SEQUENCE STRATIGRAPHY OF MIDDLE TO UPPER PENNSYLVANIAN FILL OF THE CENTRAL APPALACHIAN BASIN

by

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Introduction

The outcrops along Route 23 in Kentucky and Route 52 in West Virginia expose some of the largest continuous outcrops of Carboniferous strata in the world. Several outcrops displaying Upper Breathitt Group and Lower Conemaugh Group strata were recently excavated, exposing fresh surfaces that reveal the complex sequence stratigraphy of mostly fluvial strata. Outcrops in the area demonstrate an upward succession from upper delta plain to fluvial environments (Merrill, 1986).

Sequence stratigraphy is often used to understand fill in basins containing marine influence, such as the Appalachian Basin, leveraging the predictive nature of marine sequence stratigraphy and the interpretive power of systems tracts (Posamentier and Allen, 1999). Cyclothems, which are cyclically alternating marine and non-marine sections (Wanless and Weller, 1932; Davies et al., 1992), are easily recognized in the Middle to Upper Pennsylvanian Appalachian Basin (e.g. Busch and Rollins, 1984; Chesnut, 1992; Martino, 2004), making it possible to use sequence stratigraphy to interpret the sequences. These cyclothems are attributed to glacioeustatic cycles that drove sequence formation (Busch and Rollins, 1984; Nadon and Kelly, 2004; Heckel, 2008). These marine elements become increasingly rare in the upper parts of the Conemaugh Group where fluvial strata dominate and sequence stratigraphy has seen less application. The effects of eustasy weaken up-dip as fluvial-dominated sequences see increasing climatic and tectonic influence (Schumm, 1993). A more applicable fluvial sequence stratigraphic model places focus on accommodation state rather than relative sea level (Dahle et al., 1997; Martinson et al., 1999; Catuneanu, 2006).

The purpose of this study is to analyze the stratigraphy of Upper Breathitt Group and Lower Conemaugh Group rocks in the area of the Kentucky/West Virginia state line and use this information to understand the relationship between facies of the floodplain and the channel belts that filled the Appalachian Basin in the context of the basin fluvial sequence stratigraphy. There is little research on these strata, but notable exceptions are Thomas Arkle and others, Glen Merrill, and Ronald Martino, who all measured sections of the Glenshaw Formation in and around the study area (Arkle et al., 1979; Merrill, 1986; Martino et al., 1996; Martino, 2004). Most previous work done in the area is in stratigraphically higher (e.g. Nadon and Kelly, 2004; Belt et al., 2011; Hembree and Nadon, 2011; Dzenowski and Hembree, 2012) or lower (e.g. Aitken and Flint, 1994; Aitken and Flint, 1996; Greb and Chesnut, 2009; Ney, 2015; Atkins, 2016) sections. Additionally, this study strives to correlate stratigraphy between outcrops to understand lateral sequence variability and determine the significance of trends recognized in sequence deposition.

Fluvial Sequence Stratigraphy and Accommodation States in Up-dip Environments

A typical sequence stratigraphic model for shallow marine settings is generally straightforward where unconformities are used as sequence boundaries, and one sequence contains the deposits of one relative sea level cycle (Vail et al., 1977; Van Wagoner et al., 1988; Catuneanu, 2006). Applying this sequence stratigraphic model in the Northern and Central Appalachian Basin becomes problematic because this model assumes that facies architecture is overwhelmingly controlled by eustasy (e.g. Shanley and McCabe, 1994; Wright and Marriott, 1993; Richards, 1996). In the Northern and Central Appalachian Basin, other autocyclic or allocyclic factors, particularly climate, compete with eustatic control in sequence formation (Walker, 1992; Schumm, 1993; Shanley and McCabe, 1994). Rather than a traditional sequence stratigraphic model which relies heavily on relative sea level, a more applicable fluvial sequence stratigraphic model instead focuses on accommodation state (Dahle et al., 1997; Martinson et al., 1999; Catuneanu, 2006). Arrangement of facies within an outcrop is key for determining high and low accommodation systems tracts. For instance, the ratios of channel fills to floodplain deposits can help one infer a low or high accommodation setting independent of base level (Allen, 1978; Bridge and Leeder, 1979; Legarreta et al., 1993; Shanley and McCabe, 1994; Dahle et al; 1997; Blakey and Gubitosa, 1984; Catuneanu, 2006). A diagram that illustrates how fluvial systems respond to changes in accommodation in terms of channel fills and floodplain deposits is shown in Figure 1, which is modified from Shanley and McCabe (1994).

Sediment supply also must be considered when determining the amalgamation of channels (Bryant et al., 1995). Several authors suggest that identifying low and high accommodation tracts based only on the ratio of channel fills to floodplain deposits is not accurate (Leckie and Boyd, 2003; Catuneanu, 2006; Colombera et al., 2015). These authors found that frequently, high accommodation systems will not actually aggrade quickly enough to make isolated high accommodation deposits. Therefore, although high and low accommodation systems tracts can be mapped, the interpretation of these systems tracts largely depends on various depositional conditions such as sediment supply or other unassessed variables.

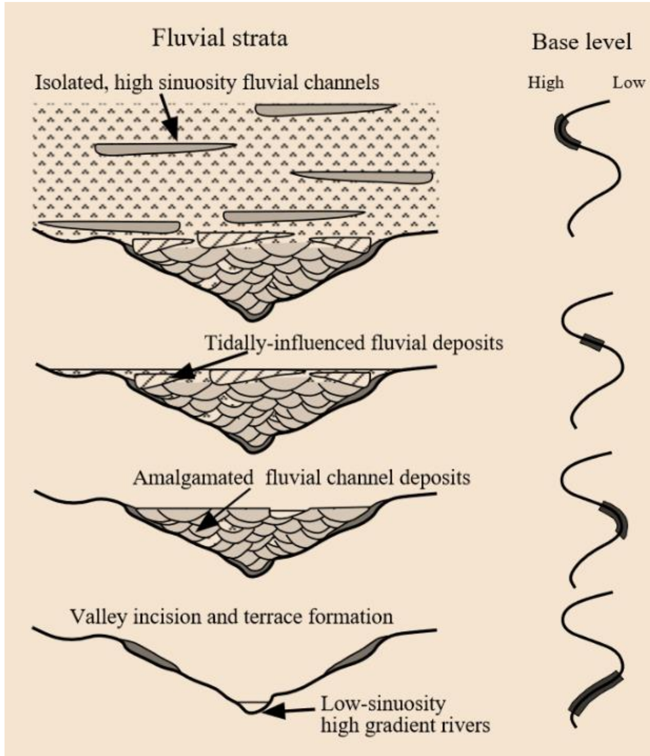


Figure 1. Fluvial system response to changes in accommodation (modified from Shanley and McCabe, 1994).

Additional features can be observed in the rocks to better recognize low and high accommodation strata. Catuneanu (2003) identified several distinguishing features for both low and high accommodation systems tracts.

Low accommodation systems tracts record amalgamation of channel belt deposits and poor preservation of floodplain deposits (see Catuneanu, 2006). The basal contact of low accommodation systems tracks is generally a sharp basal scour into underlying sediments at the base of valleys or sheets. The sediments below the scour surface are generally finer. The relatively coarse sediments that deposit at the bottom of the valleys and sheets are usually indicative of the high energy depositional environment found along the channel thalweg. Valley fills commonly grade upward into interbedded sands and silts, owing to the slowing energy as the valley transitions to estuarine systems (Catuneanu, 2003) or passes to more highly aggradational systems. Finally, coals tend to be absent in low accommodation environments, but paleosols may be generally well developed, which is indicative of low water tables.

High accommodation systems tracts record dispersion of channel belts and preservation of the floodplain fines between channel belts (e.g. Allen, 1978; Shanley and McCabe, 1994; Catuneanu, 2006). In general, the sediments found within the high accommodation systems tract are finer than those found within the low accommodation valley fill owing to an overall lower depositional energy. While silts and clays are very abundant in high accommodation strata, sand bodies tend to be thinner and less frequent. Coal seams are common. Paleosols can be common as well and reflect better drained conditions. High accommodation systems tracts are commonly associated with rising base level, but it is important to note that other factors (i.e. climate change, tectonics, subsidence, or changes in lateral accommodation) can all mirror the effects of rising base level and promote deposition of high accommodation deposits.

While high and low accommodation systems tracts are much easier to apply to largely non-marine strata, it is possible to use evidence of high and low accommodation to make inferences about sea level. In this study, once high accommodation strata are separated from the low accommodation strata, inferences are made to compare the strata to a traditional sequence stratigraphic model.

Valley Incision

Valleys consist of scours cut into underlying strata more than one stacked channel deep (Dalrymple et al., 1994; Holbrook, 2001). The sharp basal scour that results from valley incision marks a sequence boundary in traditional sequence stratigraphic models (Vail et al., 1977; Posamentier and Vail, 1988; Van Wagoner et al., 1988; Van Wagoner, 1990). This model assumes that incision occurs as a result of a falling sea level. As of late, several authors have questioned the simplicity of this statement. Rather, theories have arisen that suggest that sea level fall does not have to change a river's profile (i.e. incision and aggradation are not necessary), and furthermore, at a certain distance up-dip, sea level no longer becomes the dominant control on valley incision. Instead, climate and tectonics control the profile of the river up-dip (Blum, 1993; Schumm, 1993; Wescott, 1993; Shanley and McCabe, 1994; Törnqvist, 1998; Miall, 2010). According to Blum and Törnqvist (2000), base level effects can propagate tens to hundreds of kilometers up-dip.

Holbrook (2001) and Holbrook et al. (2006) further studied incised valleys and their down-dip and up-dip controls. Holbrook (2001) defines four types of valleys: Simple, Complex, Compound, and Compound-Complex. Low accommodation systems tracts may also form multi-valleys that record lateral amalgamation of valleys through multiple generations of valley incision. While debate persists over what makes up an incised valley (in terms of incision and valley fill), this study will follow the notion that a valley consists of more than one channel stacked on top of each other, and fill is contained within the valley wall, independent of the valley origin.

Cyclothems

Cyclothems record repetitive cycles of lithologies in stratigraphic successions and are generally ascribed to sea level change (Wanless and Shepard, 1936). Cyclothems are recognized in the Pennsylvanian System in the Appalachian Basin and have been since the 1930s (Weller, 1930; Wanless and Weller, 1932). A total of eight cyclothems are recognized in the Glenshaw Formation alone (Sturgeon and Hoare, 1968; Martino, 2004), the primary stratigraphic interval studied in this thesis.

Repetition of facies within a vertical stratigraphic section may be autocyclic (derived from within the depositional system and requiring no change in mass or energy to the system) or allocyclic (driven by changes in forces external to the system). Autocycles were recognized by many geologists in the Appalachian Basin in the 1970s. However, additional research has caused many scientists to consider an overprint of allocyclic drivers (e.g., Ferm, 1970; Donaldson, 1979). Allocycles result from factors external to the basin such as climate, tectonics and eustasy. Allocyclic processes control accommodation and sediment supply within the Appalachian Basin. The cyclothems in the Appalachian Basin can be correlated to cyclothems in Illinois and even further west into the midcontinent via marine surfaces, supporting the theory of an allocyclic overprint.

By the 1980s, two major theories emerged concerning the source of the cyclothems in the Appalachian Basin. Some argued that the cyclothems are allocyclic and correspond to changes in sea level (e.g. Busch, 1984; Busch and Rollins, 1984; Heckel, 1995). Each cyclothem consists of one transgression and one regression, and is identified with a "climate change surface" between arid, subaerially formed paleosols and overlying coals and limestones formed under more humid conditions (Busch and West, 1987). This is consistent with the application of a traditional sequence stratigraphic model for the Appalachian Basin. Conversely, others claim that 100,000- and 400,000-year climate cycles control Pennsylvanian cyclothems in the Appalachian Basin (Cecil, 1990; Cecil et al., 1994; Cecil and Dulong, 1998). Wetter portions of cycles are interpreted as sea level lowstands, and drier portions coincide with highstands. This contradicts Busch and Rollins (1984), Busch and West (1987), and Heckel (1995), who found that the wetter portions of cycles coincided with highstands, and drier portions with lowstands. If this theory is correct, then a sequence stratigraphic model is not dependent on eustasy and is climate driven in the Appalachian Basin. The origin of cyclothems in Pennsylvanian strata in the Appalachian Basin remains unresolved (Wanless and Shepard, 1936; Busch and Rollins, 1984; Busch and West, 1987; Cecil, 1990; Cecil et al., 1994; Heckel, 1995; Cecil and Dulong, 1998).

Location and Stratigraphy of Outcrops

The outcrops within the study area are positioned along Kentucky State Route 23 and West Virginia State Route 52, between the towns of Prichard, West Virginia, and Louisa, Kentucky, located within the Central Appalachian Basin (Greb et al., 2009; Figure 2).

