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Depositional Environments and Sequence Stratigraphy of a Breathitt Group Exposure, U.S. 25E, Flat Lick, Kentucky

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Abstract

The Pennsylvanian fluvial deltaic Breathitt Group is exposed along U.S. 25E near Flat Lick, Ky. This exposure is ideal for field trips because of the quality of the exposure, its accessibility, the range of facies present, and its potential for demonstrating principles of outcrop-based sequence-stratigraphic interpretation. Eight facies are present and represent deposition in fluvial, delta-plain, and delta-front environments. Several facies contain an abundance of trace fossils, and a wide range of sedimentary structures are also present. Flooding surfaces are well developed in the delta front and delta plain and are characterized by abrupt contacts with distal, deeper-water deltaic environments overlying proximal, shallower-water deltaic environments. Major flooding surfaces display evidence of condensation, including firmgrounds and enrichment of authigenic minerals such as siderite. At this exposure, most parasequence sets display progradational stacking and are interpreted as highstand systems tracts. Two sequence boundaries are present that may represent two different scales of sequences. The upper sequence boundary is more obvious and is characterized by a prominent erosional surface and is overlain by multistory fluvial channels. The lower and more subtle sequence boundary is interpreted as an interfluve surface marked by a bleached paleosol.

Introduction

The Breathitt Group is a Pennsylvanian complex of fluvial and deltaic sediments exposed over the Cumberland Plateau, between the fold and thrust belt of the Valley and Ridge to the southeast and the Cincinnati Arch to the northwest. This thick wedge of sandstone, siltstone, shale, and coal was deposited as a series of west-advancing rivers and deltas (Horne and others, 1978) in the Appalachian foreland basin in response to Alleghanian thrust sheet emplacement to the east (Tankard, 1986; Englund and Thomas, 1989). The Breathitt Group is divided into eight formations (Chesnut, 1992), of which the Pikeville Formation is exposed at the Flat Lick roadcut along U.S. 25E, approximately midway between Pineville and Barbourville, Ky. (Fig. 1). The outcrop is located on the crest of the Flat Lick Anticline, where strata are thinner than in the surrounding areas, supporting the interpretation that sedimentation was syntectonic (Rice, 1974). The Flat Lick area is located in the Artemus 7.5-minute quadrangle (Rice, 1974).

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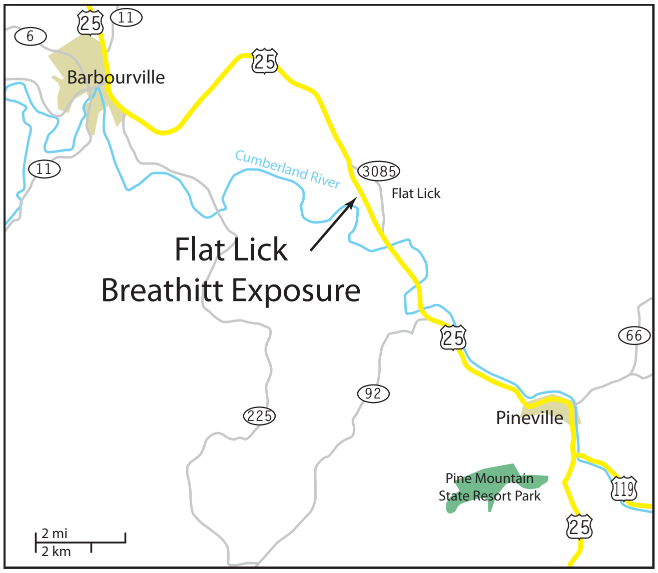

Figure 1. Location of the Flat Lick exposure of the Breathitt Group along U.S. 25E between Barbourville and Pineville, Ky. The exposure is at 36.82722°N, 83.77444°W.

The Flat Lick exposure is an excellent stop for a field trip in many regards. Part of the Breathitt Group is well exposed and accessible along recently cleared benches. The Flat Lick exposure displays eight depositional environments, many of which have excellent physical and biogenic sedimentary structures, as well as a variety of interesting sequence-stratigraphic features. A pullout provides safe parking. Camping is available at nearby Cumberland Gap National Historical Park and a lodge is available at Pine Mountain State Resort Park. Numerous other exposures of the Breathitt are present along U.S. 25E, and an even greater range of exposures spans nearly the entire Paleozoic just beyond Cumberland Gap.

