs on the bottom of bedding planes. A deltaic turbidite sand quickly buried the bivalve fauna. The bivalve's response was to make an oblique tube. Each escape tube extends through the

whole bed at a 70 to 85° angle. The base of the overlying bed shows *Lockeia* resting and crawling traces. The overlying sandstone bed is barren; the bivalves apparently moved laterally across the substratum to another area where they may have also had to escape from subsequent sandy turbidites.

Lockeia is found as a monospecific ichnofauna that may represent an opportunistic assemblage in a brackish to freshwater environment near distributary discharge areas.

Location 8: Ogden Branch

Within the south fork of Ogden Branch, Sec. 16, T11S, R5E, in the Stonefort Quadrangle, thin-bedded sandstones and gray silty shale facies are exposed in a 25-foot-high cut bank. These strata occur below the Murray Bluff Sandstone, are upper middle Tradewater (Upper Abbott), and have been informally called the "Olive shale." These strata are exposed at the dissected crest of the McCormick Anticline.

Lithologically, the Olive shale is composed of medium- to dark-gray silty shales and siltstone. Thinly laminated siltstones and fine-grained sandstones with ripple marks are common, as well as current ripples and interference ripples. Sandstone beds range from 4 to 10 inches thick and are tabular, sheet like, and interbedded with silty and shaly layers.

The dominant trace fossil is *Lockeia* sp., an almond-shaped cubichnia and its associated repichnia. *Cochlichnus augineus* is only rarely seen. This assemblage was dominantly monospecific.

Lockeia sp. has been interpreted as being produced by pelecypods (Chamberlin, 1971). The *Lockeia* specimens are quite small (10 millimeters in width) and are inclined to bedding. They are convex hyporeliefs. Some of the trails show foot movement and drag traces of the shell. These bivalves were probably filter-feeding organisms. Finding *Lockeia* and *Cochlichnus* together (Plate 12, b, a) with no other ichnofossils makes it difficult to determine the salinity, because freshwater bivalves evolved from brackish types during middle Namurian time (Eagar and others, 1983). In particular, the smaller elongate *Carbonicola* were common by Pennsylvanian time and are thought to be nonmarine (Eagar, 1974).

This shaly, sand-sheet facies is thought to be a prodeltaic deposit associated with the Murray Bluff distributary mouth bar. The sheet sands and silts are probably deltaic turbidites and may represent times of freshwater dominance during flood stages or sim-

ply a brackish prodeltaic situation. Fluctuations in salinity were probably greatest near the deltaic turbidites, permitting freshwater opportunistic forms to survive in these areas.

Another interpretation is that these are brackish-water bivalves that are found in prodeltaic muds.

Location 9: Zimmer Cemetery

In Sec. 10, T11S, R6E, 2,450 feet from the south line and 1,800 feet from the west line (Eddyville Quadrangle), a small ledge-forming sandstone crops out along a south-flowing stream. Its stratigraphic position is well below the Murray Bluff Sandstone. This sandstone is composed of thin- to medium-bedded sands and shales of the middle Tradewater Formation (Abbott).

The sandstone is yellow brown, fine to medium grained, coarse grained in places, with quartz granules. It is a poorly sorted sand with abundant mica. Planar topsets with low-angle crossbeds are found at the top. The sandstone overlies a dark-gray siltstone and shale unit. The lower part of the sandstone unit has a monospecific *Zoophycos* sp. zone (Plate 13, a). The shale directly below has siltstone interbeds, thin yellow partings, possibly sulfur laminae, *Orbiculoidea* sp., an inarticulate brachiopod, and siderite nodules.

The inarticulate brachiopod is indicative of brackish to marine conditions. The appearance of *Zoophycos* above a highly organic shale with paralic origins reinforces the view that dysaerobic niches were attractive to the *Zoophycos* trace maker. The shale was probably located in a lagoonal setting, and the overlying sandstone may have been originally deposited by a storm and later reworked by the *Zoophycos* organism. Finally, lateral accretion by shelf sands or tidal channels produced the low-angle crossbeds at the top of the exposure.

Location 10: Tunnel Hill

Near the southern portal of the tunnel of the former New York Central Railroad, south of Tunnel Hill, Illinois (Sec. 35, T11S, R3E), there is a sandstone and shale sequence that contains abundant *Conostichus broadheadi* and *Asterosoma* sp. Stratigraphically, this unit lies within the middle Tradewater Formation (Abbott).

Lithologically (from the base up), there is a dark-gray, silty shale that grades upward into a medium- to light-gray, shaly siltstone. Bioturbation increases upward, as does the grain size. A sandstone, which is thinly bedded, very fine grained, and with shaly interbeds, is found at the top. The sandstone is about 10 feet thick and contains abundant ichnofos-

sils. A 15-foot-thick shale that is dark gray, thinly laminated, with siderite lenses and nodules is found above the sandstone. Another coarsening-upward sequence is seen above the second shale unit. Light-gray, very fine-grained, argillaceous quartz sandstone is observed with shale clasts and common ichnofossils. This grades upward into a medium-gray, fine-grained quartz sandstone.

Ichnofossils found in the lower siltstone-sandstone are *Conostichus broadheadi*, *Asterosoma* sp., *Teichichnus* sp., *Sclearituba missouriensis*, and *Rhizocorallium* sp. (Plates 13-14). No fossils were found in the intervening shale or within the siderite nodules. However, the overlying sandstone and siltstone beds again had *Conostichus* sp., *Asterosoma* sp., *Eiona* sp., *Cylindrichnus* sp., and *Sclearituba missouriensis* (Plates 13-14).

The sedimentological sequence and ichnofauna are similar to those of the Old Town *Conostichus* assemblage, and likewise probably represents bay-fill sediments. This bay may have been slightly more open than the Old Town assemblage, as suggested by its slightly more diverse ichnofauna. The location must have been closer to the distributary-mouth bar, as shown by the abundance of silt-sized and fine-grained sand-sized particles.

ICHNOFOSSIL ASSEMBLAGES

From the 10 locations that were discussed, seven ichnofossil assemblages were recognized. The identification of each ichnofossil assemblage was based on the comparison of similar associations of ichnofossil types. The name of the assemblage is taken from the dominant or most abundant ichnofossil that occurs in each assemblage. The seven assemblages are: the *Zoophycos*, *Lockeia*, *Conostichus*, *Aulichnites*, *Calycraterion*, *Skolithos*, and the unnamed arthropod assemblages.

The Zimmer Cemetery and the upper bed of the Little Grassy spillway both have low-diversity, moderate- to high-density *Zoophycos* traces. Both of these locations are associated in some way with organic-rich conditions and have been interpreted as brackish-water lagoonal deposits. The Zimmer Cemetery and Little Grassy (upper bed) locations differ only slightly in that the former has a well-developed black shale below the *Zoophycos* zone. It may be that the upper bed of the Little Grassy spillway was closer to a siliciclastic-rich area, perhaps fringing a tidal delta on the landward or lagoonal side, so this deposit never fully developed a shale in this area.

The Upper I-24 Roadcut and the Ogden Branch locations have a dominantly monospecific *Lockeia* assemblage. This type of assemblage is commonly associated with flaggy sheet sands and may represent opportunistic bivalves that thrive during fresh- to brackish-water stages. The *Lockeia* assemblage is common in what has been interpreted as deltaic turbidites that can be found in prodeltaic deposits and interdistributary bay deposits.

The *Conostichus* assemblage is dominantly marine, commonly found in bay-fill sequences that are open to circulation, like the Tunnel Hill example, or restricted, like the Old Town and Trigg Tower localities. The *Conostichus* trace maker seems to have had an affinity for moderate sedimentation rates and commonly filled its burrow with fine-grained sand.

The *Aulichnites* assemblage is a marine shelf assemblage having a variety of behavior as well as diversity of trace makers. In southern Illinois the *Aulichnites* assemblage is most like the *Cruziana* ichnofacies of Seilacher (1967).

The *Calycraterion* assemblage is very similar to the *Aulichnites* assemblage. The only real difference is that *Calycraterion* is the most abundant trace and *Aulichnites* is subordinate. The diversity and types of trace makers are very similar. It follows that the environment of deposition is the same for both assemblages. The *Calycraterion* assemblage is found in subtidal shelf environments.

Upper Bay Creek represents the only location that has been found thus far in southern Illinois that has a *Skolithos* assemblage within the Caseyville orthoquartzite. This unique assemblage is rare because the preservation potential is very low in lithologies of this nature. However, this location provides evidence to support the marine character of the orthoquartzite in this area.

The unnamed arthropod resting trace assemblage has only been found at the I-57 Goreville roadcut.

CONCLUSIONS

Most of the ichnofossil assemblages discussed above support an interpretation of brackish to marine conditions for the Lower Pennsylvanian in southern Illinois. This idea is also supported by locally thin and discontinuous high-sulfur coals and the sedimentology of the rocks. The geometry and geophysical properties of the strata also indicate marine shelf sands to brackish-water deltaics, from Caseyville to Tradewater, respectively.

Although ichnofossil diversity appears to be great, this in reality may only reflect the ethological charac-

ter of a few organisms. The most diverse trace-fossil assemblage discussed probably had five to six different taxa in total. This lack of overall diversity in species is most likely due to the transitional environments that existed in siliciclastic-rich, marine to brackish waters of the Early to Middle Pennsylvanian.

Oxygen content seems to have been an important controlling factor for ichnofossil distribution. This is especially true for *Zoophycos*, which is common in dysaerobic, highly organic environments. Although depth can also influence the amount of dissolved oxygen, *Zoophycos* alone is not simply an indicator of depth, because it has been found in deposits formed in very shallow-water environments. I have found *Zoophycos* directly above coal beds and in organic-rich shales with sulfur laminae, and in carbonaceous sandstones and siltstones in the Illinois Basin.

Very important subdisciplines of ichnology are the measurement of spatial relationships within the paleocommunity and the ethological connections between resting, feeding, locomotion, and the countless other behavior patterns preserved in rocks. Trace-fossil assemblages yield detailed frames of time that can be detected by the scientific researcher and used to interpret depositional environments.

POST SCRIPT

"There is no branch of detective science which is so important and so much neglected as the art of tracing footsteps" (Doyle, 1887).

REFERENCES CITED

- Archer, A. W., and Maples, C. G., 1984, Trace-fossil distribution across a marine-to-nonmarine gradient in the Pennsylvanian of southwestern Indiana: *Journal of Paleontology*, v. 58, no. 2, p. 448-466.
- Chamberlin, C. K., 1971, Morphology and ethology of trace fossils from the Ouachita Mountains, southeast Oklahoma: *Journal of Paleontology*, v. 45, p. 212-246.
- Devera, J. A., 1986, Trace fossils in the Abbott and Caseyville Formations of the Eddyville Quadrangle, southern Illinois [abs.]: *Geological Society of America Abstracts with Programs*, v. 18, no. 4, p. 286.
- Devera, J. A., in preparation, Geology of the Glendale Quadrangle and geologic map: Illinois State Geological Survey Circular and Geologic Quadrangle Map.

- Doyle, A. C., 1887, A study in scarlet: Beeton's Christmas annual.
- Eagar, M. C., 1974, Shape of shell of *Carbonicola* in relation to burrowing: *Lethaia*, v. 7, p. 219-238.
- Eagar, M. C., Okolo, S. A., and Walters, G. F., 1983, Trace fossils as evidence in the evolution of *Carbonicola*: Proceedings, Yorkshire Geological Society, v. 44, pt. 3, no. 20, p. 282-303.
- Ekdale, A. A., Bromley, R. G., and Pemberton, S. G., 1984, Ichnology trace fossils in sedimentology and stratigraphy: Society of Economic Paleontologists and Mineralogists Short Course No. 15, 317 p.
- Ekdale, A. A., and Mason, T. R., 1988, Characteristic trace-fossil association in oxygen-poor sedimentary environments: *Geology*, v. 16, p. 720-723.
- Fenton, C. L., and Fenton, M. A., 1937, Burrows and trails from Pennsylvanian rocks of Texas: *American Midland Naturalist*, v. 18, p. 1079-1084.
- Frey, R. W., and Seilacher, A., 1980, Uniformity in marine invertebrate ichnology: *Lethaia*, v. 13, p. 183-207.
- Fraunfelner, G. H., Utgaard, J., and Ethridge, F., 1973, Abbott Formation (Pennsylvanian) exposure along Little Grassy Lake spillway, in Ethridge, F. G., Fraunfelner, G., and Utgaard, J., eds., A guidebook to depositional environment of selected Lower Pennsylvanian and Upper Mississippian sequences of southern Illinois: 37th Annual Tri-State Field Conference at Southern Illinois University, Carbondale, October 5-7, 1973, p. 84-89.
- Jacobson, R. J., Trask, C. B., and Norby, R. D., 1983, A Morrowan/Atokan limestone from the lower Abbott Formation of southern Illinois [abs.]: Geological Society of America Abstracts with Programs, v. 15, no. 6, p. 602-603.
- Karaszewski, W., 1971, Some fossil traces from the lower Liassic of the Holy Cross Mountains, central Poland: *Bulletin del'Academic poloraise des sciences, Serie des sciences de la Terre*, no. 19, p. 101-105.
- Kvale, E. P., and Uhlir, D. M., 1988, Tidal influence in an Upper Caseyville (Lower Pennsylvanian) Gilbert-type deltaic sequence, southern Illinois [abs.]: Geological Society of America Abstracts with Programs, v. 20, no. 5, p. 353.
- Lamar, J. E., 1925, Geology and mineral resources of the Carbondale Quadrangle: Illinois State Geological Survey Bulletin 48, 174 p.
- Metz, T., 1987, Sinusoidal trail formed by a recent biting midge (family Ceratopogonidae): Trace-fossil implications: *Journal of Paleontology*, v. 61, no. 2, p. 312-314.
- Moussa, M. T., 1970, Nematode fossil trails from the Green River Formation (Eocene) in the Uinta Basin, Utah: *Journal of Paleontology*, v. 44, p. 304-307.
- Seilacher, A., 1964, Biogenic sedimentary structures, in Imbrie, J., and Newell, N. D., eds., Approaches to paleoecology: New York, John Wiley, p. 296-316.
- Seilacher, A., 1967, Bathymetry of trace fossils: *Marine Geology*, v. 5, p. 413-428.
- Stanley, R. G., 1980, Trace fossils and environments of deposition of the Caseyville and Abbott Formations (Lower Pennsylvanian) of southern Illinois: Carbondale, Southern Illinois University, M.S. Thesis, 110 p.

Plate 1

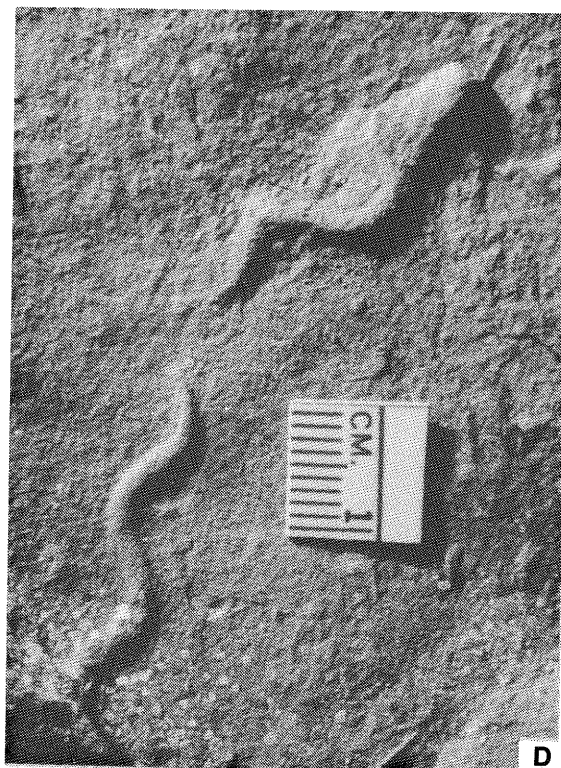
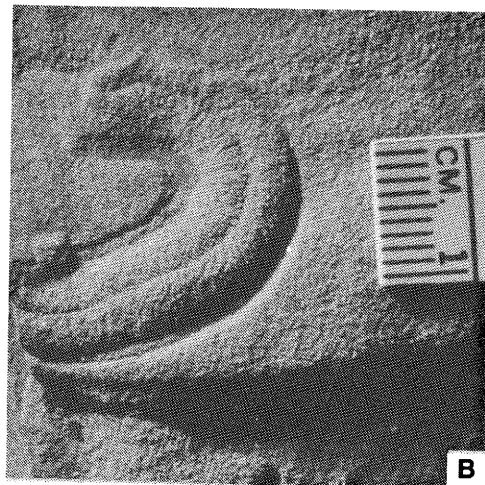
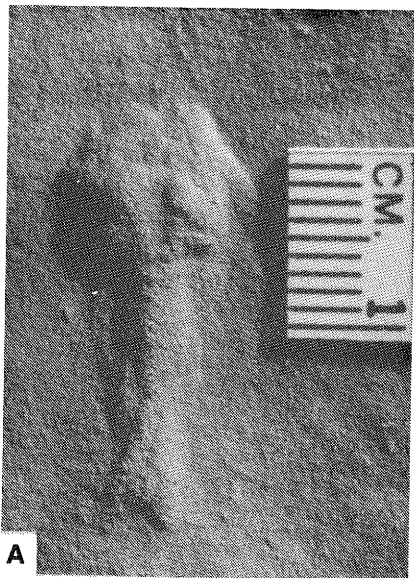
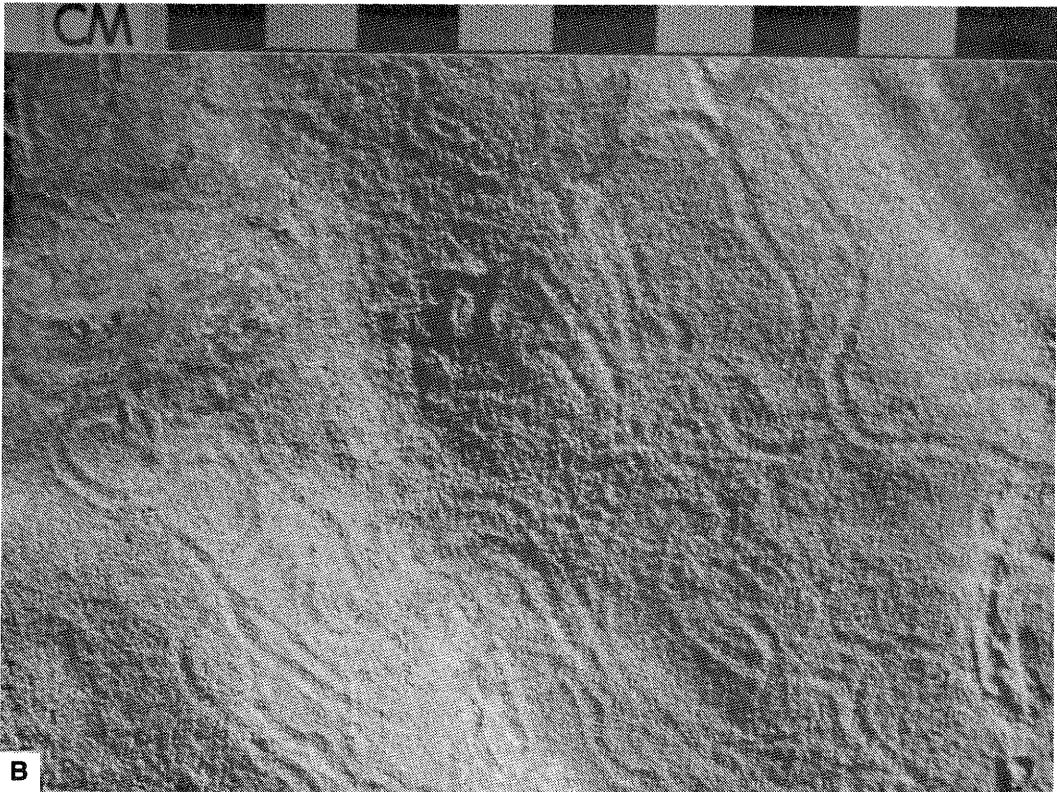