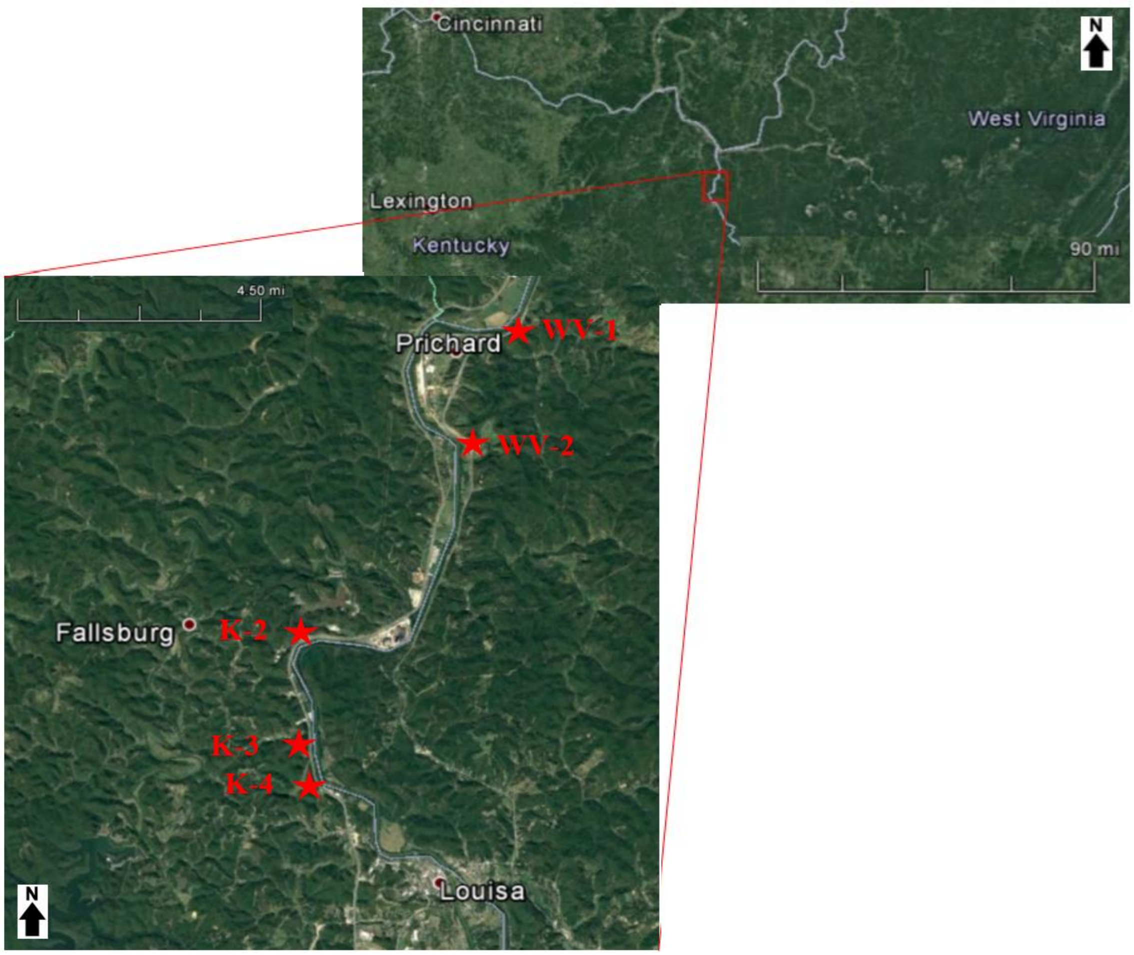


Figure 2. Location of outcrops along Kentucky State Route 23 and West Virginia State Route 52. Outcrops in Kentucky identified by K, while outcrops in West Virginia identified by WV. Images taken from Google Earth.

Three outcrops (K-2, K-3 and K-4) are along Route 23 and the other two outcrops (WV-1 and WV-2) are on Route 52. The coordinates for the outcrops used in this study are located in Table 1.

Table 1. Coordinates for outcrops used in this study.

Outcrop Identifier	**Latitude (N)**	**Longitude (W)**
K-2	38.102045	82.381722
K-3	38.084953	83.382415
K-4	38.081899	82.381836
WV-1	38.130914	82.354663
WV-2	38.144366	82.345185

All five outcrops are located along the Big Sandy River, which marks the state line between West Virginia and Kentucky, and collectively span the upper Breathitt and lower Conemaugh Groups (Figure 4). The WV-1 and WV-2 road cuts were most recently modified, so their surfaces are the freshest, making facies identification from a distance easiest on these outcrops. K-2, K-3, and K-4 are on the Kentucky side of the river and are older and more overgrown. WV-1 is the highest outcrop in the stratigraphic section, and K-4 is the lowest outcrop in the stratigraphic section. K-2, K-3, and K-4 all contain the top-most portion of the Princess Formation of the Breathitt Group and approximately the bottom half of the Glenshaw Formation of the Conemaugh Group. WV-2 contains a majority of the Glenshaw Formation. WV-1 contains most of the Glenshaw Formation, and the lowest portion of the Casselman Formation of the Conemaugh Group.

The outcrops collectively form a strike section of about 13 km of the Appalachian Basin, with about 25% exposure (Figure 3). The distance from the northernmost outcrop to the southernmost outcrop is about 18 km along the river and 13 km in straight-line distance. About one-fourth of the distance from the northernmost outcrop to the southernmost outcrop is exposed when following the river with outcrops at various orientations.

These outcrops expose Middle to Upper Pennsylvanian-aged strata preserved in the Appalachian Basin. This study adopts the stratigraphic nomenclature used in Kentucky (Figure 4).

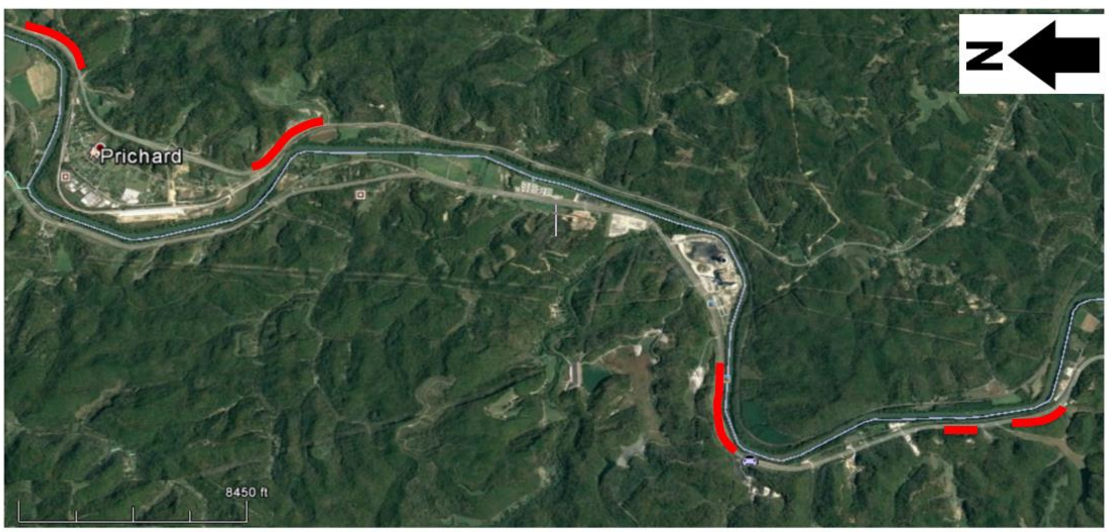


Figure 3. Location of outcrops (rotated 90 degrees to the left from **Figure 2**) showing the outcrop exposure within the study area. Images taken from Google Earth.

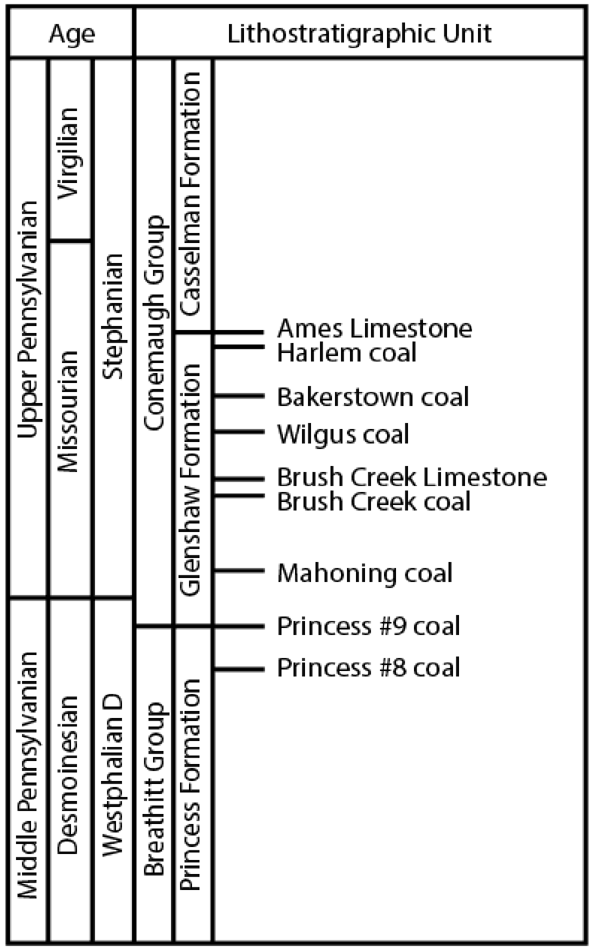


Figure 4. Stratigraphic Section of units in Middle and Upper Pennsylvanian strata within the Central and North Appalachian Basin (modified from Martino et al., 1996; Greb et al., 2004).

The Princess #9 coal bed marks the boundary between the underlying Breathitt Group and the overlying Conemaugh Group. The only part of the Breathitt Group considered in this study is the Princess Formation, just below the Princess #9 coal. The Conemaugh Group consists of the lower Glenshaw Formation and the upper Casselman Formation, which are separated by the Ames Limestone. The Glenshaw Formation is well exposed in the study area, but only the bottom-most portion of the Casselman Formation is visible. The Ames Limestone represents the last marine transgression into the study area during the filling of the Appalachian Basin (Merrill, 1988).

Where present, coals, paleosols, and marine limestones are generally laterally continuous stratigraphic markers. Coals were used primarily for correlation in this study. The coals used for correlation in this study include, in ascending order, the Princess #8, Princess #9, Mahoning, Brush Creek, Wilgus, Bakerstown, and Harlem coals. The marine limestones used for correlation in this study include, in ascending order, the Brush Creek Limestone (upper and lower) and Ames Limestone.

Paleogeographic Setting

The Appalachian Basin lays between the Cincinnati Arch to its northwest and the Appalachian fold and thrust belt to its southeast (Lebold and Kammer, 2006) (Figure 5). The Appalachian Basin is oriented northeast-southwest, and the part of the Appalachian Basin within the study area sits just above the Rome Trough, which separates the Northern Appalachian Basin from the Central Appalachian Basin (Chesnut, 1992; Greb et al., 2002). The Rome Trough is a graben that formed from intracontinental rifting in the late Proterozoic to Early Cambrian (Greb et al., 2008), and the trough is bounded by the Kentucky River Fault Zone and the Irvine-Paint Creek Fault Zone.

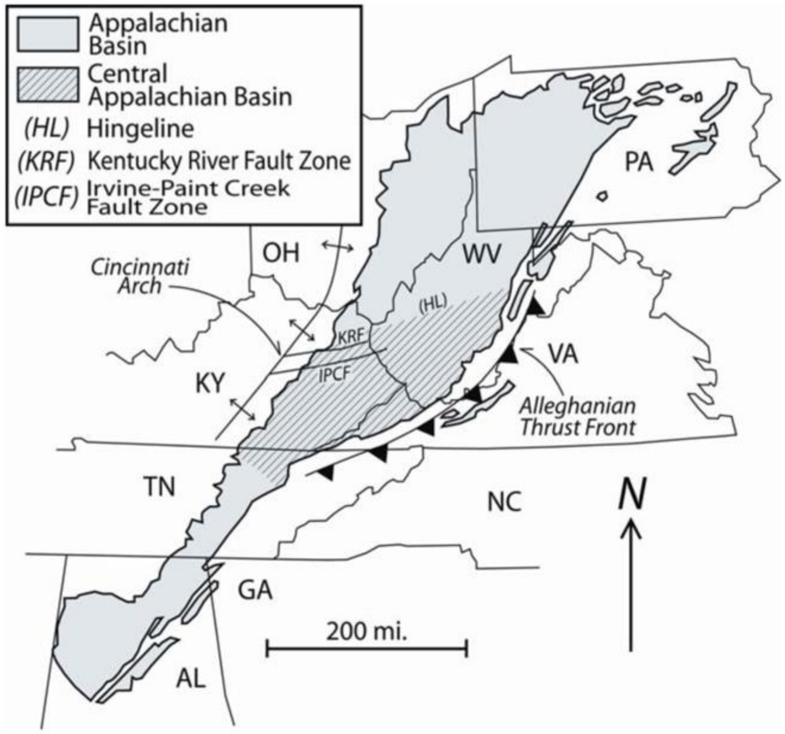


Figure 5. Map showing the extent of the Carboniferous deposits (light gray) in the Appalachian Basin. Major structures bounding the basin are shown. Note that the KRF and IPCF faults bound the Rome Trough. In addition, the Alleghenian Thrust Front labeled here is representing the location of the entire Appalachian Fold and Thrust Belt. Figure is adapted from Cecil et al., 1985; Chesnut, 1994; Greb and Chesnut, 1996; Korus, 2002; Greb et al., 2004; Greb and Martino, 2005; Bodeck Jr., 2006.