Facies described in this study are based on the facies model of Aitken and Flint (1995) and consist of descriptions of lithology, bedding, physical sedimentary structures, trace fossils, and diagenetic minerals. The sequence-stratigraphic terminology also follows the model for the Breathitt Group developed by Aitken and Flint (1995) and the terminology and principles of Catuneanu (2006).

A representative stratigraphic section (Fig. 2) and interpreted photomosaic (Plate 1) are presented in this publication. The exposure was photographed and described in December 2007 and January 2008, during which time road crews cleared talus and vegetation from the benches. The

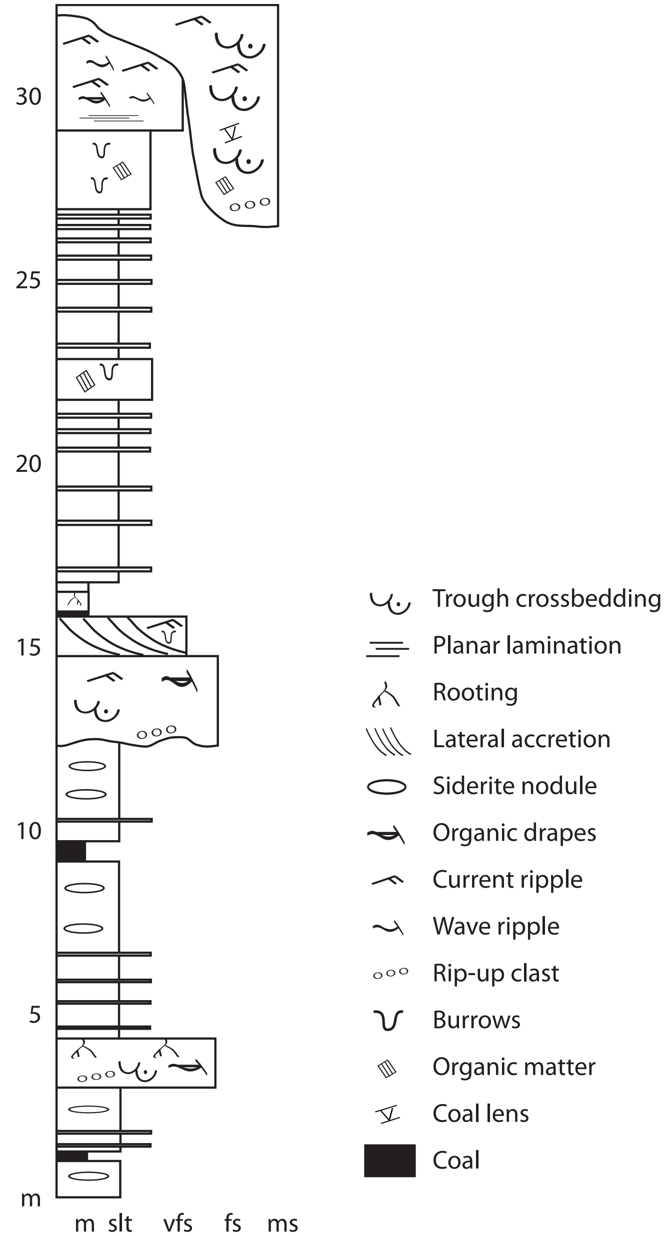

Figure 2. Stratigraphy of the Flat Lick exposure, measured at the north end of the outcrop, on the northeastern face of the exposure (across the road from the cross section shown in Plate 1).

photomosaic was prepared from a series of digital photographs, using the photomerge tool in Adobe Photoshop.

Facies

Facies 1: Distal Delta Front (Units G and I)

Description. Facies 1 consists of very thin beds of dark gray to black, laterally continuous mudstone, with thin beds and lenses of siderite (Fig. 3). Many

Figure 3. Facies 1 (distal delta front): dark gray mudstone with thin beds of siderite.