Plate 2



A



B

Plate 3

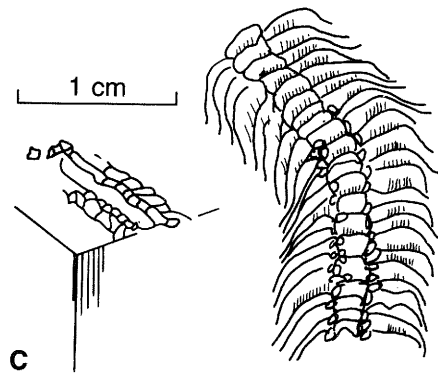
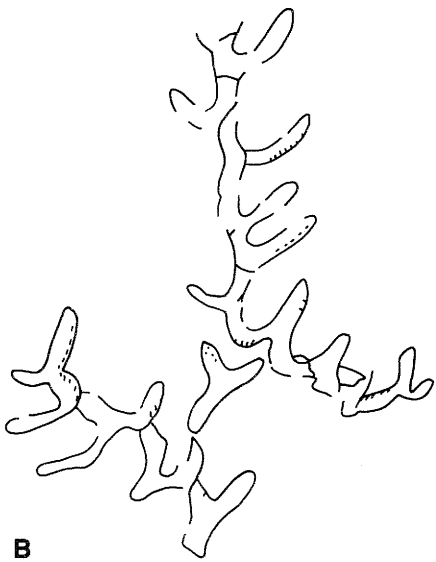
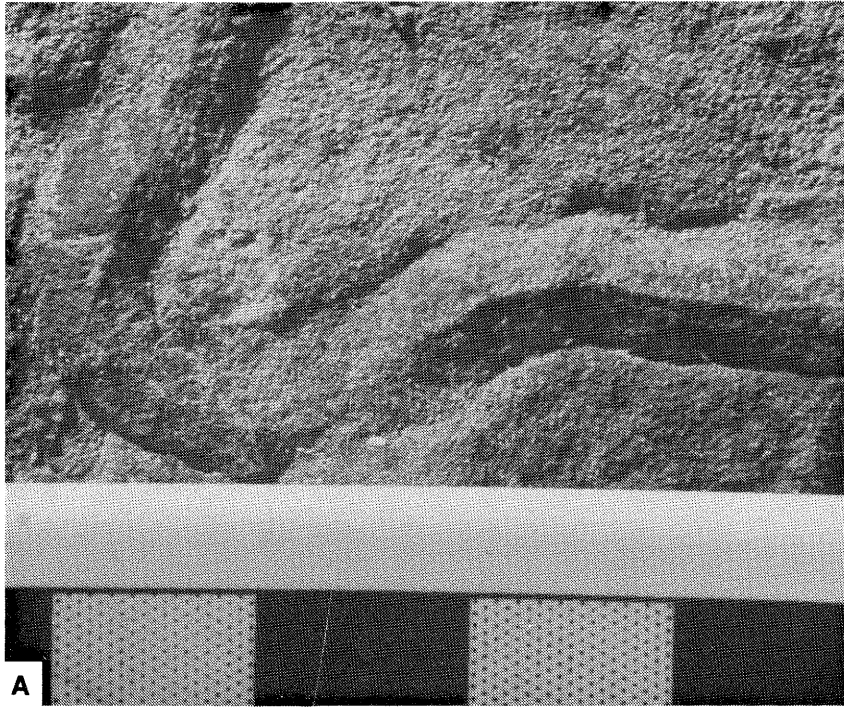
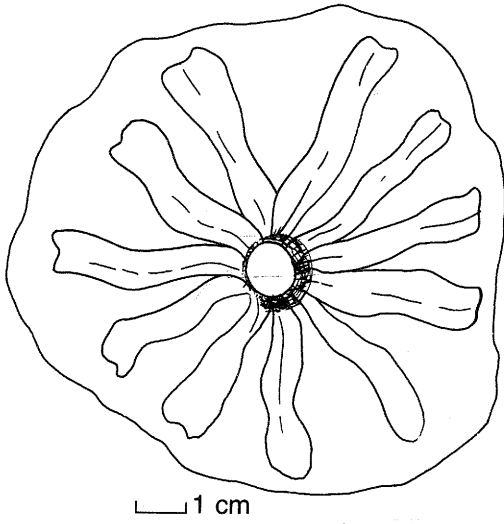
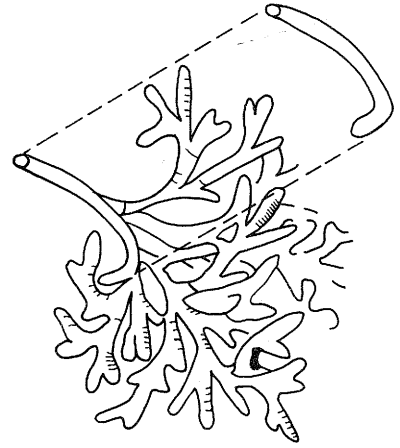


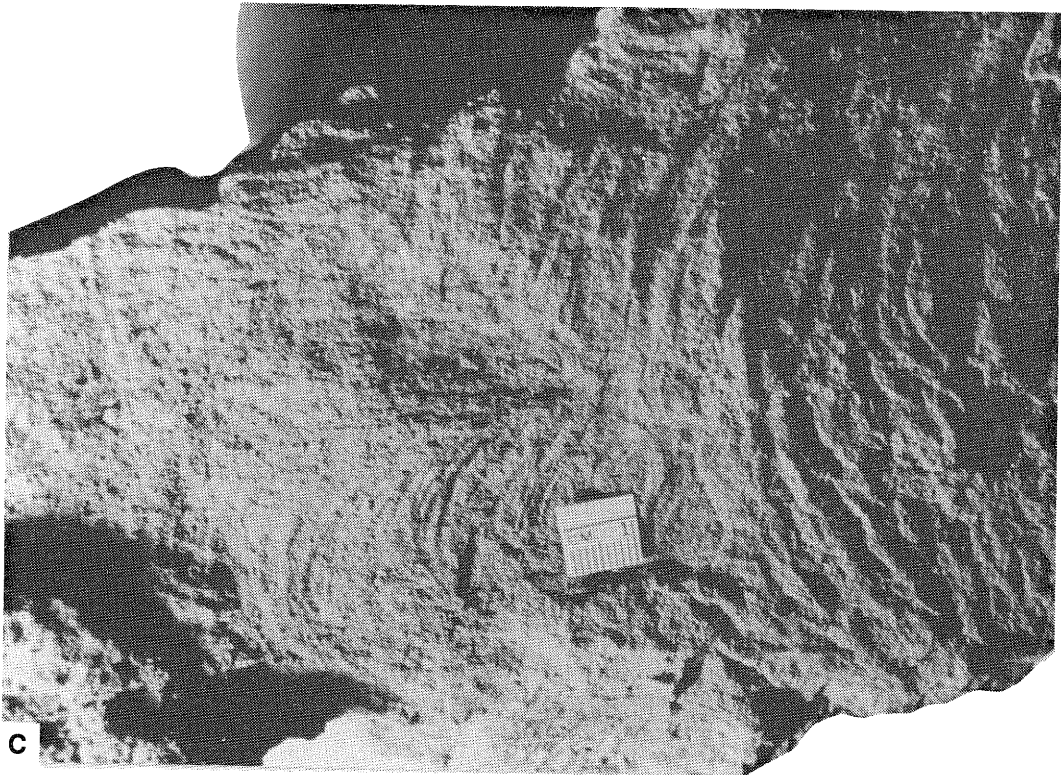
Plate 4



A



B



C

Plate 5



Plate 6

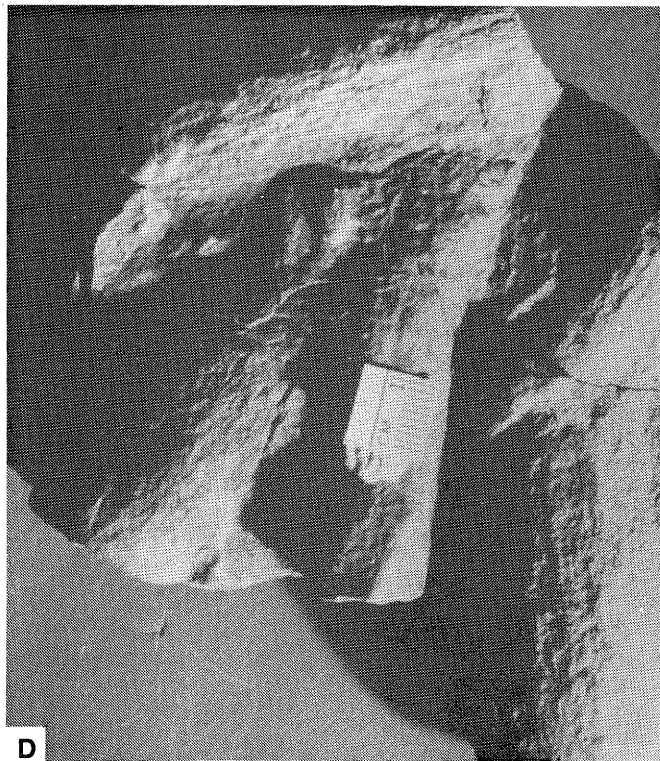
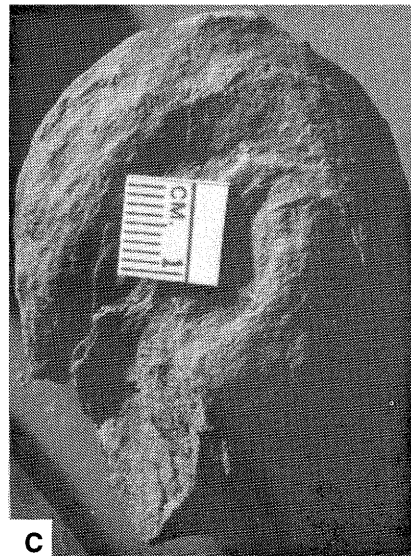
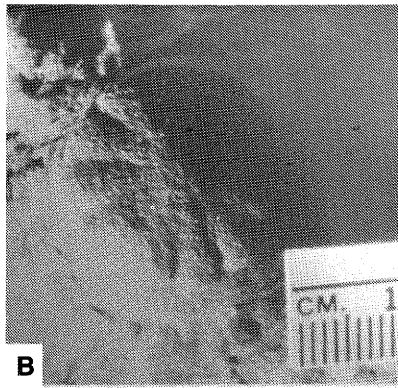
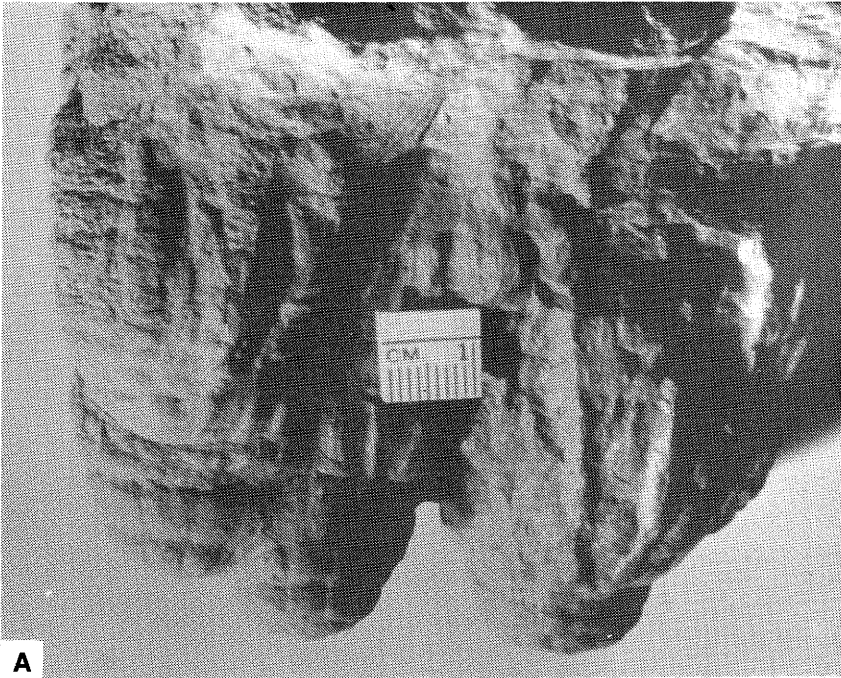


Plate 7

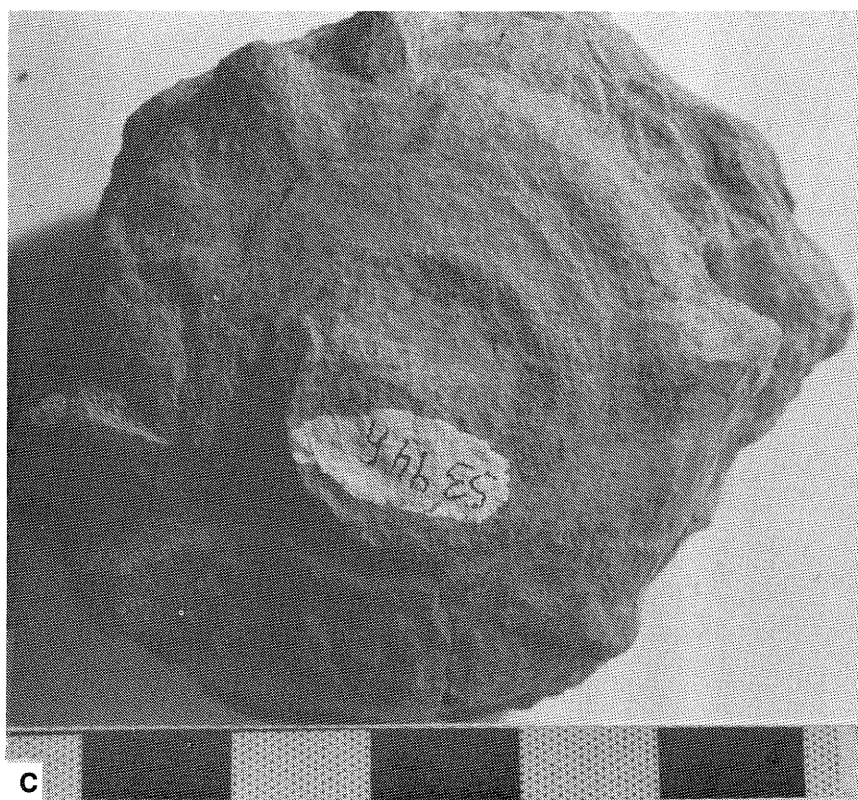
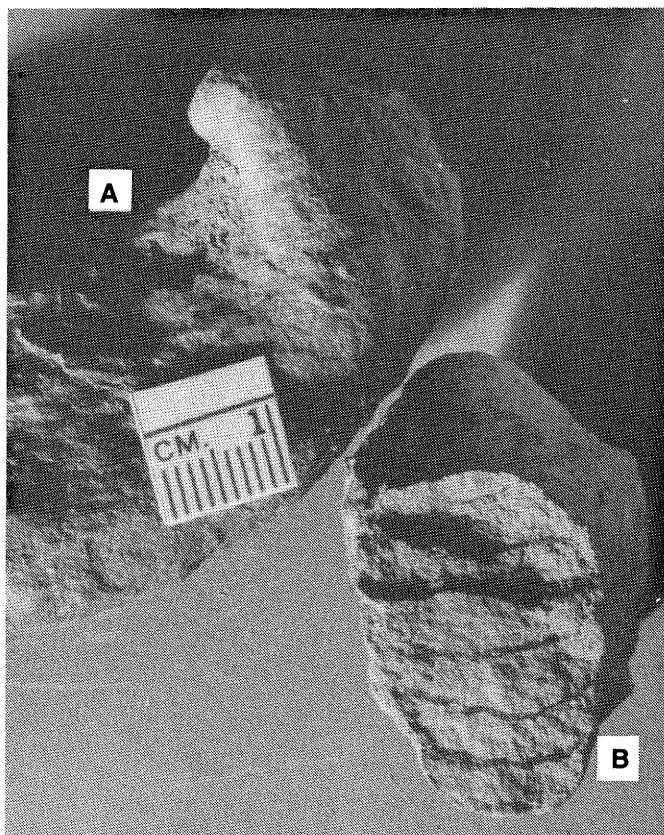


Plate 8

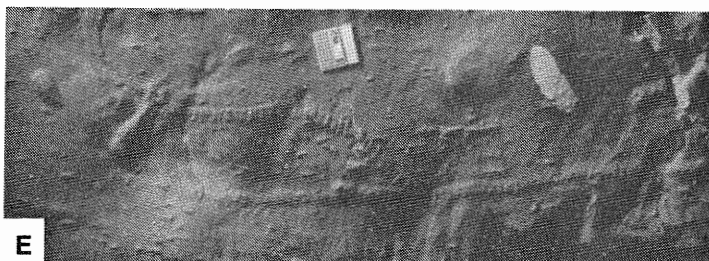
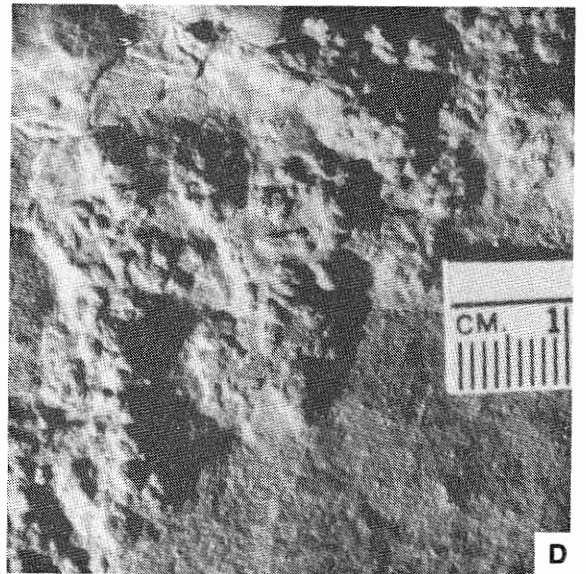
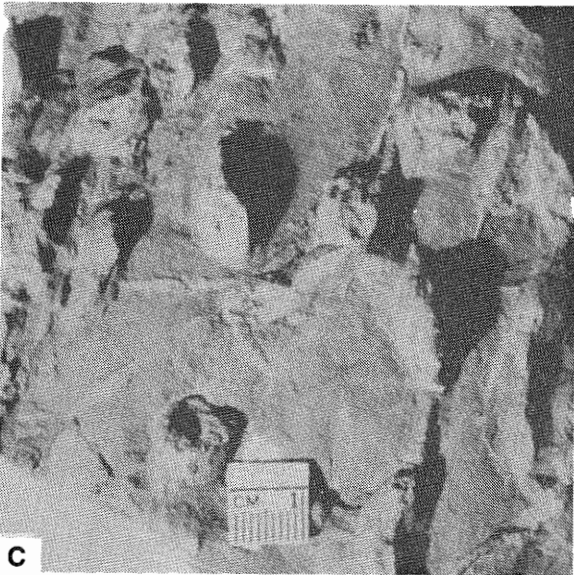
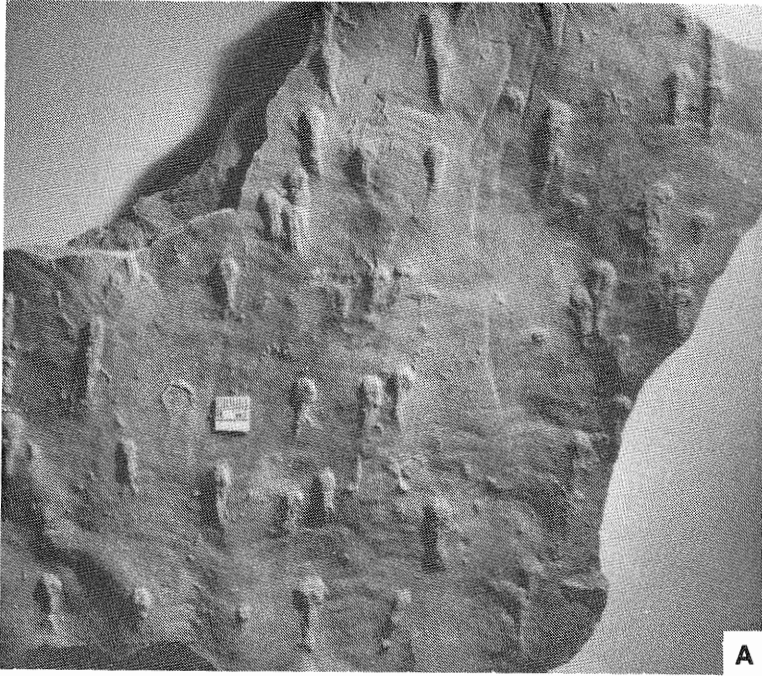
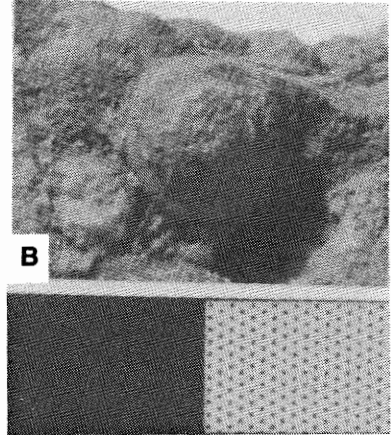
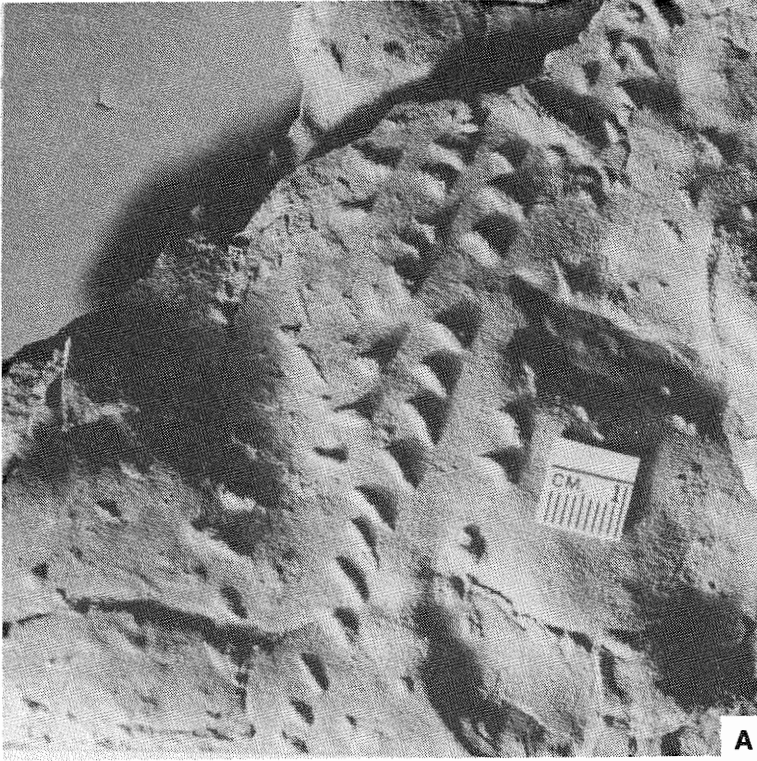