Shallow seas (the epeiric Midcontinent Sea) inundated the Appalachian Basin from the southwest numerous times during basin filling (Heckel, 1995) (Figure 6). At least eight transgressions occurred during the deposition of the Glenshaw Formation (Martino, 2004). The thin deposits these marine incursions left behind in the Glenshaw Formation of the Appalachian

Basin suggests that only the distal edges of the sea reached the basin during these times (Heckel, 1995).

Figure 6. Paleogeographic setting of the Appalachian basin during the Pennsylvanian Period (modified from R. C. Blakey). Seas inundated the basin from the southwest.

During the Middle Pennsylvanian Period, the Appalachian Basin was underfilled with sediment and contained an axial drainage system when regressed (Donaldson et al., 1985; Hembree and Nadon, 2011). An underfilled basin fills with mostly marine sediments. Rivers flowed west across the basin from the Appalachian Highlands, over forested coastal plains containing peat. Marine influence became increasingly common upward as evidenced by dark gray carbonaceous shales (Chesnut, 1991; Martino 1996; Greb et al., 2009). These marine shales divide units into sequences in the Central Appalachian Basin (Greb et al., 2008).

Through the Late Middle Pennsylvanian Period and into the Late Pennsylvanian Period, the Appalachian Basin became overfilled with sediment, and water flow trended towards the northwest (Donaldson et al., 1985; Nadon and Kelly, 2004; Hembree and Nadon, 2011), indicated by a northwest paleoflow direction (Martino, 2004). An overfilled basin fills with terrestrial clastic sedimentation. This is evidenced in the Appalachian Basin by the large volume of fluvial deposits throughout the Late Middle to Late Pennsylvanian Period (Nadon and Kelly, 2004).

Paleoclimate

The Pennsylvanian Period was an icehouse/glacial time, but the Appalachian Basin was located 5° to 10° south of the Equator within the contemporary tropics (Scotese, 1994; Heckel, 1995; Lebold and Kammer, 2006). The basin was rotated about 40° clockwise from its current location (Scotese, 1994; Greb et al., 2009). The Pennsylvanian location for the Appalachian Basin was also approximately 15° farther north than in the Mississippian Period. This northward shift caused a transition from a drier climate to a wetter climate (Cecil et al., 1994; Greb et al., 2009). The climate remained wet through the Middle Pennsylvanian Period, but became a mixture of dry to seasonably wet and dry during the Late Pennsylvanian Period (Cecil, 1990; Greb et al., 2009). This climate change was a result of the formation of Pangea and the restriction of penetration of moisture-laden air into the continental interior (Tabor and Montañez, 2002). As Laurasia and Gondwana collided resulting in mountain-building, atmospheric circulation patterns were redirected north of the mountains (Tabor and Montañez, 2002). Specifically, the Intertropical Convergence Zone flow from the east was redirected northwest. A rain shadow developed on the downwind side of the mountains (i.e. the Appalachian Basin) and this resulted in a drier climate in the Late Pennsylvanian Period for the basin (Tabor and Montañez, 2002).

Between deposits representing a dry to seasonably wet and dry climate in the Late Pennsylvanian Period are deposits that indicate transgressions and regressions of the Midcontinent Sea also influenced the climate (Heckle, 1995). Throughout the Middle to Late Pennsylvanian Period, the Appalachian Basin was about 4,000 kilometers from the nearest permanent ocean (i.e. the Tethys and Panthalassic oceans), and, therefore, that far from a permanent source of moisture (Heckel, 1995). This implies a dry Middle to Late Pennsylvanian Appalachian Basin climate, but the numerous local coals, particularly in the Breathitt Group, prove that moisture was reaching the basin. The North American Midcontinent Sea provided moisture from the west. Essentially, when the Midcontinent Sea was at its high stand, coal beds were deposited in the basin because of nearness of humid air masses and a rising water table (Heckel, 1995). Conversely, when the sea was in its lowstand phase, deltaic and terrestrial environments dominated the basin, and well-drained soils developed. The changes in climate greatly affected the amount of water and sediment the fluvial system was carrying, which in turn caused variations in the thickness of channel belts (e.g., Galloway, 1981; Blum and Törnqvist, 2000).

Tectonic Setting

The Appalachian Basin is a northeast-southwest oriented foreland basin that formed in response to the sequential Acadian, Taconic and Alleghenian Orogenies, which resulted from collisions along the eastern boundary of North America during the Paleozoic Era (Thomas, 1976; Quinlan and Beaumont, 1984; Tankard, 1986; Chesnut, 1991; Thomas, 1995; Greb et al., 2008). Three different depocenters formed to the northwest of the orogenic belt: the Northern

Appalachian, Central Appalachian and Southern Appalachian (Black Warrior) depocenters (Thomas, 1976; Quinlan and Beaumont, 1984; Thomas, 1995). The present Appalachian Basin is much smaller than the foreland basin that existed during the Pennsylvanian Period. The current basin consists of only the western part of the original basin, as the eastern part of the Pennsylvanian Appalachian Basin was thrusted during the Alleghenian Orogeny and was subject to erosion (Greb et al., 2009).

Sediment sources switched from the Late Mississippian Period to the Late Pennsylvanian Period. During Late Mississippian and Early Pennsylvanian time sediment sourced from the north and traveled in axial rivers (Chesnut, 1991). Starting in the Middle Pennsylvanian, as the ongoing Alleghenian orogenic event continued to uplift the land to the southeast, the sediment source changed. Sediment began sourcing off mountains to the southeast and was transported northwestward across the basin floodplain (Donaldson, 1979; Aiken and Flint, 1994).

Methods

This study is a combination of observations and measured sections completed in the field and 3D renderings of outcrops created using a DJI Phantom 4 Pro+ drone and Agisoft Photoscanner 3D software. Five road cuts were selected along Kentucky State Route 23 and West Virginia State Route 52 along an approximately 13-kilometer discontinuous exposure. These exposures are labeled K-2, K-3, K-4, WV-1, and WV-2. Each of these outcrops span parts of the Princess Formation, Glenshaw Formation, and Casselman Formation, and collectively encompass the uppermost Princess Formation through the lowermost Casselman Formation.

A minimum of two vertical sections were measured for each outcrop to identify vertical and horizontal variations in lithofacies, as well as to correlate sequence stratigraphic surfaces and systems tracts between outcrops. Changes in rock characteristics observed when measuring sections were used to distinguish between different depositional environments. Martino (2004) previously measured sections at the K-2 and WV-2 outcrops, which provided a starting point for correlation. Additionally, Dr. Cortland Eble of the Kentucky Geological Survey conducted a petrographic analysis of several different coal samples from the outcrops to provide a more accurate constraint on correlation of these stratigraphic markers. These coal beds, as well as sections from Martino (2004), were used to develop a regional stratigraphic framework. The correlated measured sections produce a cross-section across the strike of the basin in the study interval. This cross section captures sequence-stratigraphic trends and transitions from marine to fluvial dominance during basin filling.

Digital photos were taken at each outcrop using a DJI Phantom 4 Pro+ drone, and these digital images were loaded into Agisoft PhotoScan, a software product that performs photogrammetric processing of digital images to generate three dimensional models. A three-dimensional model was produced for each outcrop. Each photo taken with the drone was georeferenced, which allowed the software to align the photos. Second, a dense point cloud was made from the aligned photos, resulting in a large number of data points in the shape of each outcrop. Next, a mesh and texture were generated by triangulating points from the dense point cloud, which resulted in a three-dimensional rendering of the outcrop. Finally, the three-dimensional model was flattened to create an orthomosaic.

The orthomosaics were used to map lithofacies for each outcrop. Changes in lithofacies are generally easily distinguishable on the orthomosaics. Additionally, when visible, architectural elements were mapped onto the orthomosaics and sequence boundaries were identified.

Along with measured sections, lithofacies and architectural elements that were mapped onto orthomosaics allowed for correlation of surfaces between outcrops. These correlations were used to evaluate accommodation states, systems tracts and sequence stratigraphic trends.

Results

Lithofacies

The outcrops along State Highway 23 and State Highway 52 between Prichard, West Virginia, and Louisa, Kentucky, contain ten lithofacies. Table 2 summarizes the physical characteristics of these lithofacies and offers interpretations. These lithofacies are mapped individually or as components of lithofacies assemblages within architectural elements across digital outcrop models.

Table 2. Lithofacies identified in outcrop.

Lithofacies	Lithology	Structures	Fossils	Interpretation
Cross-laminated sandstone	Very fine to coarse grained sandstone	Planar laminated and trough cross bedded, commonly near base of sandstone scour, concave up channel form geometry, vertical and lateral accretion surfaces, local mud rip up clasts, local gravel layers. Sets range from only centimeters thick up to several meters thick	Rare plant fragments	Migration of ripples and dunes
Ripple-laminated sandstone	Very fine to medium grained sandstone	Ripple laminations, local climbing ripples, commonly get clay and silt partings less than one centimeter thick, local siderite beds and nodules,	Common plant fragments	Migration of ripples in low to moderate flow (i.e., Channel, splay, blowout

		commonly exhibits concave up channel form or sheet geometry. Beds range in thickness from one centimeter to one meter thick		wing, and delta front)
Planar-laminated sandstone	Very fine to medium grained sandstone	Horizontal laminations, commonly with clay and silt partings less than one centimeter thick, most commonly exhibits sheet geometry. Beds range in thickness from one millimeter thick to two meters thick	Common plant fragments	High energy flow or tidally influenced deposits. (i.e., splay deposits and blowout wings during flooding events)
Heterolithic sandstone, siltstone, and mudstone	Ranges from muddy siltstone to medium grained sandstone, occurs in alternating beds	Planar laminations, ripple laminations, commonly exhibits concave up channel form geometry or sheet geometry thickness ranges from 0.5 meters to 10 meters	Common plant fragments	Unstable flow conditions (i.e., Delta front, waning flows and abandoned channel fills)
Laminated siltstone and mudstone	Ranges from mudstone to siltstone	Planar laminations, siderite nodules, sheet geometry, commonly occurs in thick sections (up to 10 meters or more), gradational contact with floodplain mudflat deposits	Root balls and tree stumps, indicating period of exposure before drowning	Subaqueous accumulation of settled suspended load (i.e., Floodplain lake)
Bioturbated siltstone and mudstone	Ranges from mudstone to siltstone	Siderite nodules, commonly occurs in thick sheets (10 meters or more), commonly exhibits gradational contact with floodplain lake deposits	Plant fragments, burrowing, rooting, heavily bioturbated	Subaerially exposed settled suspended load (i.e., Floodplain mudflat)
Well-drained paleosol	Red and gray mudstone and siltstone	Blocky, hackly, peds and slickensides, local siderite beds and nodules, sheet geometry that thins and thickens laterally (generally ranges from one meter to 10 meters	Rooting	Well drained/oxidized paleosol indicating long periods of subaerial exposure

		thick), sharp contact with underlying sandstone facies, gradational contact with mudflat facies		
Poorly-drained paleosol	Gray, purple, and yellow mudstone and siltstone, locally with very fine grained sandstone	Mottled, blocky, hackly, peds and slickensides, local siderite beds and nodules, sheet geometry that thins and thickens laterally (generally ranges from one to five meters thick), gradational contact with mudflat or floodplain lake facies	Rooting, bioturbated	Poorly drained paleosol indicating a simple soil with a short period of subaerial exposure and frequent saturation
Coal	Coal and carbonaceous shale, locally with organic-rich siltstone partings	Laminated sheets that thin and thicken laterally. Coal seams generally are less than 80 centimeters thick, siltstone partings are up to two meters thick	Rooting, plant fragments	Peat swamp, mire (histosol)
Limestone	Gray to red wackestone to packestone and shale	Thin-bedded sheet geometry. Limestone beds usually less than 75 centimeters thick, laminated shale beds up to 1.5 meters thick.	Brachiopods, crinoids, Bryozoans, other shell fragments	Shallow marine, with periods of oxidation

Lithofacies Assemblages

Lithofacies observed in outcrop are grouped into four genetically related lithofacies assemblages: channel-belt, floodplain lake, floodplain mudflat, and delta front. Furthermore, these lithofacies assemblages combine to make up three super-assemblages: valley fill, poorly-drained floodplain, and well-drained floodplain. Besides the valley fill super-assemblage, the super-assemblages are generally not mapped and their comprising assemblages are mapped individually instead.