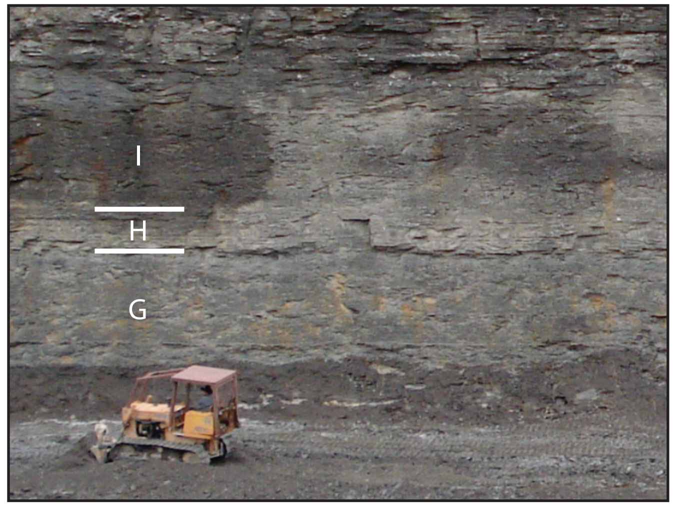

Figure 4. Medial delta-front strata (unit H) are more resistant and coarse-grained than distal delta-front strata (units G and I).

of the siderite beds contain cores and fractures filled with pyrite. The abundance of siderite increases from 10 percent at the base of the facies to 30 percent near the top. Although trace fossils were not observed, the blocky weathering of the mudstone suggests moderate bioturbation. No sedimentary structures were observed within facies 1. Facies 1 ranges from 2.6 to 8.6 m thick. It is gradationally overlain by facies 2 and sharply overlies facies 2 or facies 5 (Plate 1).

Interpretation. Facies 1 is interpreted to have been deposited in a low-energy, distal delta front; clay- and silt-size particles were deposited from suspension. The abundance of siderite, often with cores of pyrite, suggests deposition in a brackish environment in which the sulfate supply was limited and consumed, followed by continued precipitation of ferrous iron as siderite (Berner and others, 1979). Brackish conditions may also explain the lack of body fossils, which might be expected given that this is the most open marine facies observed at this outcrop.

Facies 2: Medial Delta Front (Unit H)

Description. Facies 2 consists of very thin beds of dark gray, laterally continuous, coarse siltstone to very fine sandstone (Fig. 4). Parallel lamination is common, with little disruption by bioturbation. Horizontal traces are common on bedding planes and include *Tasmanadia* (Fig. 5), *Scolicia,* and *Cochilichnus*. Less common are *Planolites* and *Monocraterion*. Compressed and macerated plant remains *(Cordaites)* are also common, although individual bedding planes typically display either trace or plant fossils, but not both. Facies 2 gradationally overlies facies 1 and may be gradationally overlain by facies 3 or sharply overlain by facies 1 (Plate 1).

Interpretation. Facies 2 is interpreted to have been deposited in a medial delta front where silt and fine-grained sand were deposited by plume-derived turbidity currents. The layers of planar lamination are interpreted as Bouma unit Tb. The abundance of bedding-plane traces suggests an environment capable of supporting a rich fauna, but the lack of significant disruption of lamination by vertical burrowers suggests relatively rapid sedi-

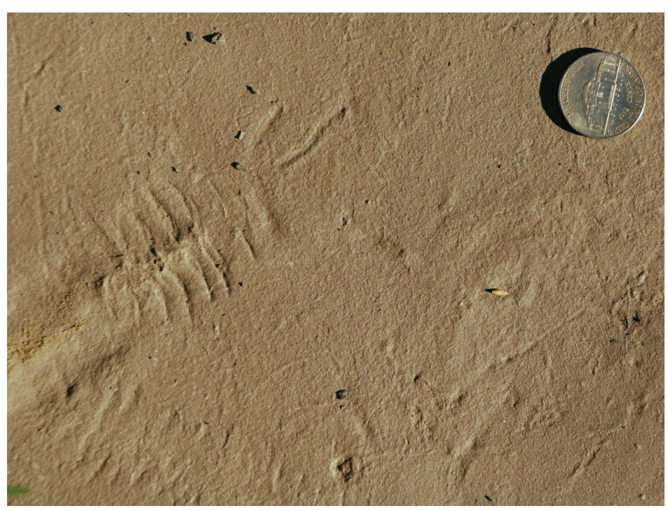

Figure 5. *Tasmanadia* in siltstone bedding plane in facies 2 (medial delta front).

mentation rates. The gradational upward transition from facies 1 to facies 2 indicates a genetic relationship between these two facies.