Plate 9



1 cm

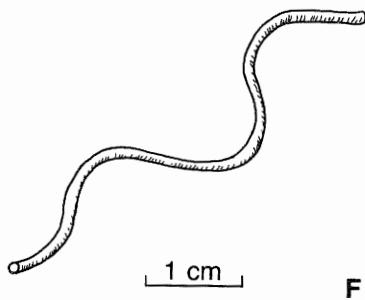
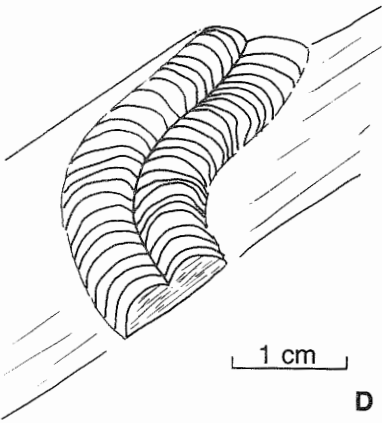
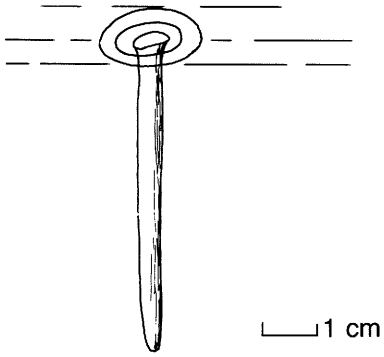
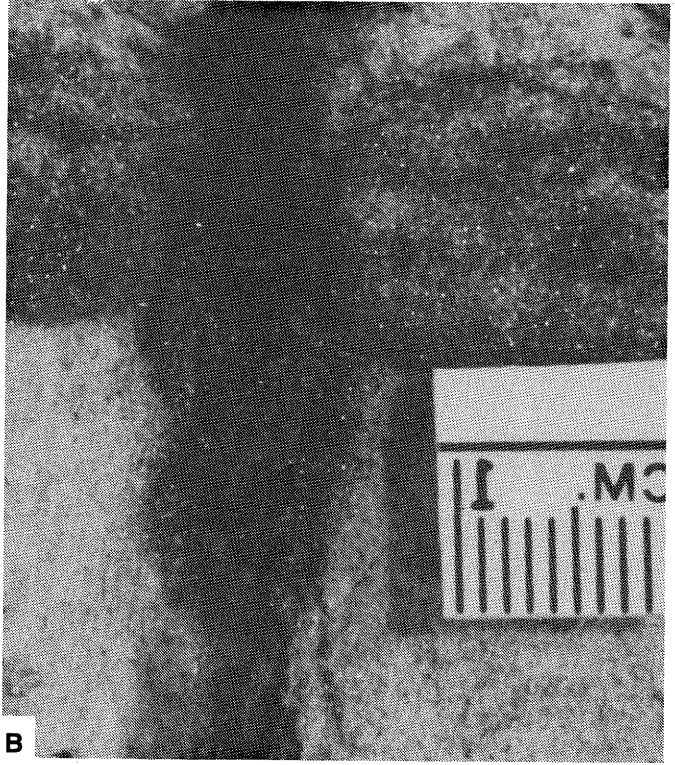


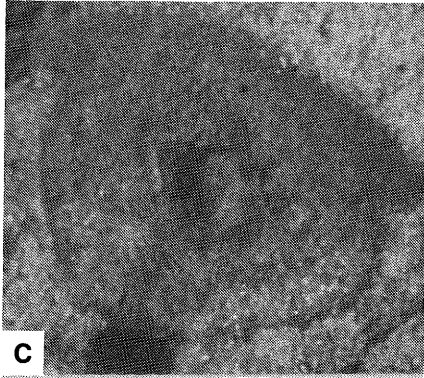
Plate 10



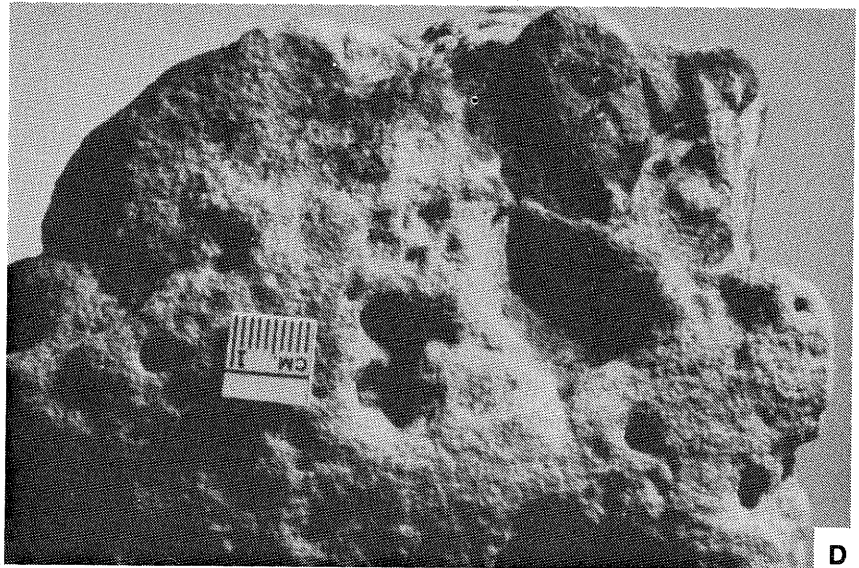
A



B



C



D

Plate 11

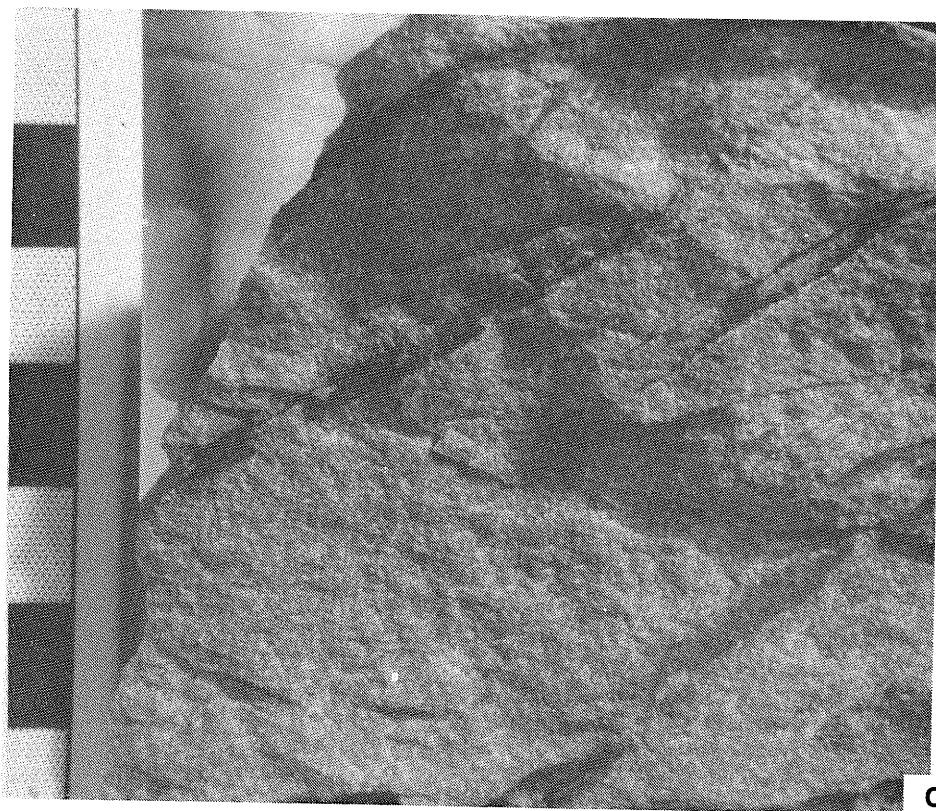
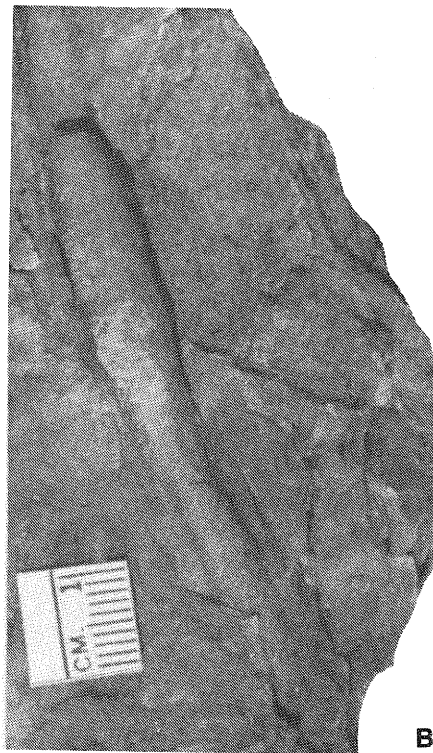
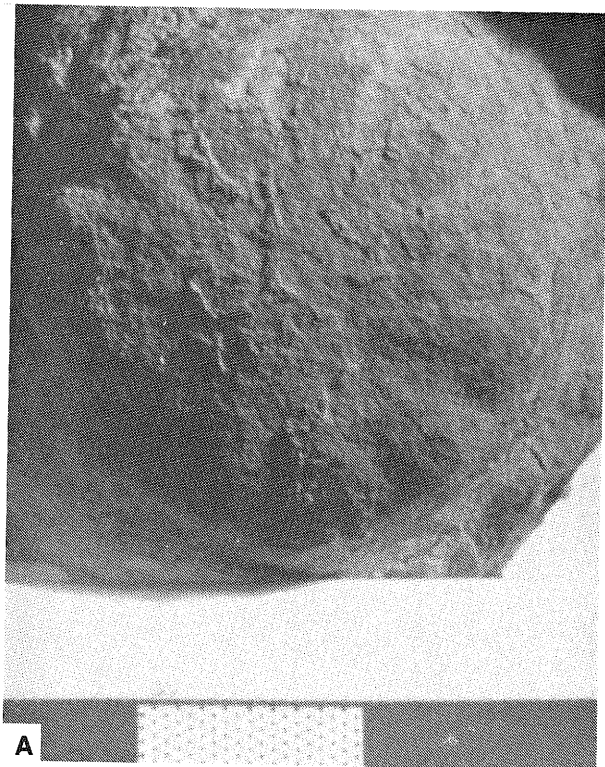
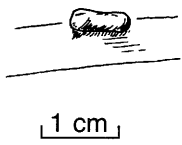
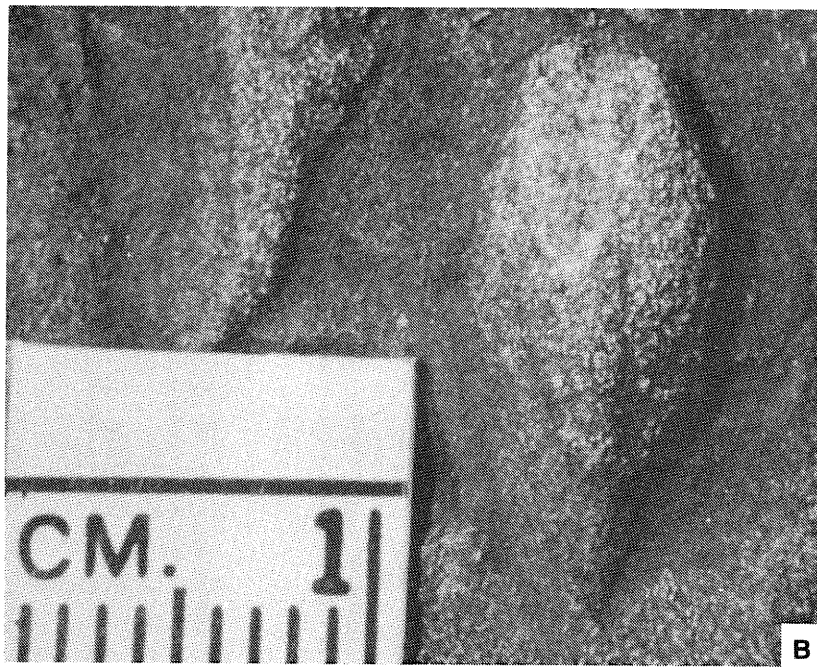
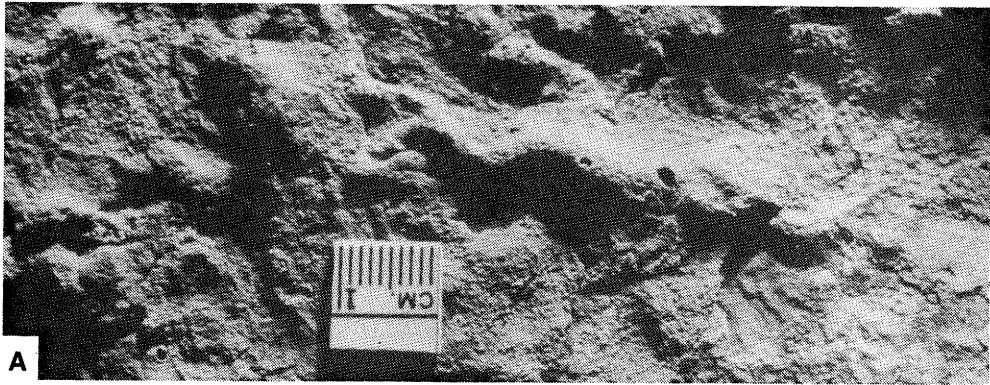
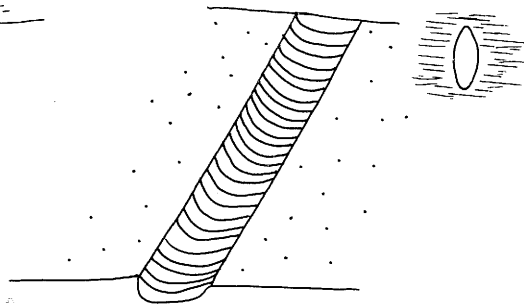