Channel-Belt Assemblage

The channel-belt assemblage contains cross-laminated sandstone, ripple-laminated sandstone, planar-laminated sandstone, heterolithic sandstone, siltstone, and mudstone lithofacies (see also Aitkin and Flint, 1995). This assemblage ranges from muds to coarse-grained sandstone, with local gravel layers observed in some coarse sandstones. Individual channel fills range from centimeters up to several meters thick, but are only rarely thicker than 2 meters. Commonly, this assemblage fines upwards. The channel-belt assemblage contains three elements: channel fills, blowout wings, and bars. This assemblage is observed in outcrop as both isolated channel belts, with its associated elements, and as an amalgamation of several channel-belt assemblages. The channel-belt assemblage is most commonly incised into the floodplain lake or floodplain mudflat assemblage. Within the channel-belt assemblage, channel fills and their associated blowout wings are both very common, and bar elements are less common. This assemblage is observed in all 5 outcrops. The channel fill, blowout wing, and bar elements of the channel-belt assemblage are each discussed individually bellow. Elements of this assemblage are very commonly found within all of the other assemblages (i.e. they are co-occurring).

Channel Fill Element

Channel fill elements commonly contain cross-laminated sandstone, ripple-laminated sandstone, planar-laminated sandstone, heterolithic sandstone, siltstone, and mudstone lithofacies. Channel fills are marked by a sharp basal scour and a concave up channel form geometry. This element most commonly fines upwards into the heterolithic sandstone, siltstone, and mudstone lithofacies, and appears in outcrop as both single-story isolated channels and amalgamated channels. A single-story channel fill is exhibited in Figure 7.

A typical channel fill exhibits a sharp basal scour into underlying strata, most commonly floodplain lake or floodplain mudflat. The channel in Figure 7 is deposited within floodplain mudflat deposits. Most channel fills are a fining upward progression of sandstone with cross-laminations near the basal scour topped by ripple-laminations and then planar laminations. The sandstone often transitions upwards into heterolithic sandstone and siltstone/mudstone fill. The fining upward trend and sequence of sedimentary structures indicates waning flow as the channel fills. Plant fragments and traces occur locally in channel fills but fossils are otherwise rare.

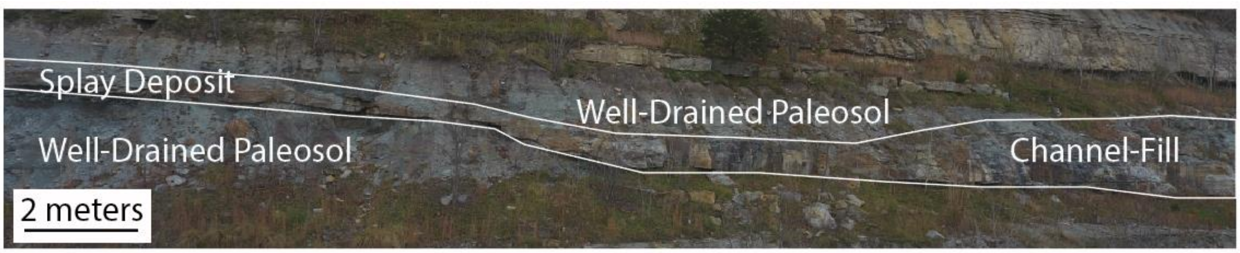


Figure 7. Channel fill deposited within floodplain mudflat assemblage elements. A splay deposit sourced from the channel wall is visible on left. Photograph taken at outcrop WV-1.

Blowout Wing Element

The blowout wing element is characterized by very fine to fine grained ripple-laminated sandstone and planar-laminated sandstone lithofacies. This element drapes down away from the channel fill element as a thin sheet that can maintain its thickness laterally for multiple channel widths (Figure 8). Individual sheets are usually less than 30 centimeters thick but are locally up to approximately 60 centimeters thick. Blowout wings are commonly truncated by other channels or blowout wings and commonly transcend the length of an outcrop, making it hard to estimate a lateral extent.

Tomanka (2013) first identified this element as sheets of sand perpendicular to channels that deposit into floodplain lake environments as a density flow during flooding events (Tomanka, 2013; Huling, 2014; Howe, 2017). Sedimentary structures are preserved in the blowout wings and bioturbation is minimal because they are deposited in water that is too deep to support plant life or terrestrial fauna (Figure 9).

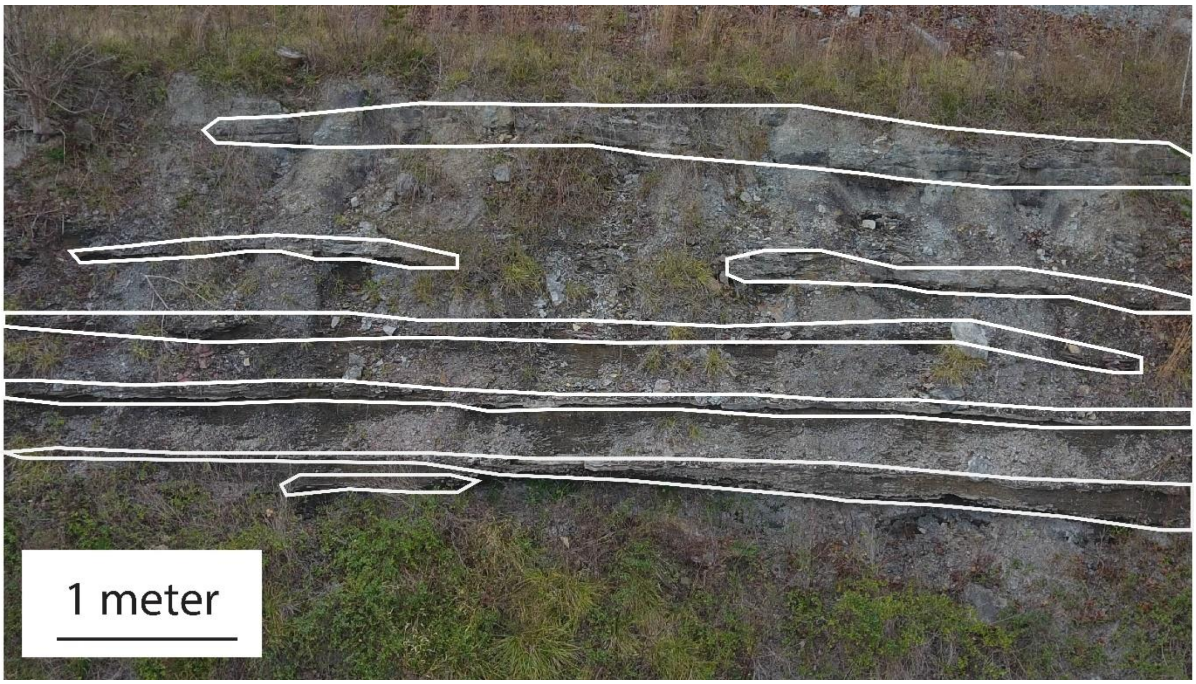


Figure 8. Blowout wings encased in floodplain lake assemblage. Photograph from K-3 outcrop.

Figure 9. Ripple-laminations and planar-laminations in a blowout wing are well-preserved owing to little bioturbation. Photograph from K-3 outcrop. Pencil for scale.

Bar Element

Bar elements are characterized by cross-laminated sandstone, ripple-laminated sandstone, planar-laminated sandstone, and heterolithic lithofacies. While some bars are heterolithic throughout, others are composed of a fining upward sandstone sequence. This element most commonly preserves at the top of channel belts and valley fills (Figure 10). They typically exhibit a sheet-like geometry and are observed to laterally accrete in outcrop. Bars exhibit a sharp basal scour into the underlying channel fill element, are overlain by either the floodplain lake or floodplain mudflat assemblage, and are laterally associated with channel fills. This element is generally 2 to 5 meters thick.

Figure 10. *Bar element at the top of a valley-fill from WV-2 outcrop.*

Floodplain Lake Assemblage

The floodplain lake assemblage is dominated by lithofacies found in poorly-drained environments, namely planar-laminated sandstone, ripple-laminated sandstone, heterolithic sandstone, siltstone, and mudstone, laminated siltstone and mudstone, poorly-drained paleosol, and coal lithofacies. This assemblage is very commonly incised into by the valley fill super-assemblage and the channel-belt assemblage. Most commonly, this assemblage presents as laminated siltstones and mudstones and coals that form a gradational contact with poorly-drained paleosols with intermittent channel fills with their associated blowout wings (also see Horne et al., 1978; Donaldson, 1979; Figure 11). Alternating deposits of laminated siltstones and mudstones (i.e. floodplain lake) and poorly-drained paleosols indicate a fluctuating water table. This assemblage commonly grades into the floodplain mudflat assemblage, a more moderately-drained assemblage, further supporting the evidence for a fluctuating water table. The poorly-drained paleosols are gray to yellow and purple, commonly thin (usually no more than 5 meters thick), weakly developed, and present as a sheet-like geometry. In addition, these paleosols are rooted and bioturbated, indicating periods of shallow water to subaerial exposure. The laminated siltstone and mudstone assemblage deposits as thick (up to 10 meters or more) and laterally extensive sheets. These deposits are devoid of rooting and bioturbation, indicating that the lake was too deep to support flora and fauna (Hasiotis, 1993; Hasiotis and Mitchell, 1993; Hasiotis and Honey, 2000). However, the tree stumps and root balls found within this lithofacies suggest that at times the water level was low enough to support plant life before drowning occurred. Common tree and plant traces include *Calamites*, *Sigillaria*, *Lepidodendron*, and many types of ferns.

Channel fill and blowout wing elements from the channel-belt assemblage are commonly observed within the floodplain lake assemblage (Figure 8, Figure 11). These sandstone elements contain ripple-laminations and planar-laminations and are generally devoid of any rooting or bioturbations. They record propagation of fluvial channels into and sometimes across open lakes as non-bifurcating mud-dominant deltas (Huling, 2014).

Coal and carbonaceous shale deposits record lake shallowing and establishment of swamps. These organic seems are typically thin (less than 80 centimeters thick) and commonly are interbedded with organic siltstone partings up to 2 meters thick. This lithofacies contains abundant rooting and plant fragments. While the coals are laterally extensive, their exposure in outcrop is often limited due to weathering and a tendency for vegetation to cover this lithofacies.

Figure 11. Floodplain lake assemblage. Note blowout wing elements from the channel-belt assemblage are commonly associated with the floodplain lake assemblage. Photograph from K-4 outcrop.

Floodplain Mudflat Assemblage

The floodplain mudflat assemblage is characterized by lithofacies found in moderate to well-drained environments (i.e. better drained than the floodplain lake assemblage). These lithofacies include ripple-laminated sandstone, planar-laminated sandstone, heterolithic sandstone, siltstone, and mudstone, bioturbated siltstone and mudstone, well-drained paleosol, and poorly-drained paleosol (Figure 12). Most commonly, this assemblage exposes bioturbated siltstones and mudstones that grade into either well-drained or poorly-drained paleosols. The degree of paleosol development depends on the exposure time (i.e. time for soil development) (Retallack, 1990; Martino, 2004). This assemblage commonly grades into the floodplain lake assemblage, a more poorly-drained assemblage. The alternation between the two assemblages indicates a fluctuating water table. Crevasse, or overbank, splays sharply part this assemblage. The floodplain mudflat and paleosols are distinct lithofacies and therefore are not included in the elements discussion below.

Crevasse Splay Element

The crevasse splay element consists of very fine to fine grained sandstone splay channels and mouth bars with associated intersplay siltstones and mudstones. Some crevasse splays exhibit ripple laminations and planar laminations, but very commonly these structures are erased owing to bioturbation from rooting and vertical burrows (see also Aitkin and Flint, 1995). Individual splays are observed in outcrop up to 1 meter thick, but are more commonly much thinner (approximately 30 to 50 centimeters). These sheets create a sharp basal contact with the underlying strata owing to floodplain scour during their deposition. This is because deposition occurs quickly during a flood event when a river breaches its banks and sediment deposits on top of the adjacent mudflat (Coleman, 1988; Mjos et al., 1993; Cahoon et al., 2011; Hampson et al., 2013). The sheets thin laterally away from the breached channel wall, indicating that sediment deposited as energy in the sheet flow waned. These deposits are distinguished from underlying and overlying mudstone because they tend to be slightly coarser grained.