Facies 3: Proximal Delta Front (Unit J)

Description. Facies 3 contains thinly bedded, laterally continuous, poorly cemented siltstone that coarsens up into very fine-grained to fine-grained sublitharenite. Ripples are common and include both current ripples with a south-southwest flow direction and wave (vortex) ripples indicating north-south flow. Organic-rich shale drapes with dark gray color (Fig. 6) are common and locally define thick-thin pairs. Soft-sediment deformation is also locally present. Weathered pyrite and nodules of siderite are common throughout this facies. No body or trace fossils were observed, and laminae are only rarely disrupted by bioturbation. Facies 3 gradationally overlies facies 2 and is erosionally overlain by distributary channel deposits of facies 4 (Plate 1).

Interpretation. This facies is interpreted as proximal delta-front deposits, based on its lithology, sedimentary structures, and gradational relationship with facies 2. Abundant current ripples are interpreted as deposition from plume-derived turbidity currents, and the common occurrence of wave ripples confirms the shallow setting of this facies. Organic drapes suggest tidal modulation of hyperpycnal flows. The mix of pyrite and siderite suggests sulfide-limited brackish-water conditions (Berner and others, 1979) and the presence of soft-sediment deformation may indicate rapid deposition, which would have induced dewatering of shallowly buried sediment.

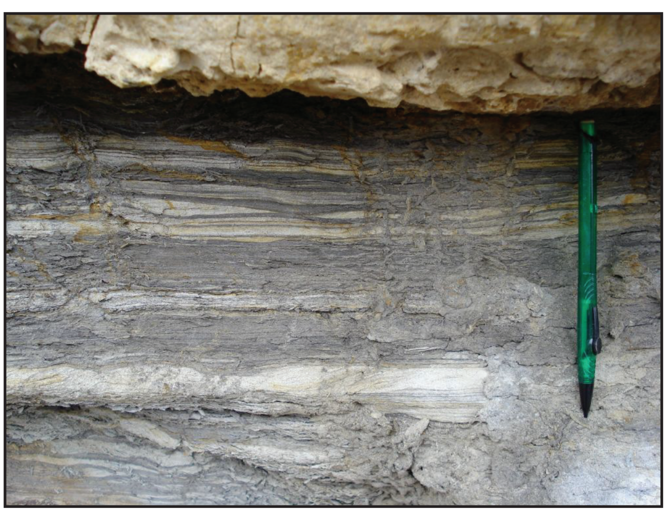

Figure 6. Organic and clay drapes on ripple cross lamination in facies 3 (proximal delta front).

Facies 4: Distributary Channel (Units A, E, and K)

Description. Facies 4 contains medium to thick beds of light gray, well-sorted, well-cemented sublitharenite. Lateral accretion surfaces are common, as are organic drapes, which rarely form thick-thin bundles. Trough crossbedding overlain by trough cross lamination is common near the top of the facies (Fig. 7). Climbing-ripple lamination is also present. The bases of some units contain a lag composed of mudstone rip-up clasts and organic debris. Where capped by facies 5 and 6, facies 4 displays rooting and abundant plant remains. Soft-sediment deformation is locally present at the top of facies 4. Facies 4 erosionally overlies facies 3 and 6 (Plate 1).