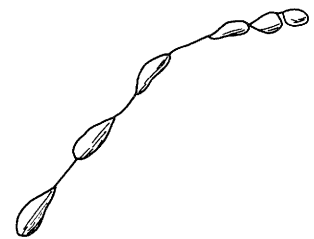
Plate 12



C

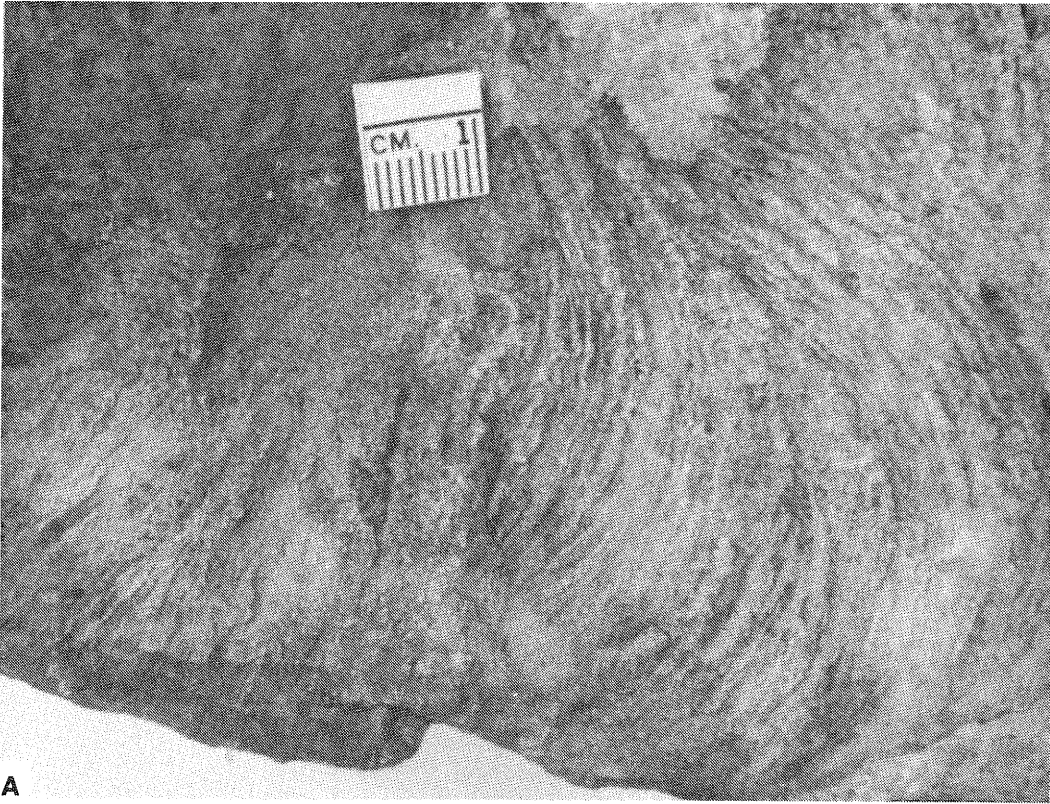


D

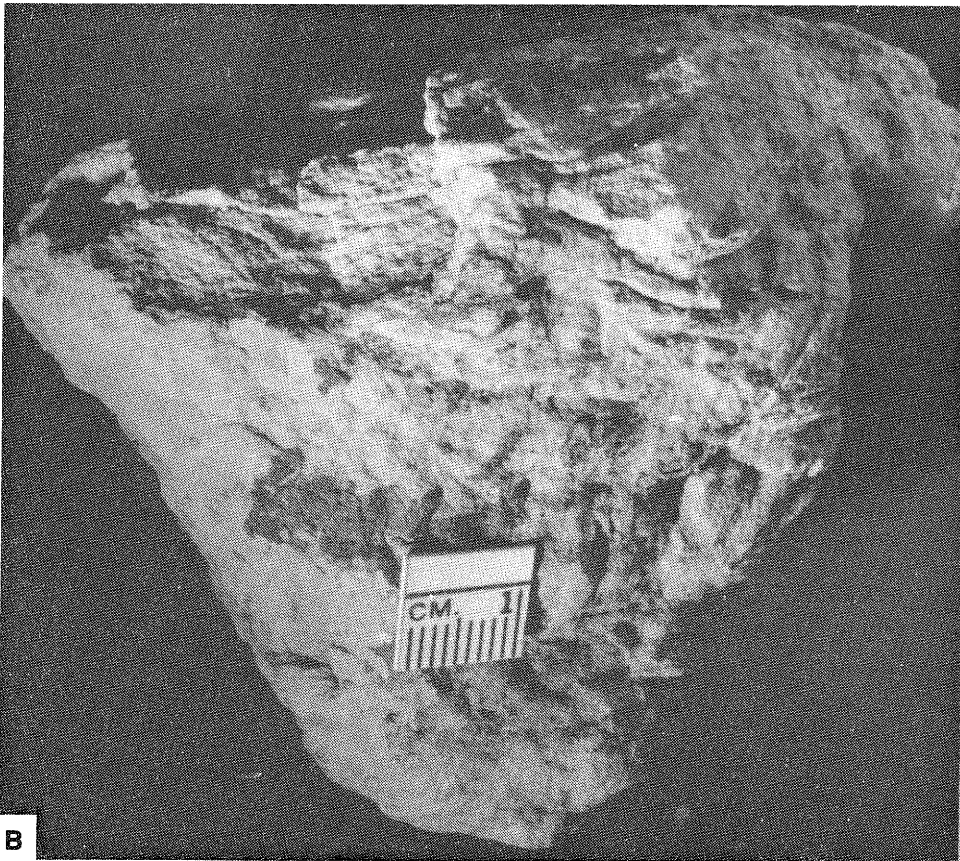


E

Plate 13

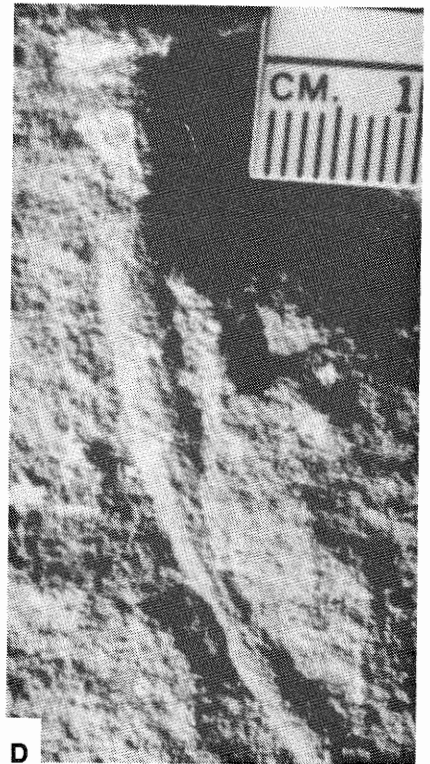
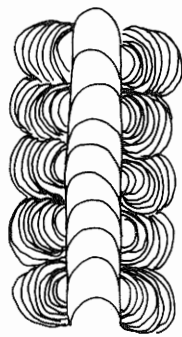
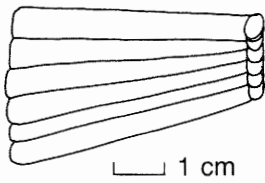
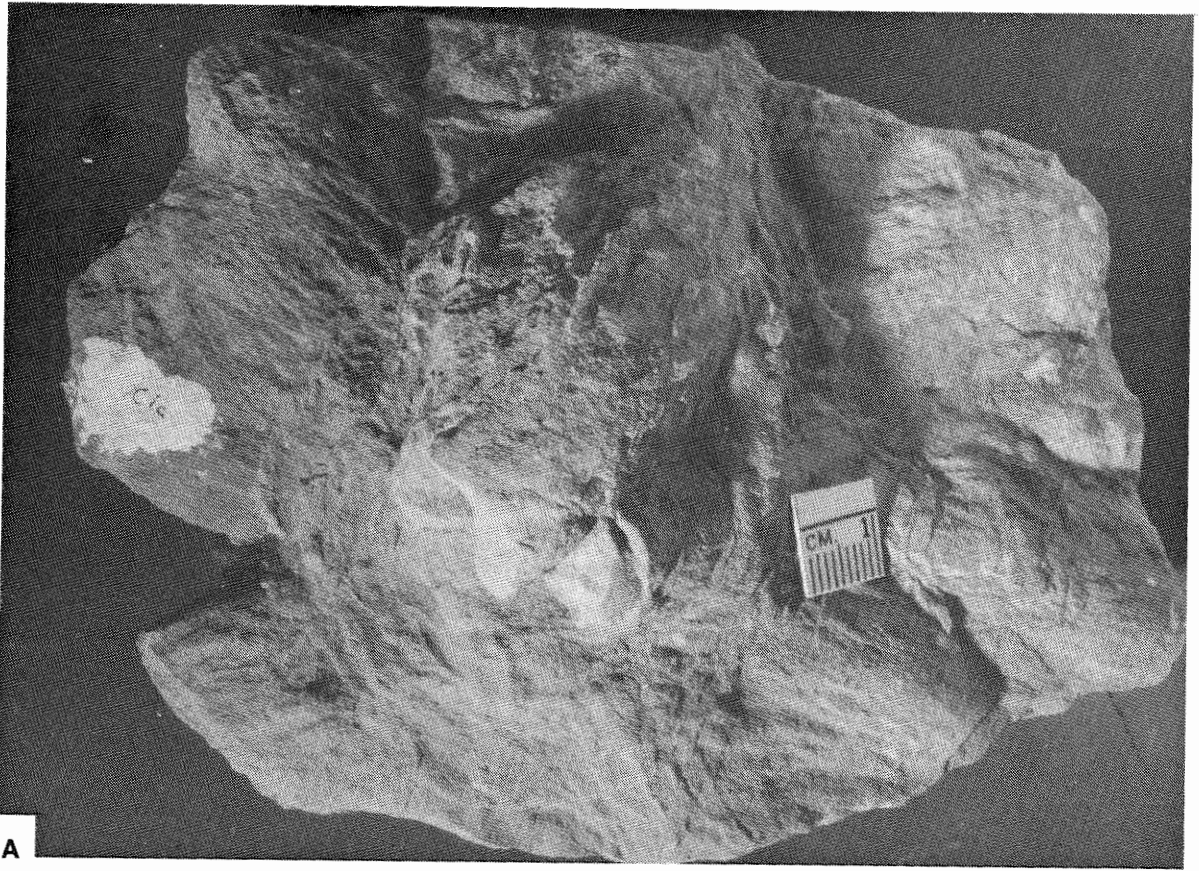


A



B

Plate 14



EXPLANATIONS FOR PLATES

Plate 1

- a. Unnamed arthropod cubichnia from the I-57 roadcut near Goreville, location 3, shows shrimp(?) resting trace.
- b. *Aulichnites parkerensis*, found at the Little Grassy spillway, location 1, lower bed.*
- c. *Scarituba missouriensis*, collected from the Little Grassy spillway, location 1, lower bed.*
- d. *Cochlichnus auguineus*, taken from the lower bed at location 1.*

Plate 2

- a. *Eiona* sp. was collected from the lower bed at Little Grassy spillway, location 1, by Stanley, and is deposited in the Southern Illinois University Museum at Carbondale, Illinois.
- b. *Torrowangea* sp., cf. *T. rosei* was collected by Stanley from the lower sandstone bed at the Little Grassy spillway, location 1, and is deposited in the Southern Illinois University Museum at Carbondale, Illinois.

Plate 3

- a. *Olivellites plummeri* was found at the Little Grassy spillway, lower bed, location 1.*
- b. *Rhabdoglyphus* sp. was drawn at the outcrop. The specimen could not be collected from the lower bed at location 1.
- c. *Scolica* sp. was not collected from the lower sandstone at the Little Grassy spillway, location 1. A drawing was made at the outcrop.

Plate 4

- a. *Stelloglyphus* sp. could not be collected and was sketched from the lower bed at location 1.
- b. *Chondrites* sp. was sketched from the upper bed at location 1. *Chondrites* was also found in the lower bed at location 1.
- c. *Zoophycos* sp. was collected from the upper sandstone bed at the Little Grassy spillway, location 1.

Plate 5

- a. *Conostichus broadheadi*, found at the Old Town railroad cut, location 2. This specimen shows a cross section through a *Conostichus*.*
- b. *Conostichus broadheadi*, found at location 2, shows duodecimal symmetry of the apical disc.* Scale at bottom in centimeters.

Plate 6

- a. *Conostichus stouti*, collected from location 2, showing longitudinal furrows and cylindrical shape.*
- b. Apical disc of *C. stouti* from location 2. This specimen displays moderate septation on the disc.
- c. *Gyrolithes* sp., collected from location 2.*
- d. *Asterosoma* sp., collected from location 2.*

*Deposited within the Devera ichnofossil collection at the Illinois State Geological Survey.

Plate 7

- a. *Teichichnus* sp., from location 2, showing a J-shaped appearance, also found as straight, horizontal burrows.*
- b. *Teichichnus* sp., from location 2, displaying the gutter-stacked nature of this trace fossil.*
- c. *Conostichus* with an “*Asterosoma*” component was collected from location 2. Elongate oval structure can be seen branching from the apical disc area.* Scale at bottom in centimeters.

Plate 8

- a. Unnamed arthropod cubichnia, from the I-57 Goreville location (location 3). This slab shows the spacing and orientation of 57 individuals at rest on shallow marine muds of early Middle Pennsylvanian time.*
- b. *Lockeia* sp. and connected *Uchirites* sp. were found at location 3. This specimen shows the *Lockeia* as a resting trace, and connected to it is the *Uchirites* repichnia.*
- c. *Lockeia* sp. cubichnia with shell drag marks. This specimen was collected at location 3.*
- d. Fecal pellets possibly from the unnamed arthropod cubichnia were found on the same bedding plane as the arthropod cubichnia. This sample was found at location 3.*
- e. Unnamed arthropod repichnia were found at location 3. These repichnia are thought to be produced by the unnamed arthropods. The trails occur on the same bedding planes, and one trail was found to terminate within one of these arthropod cubichnia traces.*

Plate 9

- a. Unknown trackway found at location 3.*
- b. *Calycraterion* sp. was found as a convex hyporelief at the Hayes Creek locality (locality 4).
- c. *Calycraterion* sp. showing “worms eye” view and side view of a specimen.
- d. *Aulichnites parkerensis* was drawn from the outcrop at location 4.
- e. *Teichichnus* sp. shows gutter stacking typified by this ichnogenus. This specimen was recovered from location 4.*
- f. *Cochlichnus auguineus* was sketched from location 4.
- g. *Kouphichnium* sp. was collected from location 3. It is a trackway of a horseshoe crab.

Plate 10

- a. *Skolithos* sp. was common at location 5 near Upper Bay Creek.
- b. *Skolithos* sp. collected from location 5.
- c. Top view of *Skolithos* taken from location 5. This specimen shows iron staining on the upper surface of the trace.
- d. Double holes of the U-shaped tubes associated with *Skolithos* at location 5.

Plate 11

- a. A basal disc of *Conostichus stouti* collected at the Trigg Tower, location 6. This specimen shows 12-part symmetry and weak septation of the disk.
- b. This specimen is a nondescript horizontal burrow found at location 6.
- c. Stigmarian rootlets found in a fine-grained sandstone at location 6.

Plate 12

- a. *Cochlichnus* sp. was collected at the Ogden Branch, locality 8.*
- b. *Lockeia* sp. was the most common trace fossil occurring at location 8.*
- c. *Lockeia* sp. cubichnia was sketched from location 7, I-24 roadcut.
- d. Bivalve fugichnia was sketched from sandstone beds at location 7.
- e. Bivalve repichnia drawn from location 7.

Plate 13

- a. *Zoophycos* sp. was collected from locality 9.*
- b. *Conostichus broadheadi* was collected from location 10.*

Plate 14

- a. *Asterosoma* sp. was found at location 10, along with many *Conostichus* specimens.*
- b. *Teichichnus* sp. was observed and sketched at locality 10.
- c. *Sclarituba missouriensis* was sketched at locality 10. *Eiona* was also found at this location, but is not figured here.
- d. *Cylindrichnus* sp. was collected at location 10.*

THE CASEYVILLE FORMATION (MORROWAN) OF THE ILLINOIS BASIN: REGIONAL SETTING AND LOCAL RELATIONSHIPS

W. John Nelson
Illinois State Geological Survey
Urbana, Illinois

INTRODUCTION

The Caseyville Formation is the oldest Pennsylvanian rock unit in the Illinois Basin. Although the name "Caseyville" was first used more than 130 years ago, definition and usage of the Caseyville Formation remain inconsistent to this day. Disagreement on classification has hampered understanding of the Caseyville as part of a body of sediment that originally covered much of the eastern United States. Thus, the relationship of the Caseyville to equivalent deposits in other basins has been controversial.

Goals of this paper are several. One is to attempt to define the Caseyville more clearly than has been done, and to advocate consistent usage of the Caseyville throughout the Illinois Basin. Another goal is to point out problems that require further surface and subsurface studies to resolve. A third purpose is to relate the Caseyville to equivalent deposits in other basins. A fourth purpose is to present findings of some recent studies in southern Illinois, and to suggest regional implications. A final goal is to provide background for the Caseyville core workshop (Weibel, this volume), and for the Caseyville-equivalent Lee Formation, which will be viewed on this field trip in eastern Kentucky.

Name and Definition

Owen (1856) referred in passing to the "Caseyville conglomerate" at several places (p. 48, 49, 62) in his report on the first geological survey of Kentucky. Owen's Caseyville conglomerate is a pebbly sandstone that crops out along the Ohio River near the settlement of Caseyville, about 45 miles northeast of Paducah. Owen indicated that the Caseyville conglomerate underlay his oldest recognized coal bed and, together with the older Battery Rock conglomerate and intervening shaly strata, constituted the "Millstone grit." The earliest usage of Caseyville conglomerate in a modern formational sense was in a chart by Glenn (1912). He proposed that the name be applied to the interval of strata

from the top of Owen's Caseyville conglomerate downward to the base of the Pennsylvanian System. Lee (1916) revised the name to Caseyville sandstone (in Pottsville Group), and described the type section of the Caseyville (Fig. 1).

After 1916 the Caseyville gradually gained acceptance as a recognized unit in western Kentucky and southern Illinois. Although geologists have debated the rank of the Caseyville and the placement of its upper boundary, Lee's (1916) type section description has remained the basic definition of the unit. Currently, the Kentucky, Illinois, and U.S. Geological Surveys regard the Caseyville as a formation. Equivalent rocks in Indiana have been assigned to the lower part of the Mansfield Formation.

Definition of the Caseyville away from its type area has been somewhat problematic. Thick-bedded to massive, bluff-forming sandstone, containing numerous well-rounded pebbles of white quartz $\frac{1}{2}$ inch or larger, is considered diagnostic of the formation. These sandstones are lenticular and vary laterally in character. In many places Caseyville sandstones lack pebbles; conversely, quartz granules and small pebbles (less than $\frac{1}{2}$ inch) occur in younger Pennsylvanian sandstones. Most Caseyville sandstones, whether fine or coarse grained, are clean quartz sandstones. They are classified petrographically as orthoquartzites or quartzarenites (Potter and Siever, 1956; Potter and Glass, 1958; Potter and Pryor, 1961; Morrow, 1979; Bohm, 1981). Mica flakes, feldspar grains, and lithic fragments are rare in Caseyville sandstones. Little or no matrix is present; silica overgrowths on the grains give the rock a sparkly appearance. In these qualities Caseyville sandstones do not differ from sandstones of the underlying Chester Group, but the latter rarely include coarse sand and quartz granules. Sandstones of the Tradewater Formation, above the Caseyville, contain noticeably more non-quartz grains and generally have a conspicuous clay matrix. These younger sandstones are classified petrographically as subgraywackes or lithic arenites

(Potter and Siever, 1956). The upward decrease in maturity generally is gradational through an interval that ranges from several tens of feet to more than 100 feet thick. The top of the Caseyville is generally mapped at the highest occurrence of ledge-forming clean quartz sandstone that commonly contains

quartz pebbles, or at the base of the Bell (1-b) coal bed, where present, in parts of western Kentucky.

Interbedded with sandstone in the Caseyville Formation are varying proportions of siltstone, shale, thin lenticular coal beds, and in rare cases, limestone. Siltstone is commonly white to gray and bears horizontal laminations and ripple marks. Shale varies from light gray to black, and generally is silty. Some shale contains ironstone nodules; dark-gray and black shales commonly are carbonaceous and contain plant fossils. Caseyville siltstones and shales do not differ noticeably from those of younger Pennsylvanian formations or from those of the various siliciclastic formations of the Chester Group. Caseyville coals tend to be shaly and rarely are more than 2 feet thick. The Gentry Coal Bed (Fig. 1), near the middle of the formation, probably is the most persistent coal. Limestone and calcareous shale are known at the type locality (Fig. 1), and a handful of other sites. Caseyville limestones are argillaceous to sandy, ferruginous, and contain restricted to diverse marine and brackish-water fauna (Wanless, 1939; Fraunfelter, 1979; Devera and others, 1987).

The base of the Caseyville Formation, and of the Pennsylvanian System, is a regionwide unconformity—the sub-Absaroka unconformity of Sloss and others (1949). Recognition of this unconformity is easy where the subjacent Chester Group strata include limestone, red and green shale, and other rock types unusual for the Caseyville. Placement of the contact is difficult where uppermost Chester rocks are siliciclastics, and where basal conglomerate, scoured contact, or other evidence of erosion is lacking.

EXTENT OF THE CASEYVILLE

The Caseyville Formation crops out around the rim of the Western Kentucky Coal Field and in a belt across southern Illinois (Fig. 2). In most of this area its resistant sandstones produce a rugged topography of scenic forested bluffs, cut by deep ravines. Adjacent formations are less resistant and erode to rolling lowlands.

The Caseyville pinches out westward due to non-deposition in Randolph County, Illinois. The older members of the Caseyville progressively pinch out and are overlapped westward by younger members (Sonnefield, 1981). The Caseyville itself is conformably overlapped by the Abbott (lower Tradewater) Formation northwest of Randolph County.

In the western half of the Western Kentucky Coal Field the Caseyville and Tradewater Formations were

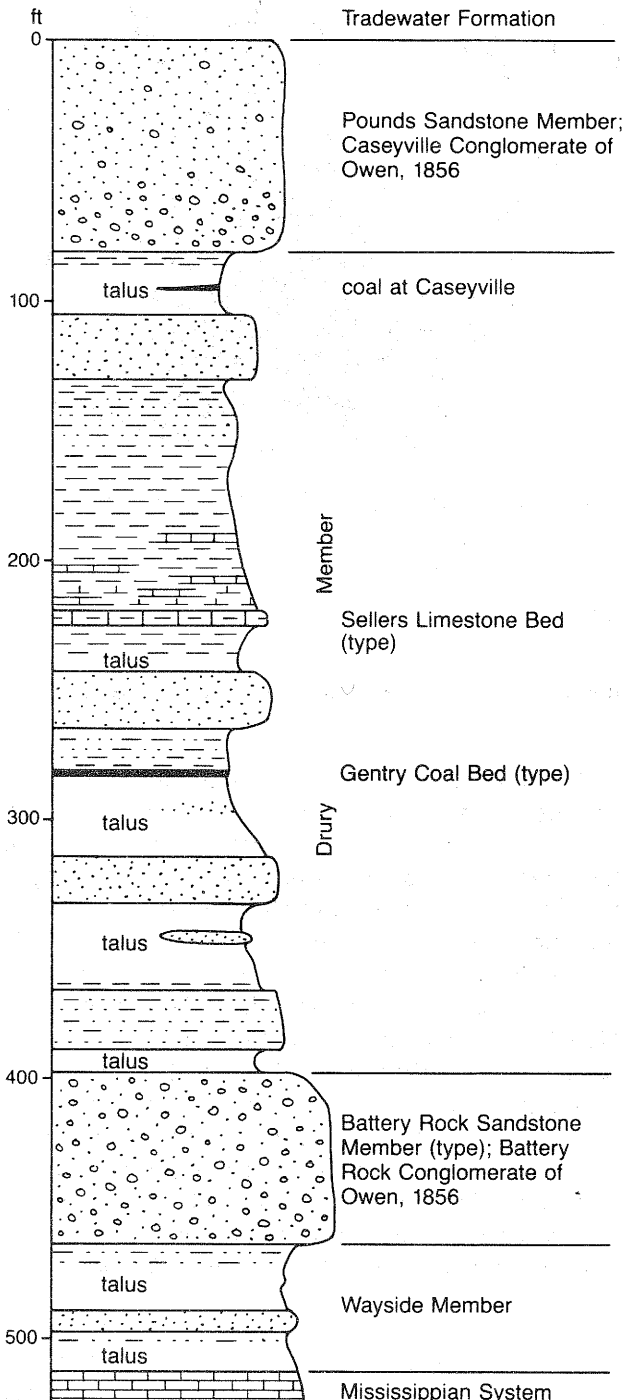


Figure 1. Type section of the Caseyville Formation, as described by Lee (1916), with current names of members and beds.

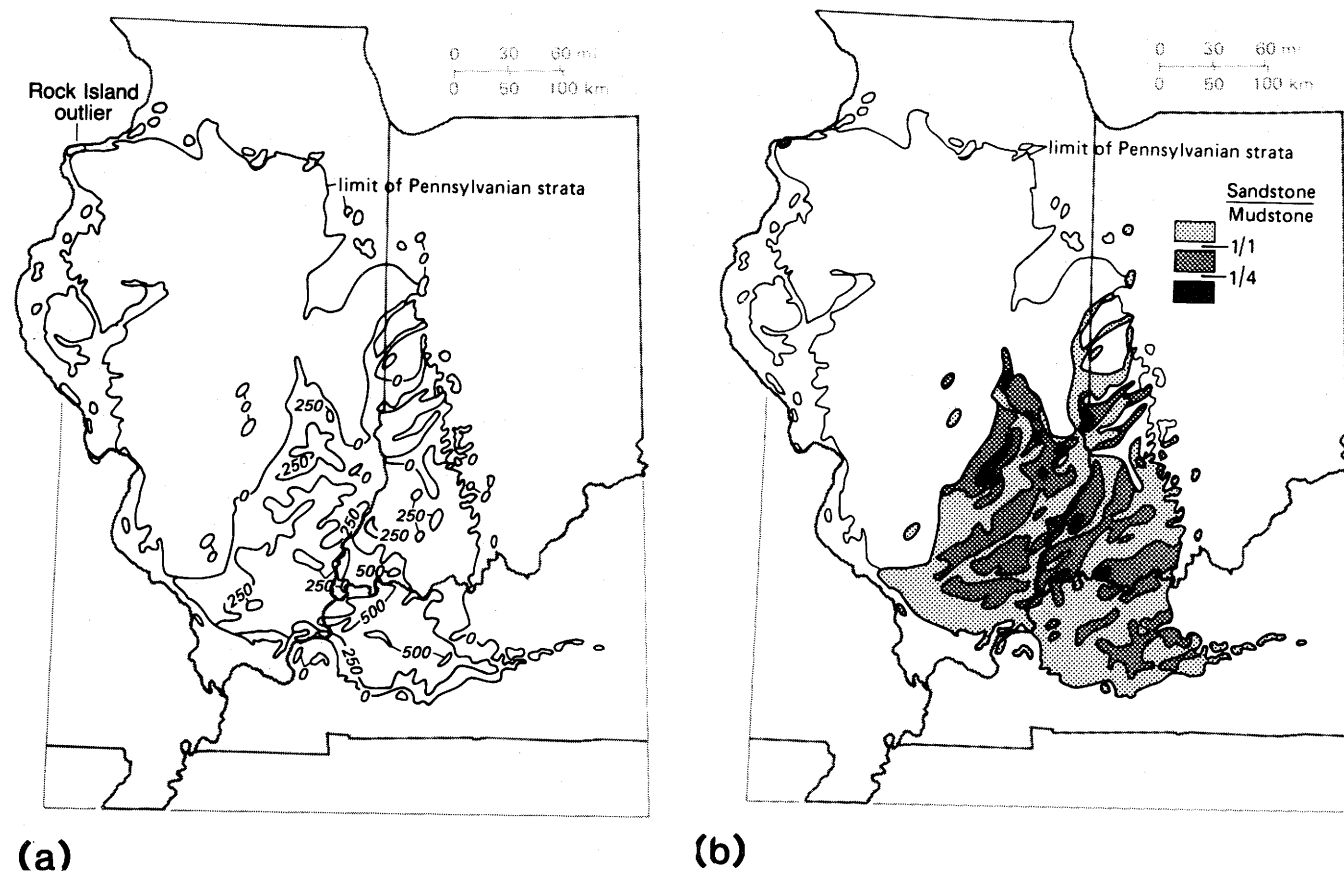


Figure 2. Isopach map of Caseyville Formation; contour interval 250 feet. (a) Sandstone/mudstone ratios of Caseyville Formation. (b) After Wanless (1975).

differentiated on the geologic quadrangle maps prepared jointly by the Kentucky and U.S. Geological Surveys during the 1960's and 1970's. However, the two formations were not differentiated in most of the eastern half of the coal field, particularly in Butler, Daviess, and Ohio Counties. It is possible that the boundary between these two formations is present in the eastern half, but that for several reasons it was not mapped. One reason is that mapping began in the eastern part of the coal field, well away from the type area of the Caseyville and Tradewater; another factor is that outcrops appear to be larger and more numerous in the west than to the east. A third reason is that pebbly sandstones and conglomerates are not as thick or conspicuous in Butler, Daviess, and Ohio Counties as elsewhere in the coal field. Stratigraphic columns and lithologic descriptions for the western part of the coal field are more detailed than those for the east, where they appear to be highly generalized. Additional studies in the eastern area are needed to determine whether Caseyville lithologies exist, and, if so, how they relate to adjacent strata.