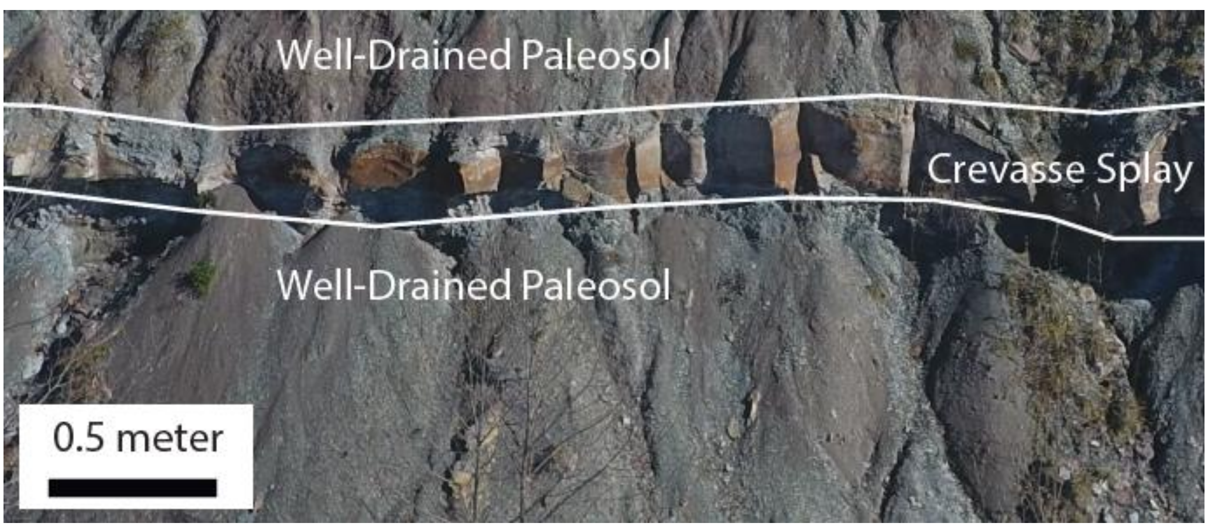


Figure 12. Crevasse splay and well-drained paleosol (altered mudflat) associated with the floodplain mudflat assemblage. Photograph taken from WV-1 outcrop.

Delta Front Assemblage

The delta front assemblage is characterized by cross-laminated sandstone, ripple-laminated sandstone, planar-laminated sandstone, and heterolithic lithofacies. This assemblage typically coarsens upwards overall and ranges from siltstone to fine-grained sandstone. The delta front lobes present as predominantly laminated and rippled sandstone bodies with lobate/mounded geometries. Individual lobes are easily distinguished at K-2, K-3, and K-4 because the strata that deposits on top of these lobes will follow the same lobate topography (Figure 13). Additionally, deltaic concave up distributary channels and sheets (sheets are amalgamated channel fills) cut into the lobes of the delta front (see channel fill element described above). Plant fragments and vertical burrows are commonly found within this association (Figure 14). Some of the planar laminations at the top of this assemblage are interpreted as tidal rhythmites, as spring and neap tidal cycles can be distinguished (Martino, 1996; Martino, 2004; Figure 15). This assemblage is observed in outcrop at the top of valley fill super-assemblages. This assemblage is overlain by either floodplain lake or floodplain mudflat assemblages.

Figure 13. Delta lobe with mounded geometry from outcrop K-4.

Figures 14 and 15. Burrows and tidal rhythmites associated with delta front assemblage. Photographs from WV-1 and K-4 outcrops.

Delta Lobe Element

Individual lobes of a delta are distinguishable at K-2, K-3, and K-4. These lobes consist of ripple and planar-laminated sandstone, as well as heterolithic fill. These lobes have a mounded structure, and sediments deposited on top of the lobes will follow the same topography. Individual delta lobes are observed in outcrop up to 2.5 meters thick. The lobes coarsen upward and commonly contain plant fragments and vertical burrows. This element is always found in the delta front assemblage, and the delta front assemblage is most commonly associated with the poorly-drained super-assemblage.

Valley Fill Super-Assemblage

A valley fill, by definition, must include at least two vertically stacked channels, meaning the valley fill is multistory (Friend et al., 1979; Bridge, 2003; Gibling, 2006). The valley fill super-assemblage is dominated by amalgamated channel-belt assemblages. Valley fills with amalgamated channel fills average approximately 14 meters thick but range from 7 to 20 meters thick. The valley fill super-assemblage is most commonly incised into the floodplain lake or floodplain mudflat assemblage. Channel fills and blowout wings are both very common in the valley-fill super-assemblage, but bar elements are more frequently observed in the valley fill super-assemblage than in the channel-belt assemblage.

Poorly-Drained Floodplain Super-Assemblage

The poorly-drained floodplain super-assemblage is dominated by the floodplain lake assemblage but can also contain elements from the channel-belt assemblage, particularly blowout wings. This super-assemblage is also often found surrounding the delta front assemblage. The poorly-drained floodplain can occur in very thick sections, especially in the Kentucky outcrops. For example, K-3 contains a continuous section of poorly-drained deposits more than 40 meters thick.

Well-Drained Floodplain Super-Assemblage

The well-drained floodplain super-assemblage is dominated by elements from the floodplain mudflat assemblage, particularly well-drained paleosols and floodplain mudflat.

Elements from the channel-belt assemblage can also be associated with this super-assemblage. Well-drained deposits are more prevalent in up-dip sections of the study area. For example, WV-1 contains a well-drained paleosol more than 20 meters thick.

Outcrop Facies Architecture

The figures below illustrate uninterpreted and interpreted plates of the distribution of the lithofacies and lithofacies assemblages described in the above sections. Digital outcrop models were constructed for each outcrop and appear below in order of ascending stratigraphy (Figures 16-21). In addition, a figure is included correlating between outcrops (Figure 22). Measured sections are included as appendices.

One notable feature observed at WV-2 is a large slump structure on the left side of the outcrop. The slumped section is identified on the interpreted plate for WV-2 and is marked by diagonal lines. The stratigraphic order around this slump block is completely destroyed, and approximately 20 meters of strata are missing from the section on the left side of the outcrop. Note that in the correlation of outcrops figure (Figure 22) the WV2.1 measured section has been corrected for this slump in order to better correlate between outcrops. Martino states that the slump block in WV-2 is due to mass wasting of over-steepened valley walls (Martino, 2004).

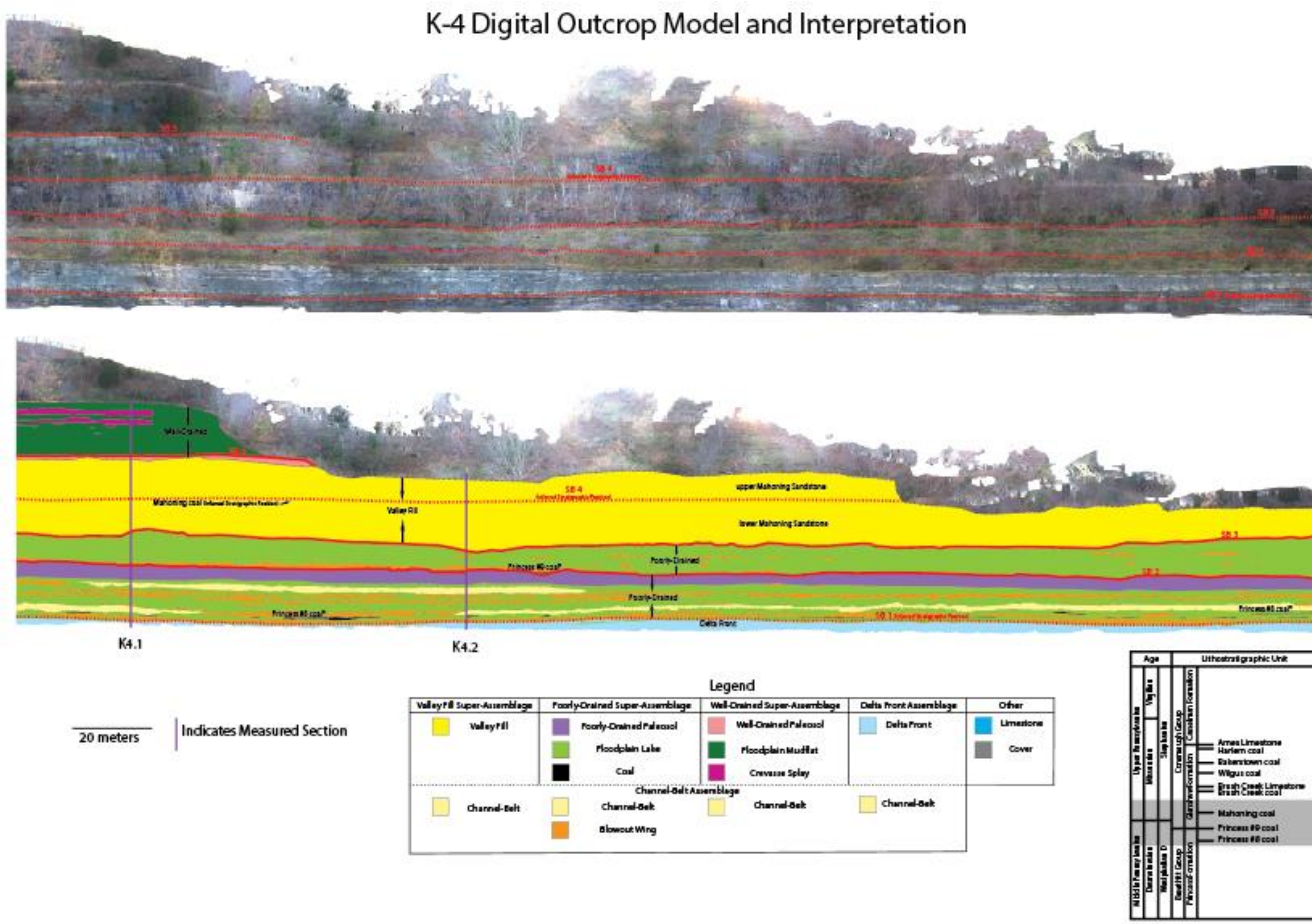


Figure 16. Uninterpreted and interpreted digital outcrop model of the K-4 outcrop illustrating the facies architecture recorded in this outcrop. An asterisk (*) indicates a confirmed coal location from samples collected for testing.

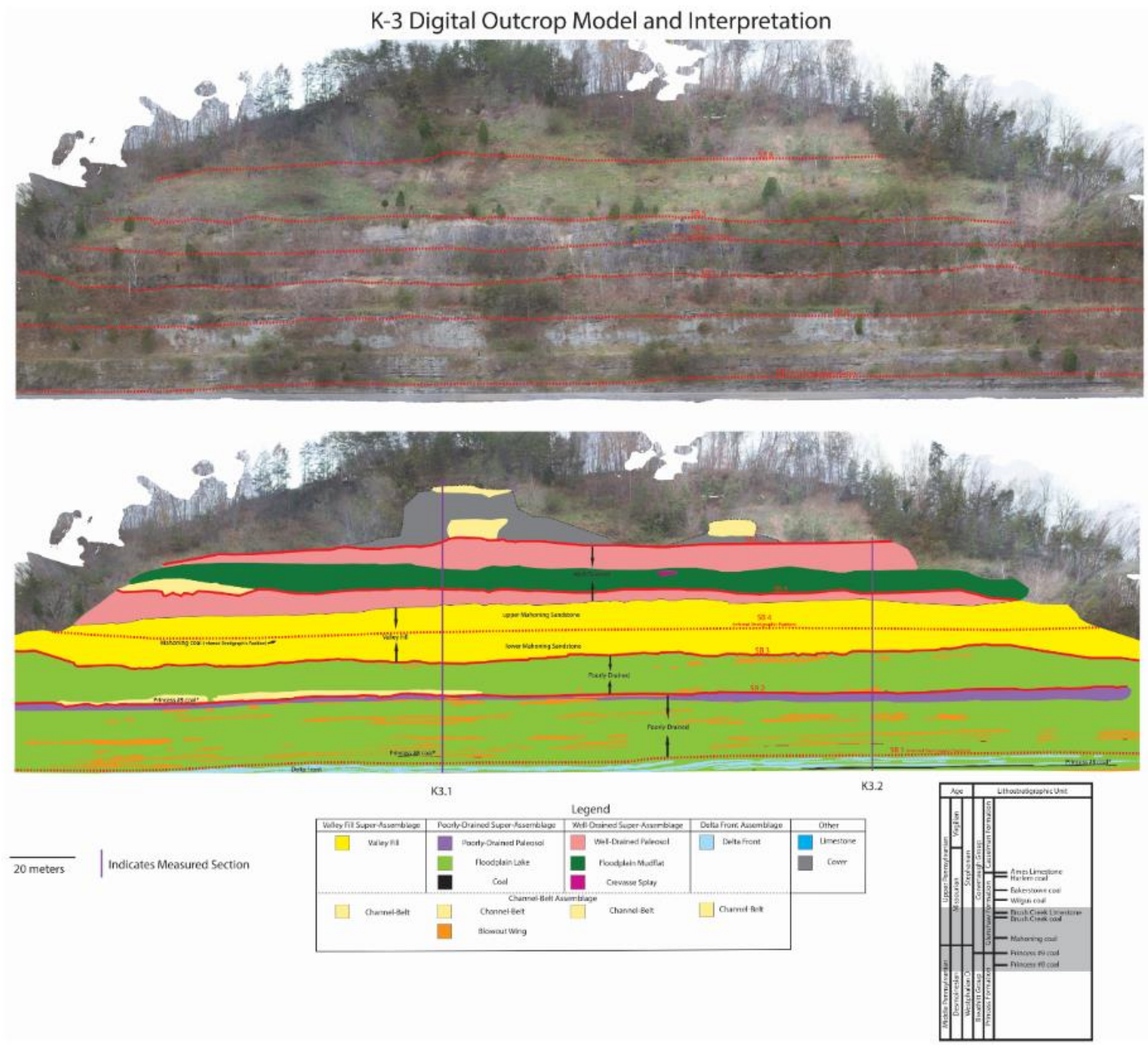


Figure 17. Uninterpreted and interpreted digital outcrop model of the K-3 outcrop illustrating the facies architecture recorded in this outcrop. An asterisk (*) indicates a confirmed coal location from samples collected for testing.