Interpretation. Facies 4 is interpreted to have been deposited by minor distributary channels in a deltaic environment. The rip-up clasts and wood

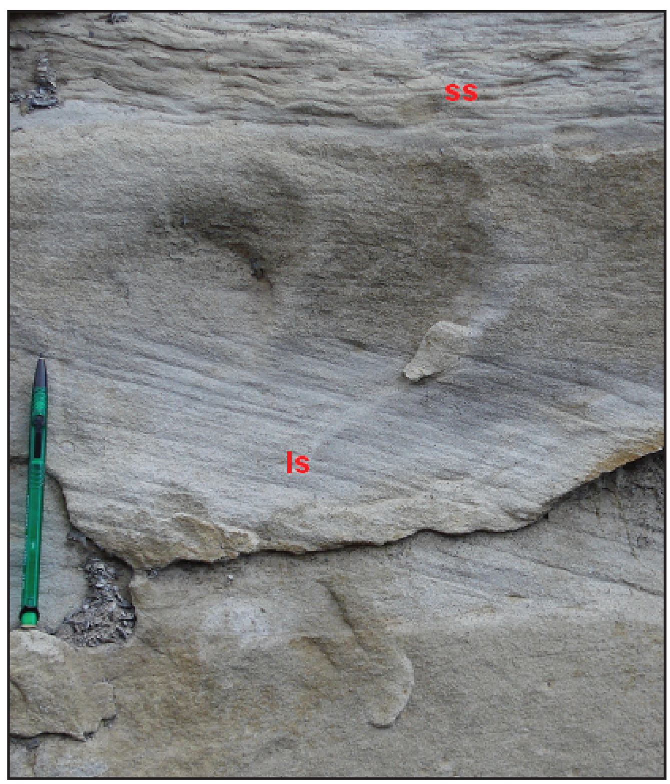

Figure 7. Upward transition from large-scale cross stratification (ls) to small-scale cross stratification (ss) in facies 4 (distributary channel).

fragments at bedding surfaces near the base of the facies are interpreted as channel lags. Lateral accretion and an upward transition from crossbedding to cross lamination indicate the presence of point bars within sinuous channels. Climbing-ripple lamination indicates episodically elevated rates of deposition within the channel. Organic drapes, particularly the paired drapes, indicate tidal influence in the channel (Nio and Yang, 1992).

Facies 5: Levee (Unit F)

Description. Facies 5 consists of thin to very thin beds of silty, reddish gray sandstone that thin and pinch out laterally. Lateral accretion surfaces are well developed (Fig. 8). Bioturbation is moderate, and locally traces of *Lophoctenium* are abundant (Fig. 9). Small-scale current ripples and climbing ripples indicate flow to the south and west. The top of this facies is often rooted and bears abundant plant remains, especially of *Calamites*. The top of this facies is leached to yellow, brown, and red colors, and it is abruptly overlain by facies 1. Facies 5 gradationally overlies facies 4 and is typically 1 to 2 m thick (Plate 1).

Interpretation. Facies 5 is interpreted to have been deposited on the upper point bar and levee of a distributary channel, based on the rooting, plant remains, lateral thinning (Bridge and Leader, 2006), silt content, and gradational lower contact with facies 4. Current ripples and climbing-ripple lamination record rapid deposition during bank-full

Figure 9. *Lophoctenium*, facies 5 (levee).

events. The trace fossil *Lophoctenium* indicates the lower part of the levee was deposited in brackish water (Archer and Maples, 1984). The rooting and plant remains at the top of the facies indicate colonization by plants. Leaching at the top of this facies is interpreted as evidence of prolonged subaerial exposure *(see* **Sequence Boundaries).**

Facies 6: Interdistributary Bay (Units B and D)

Description. Facies 6 consists of moderately bioturbated, very thin beds of laterally continuous black mudstone and siderite that coarsen upward into a sandy mudstone (Fig. 10). Dark organic material increases near the top (total organic carbon values

Figure 8. Lateral accretion surfaces dipping to the right (northeast) in facies 5 (levee), overlying facies 4 (distributary channel).

Figure 10. Interbedded mudstone with numerous 1-cm-thick beds of siderite, facies 6 (interdistributary bay). Compare thickness and number of siderite layers to that of facies 1 (distal delta front; Figure 3).

of 1.26 and 2.09 percent). Very thin siderite beds constitute half of the facies and give way to 1- to 2-cm-diameter nodules of siderite in the upper 50 cm of this facies, which is then overlain by facies 8. Planar lamination is visible in the lower part of the facies but is disrupted by bioturbation in the upper half meter. No trace or body fossils were observed. Facies 6 is 3 to 5 m thick and either grades upward into facies 8 or is erosionally overlain by facies 4. Facies 6 sharply overlies facies 8 (Plate 1).