The lower part of the Mansfield Formation in Indiana contains clean quartz sandstone and quartz-pebble conglomerates similar to those of the type Caseyville. These lithologies occur along nearly the full length of the outcrop belt in Indiana (Fig. 2; Potter and Siever, 1956; Wanless, 1975). The Caseyville lithologies seem to thin northward, and may be confined to paleovalley fills in places. The Mansfield Formation, as presently defined, includes both quartzarenites and lithic arenites, along with siltstone, shale, and lenticular coal beds, all lithologically indistinguishable from the overlying Brazil Formation. The Mansfield-Brazil contact currently is defined (Shaver and others, 1986) as the base of the Lower Block Coal, a lenticular unit that cannot be reliably identified away from its type locality.

Little progress has been made in mapping the Caseyville in the subsurface. No distinctive geophysical characteristics of the formation have been identified; the sandstones are lenticular, and marker beds apparently are lacking. The clean quartz sandstones and conglomerates, however, are distinctive

in cores and well cuttings. Wanless (1975) apparently relied on cores and cuttings in constructing his basinwide isopach and lithofacies maps of Interval A (Morrowan Series), which is essentially identical to the Caseyville Formation (Fig. 2). Other geologists such as Howard and Whitaker (1988) have identified Caseyville lithologies in wells in small areas. Available data indicate that the main body of Caseyville is confined to an area southeast of a line drawn approximately from Lafayette, Indiana, to Chester, Illinois.

An outlier of Morrowan strata has been identified in parts of Rock Island County, Illinois, and Scott and Muscatine Counties, Iowa (Figs. 2a and 3). The name "Caseyville Formation" has been applied to these rocks on the basis of lithologic similarity to the type Caseyville. The outlier contains quartzarenites, some pebbly, along with siltstone, shale, and coal beds. The Caseyville outlier unconformably overlies Devonian strata, and in turn is unconformably overlain by rocks of Desmoinesian age. Petrographic study and paleocurrent analysis indicate that the outlier represents a small basin of deposition that is isolated from the main body of Caseyville and has a different source area (Potter and Siever, 1956; Ravn and others, 1984; Ravn, 1986; Ludvigson and Swett, 1987). Perhaps the northwestern outlier should be given a different name, to distinguish it from the main body of Caseyville.

AGE OF THE CASEYVILLE

The age of the Caseyville Formation has been determined by palynological study of coal and carbonaceous shale from numerous sites in western Kentucky and southern Illinois (Peppers, 1988), and by study of goniatites from a locality in Pope County, Illinois (Wanless, 1939; Devera and others, 1987). These studies show that the Caseyville in these areas is equivalent to most of the Morrowan Series of the North American Midcontinent, and to the upper part of the Lower Pennsylvanian and lower part of the Middle Pennsylvanian Series of the Appalachian region. These, in turn, are equivalent to the late Namurian C and essentially all of the Westphalian A Stages of the Upper Carboniferous Series of western Europe. Basal Pennsylvanian strata become younger northward from the southern outcrop belt (Potter and Siever, 1956).

REGIONAL SETTING AND PROVENANCE

Pebbly quartzarenite and quartz-pebble conglomerate, very similar in age and lithology to the

Caseyville Formation, are found from New York to Alabama and from Michigan to Arkansas. These sediments were deposited by a system that drained west and southwest from highlands in the northern Appalachians and Canadian Shield to the rapidly subsiding Arkoma Basin (Fig. 3). Caseyville equivalents include the Olean Conglomerate of Pennsylvania and New York (Edmunds and others, 1979), the Sharon Conglomerate in Ohio (Fuller, 1955; Collins, 1979); parts of the New River Formation in West Virginia (Arkle and others, 1979; Englund, 1979); the Lee Formation of eastern Kentucky (Rice and others, 1979; Rice, 1984); the Gizzard and Crab Orchard Mountain Groups in Tennessee (Milici, 1974; Milici and others, 1979); portions of the Pottsville Formation in Alabama (Davis and Ehrlich, 1974; Hobday, 1974; Thomas, 1974); and the Parma Sandstone Member of the Saginaw Formation in Michigan (Potter and Siever, 1956; Wanless and Shideler, 1975). Quartzarenite containing quartz granules and small pebbles occurs in Morrowan and basal Atokan strata on the southern flank of the Ozark Dome and in the Arkoma Basin, Arkansas (Henbest, 1953; Glick, 1975; Sutherland and Manger, 1979; Sutherland, 1988). Within the Ouachita Trough, the Jackfork Sandstone of Morrowan age contains clean quartz sand and quartz granules, but petrographic analyses and cathodoluminescence studies indicate that the primary source area for the Jackfork was to the south, and not from the Illinois Basin (Owen and Carozzi, 1986).

Southward paleoslope and sediment transport during the Morrowan Epoch was inherited from Chesterian time (Swann, 1963). Sub-Pennsylvanian paleovalleys and major basal Morrowan sand bodies trend dominantly southwest (Bristol and Howard, 1971; Rice, 1984). The longest preserved paleovalley system, the Brownsville-Sharon, extended from western New York and Pennsylvania across southern Ohio and into the Western Kentucky Coal Field (Fig. 3). Residual quartz-pebble conglomerate on the Cincinnati Arch shows that the Brownsville-Sharon Paleovalley crossed this structure (Rice, 1984). Paleocurrent studies, chiefly of crossbedding, substantiate southwestward transport (Potter and Siever, 1956; Potter, 1963; Rice and others, 1979; Hester, 1981; Chesnut, 1988). The decrease in size of quartz pebbles to the southwest, from 3½ inches in New York and Pennsylvania (Bement, 1976; Edmunds and others, 1979) to granule size in Arkansas (Glick, 1975) supports the same conclusion. Moreover, the degree of marine influence increases from

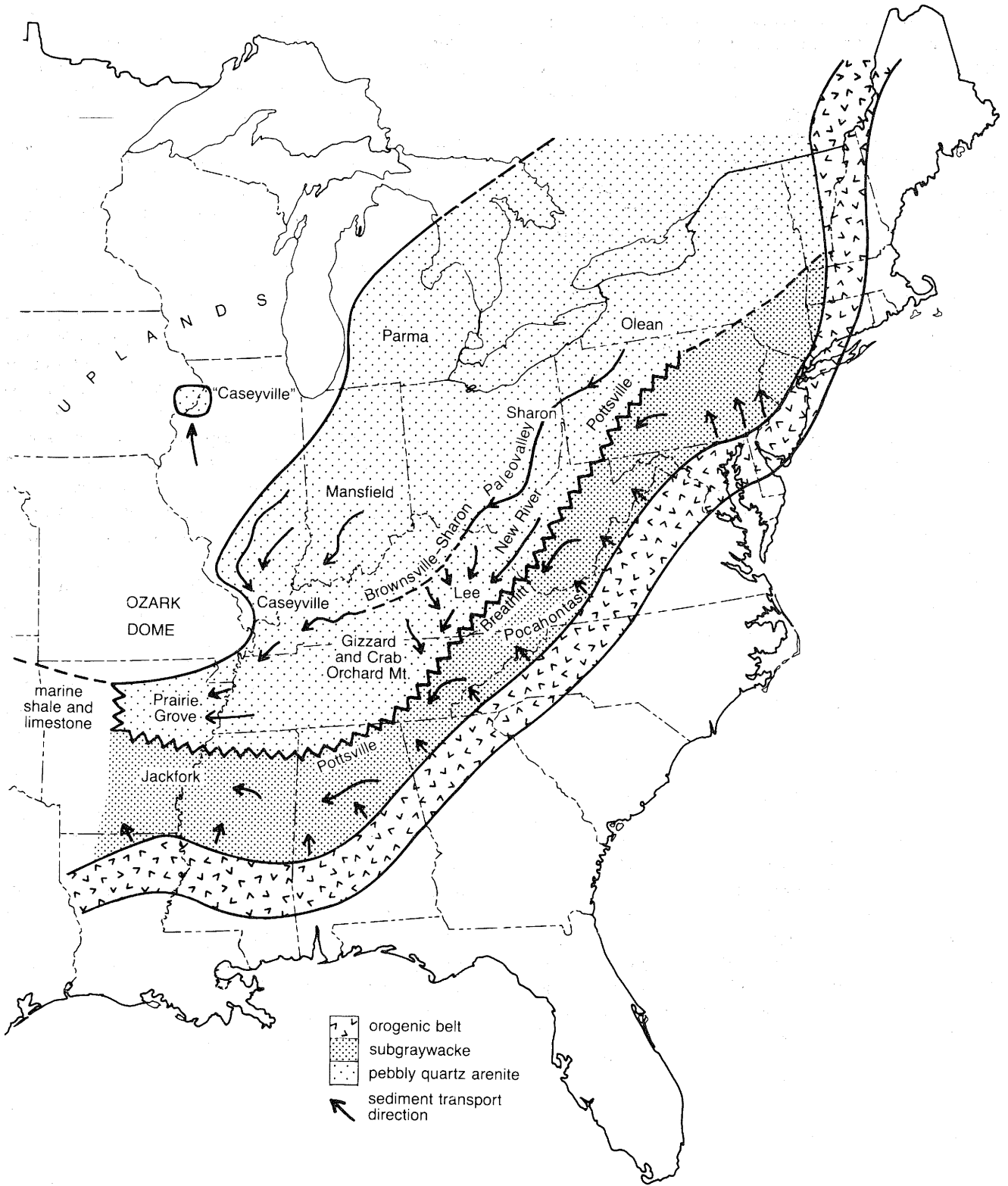


Figure 3. Map indicating lithologies, source areas, and sediment transport directions for the Caseyville Formation and equivalent strata.

slight (if any) on the northeast to moderate in the Illinois Basin, to dominant in Arkansas.

Coeval with deposition of Caseyville-type quartzarenites, thick intervals of subgraywacke, conglomerate, mudstone, and coal were deposited in rapidly subsiding foreland basins adjacent to the Appalachian orogenic belt (Fig. 3). Lithofacies mapping indicates that the primary sediment sources were orogenic highlands being uplifted south and southeast of the basins (Chesnut, 1988). The orogenic sediments intertongue northward and northwestward with the quartzarenites. These relationships are documented in the Black Warrior Basin by Davis and Ehrlich (1974), Hobday (1974), Thomas (1974), and Mack and others (1983); in the Pocahontas Basin by Arkle and others (1979), Englund (1979), and Englund and others (1986); and in the Pennsylvania anthracite region by Wood and others (1986). Early Pennsylvanian tectonism and sedimentation also took place in southern New England (Skehan and others, 1986) and in Nova Scotia (Bell, 1938; Rust and others, 1987).

Thus, two distinct Early Pennsylvanian sediment packages in eastern North America are indicated: subgraywackes from a southeastern orogenic source and quartzarenites from a northeastern source (Fig. 3). Petrography of the latter points to derivation from older sedimentary rocks or low-rank metamorphic rocks (Pryor and Potter, 1979). Apparently, no one has directly compared the Pennsylvanian quartzarenites in Illinois with rocks in potential source areas. Potter and Siever (1956) and Potter and Glass (1958) were not specific in designating a source area. They referred to the middle and northern Appalachians and southeastern Canadian Shield as probable source areas. Sloss (1979), with little supporting data, specified block-faulted uplifts on the Canadian Shield in central Quebec. I consider a source on the Shield unlikely. The Shield is composed largely of Precambrian igneous and high-rank metamorphic rocks, overlain by a veneer of carbonates and fine-grained sandstones; these should yield arkose or subgraywacke, not pebbly quartzarenite. Also, I doubt that (undocumented) block-faulted uplifts in Quebec would provide streams with sufficient gradient and flow to carry coarse sand and gravel more than 1,000 miles to southern Illinois. More likely the source was in the northern Appalachians. Proterozoic through Mississippian metaquartzite, vein quartz, and quartz sandstone and conglomerate occur widely today in eastern New York state, northern New England, and southeastern Quebec. Mountain-building here could

have provided both the gradient and the rainfall to transport the quartzose sediment southwestward. By the time of Tradewater sedimentation, the quartzose sedimentary cover might have been stripped off the uplifts, exposing older crystalline rocks and yielding subgraywacke (Potter and Glass, 1958).

As an alternate hypothesis, Horne and others (1971, 1974), Hobday (1974), and Milici and others (1979) have proposed that quartzarenites and subgraywackes in the Appalachian Basin were derived from the same source area but deposited in different environments. In this model subgraywackes are interpreted as coastal-plain or fluvial/deltaic sediments, whereas quartzarenites represent barrier bars and related nearshore marine facies from which waves and currents have winnowed the non-quartz component. Such a model may be partly applicable in the zone of intertonguing in the Appalachian Basin. However, sedimentological evidence strongly indicates that some major sand bodies in the Lee Formation of eastern Kentucky (Rice and others, 1979; Hester, 1981; Rice, 1984) and in the Caseyville Formation of southern Illinois and western Kentucky (Potter, 1963; Ethridge and others, 1973; Pryor and Potter, 1979) were deposited in fluvial and deltaic distributary channels.

In summary, continental collision triggered major mountain-building along the length of the Appalachians, from Alabama to Nova Scotia, in Late Mississippian and Early Pennsylvanian time. Adjacent foreland basins from Pennsylvania southward filled with subgraywacke derived directly from crystalline rocks in the new mountains. Northeast of Pennsylvania, clean quartz sand and gravel were stripped from new mountains and carried southwestward from a broad trough to the north flank of the developing Arkoma Basin. Intermixing and intertonguing took place along the border between the narrow belt of subgraywacke and the broad belt of the quartzarenite. By about Atokan time, crystalline rocks were being eroded in both source areas, and the Caseyville-type quartzarenites graded upward to subgraywackes.

LOCAL RELATIONSHIPS

My studies and those of my associates show that in southeastern Illinois the Caseyville Formation contains two widespread units of sandstone commonly containing quartz pebbles, underlain by fine-grained clastic intervals. The pebbly sandstones are the Battery Rock Sandstone Member, in the lower part of the Caseyville, and the Pounds Sandstone Member, at or near the top (Fig. 1). The Wayside Member,

below the Battery Rock, and the Drury Member, between the Battery Rock and Pounds Sandstones, are dominantly composed of fine-grained, thin-bedded sandstone, siltstone, and shale. The Pounds and Battery Rock generally are mappable, resistant, ledge- and cliff-forming units. They have been mapped through Hardin and Gallatin Counties, southeastern Illinois (Baxter and others, 1963, 1967; Baxter and Desborough, 1965; Nelson and Lumm, 1986a-c), and adjacent counties in Kentucky (Amos, 1965, 1966) westward into Pope and Johnson Counties, Illinois (Nelson and others, in preparation; Weibel and others, in preparation; Jacobson, in preparation; Weibel and Nelson, in preparation). Farther west these sandstones become finer grained and lose their massive character. The Pounds and Battery Rock Sandstones have not been traced very far eastward into Kentucky.

The Battery Rock and Pounds Sandstones display features consistent with deposition in deltaic distributary channels. These features include: erosional lower contacts, basal lags of quartz and chert pebbles and fossil logs, large-scale planar crossbedding with strongly unidirectional dips (most often southwest), slumped bedding, and fining-upward sequences. Multiple scour surfaces are common. Both sandstones are overlain by rooted zones and coal in many places. Where the sandstones become thinner, finer grained, and shaly, crossbed orientations are more variable. Herringbone crossbedding and coupled bedding—evidence of tidal reworking—locally are present (Joseph Devera and Erik Kvale, personal commun., 1989).

The widespread, almost sheetlike character of Battery Rock and Pounds sand bodies implies frequent lateral shifting of channels. Thus, the Caseyville probably was not deposited by a Mississippi-style "birdfoot" delta, but rather a system of anastomosing channels (Morrow, 1979; Bohm, 1981). The Rio Caroni in Venezuela has been suggested as a modern analog (Garner, 1974; Howard, 1979).

The fine-grained Wayside and Drury Members include both marine and nonmarine sediments. Marine fossils of the Wayside were described by Weller (1940), Rexroad and Merrill (1985), and Jennings and Fraunfelter (1986). The Hindostan Whetstone beds of southern Indiana, a probable Wayside equivalent, are interpreted as tidal deposits on the basis of sedimentology (Kvale and others, 1989). Marine fossils of the Drury Member were described by Wanless (1939) and Devera and others (1987). Probable nonmarine deposits in both members in-

clude coals, rooted zones, and shales containing well-preserved foliage of land plants. Most Wayside and Drury strata, however, consist of laminated or ripple-marked mudstone, siltstone, and sandstone not readily assignable to specific depositional settings. Environments may range from delta front and interdistributary bay to lake, floodplain, and marsh (Ethridge and others, 1973; Koeninger and Mansfield, 1979).

In any event, the Wayside and Drury reflect greatly reduced clastic input relative to the Battery Rock and Pounds Sandstones. Thus, the Wayside/Battery Rock and Drury/Pounds may represent two cycles of transgression and progradation (Koeninger and Mansfield, 1979; Morrow, 1979; Bohm, 1981). A third cycle, the basal Wayside Member, was inferred from a roadcut in which the Wayside is unusually thick and well exposed (Koeninger and Mansfield, 1979). These cycles may have regional significance.

In the Arkoma Basin, Sutherland and Henry (1977) and Sutherland (1988) identified two shallowing-upward carbonate-shelf cycles in the Morrowan Series. I propose that the two Arkoma Basin cycles may correlate with the upper two Caseyville cycles. The Baldwin Coal, at the top of the middle cycle in Arkansas, correlates with the Gentry Coal, at the top of the lower Caseyville cycle, on the basis of palynology (Peppers, 1988). The basal part of the upper cycle in Oklahoma is in the goniatite zone of *Axinolobus modulus* (Sutherland and Henry, 1977). The goniatites *Axinolobus* sp. and *Gastrioceras* sp. are abundant in the Drury Member (lower part of upper Caseyville cycle) at a site in Pope County, Illinois (Devera and others, 1987). The genus *Axinolobus* is confined to the latest Morrowan Series and possibly earliest Atokan Series, and to the upper of the two shoaling-upward cycles in the Arkoma Basin (Walter L. Manger, written commun., 1986).

The Wayside Member has not yielded the kinds of fossils needed for precise biostratigraphic correlation to strata in the Arkoma Basin. Documented Wayside marine fauna came from near the base of the member, where it is relatively thin and situated on an interfluvial between sub-Pennsylvanian paleovalleys (Rexroad and Merrill, 1985; Jennings and Fraunfelter, 1986). The Wayside must be older near the bottoms of paleovalleys than on interfluvies.

Correlations from the Illinois Basin to the Appalachian Basin are tenuous. According to Rice (1984), a persistent marine zone in the Appalachian Basin occurs immediately above the Sharon Coal in Ohio and below the Rockcastle Sandstone Member of the Lee Formation in eastern Kentucky. This interval cor-

relates palynologically with the middle part of the Caseyville (Peppers, 1988). Chesnut (1981) reported 16 occurrences of marine fossils in the Lee and Breathitt Formations, but biostratigraphically useful fossils have not been recovered from them. The widespread Kendrick Shale Member of the Breathitt Formation has been correlated with the upper Morrowan Bloyd Shale of Arkansas on the basis of goniatites (Furnish and Knapp, 1966) and crinoids (Strimple and Knapp, 1966). However, this conflicts with palynological findings of Peppers (1988), who assigned the Kendrick to the Atokan Series.