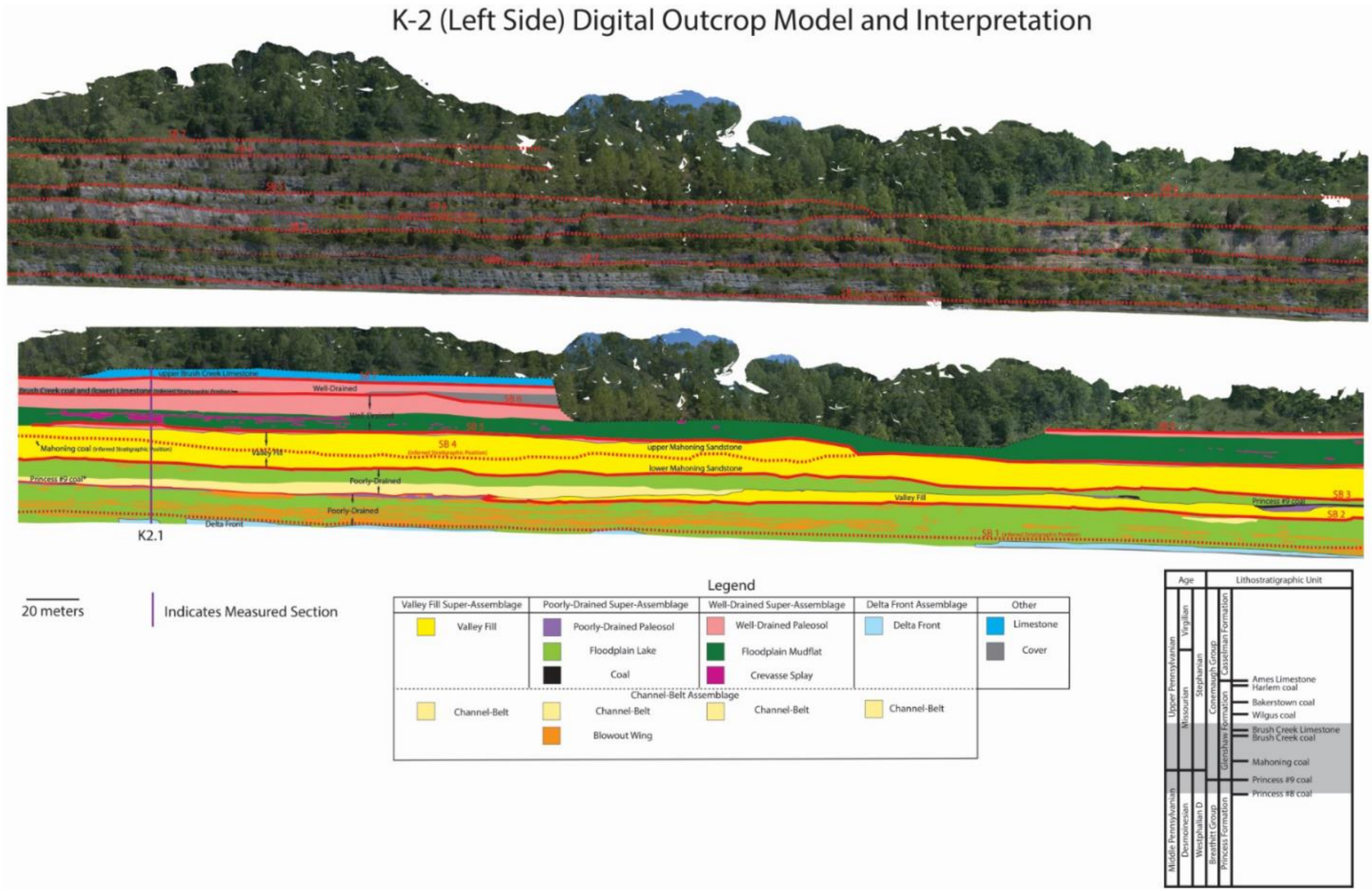


Figure 18. Uninterpreted and interpreted digital outcrop model of the K-2 (Left) outcrop illustrating the facies architecture recorded in this outcrop. An asterisk (*) indicates a confirmed coal location from samples collected for testing.

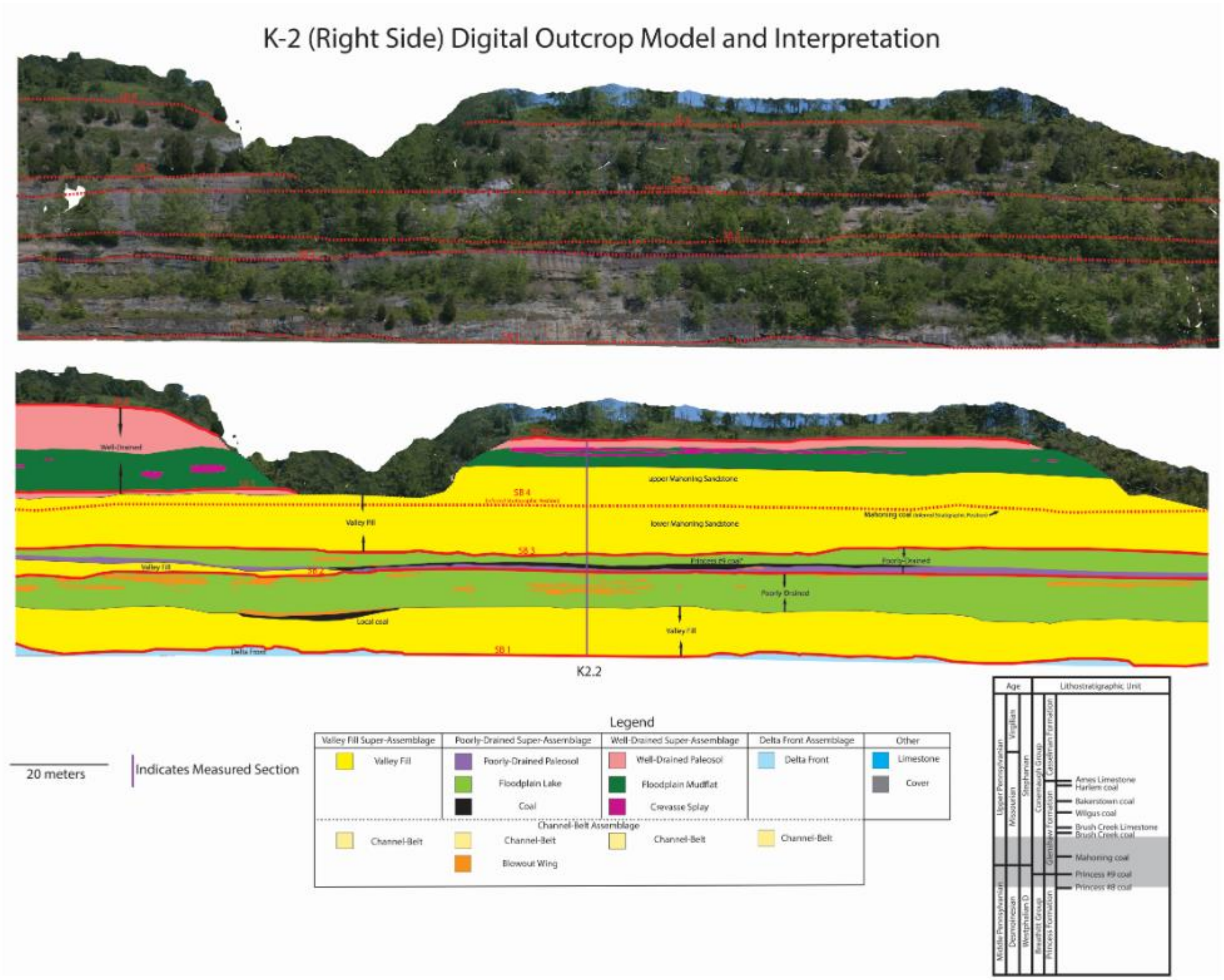


Figure 19. Uninterpreted and interpreted digital outcrop model of the K-2 (Right) outcrop illustrating the facies architecture recorded in this outcrop. An asterisk (*) indicates a confirmed coal location from samples collected for testing.

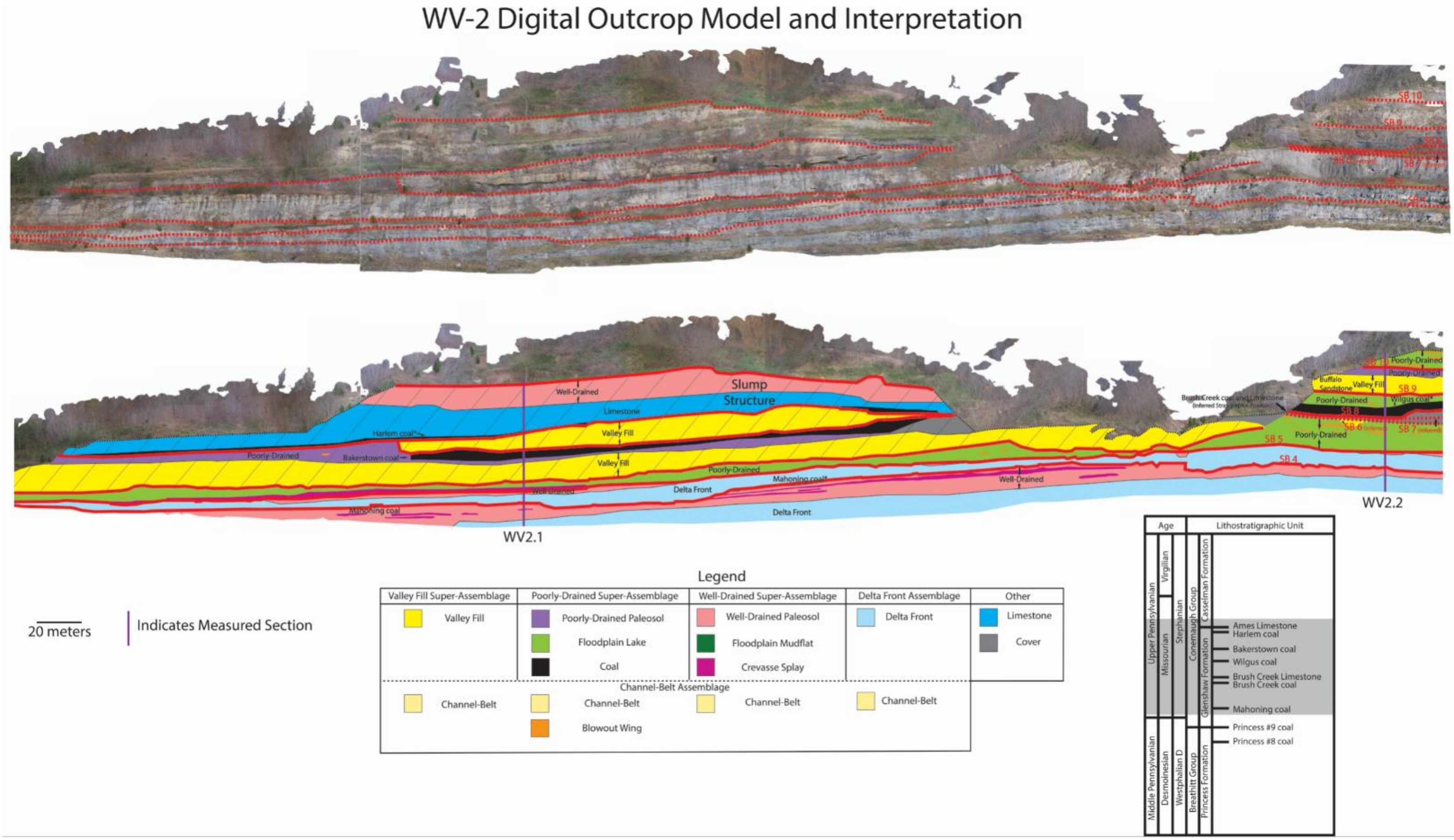


Figure 20. Uninterpreted and interpreted digital outcrop model of the WV-2 outcrop illustrating the facies architecture recorded in this outcrop. An asterisk (*) indicates a confirmed coal location from samples collected for testing. Note that no sequence interpretations are made for the left side of the outcrop in the area of the slumped section.