Interpretation. Facies 6 is interpreted to have been deposited in a protected interdistributary area of a delta with characteristics similar to those described by Bhattacharya (2006). The fine-grained material reflects deposition from suspension of material inferred to have been supplied during river floods. Moderate bioturbation of fine-grained mud is consistent with interdistributary marsh environments that are rooted by vegetation. The abundance of siderite and a lack of pyrite is attributed to nearly freshwater conditions lacking in sulfate, differing from facies 1, in which pyrite was abundant.

Facies 7: Incised Valley Fill (Unit L)

Description. Facies 7 contains thickly bedded, medium-grained, subangular- to angular-grained sublitharenite, with rare thin siltstone partings. The base of this facies is erosional, and nearly 10 m of relief is visible at this outcrop alone. The basal surface is overlain by a lag of sideritized pebbles up to 4 cm in diameter, rip-up clasts of siltstone (Fig. 11), thin coal lenses, and fossil logs (Fig. 12).

Figure 11. Basal lag of siltstone rip-up clasts, facies 7 (incised valley fill).

Figure 12. *Lepidodendron* log, facies 7 (incised valley fill).

Facies 7 consists of a series of sand bodies defined by lateral accretion (Fig. 13). Trough crossbedding is ubiquitous and indicates an approximately western paleoflow. Flute casts are present at the base of some of these sets. The base of this facies erosionally overlies facies 3 and facies 4, and the top of this facies could not be observed (Plate 1).

Interpretation. Facies 7 is interpreted to have been deposited by meandering rivers that occupied an incised valley. The relatively coarse grain size and angularity of sand grains suggest a more proximal setting relative to all other facies at this outcrop. The coarse lag at the bottom of this facies and the bottom of each set of lateral accretion surfaces indicates the relatively strong currents flowing through these rivers. The presence of lateral accretion surfaces and trough crossbedding indicates deposition on the lower parts of point bars. The incision of this facies into delta-front deposits and the depth of incision that is much greater than the thickness of individual channels indicate that this facies fills an incised valley. The occurrence of coal lenses draping the base of some channels is

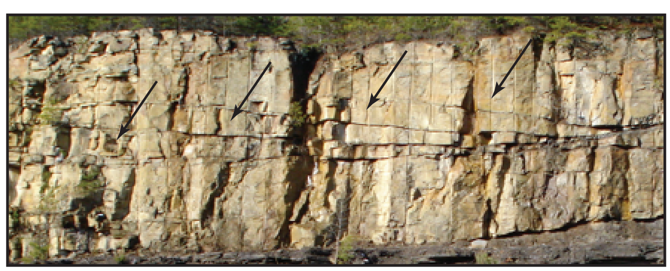

Figure 13. Lateral accretion surfaces (arrows) in facies 7 (incised valley fill).

evidence of channel abandonment and mire conditions before infilling.

Facies 8: Mire (Unit C)

Description. Facies 8 consists of laterally continuous coal seams (Fig. 14) underlain by rooted mudstone. Small cubic crystals of pyrite are visible with a hand lens. Bleaching is common in the top few centimeters of the facies below the coal. Facies 8 is overlain sharply by facies 6 and rests gradationally on facies 6 (Plate 1).

Interpretation. The unit C coal seam was deposited on an abandoned part of the delta plain, given its association with the mudstones of the interdistributary environment. The water table associated with the mire exceeded local base level, allowing rooting plants to grow for a relatively long period, as suggested by the low ash content of the coal (Aitken and Flint, 1995).

Sequence Stratigraphy

Parasequences and Parasequence Sets

Parasequences are defined as relatively conformable (and generally shallowing-upward) strata bounded by flooding surfaces, which are sharp contacts that separate overlying deeper-water strata from underlying shallower-water strata (Van Wagoner and others, 1988). Parasequences are generally grouped into sets that display net progradational, aggradational, or retrogradational patterns.

Seven parasequences (ps 1–7) are recognized at the Flat Lick exposure and occur within the delta-front and delta-plain facies associations. Most parasequences at this outcrop are a few meters thick.