In summary, the evidence suggests that upper Wayside/Battery Rock and Drury/Pounds represent regional episodes of transgression/progradation. Regional extent of a lower Wayside cycle is unverified.

One possible cause for regional transgression/regression is eustatic changes in sea level, perhaps glacially controlled (Wanless and Shepard, 1936; Heckel, 1977; Ross and Ross, 1985; Saunders and Ramsbottom, 1986). Another possible cause, or modifying agent, is episodes of tectonic uplift in the source area (Weller, 1956; Quinlan and Beaumont, 1984; Greb, in press). Pulses of uplift would not only increase the gradient and carrying capacity of streams, but also might increase rainfall in and near the new mountains. Wood and others (1986) inferred three pulses of uplift during Early Pennsylvanian time in eastern Pennsylvania. Early Pennsylvanian pulses of uplift are also indicated in Nova Scotia, a potential source area for Caseyville sediments (Bell, 1938; Rust and others, 1987). A third possibility is that both processes acted in conjunction (Klein and Willard, 1989). Yet another possibility is that sedimentary cycles reflect alternating periods of wet and dry climate, which would have controlled vegetation, runoff and erosion (Blaine Cecil, personal commun., 1989). Resolving the issue will require, among other things, more detailed lithofacies mapping and improved correlation between basins.

CONCLUSIONS

The Caseyville is distinguished from adjacent formations by the clean quartzarenitic character of its sandstones, which commonly contain quartz pebbles. The Caseyville occurs in the southeastern part of the Illinois Basin. It is a lithologic and temporal equivalent of numerous formations from New York to Arkansas and Michigan to Alabama.

The source area of the Caseyville is inferred to have been orogenic highlands, uplifted during an

Early Pennsylvanian phase of the Alleghenian Orogeny, in the northeastern United States and southeastern Canada. Source rocks were older Paleozoic and Proterozoic sedimentary and low-rank metamorphic rocks of miogeosynclinal facies. Dominant sediment transport was southwestward to the Arkoma Basin. In the central and southern Appalachian Basin, Caseyville-type rocks intertongue with subgraywackes derived from crystalline rocks in southern and southeastern sources.

The Caseyville in southern Illinois displays three progradational cycles, the upper two of which may be correlated with cycles in the Arkoma Basin. Eastward, correlations are more tenuous due to lack of paleontologic data.

Depositional setting of the Caseyville was largely deltaic. Most previous workers overestimated the fluvial component and underestimated the marine component.

Further sedimentologic study is needed, particularly along the eastern margin of the basin, and in the subsurface throughout the basin.

REFERENCES CITED

- Amos, D. H., 1965, Geologic map of the Shettlerville and Rosiclare Quadrangles, Livingston and Crittenden Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-400.
- Amos, D. H., 1966, Geologic map of the Golconda and Brownfield Quadrangles, Livingston County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-546.
- Arkle, T., and others, 1979, West Virginia and Maryland, *in* The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States: U.S. Geological Survey Professional Paper 1110-D, p. D1-D35.
- Baxter, J. W. and Desborough, G. A., 1965, Areal geology of the Illinois Fluorspar District. Part 2—Karbers Ridge and Rosiclare Quadrangles: Illinois State Geological Survey Circular 385, 40 p.
- Baxter, J. W., Desborough, G. A., and Shaw, C. W., 1967, Areal geology of the Illinois Fluorspar District. Part 3—Herod and Shettlerville Quadrangles: Illinois State Geological Survey Circular 413, 41 p.
- Baxter, J. W., Potter, P. E., and Doyle, F. L., 1963, Areal geology of the Illinois Fluorspar District: Part 1, Saline Mines, Cave-in-Rock, Dekoven, and Repton Quadrangles: Illinois State Geological Survey Circular 342, 43 p.

- Bell, W. A., 1938, Fossil flora of Sydney coal fields, Nova Scotia: Geological Survey of Canada Memoir 215, 334 p.
- Bement, W. D., 1976, Sedimentological aspects of middle Carboniferous sandstones on the Cumberland Overthrust Sheet: Cincinnati, Ohio, University of Cincinnati, Ph.D. Dissertation, 182 p.
- Bohm, S. M., 1981, Regional facies of the Caseyville Formation (Lower Pennsylvanian) in Johnson and Pope Counties, Illinois: Carbondale, Illinois, Southern Illinois University, M.S. Thesis, 110 p.
- Bristol, H. M., and Howard, R. H., 1971, Paleogeologic map of the sub-Pennsylvanian Chesterian (Upper Mississippian) surface in the Illinois Basin: Illinois State Geological Survey Circular 458, 16 p.
- Chesnut, D. R., Jr., 1981, Marine zones in the upper Carboniferous of eastern Kentucky, *in* Cobb, J. C., Chesnut, D. R., Hester, N. C., and Hower, J. C., eds., Coal and coal-bearing rocks of eastern Kentucky (Guidebook and roadlog for Coal Division of Geological Society of America Field Trip No. 14): Kentucky Geological Survey, ser. 11, p. 57-66.
- Chesnut, D. R., Jr., 1988, Stratigraphic analysis of the Carboniferous rocks of the Central Appalachian Basin: Lexington, University of Kentucky, Ph.D. Dissertation, 296 p.
- Collins, H. R., 1979, The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States—Ohio: U.S. Geological Survey Professional Paper 1110-E, p. E1-24.
- Davis, M. W., and Ehrlich, R., 1974, Late Paleozoic crustal composition and dynamics in the southeastern United States: Geological Society of America Special Paper 148, p. 171-185.
- Devera, J. A., Mason, C. E., and Peppers, R. A., 1987, A marine shale in the Caseyville Formation (Lower Pennsylvanian) in southern Illinois [abs.]: Geological Society of America Abstracts with Programs, p. 220.
- Edmunds, W. E., and others, 1979, Pennsylvania and New York, *in* The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States: U.S. Geological Survey Professional Paper 1110-B, p. B1-33.
- Englund, K. J., 1979, Virginia, *in* The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States: U.S. Geological Survey Professional Paper 1110-C, p. C1-21.
- Englund, K. J., Windolph, J.F., Jr., and Thomas, R. E., 1986, Origin of thick, low-sulfur coal in the Lower Pennsylvanian Pocahontas Formation, Virginia and West Virginia: Geological Society of America, Special Paper 210, p. 49-62.
- Ethridge, F. G., Fraunfelter, G., and Utgaard, J., eds., 1973, Depositional environments of selected Lower Pennsylvanian and Upper Mississippian sequences of southern Illinois: Guidebook, 37th Tri-State Field Conference, Carbondale, Illinois, Southern Illinois University, 158 p.
- Fraunfelter, G. H., 1979, Lower Pennsylvanian limestones in southern Illinois, *in* Palmer, J. E., and Dutcher, R. R., eds., Depositional and structural history of the Pennsylvanian System of the Illinois Basin, Part 2, Invited papers (Field Trip No. 9, Ninth International Congress of Carboniferous Stratigraphy and Geology): Illinois State Geological Survey Guidebook 15a, p. 73-75.
- Fuller, J. O., 1955, Source of Sharon Conglomerate of northeastern Ohio: Geological Society of America Bulletin, v. 66, no. 2, p. 159-176.
- Furnish, W. M. and Knapp, W. D., 1966, Lower Pennsylvanian fauna from eastern Kentucky: Part 1. Ammonoids: Journal of Paleontology, v. 40, no. 2, p. 296-308.
- Garner, H. F., 1974, The origin of landscapes: London, Oxford University Press, p. 646-667.
- Glenn, L. C., 1912, A geological reconnaissance of the Tradewater River region, with special reference to the coal beds: Kentucky Geological Survey, ser. 3, Bulletin 17, 75 p.
- Glick, E. E., 1975, Arkansas and northern Louisiana: U.S. Geological Survey Professional Paper 853-I, p. 157-175.
- Greb, S. F., in press, A sub-rectangular paleovalley system, Caseyville Formation, Eastern Interior Basin, western Kentucky: Southeastern Geology.
- Heckel, P. H., 1977, Origin of phosphatic black shale facies in Pennsylvanian cyclothems of Mid-continent North America: American Association of Petroleum Geologists Bulletin, v. 61, p. 1045-1068.
- Henbest, L. G., 1953, Morrow Group and lower Atoka Formation of Arkansas: American Association of Petroleum Geologists Bulletin, v. 37, no. 8, p. 1935-1953.
- Hester, N. C., 1981, Origin of the Corbin Sandstone Member of the Pennsylvanian Lee Formation, *in* Cobb, J. C., Chesnut, D. R., Hester, N. C., and Hower, J. C., eds., Coal and coal-bearing rocks

- of eastern Kentucky (Guidebook and roadlog for Coal Division of Geological Society of America Field Trip No. 14): Kentucky Geological Survey, ser. 11, p. 127–130.
- Hobday, D., 1974, Beach- and barrier-island facies in the Upper Carboniferous of northern Alabama: Geological Society of America Special Paper 148, p. 209–223.
- Horne, J. C., Ferm, J. C., and Swinchatt, J. P., 1974, Depositional model for the Mississippian-Pennsylvanian boundary in northeastern Kentucky: Geological Society of America Special Paper 148, p. 97–114.
- Horne, J. C., Swinchatt, J. P., and Ferm, J. C., 1971, Lee-Newman barrier shoreline model, *in* Ferm, J. C., and others, Carboniferous depositional environments in northeastern Kentucky (Roadlog for Geological Society of Kentucky 1971 Field Excursion): Kentucky Geological Survey, ser. 10, p. 5–9.
- Howard, R. H., 1979, The Mississippian-Pennsylvanian unconformity in the Illinois Basin—Old and new thinking, *in* Palmer, J. E., and Dutcher, R. R., eds., Depositional and structural history of the Pennsylvanian System of the Illinois Basin, Part 2, Invited papers (Field Trip No. 9, Ninth International Congress of Carboniferous Stratigraphy and Geology): Illinois State Geological Survey Guidebook 15a, p. 34–42.
- Howard, R. H., and Whitaker, S. T., 1988, Hydrocarbon accumulation in a paleovalley at Mississippian-Pennsylvanian unconformity near Hardinville, Crawford County, Illinois: A model paleogeomorphic trap: Illinois State Geological Survey Illinois Petroleum 129, 26 p.
- Jacobson, R., in preparation, Geologic map of the Goreville Quadrangle, Johnson County, Illinois: Illinois State Geological Survey Geologic Quadrangle Map.
- Jennings, J. R., and Fraunfelter, G. H., 1986, Preliminary report on macropaleontology of strata above and below the upper boundary of the type Mississippian: Illinois Academy of Science Transactions, v. 79, p. 253–262.
- Klein, G. de V., and Willard, D., 1989, Origin of the Pennsylvanian coal-bearing cyclothems of North America: Geology, v. 17, no. 2, p. 152–155.
- Koeninger, C. A., and Mansfield, C. F., 1979, Earliest Pennsylvanian depositional environments in central southern Illinois, *in* Palmer, J. E., and Dutcher, R. R., eds., Depositional and structural history of the Pennsylvanian System of the Illinois Basin, Part 2, Invited papers (Field Trip No. 9, Ninth International Congress of Carboniferous Stratigraphy and Geology): Illinois State Geological Survey Guidebook 15a, p. 76–80.
- Kvale, E. P., Archer, A. W., and Johnson, H. R., 1989, Daily, monthly, and yearly tidal cycles within laminated siltstones of the Mansfield Formation (Pennsylvanian) of Indiana: Geology, v. 17, p. 365–368.
- Lee, W., 1916, Geology of the Shawneetown Quadrangle in Kentucky: Kentucky Geological Survey, ser. 4, v. 4, pt. 2, 73 p.
- Ludvigson, G., and Swett, K., 1987, Pennsylvanian strata at Wyoming Hill and Wildcat Den State Park, Muscatine County, Iowa: 51st Annual Tri-State Geological Field Conference Guidebook, University of Iowa, Iowa City, p. C1–C20.
- Mack, G. H., Thomas, W. A., and Horsey, C. A., 1983, Composition of Carboniferous sandstones and tectonic framework of southern Appalachian-Ouachita orogen: Journal of Sedimentary Petrology, v. 53, no. 3, p. 931–946.
- Milici, R. C., 1974, Stratigraphy and depositional environments of Upper Mississippian and Lower Pennsylvanian rocks in the southern Cumberland Plateau of Tennessee: Geological Society of America Special Paper 148, p. 115–133.
- Milici, R. C., Briggs, G., Knox, L. M., Sitterly, P. D., and Statler, A. T., 1979, The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States—Tennessee: U.S. Geological Survey Professional Paper 1110–G, p. G1–G38.
- Morrow, L. R., 1979, Regional facies of the Caseyville Formation (Lower Pennsylvanian) in southeastern Illinois: Carbondale, Southern Illinois University, M.S. Thesis.
- Nelson, W. J., and Lumm, D., 1986a, Geologic map of the Shawneetown Quadrangle, Gallatin County, Illinois: Illinois State Geological Survey Geologic Quadrangle Map GQ–1, Scale 1:24,000.
- Nelson, W. J., and Lumm, D., 1986b, Geologic map of the Equality Quadrangle, Gallatin and Saline Counties, Illinois: Illinois State Geological Survey Geologic Quadrangle Map GQ–2, Scale 1:24,000.
- Nelson, W. J., and Lumm, D., 1986c, Geologic map of the Rudement Quadrangle, Saline County, Illinois: Illinois State Geological Survey Geologic Quadrangle Map GQ–3, Scale 1:24,000.
- Nelson, W. J., Lumm, D. K., Jacobson, R. T., Trask, C. B., and Devera, J. A., in preparation,

- Geology and mineral resources of the Eddyville, Stonefort, and Creal Springs Quadrangles, southern Illinois: Illinois State Geological Survey Circular.
- Owen, D. D., 1856, Report on the geological survey in Kentucky made during the years 1854 and 1855: Kentucky Geological Survey, ser. 1, v. 1, 416 p.
- Owen, M. R., and Carozzi, A. V., 1986, Southern provenance of upper Jackfork Sandstone, southern Ouachita Mountains: Cathodoluminescence petrology: Geological Society of America Bulletin, v. 97, p. 110-115.
- Peppers, R. A., 1988, Palynological correlation of major Pennsylvanian (upper Carboniferous) time-stratigraphic boundaries in the Illinois Basin with those in other coal regions of Euramerica [abs.]: Geological Society of America Abstracts with Programs, p. 384.
- Potter, P. E., 1963, Late Paleozoic sandstones of the Illinois Basin: Illinois State Geological Survey Report of Investigations 217, 92 p.
- Potter, P. E., and Glass, H. D., 1958, Petrology and sedimentation of the Pennsylvanian sediments in southern Illinois: A vertical profile: Illinois State Geological Survey Report of Investigations 204, 60 p.
- Potter, P. E., and Pryor, W. A., 1961, Dispersal centers of Paleozoic and later clastics of the Upper Mississippi Valley and adjacent areas: Geological Society of America Bulletin, v. 72, no. 8, p. 1195-1249.
- Potter, P. E., and Siever, R., 1956, Sources of basal Pennsylvanian sediment in the Eastern Interior Basin: Journal of Geology, pt. I, Cross-bedding, v. 64, no. 3, p. 225-244; pt. II, Sedimentary petrology, v. 64, no. 4, p. 317-335.
- Pryor, W. A., and Potter, P. E., 1979, Sedimentology of a paleovalley fill: Pennsylvanian Kyrrock Sandstone in Edmonson and Hart Counties, Kentucky, in Palmer, J. E., and Dutcher, R. R., eds., Depositional and structural history of the Pennsylvanian System of the Illinois Basin, Part 2, Invited papers (Field Trip No. 9, Ninth International Congress of Carboniferous Stratigraphy and Geology): Illinois State Geological Survey Guidebook 15a, p. 49-61.
- Quinlan, G. M., and Beaumont, C., 1984, Appalachian thrusting, lithospheric flexure, and the Paleozoic stratigraphy of the Eastern Interior of North America: Canadian Journal of Earth Science, v. 21, p. 973-996.
- Ravn, R. L., 1986, Palynostratigraphy of the Lower and Middle Pennsylvanian coals of Iowa: Iowa Geological Survey Technical Paper 7, 245 p.
- Ravn, R. L., Swade, J. W., Howes, M. R., Gregory, J. L., Anderson, R. R., and Van Dorpe, P. E., 1984, Stratigraphy of the Cherokee Group and revision of Pennsylvanian stratigraphic nomenclature in Iowa: Iowa Geological Survey Technical Information Series 12, 76 p.
- Rexroad, C. B. and Merrill, G. K., 1985, Conodont biostratigraphy and paleoecology of middle Carboniferous rocks in southern Illinois: Courier Forschungs Institut Senckenberg, v. 74, p. 35-64.
- Rice, C. L., 1984, Sandstone units of the Lee Formation and related strata in eastern Kentucky: U.S. Geological Survey Professional Paper 1151-G, 53 p.
- Rice, C. L., Sable, E. G., Dever, G. R., Jr., and Kehn, T. M., 1979, The Mississippian and Pennsylvanian (Carboniferous) systems in the United States—Kentucky: U.S. Geological Survey Professional Paper 1110-F, p. F1-F32.
- Ross, C. A., and Ross, J. R. P., 1985, Late Paleozoic depositional sequences are synchronous and worldwide: Geology, v. 13, p. 194-197.
- Rust, B. R., Gibling, M. R., Best, M. A., Dilles, S. J., and Masson, A. G., 1987, A sedimentological overview of the coal-forming Morien Group (Pennsylvanian), Sydney Basin, Nova Scotia, Canada: Canadian Journal of Earth Science, v. 24, p. 1869-1885.
- Saunders, W. B., and Ramsbottom, W. H. C., 1986, The mid-Carboniferous eustatic event: Geology, v. 14, p. 208-212.
- Shaver, R. H., and others, 1986, Compendium of Paleozoic rock-unit stratigraphy in Indiana, a revision: Indiana Geological Survey Bulletin 59, 203 p.
- Skehan, J. W., Rast, N., and Moshier, S., 1986, Paleoenvironmental and tectonic controls of sedimentation in coal-forming basins of southeastern New England: Geological Society of America Special Paper 210, p. 9-30.
- Sloss, L. L., 1979, Plate-tectonic implications of the Pennsylvanian system in the Illinois Basin, in Palmer, J. E., and Dutcher, R. R., eds., Depositional and structural history of the Pennsylvanian System of the Illinois Basin, Part 2, Invited papers (Field Trip No. 9, Ninth International Congress of

- Carboniferous Stratigraphy and Geology): Illinois State Geological Survey Guidebook 15a, p. 107–111.
- Sloss, L. L., Krumbain, W. C., and Dapples, E. C., 1949, Integrated facies analysis, *in* Sedimentary facies in geologic history: Geological Society of America Memoir 39, p. 91–123.
- Sonnefield, R. D., 1981, Geology of northwestern Jackson County, with special emphasis on the Caseyville Formation: Carbondale, Southern Illinois University, M.S. Thesis, 84 p.
- Strimple, H. L., and Knapp, W. D., 1966, Lower Pennsylvanian fauna from eastern Kentucky: Pt. 2, crinoids: *Journal of Paleontology*, v. 40, no. 2, p. 309–314.
- Sutherland, P. K., 1988, Late Mississippian and Pennsylvanian depositional history in the Arkoma Basin area, Oklahoma and Arkansas: *Geological Society of America Bulletin*, v. 100, p. 1787–1802.
- Sutherland, P. K., and Henry, T. W., 1977, Carbonate platform facies and new stratigraphic nomenclature of the Morrowan Series (Lower and Middle Pennsylvanian), northeastern Oklahoma: *Geological Society of America Bulletin*, v. 88, p. 425–440.
- Sutherland, P. K., and Manger, W. L., 1979, Mississippian–Pennsylvanian shelf-to-basin transition, Ozark and Ouachita regions, Oklahoma and Arkansas, *in* Ninth International Congress of Carboniferous Stratigraphy and Geology, Field Trip 11: Oklahoma Geological Survey Guidebook 19, 81 p.
- Swann, D. H., 1963, Classification of Genevievian and Chesterian (Late Mississippian) rocks of Illinois: Illinois State Geological Survey Report of Investigations 216, 91 p.
- Thomas, W. A., 1974, Converging clastic wedges in the Mississippian of Alabama: *Geological Society of America Special Paper* 148, p. 187–207.
- Wanless, H. R., 1939, Pennsylvanian correlations in the Eastern Interior and Appalachian Coal Fields: *Geological Society of America Special Paper* 17, 130 p.
- Wanless, H. R., 1975, Illinois Basin region, *in* McKee, E. D., and Crosby, E. J., eds., Paleotectonic investigations of the Pennsylvanian System in the eastern United States: U.S. Geological Survey Professional Paper 853–E, p. 71–95.
- Wanless, H. R., and Shepard, F. P., 1936, Sea level and climatic changes related to late Paleozoic cycles: *Geological Society of America Bulletin*, v. 47, p. 1177–1206; comments, Chamberlain, p. 2008–2010; Shepard and Wanless, p. 2010–2011; Weller, p. 2011–2013; Shepard, p. 2013–2014.
- Wanless, H. R., and Shideler, G. L., 1975, Michigan Basin region: U.S. Geological Survey Professional Paper 853–0, p. 63–70.
- Weibel, C. P., and Nelson, W. J., in preparation, Geologic map of the Lick Creek Quadrangle, Johnson, Union, and Williamson Counties, southern Illinois: Illinois State Geological Survey Geologic Quadrangle Map.
- Weibel, C. P., Nelson, W. J., and Devera, J. A., in preparation, Geologic map of the Waltersburg Quadrangle, Pope County, Illinois: Illinois State Geological Survey Geologic Quadrangle Map.
- Weller, J. M., 1940, Geology and oil possibilities of extreme southern Illinois, Union, Johnson, Pope, Hardin, Alexander, Pulaski, and Massac Counties: Illinois State Geological Survey Report of Investigations 71, 71 p.
- Weller, J. M., 1956, Argument for diastrophic control of late Paleozoic cyclothems: *American Association of Petroleum Geologists Bulletin*, v. 40, no. 1, p. 17–50.
- Wood, G. H., Kehn, T. M., and Eggleston, J. R., 1986, Depositional and structural history of the Pennsylvania anthracite region: *Geological Society of America Special Paper* 210, p. 31–48.