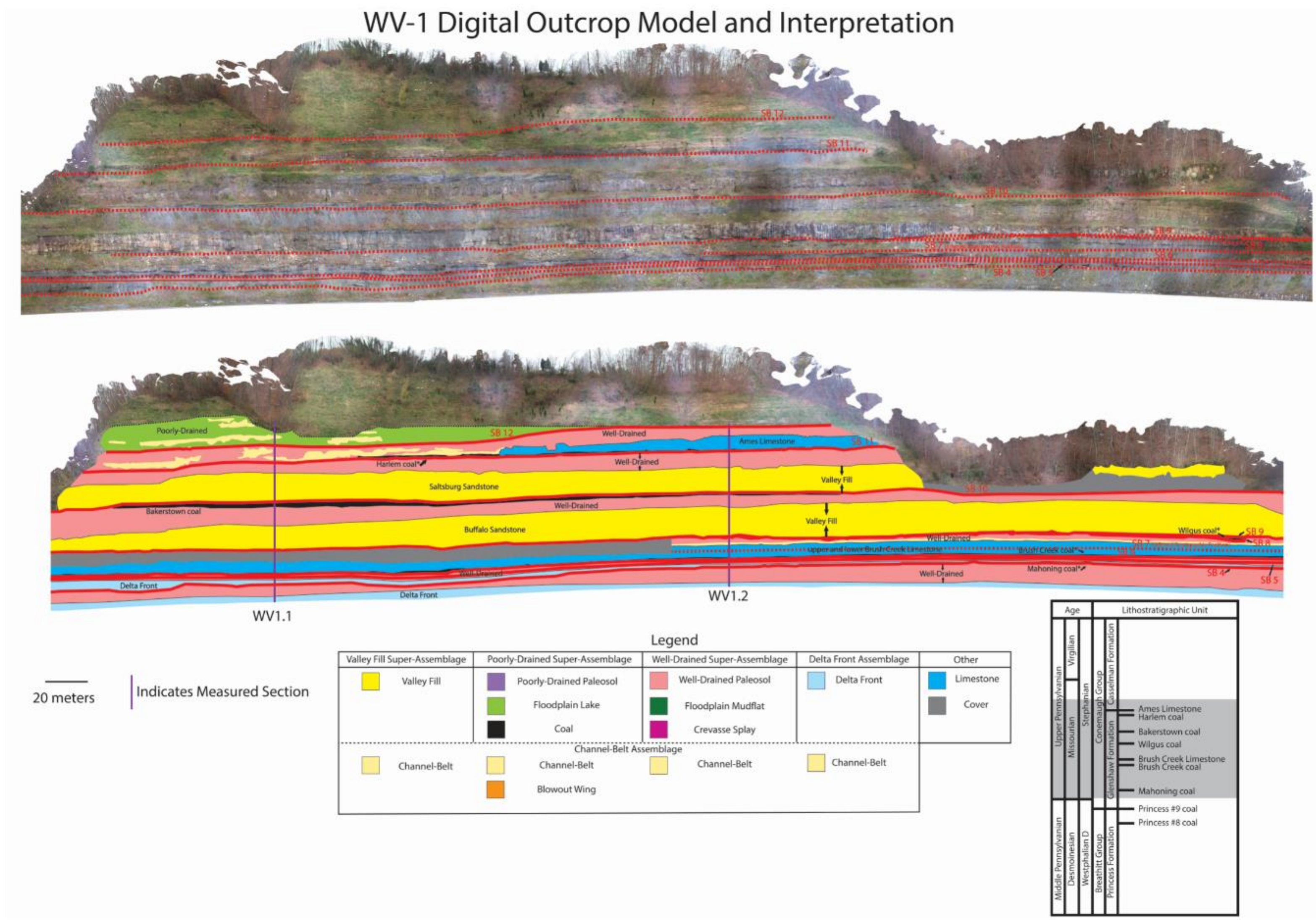


Figure 21. Uninterpreted and interpreted digital outcrop model of the WV-1 outcrop illustrating the facies architecture recorded in this outcrop. An asterisk (*) indicates a confirmed coal location from samples collected for testing.

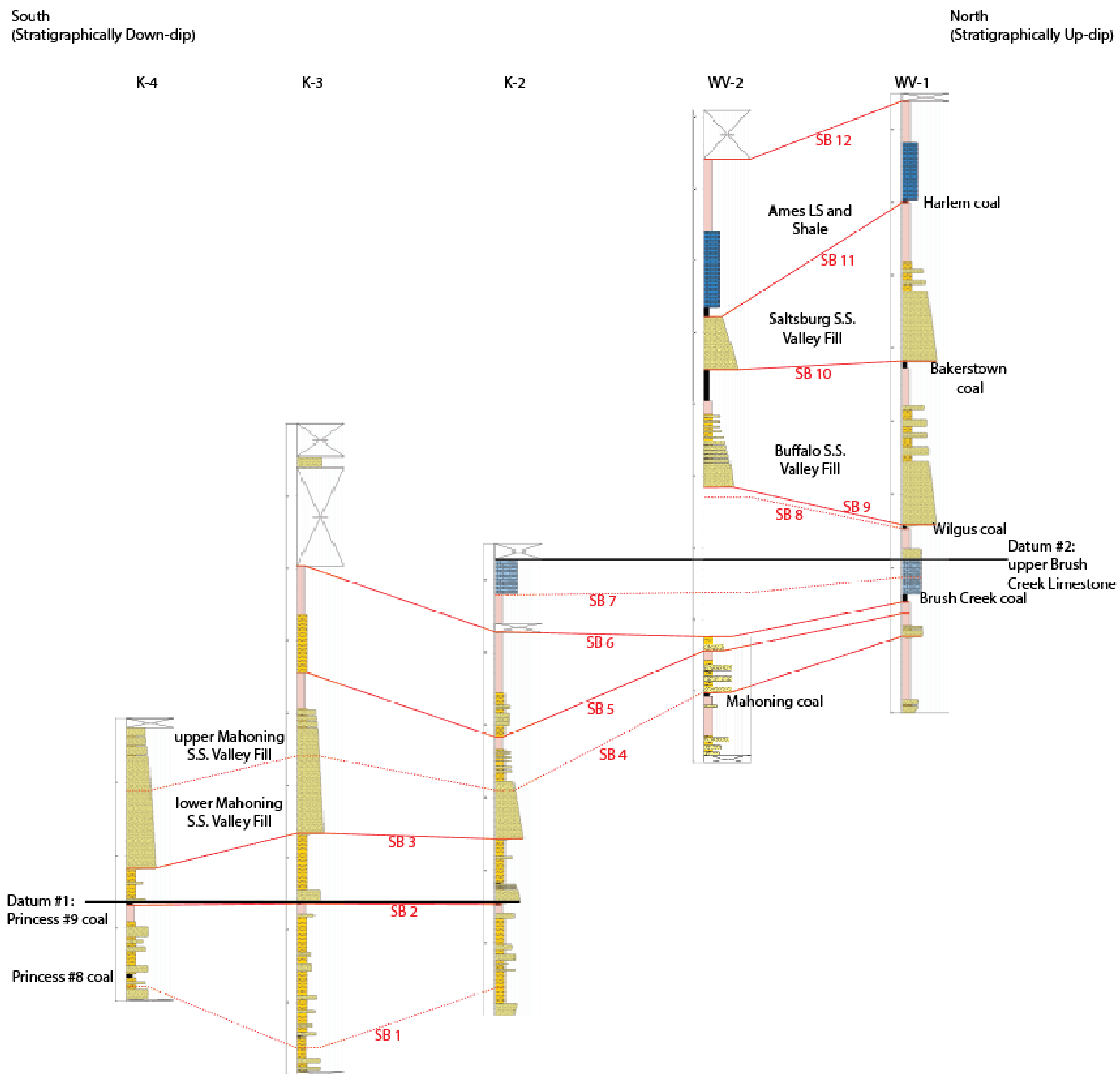


Figure 22. Correlation of outcrops in study area. Dashed sequence boundaries indicate that the sequence boundary is interpreted. The section for WV-2 has been corrected to accommodate for the slump structure.

Discussion

Similarities and Differences with Stratigraphy of Prior Studies

The findings of this study build on and add to the prior work of Martino (2004). Martino (2004) generated a composite section of the Glenshaw Formation of the Conemaugh Group based on the sections he measured in and around the Prichard, West Virginia, to Louisa, Kentucky, cross section of this investigation (Figure 23). He identified nine sequences when he applied the traditional fluvial sequence stratigraphic models (e.g. Wright and Marriot, 1993; Shanley and McCabe, 1994) to his composite section of the Glenshaw Formation. These sequences are also identified in this study using both the tops of paleosols and valley scours as sequence boundaries. This study identifies ten sequences in the Glenshaw Formation, as well as one complete sequence and one partial sequence in the underlying Princess Formation, and one partial sequence in the overlying Casselman Formation. The sequence stratigraphic model generated in this study shares similarities with the composite section created by Martino, but with several updates considering new ideas by (Bryant et al., 1995; Holbrook and Bhattacharya, 2012; Colombera et al., 2015). Additionally, this study considers floodplain architecture in greater detail than the previous model.

The area considered for this study is much smaller than the area considered for Martino's study (Figure 24), and therefore, the composite section created for this study contains some key differences (Figure 25). Namely, because this study was completed on a much smaller scale, outcrops were observed in much finer detail. More architectural elements were accounted for than a larger scale project could capture. Similarly, additional insight into sequence stratigraphic processes is gained.

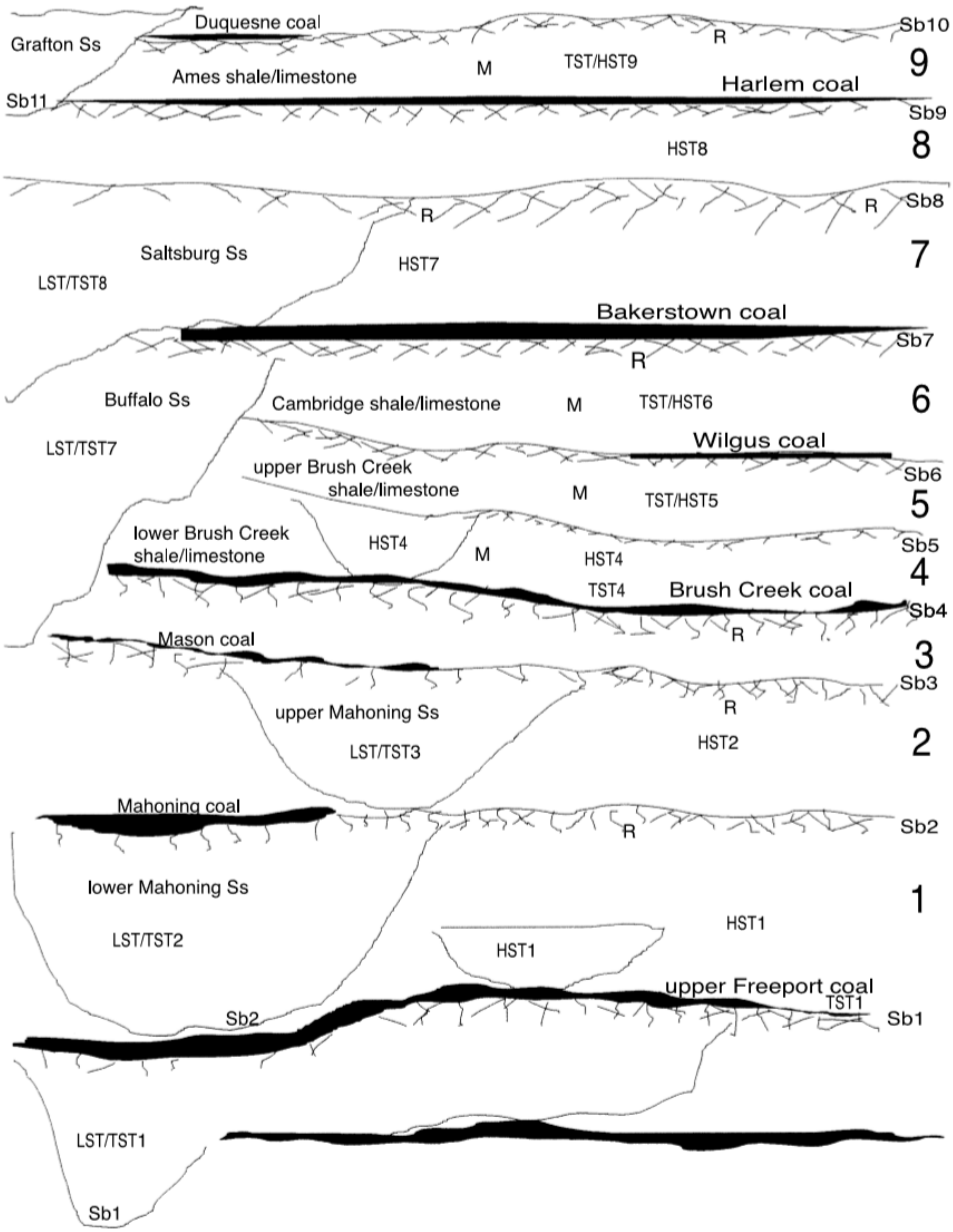


Figure 23. Composite section derived from sections measured by R. Martino. (Martino, 2004).