Figure 14. Coal seam of facies 8 bounded above and below by interdistributary mudstones. Notebook for scale.

The first four parasequences formed in a lower delta-plain setting. At the extreme southern end of the outcrop (at the left of Plate 1), poorly exposed interdistributary mudstone is capped by mire facies and represents parasequence 1. The next parasequence (ps 2) consists of more interdistributary mudstone capped by distributary channel facies with a rooted surface at its top. Parasequence 3 also contains interdistributary facies capped by mire facies. The fourth parasequence consists of interdistributary mudstone, erosionally overlain by distributary channel facies, capped by levee facies with minor mire facies locally. Each of these parasequences is similar in thickness and facies composition, and each may have been produced via local delta switching or through small-scale relative changes in sea level. The similarity of the facies that compose the parasequences and facies thickness suggests aggradational to progradational stacking.

The remaining three parasequences formed in a delta front. Parasequence 5 is quite thin (only 50 cm) and begins at a major flooding surface at which levee and mire facies of ps 4 are abruptly overlain by dark mudstone of the distal delta-front facies. This mudstone is capped by a 20-cm-thick, lumpy bed of sideritized mudstone, suggesting a prolonged period of nondeposition with stratigraphic condensation. Parasequence 6 consists of distal delta-front facies overlain by a couple of meters of medial delta-front facies. Parasequence 7 is nearly identical to ps 6, but is overlain by proximal delta-front and distributary facies. These parasequences also could reasonably have formed either through delta switching or relative changes in sea level. The first of these parasequences (ps 5) is characterized by a major deepening event at its base, extreme thinness, and a capping, highly condensed siderite horizon. The remaining two parasequences (ps 6 and 7) show net upward shallowing; that is, progradational stacking.

Sequence Boundaries

Sequence boundaries are subaerial unconformities and their correlative marine surfaces (Van Wagoner and others, 1990; Catuneanu, 2006). Two sequence boundaries are present in the Flat Lick outcrop. The lower sequence boundary (SB 1 of

Plate 1) is subtle and lies at the contact of an underlying aggradational to progradational set of parasequences (ps 1–4) and an overlying retrogradational parasequence set (ps 5). This contact is also characterized in places by a leaching of mudstone of dark gray to various shades of buff, yellow, and red-brown (Fig. 15). This leached horizon is cut by sharp-walled burrows, suggesting a firm substrate, and these burrows have subsequently been filled with siderite (Fig. 16). The leached horizon is developed a few centimeters above a coal, suggesting a change from poorly drained soil with well-preserved organic matter and reduced iron mineralogy (pyrite and siderite) to a moderately well-drained soil with minimal organic matter and oxidized iron minerals (hematite and goethite) (Fig. 17). This horizon is interpreted as a paleosol developed on an interfluve; that is, an upland between incised valleys. Aitken and Flint (1995, 1996) described other such surfaces from the Breathitt Group and were able to show how these can be traced laterally to incision surfaces. More work is necessary to test if this surface can be traced laterally to connect with correlative paleovalleys.

Figure 15. Strong bleaching beneath sequence boundary 1 (red line).

Figure 16. Firmground burrows (arrows) beneath sequence boundary 1 (red line).