CORE WORKSHOP: SEDIMENTOLOGICAL ANALYSIS AND DEPOSITIONAL ENVIRONMENTS OF THE LOWER PENNSYLVANIAN CASEYVILLE FORMATION, SOUTHERN ILLINOIS

**C. Pius Weibel
Illinois State Geological Survey
Urbana, Illinois**

INTRODUCTION

The Caseyville Formation in the Illinois Basin is a dominantly clastic sequence, characteristic of basal Pennsylvanian strata throughout the eastern interior of North America (McKee and Crosby, 1975). The formation crops out in southeastern Indiana, western Kentucky, southern Illinois, and a small outlier in western Illinois-eastern Iowa. In the subsurface, Wanless (1962) restricted the formation to roughly the southeastern half of the basin, but considered the lateral boundaries to be "uncertain." On-going surface mapping of the Caseyville and associated strata in southern Illinois indicates that most exposures consist of the thick-bedded sandstone portion of the unit. Finer grained intervals (typically siltstone, shale, coal) are poorly exposed and rarely completely exposed, even in man-made exposures. Studies based on individual outcrops are biased by the nature of this outcrop habit and are valid only for the exposed portions. A complete bottom-to-top outcrop of the Caseyville Formation is not known. Interpretation of the depositional environments of a complete vertical sequence, therefore, has not been possible on the basis of surface data only. This problem has hampered local and regional study of Caseyville depositional environments. Examination of cores recently obtained via the COGEOMAP geologic mapping project, jointly supported by the Illinois State Geological Survey and the U.S. Geological Survey, offers an opportunity to overcome the restrictions imposed by outcrop study.

CORE WORKSHOP GOAL

The goal of this workshop is to interpret the depositional environments revealed in three cores of the Caseyville Formation and to acquire a better understanding of the lithologic variability within and between lithofacies of the formation. Other aspects, such as diagenesis, resolution of source area, and

sedimentary structure formation, cannot be covered in the short time allotted for this workshop.

WORKSHOP FORMAT

The workshop will consist of a brief introduction and review of the sedimentological logs, followed by a period for core examination. The core examination should focus on defining individual lithofacies, interpreting the corresponding depositional environments, and comparing the succession of environments of the cores. It is suggested that you quickly learn to "read" the sedimentological logs and use them as the descriptive log; there will not be enough time to redescribe the cores. Note that the scale of the graphic logs does not permit recording of all lithologic characteristics. Cutting of the core into slabs, which occurred after construction of the graphic logs, may have revealed additional features. The workshop will end with a discussion of the depositional environments of the cores as interpreted by all participants.

GEOLOGIC SETTING AND WELL LOCATIONS

The cores were retrieved from three wells in Pope and Johnson Counties, Illinois (Table 1), near the western edge of the Illinois-Kentucky Fluorspar District. This area, at the southern margin of the Illinois Basin, is deformed by dominantly northeast-trending structures (Fig. 1). Two of the wells (GD-1, E-4) were drilled distant from major faults. Well W-1 was drilled proximal to a major fault zone, but the sequence does not appear to be offset. The wells were drilled for stratigraphic tests and were cored continuously from the top of the bedrock to the well bottom.

STRATIGRAPHIC RELATIONSHIPS

Diagnostic fossils suitable for biostratigraphic correlation of the three wells have not been recovered.

Table 1.—Wells Utilized in Core Workshop.

Company	Farm	No.	Depth	Location
ISGS-COGEOMAP	W. Bradley	GD-1	246 ft.	2500 ft. FNL, 1400 ft. FWL, Section 12, T. 12 S., R. 4 E., Johnson County.
ISGS-COGEOMAP	K. Keller	W-1	166 ft.	2070 ft. FSL, 1590 ft. FEL, Section 14, T. 12 S., R. 6 E., Pope County.
ISGS-COGEOMAP	O. Barnes	E-4	181 ft.	2600 ft. FNL, 2500 ft. FEL, Section 32, T. 11 S., R. 6 E., Pope County.

Thus, stratigraphic correlation of the cores (Fig. 2) is based on lithology, similarity of lithological sequences, and field observation of exposures near well sites.

Outcrops of the Caseyville Formation (Owen, 1856; Lee, 1916; Kosanke and others, 1960) in the southernmost portion of the Illinois Basin characteristically consist of two prominent cliff- to ledge-forming sandstone members (the lower Battery Rock Sandstone Member [Cox, 1875] and the upper Pounds Sandstone Member [Weller, 1940]) and two

members that are generally poorly exposed (the Wayside sandstone and shale and Drury shale and sandstone members [Lamar, 1925]). The latter members are used informally herein because both are in need of redefinition. These units generally comprise the finer grained portion of the formation, although either may contain ledge-forming sandstone beds locally. The outcrop pattern of the Caseyville Formation on geologic maps suggests that the Pounds and Battery Rock Sandstone Members are laterally more persistent than either the

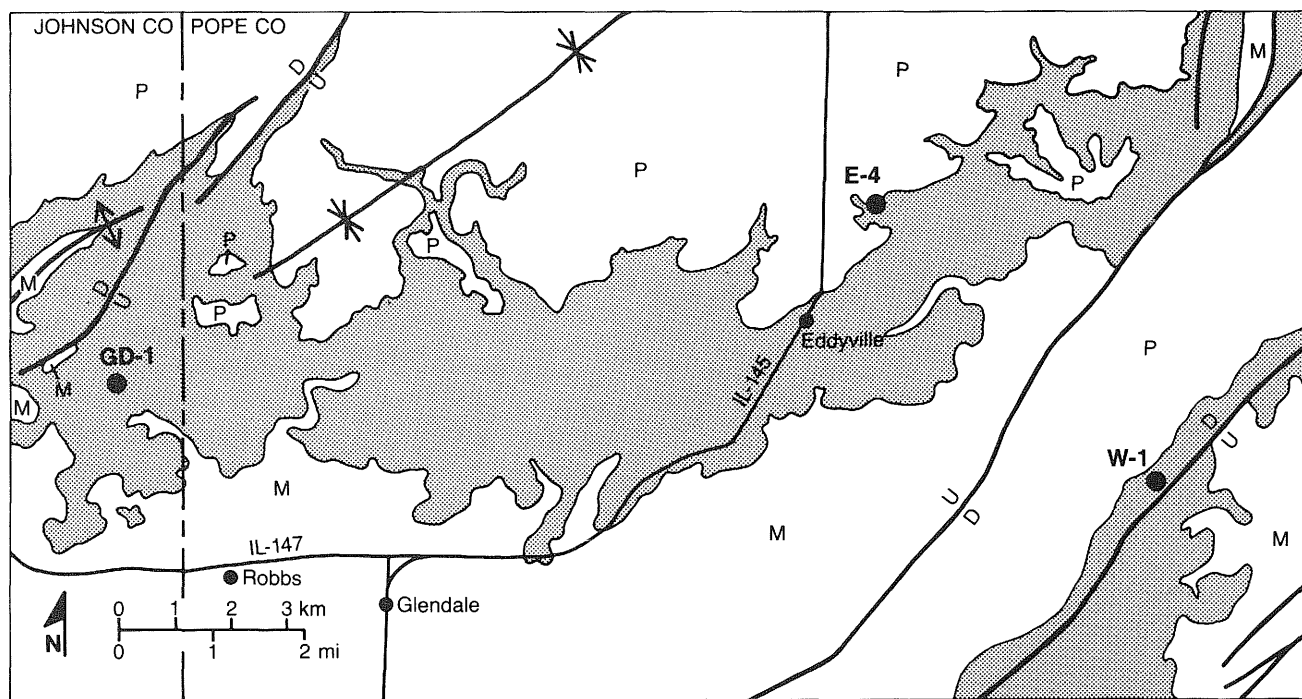


Figure 1. Generalized geologic map of parts of Pope and Johnson County, Illinois, showing location of the wells, major folds and high-angle faults, and outcrops of Mississippian strata (M), Caseyville Formation (shaded), and younger Pennsylvanian strata (P). Map modified after unpublished compilation by W. J. Nelson, based on mapping by Nelson, Weibel, and J. A. Devera.

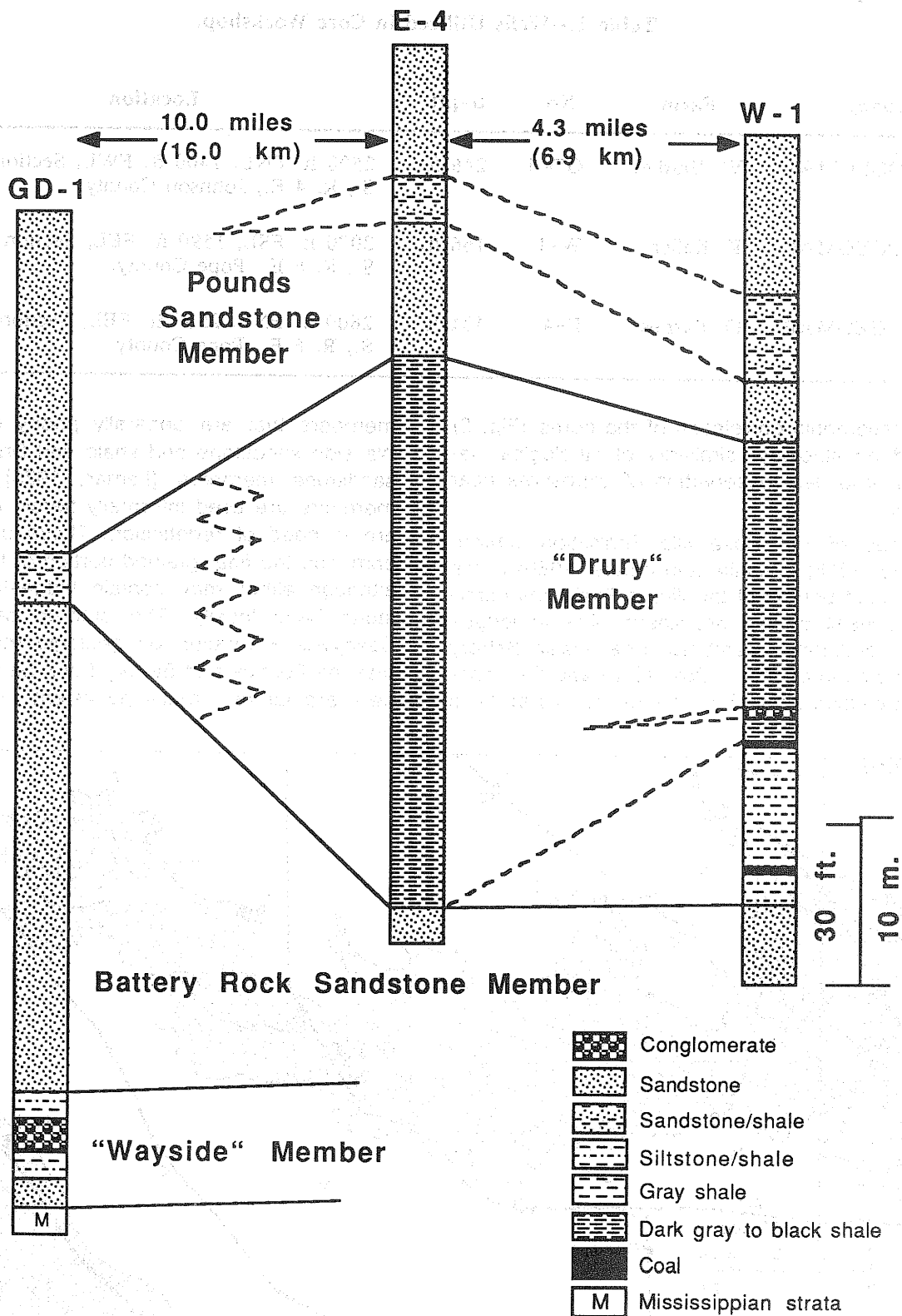


Figure 2. Lithologic correlation of the three cores. Solid lines indicate correlation of member boundaries.

Wayside or the Drury. However, the Pounds and Battery Rock probably consist of a series of sandstone bodies that are either laterally or nearly laterally equivalent. The sandstone bodies may laterally split (see Pounds Sandstone in Fig. 2), coalesce, or pinch out and be replaced by an adjacent sandstone. Thicknesses of the Battery Rock and Pounds are variable, and locally increase to the extent that either the Wayside or the Drury is absent.

None of the three wells drilled through the entire Caseyville Formation, but only the very top of the Pounds Sandstone Member is absent from well GD-1. The top of the Pounds is missing in wells E-4 and W-1, as well as the lower portion of the Battery Rock Sandstone Member and the underlying Wayside member.

SEDIMENTOLOGICAL LOGS

The graphic sedimentological logs of each core (Figs. 3-6) are modified after graphic logs in Bouma (1962). Average grain sizes were determined by comparison with a grain-size chart, using parameters defined by Folk (1974).

The average grain size is recorded in the column adjacent to the depth column. The widths of the polygons correspond to the average grain size. In addition, the polygons may contain symbols referring to presence of the minor constituents of shale clasts, scattered shale laminae, and quartz pebbles and granules. The nature of the contact is recorded in the next column. Note that absence of a symbol indicates a gradational contact. The "Bedding" column records either laminated bedding, horizontal bedding (having regular horizontal bedding planes, but excluding laminated bedding), massive bedding (lacking or having few scattered bedding features), and oblique bedding. Oblique bedding includes inclined bedding or indiscernible crossbedding.

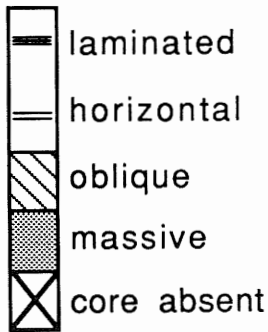
The "As Str" column consists of structures associated with bedding. The "Fos/Bio" column records occurrences of fossils and bioturbation. The "Organic" column refers to perceived relative organic content, based primarily on color and secondarily on lithology. The shales range from gray, having a low organic content, to black, having a high organic content. Coals have the perceived highest organic con-

tent, while sandstones lack perceived organic material. Additional features are recorded in the "Remarks" column. The column to the far right is reserved for environmental interpretations by workshop participants.

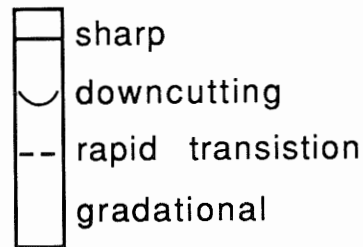
REFERENCES CITED

- Bouma, A. H., 1962, *Sedimentology of some flysch deposits: A graphic approach to facies interpretation*: Amsterdam, Elsevier, 168 p.
- Cox, E. T., 1875, *Geology of Gallatin County*, in Worthen, A. H., *Geology and paleontology: Geological Survey of Illinois*, v. 6, p. 197-219.
- Folk, R. L., 1974, *Petrology of sedimentary rocks*: Austin, Texas, Hemphill Publishing Company, 182 p.
- Kosanke, R. M., Simon, J. A., Wanless, H. R., and Willman, H. B., 1960, *Classification of the Pennsylvanian strata of Illinois: Illinois State Geological Survey Report of Investigations 214*, 84 p.
- Lamar, J. E., 1925, *Geology and mineral resources of the Carbondale Quadrangle: Illinois State Geological Survey Bulletin*, v. 48, 172 p.
- Lee, W., 1916, *Geology of the Kentucky part of the Shawneetown Quadrangle in Kentucky: Kentucky Geological Survey, ser. 4, Bulletin 4, pt. 2*, 73 p.
- McKee, E. D., and Crosby, E. J., 1975, *Paleotectonic investigations of the Pennsylvanian System in the United States: Part 1. Introduction and regional analyses of the Pennsylvanian System: U.S. Geological Survey Professional Paper 853*, 349 p.
- Owen, D. D., 1856, *Report of the geological survey in Kentucky made during the years 1854 and 1855: Kentucky Geological Survey, ser. 1, v. 1*, 416 p.
- Wanless, H. R., 1962, *Pennsylvanian rocks of Eastern Interior Basin*, in Branson, C. C., ed., *Pennsylvanian System in the United States—A symposium: American Association of Petroleum Geologists*, p. 4-59.
- Weller, J. M., 1940, *Geology and oil possibilities of extreme southern Illinois: Illinois State Geological Survey, Report of Investigations 71*, 71 p.

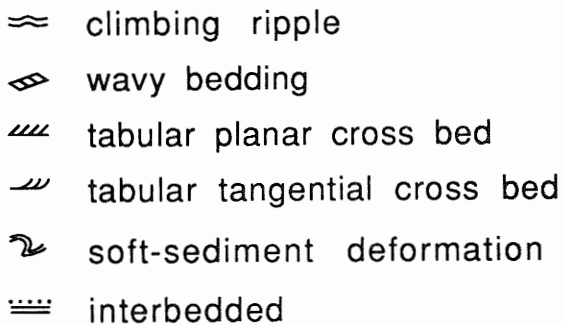
Bedding



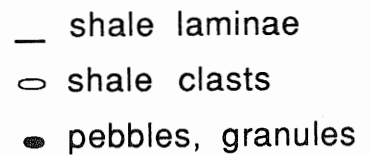
Contact



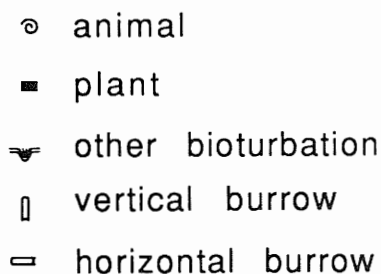
Structures



Other symbols



Fossils/bioturbation



Organic content

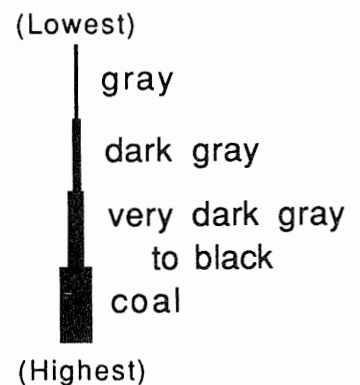


Figure 3. Explanation of symbols used in sedimentological logs of Figures 4 through 6.

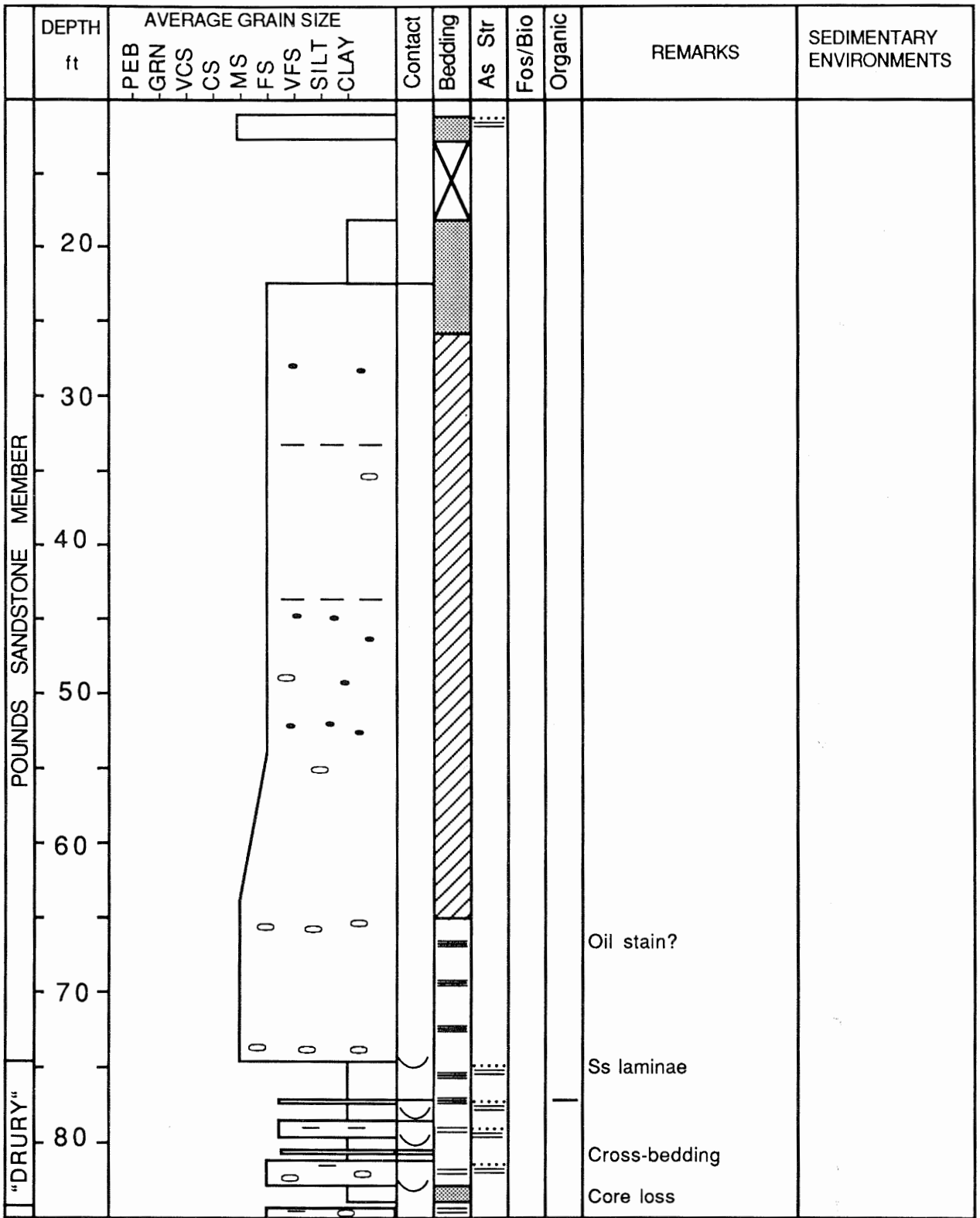


Figure 4. Sedimentological log of COGEOMAP drill hole GD-1.

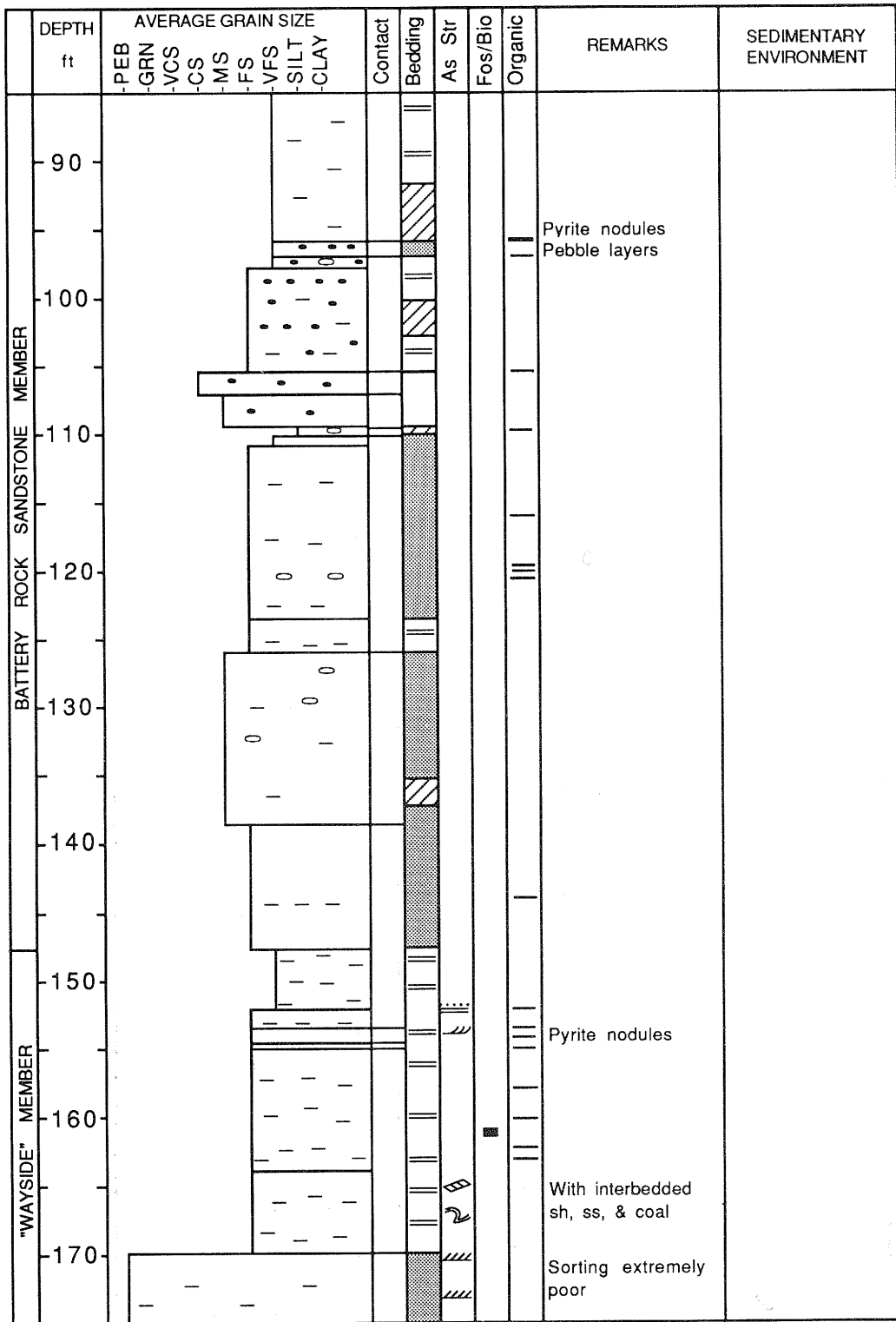


Figure 4. Continued.

DEPTH ft	AVERAGE GRAIN SIZE									Contact	Bedding	As Str	Fos/Bio	Organic	REMARKS	SEDIMENTARY ENVIRONMENT
	PEB	GRN	VCS	CS	MS	FS	VFS	SILT	CLAY							
"WAYSIDE" MBR -180															Ss laminae	
-190															Mississippian	

Figure 4. Continued.

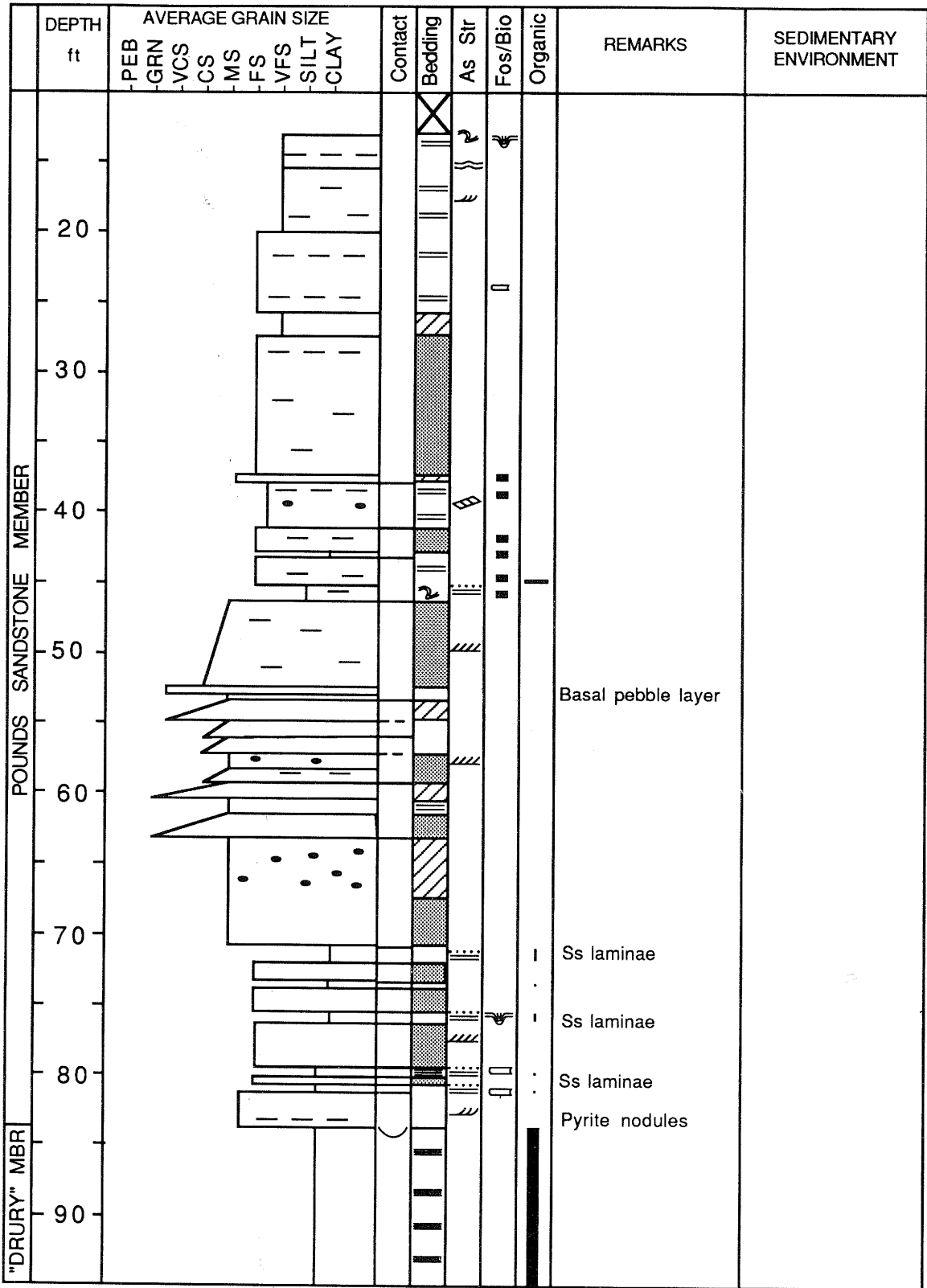


Figure 5. Sedimentological log of COGEOMAP drill hole E-4.

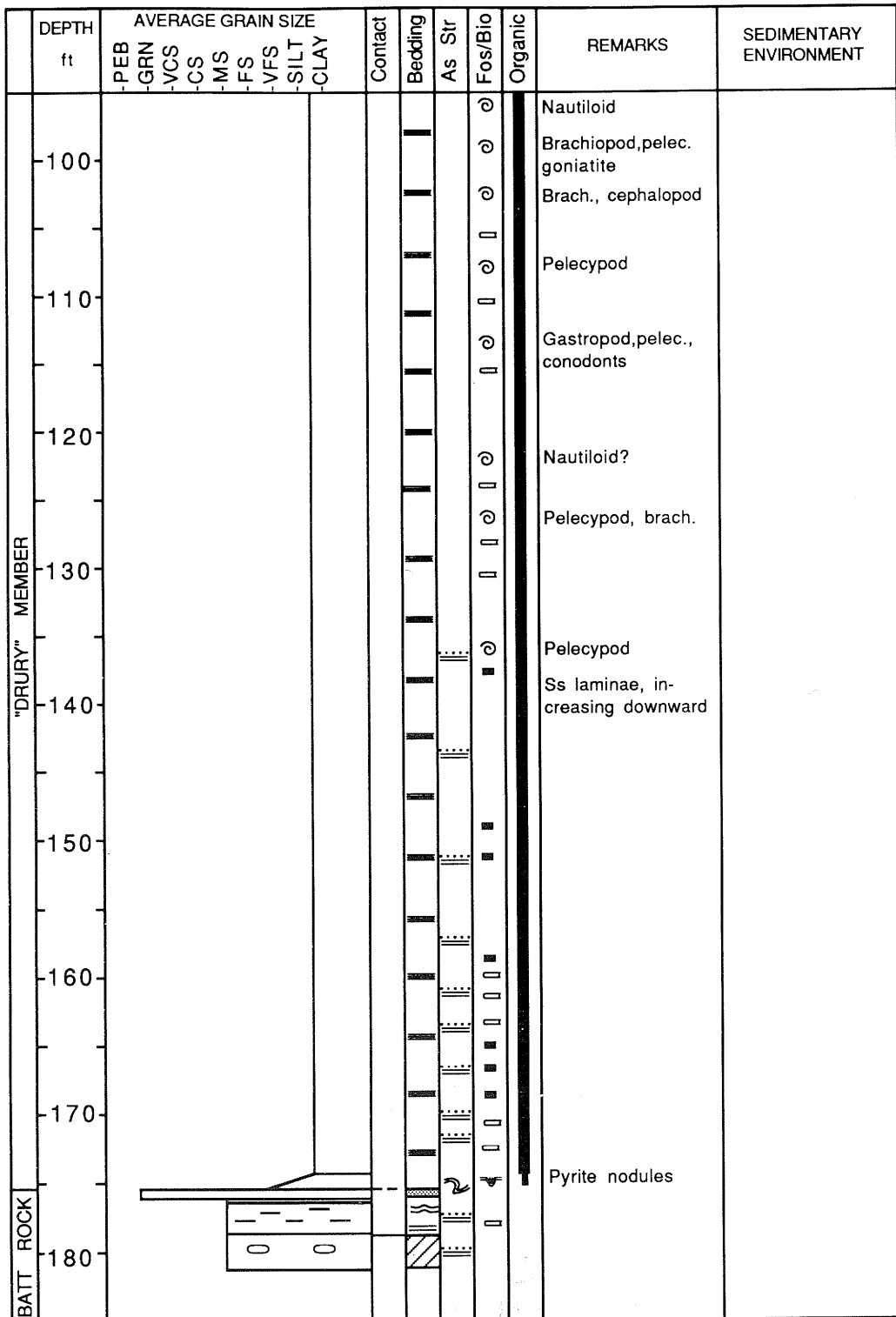


Figure 5. Continued.

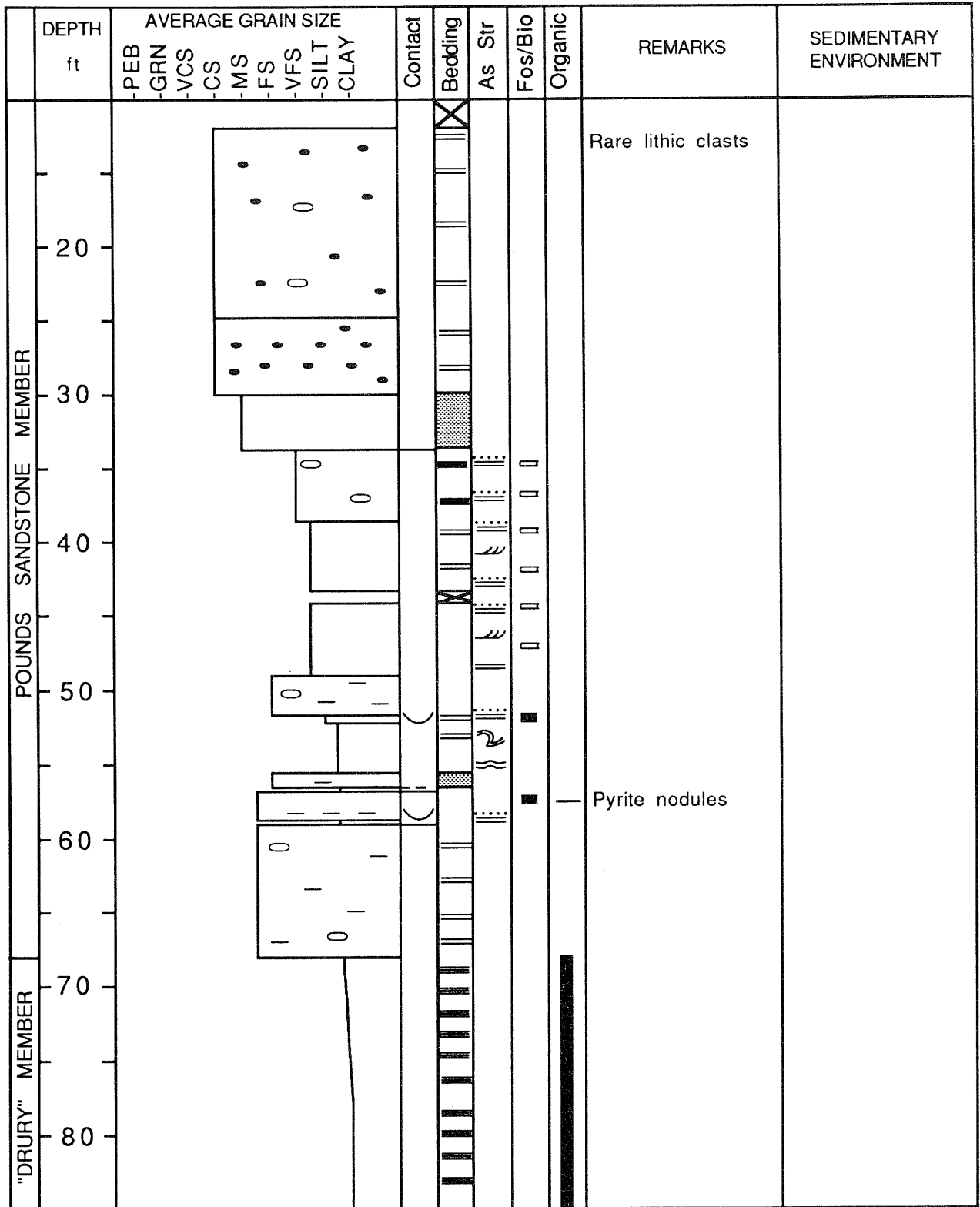


Figure 6. Sedimentological log of COGEOMAP drill hole W-1.

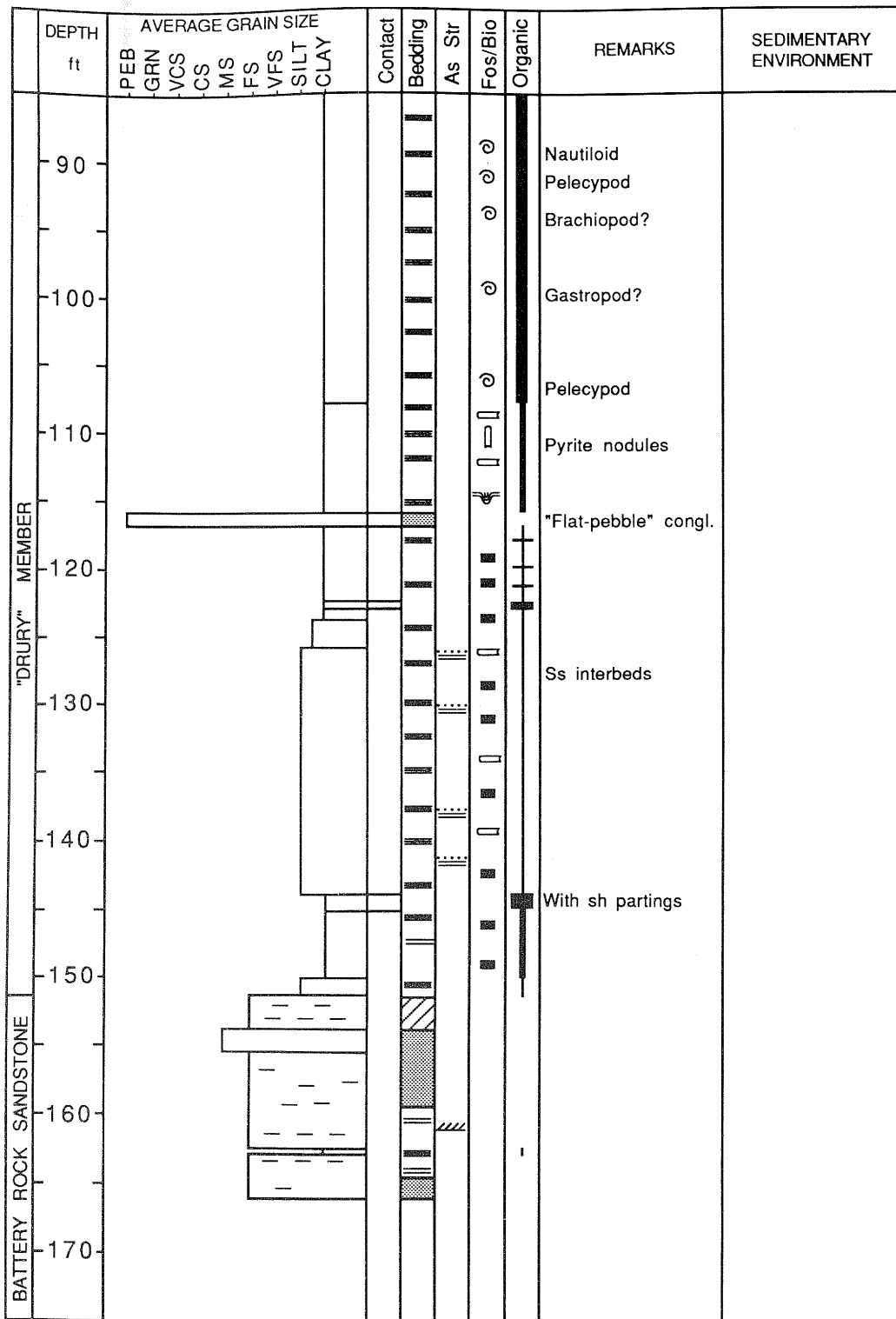


Figure 6. Continued.