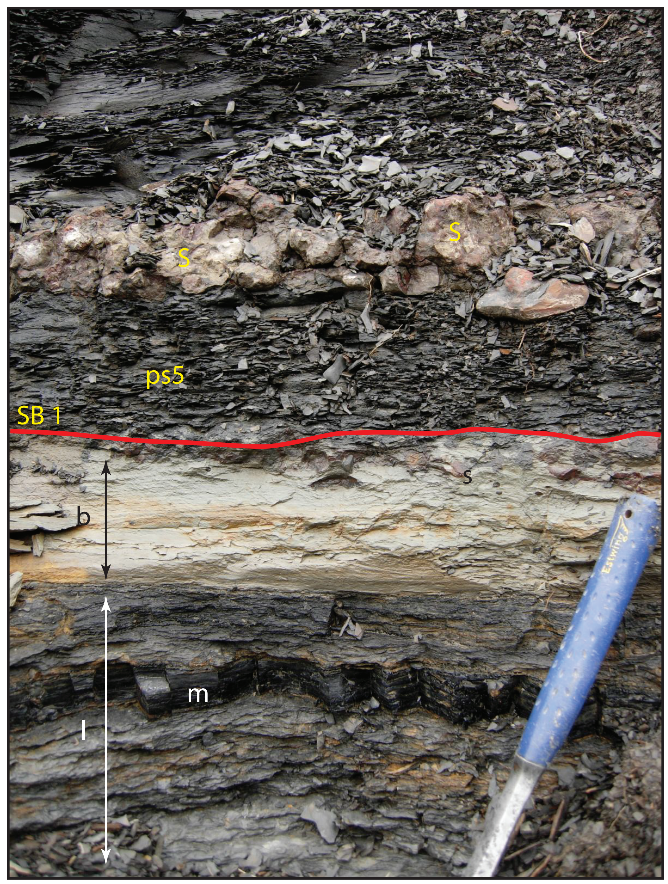

Figure 17. Stratigraphy of the sequence boundary 1 interval. l: levee facies, with thin mire (m). b: leached paleosol beneath sequence boundary (red line). s: sideritized burrows. S: thick pyritized and sideritized mudstone.

The upper sequence boundary (SB 2) is more prominent and may represent the boundary of a low-order sequence. It is marked by an erosional surface with as much as 13 m of relief at this outcrop (Plate 1). SB 2 is overlain by multistory, fluvial-channel sandstones of substantially coarser grain size than any other facies at this outcrop (Fig. 18). The base of this sandstone unit contains a well-developed coarse lag, consisting of siltstone-pebble conglomerate, siderite-pebble conglomerate, and accumulations of fossil logs. Distributary channels commonly incise into proximal delta-front deposits because of lobe switching (e.g., facies 4 and 3) (*also see* Bowen and Weimer, 2003). Based on the amount of erosional relief, the abrupt increase in grain size, and the overlying multistory channel fill, we interpret this surface to be a sequence boundary and not merely the base of a fluvial channel.

Depositional Sequences and Systems Tracts

The two sequence boundaries separate parts of three depositional sequences; that is, units bounded by subaerial unconformities and their correlative surfaces (Van Wagoner and others, 1990; Catuneanu, 2006). Only the top of the lowest sequence is exposed, and it consists of an aggradational to progradational set of delta-plain parasequences, interpreted as the highstand systems tract, based on its relatively updip setting compared to other units in this exposure.

The second sequence begins with SB 1, which indicates subaerial exposure and weathering, resulting in a leached paleosol horizon. SB 1 is overlain by one very thin parasequence that shows rapid deepening from the underlying facies and is capped by a distinctive pyritic to sideritic cemented horizon. This single thin parasequence (ps 5) is interpreted as the transgressive systems tract and records net upward deepening to a condensed horizon. The remaining two parasequences (ps 6 and 7) show net upward shallowing and are interpreted as the highstand systems tract. The abrupt transition from highstand systems tract (ps 1–4) to a subsequent transgressive systems tract (ps 5) indicates that the falling-stage systems tract of the lower sequence and the lowstand systems tract of the middle sequence are absent. This is a common architecture in cratonic settings, and the missing systems tracts are expected in a depositionally downdip position, or possibly along strike in an incised valley.

Figure 18. Erosional truncation below sequence boundary 2 (red line), overlain by multistory fluvial-channel sandstone.

The base of the third sequence is marked by a prominent subaerial unconformity with as much as 13 m of relief and is overlain by stacked, multistory, fluvial sandstone bodies. From their lack of tidal indicators such as inclined heterolithic strata, we interpret these as part of the lowstand systems tract (*see* Shanley and McCabe, 1993) similar to lowstand incised-valley sandstones in other parts of the basin (Aitken and Flint, 1996).

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Plate 1. Photomosaic of the southwestern face of the Flat Lick exposure. Individual facies units are labeled in white, from A at the lower left to L at the upper center; facies names are in parentheses. Sequence-stratigraphic units are labeled in yellow. Flooding surfaces are indicated as yellow lines, sequence boundaries as red lines. SB: sequence boundary. HST: highstand systems tract. LST: lowstand systems tract.