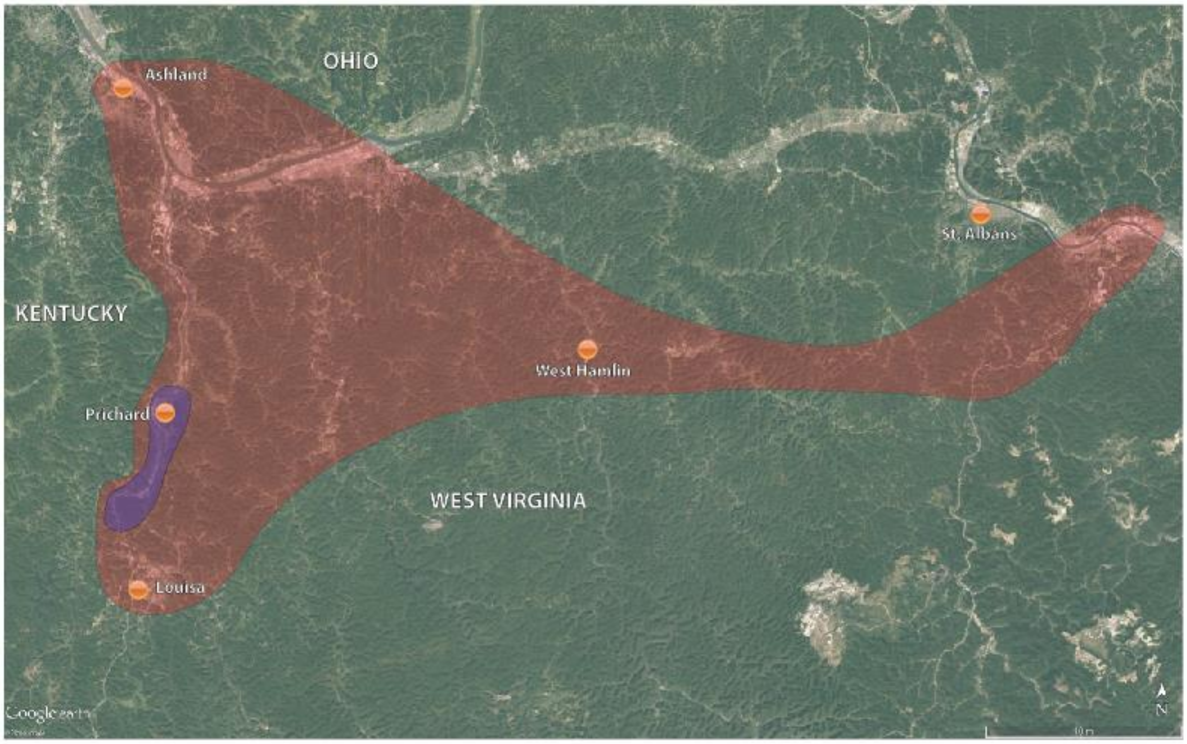


Figure 24. Area of study taken into account for Martino's composite section (red) versus my composite section (purple). Figure taken from Google Earth.

Certain units identified in Martino's section are not present within the study area, notably, the Mason coal, the Cambridge Limestone, the Duquesne coal, and the Grafton Sandstone. It is interpreted that the Mason coal locally pinches out in the study area, as it already appears to be variable within the area that Martino studied. Next, the Cambridge Limestone is interpreted as missing in the study area due to the incision of the Buffalo Sandstone. Finally, both the Duquesne coal and the Grafton Sandstone are interpreted as being in the covered sections near the very top of the WV-2 and WV-1 outcrops and were unidentifiable in both the digital outcrop models and when measuring sections.

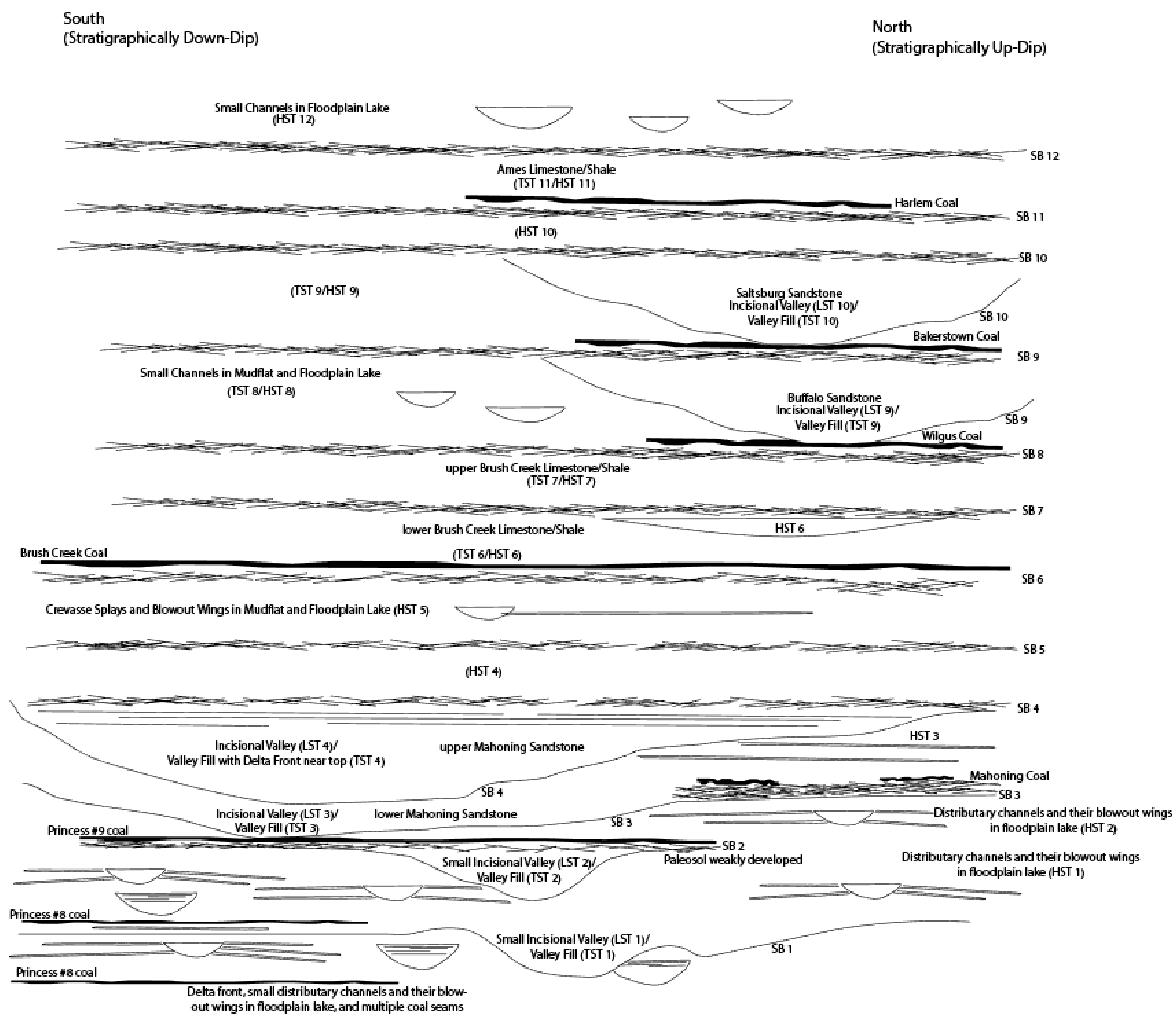


Figure 25. Composite section created from vertical sections measured in this investigation. An effort was made to show the units as they are exposed from south to north on a strike section.

Sequences were interpreted from the composite vertical section made for this study using the traditional fluvial sequence stratigraphic models (e.g. Wright and Marriot, 1993; Shanley and McCabe, 1994) similar to Martino, but with updated modifications to the model (e.g., Bryant et al., 1995; Holbrook and Bhattacharya, 2012; Colombera et al., 2015) and additional consideration of floodplain architecture. Eleven complete sequences and two partial sequences are identified in the five outcrops. In the composite section, an effort was made to display the units as they are exposed from south to north on a strike section. The composite section generated for this study broadly fits a traditional fluvial sequence stratigraphic model.

Interpretation of Sequences

Sequence boundaries in the Northern and Central Appalachian Basin are marked by scours below incised valleys, and paleosols formed during periods of little to no deposition on the interfluves between incised valleys. A basal peat tops most paleosols, which marks a basin-ward facies shift and the beginning of a new sequence. These sequence boundaries are generally laterally continuous throughout the study area.

Eleven complete sequences (and two partial sequences) are exposed in the five outcrops considered for this study (Figure 25). In some cases, parts of sequences are missing owing to the incisional nature of the valleys that form during sequence lowstands. These sequences make up the very top part of the Princess Formation of the Breathitt Group, the entirety of the Glenshaw Formation of the Conemaugh Group, and the very base of the Casselman Formation of the Conemaugh Group.

Sequence 1

Sequence 1 is the first complete sequence observed in outcrop. Sequence boundary 1 is laterally continuous throughout the K-2, K-3, and K-4 outcrops, but a discernable sequence boundary is only observed at K-2 below an incised valley. At K-3 and K-4, the sequence boundary is on the interfluve, and no associated paleosol or coal development is observed at this interfluvial sequence boundary. Therefore, the inferred location for the sequence boundary is above the deltaic facies within a poorly-drained floodplain lake interval that is largely devoid of blowout wings. No other features are available to stratigraphically place this sequence boundary at the K-3 and K-4 outcrops. At K-2, an incisional sequence boundary is observable at the basal scour of a small valley incising into deltaic deposits. The scour surface represents the lowstand incision for sequence 1. The sedimentary fill that deposits within the valley records falling stage through early transgression for sequence 1. The valley fill for this sequence includes fining upward sandstone channel belts topped by interfingering silt and sand channels indicative of slowing energy as the valley fills. One local, channelized coal is observed at the top of the valley fill, recording channel abandonment after an avulsion event, indicating that poorly-drained conditions were dominating (Martino, 2015). Additionally, the absence of an interfluvial paleosol for this sequence further supports the notion that the environment remained poorly-drained throughout incision and aggradation. Highstand deposits for this sequence include a continuation of the poorly-drained super-assemblage consisting predominantly of floodplain lake and blowout wing elements. This environment persists until the start of the next sequence suggesting that accommodation state remained high or later deposits are eroded.

A partial sequence is exposed locally below sequence 1 that encompasses strata from the upper portion of the Princess Formation. This partial sequence is visible at outcrops K-2, K-3, and K-4, and includes only the highstand portion of the sequence. The lowest visible strata is heavily burrowed sandstone (Figure 26) with cross lamination, ripples, climbing ripples and planar laminations. Beds at the top of these strata display parallel laminations that exhibit thick and thin coupling indicative of tidal influence (Figure 27). These parallel laminations are interpreted as tidal rhythmites associated with tidal cycles. Similar features have been recognized in the Breathitt Group by Greb and Chesnut (1992) and in the Middle Pennsylvanian Kanawha Formation by Martino (1996). The sandstone is mostly channelized, in some places demonstrating a clear lobate geometry. Channel sandstone is also amalgamated into sheets of sand. This sandstone is interpreted as delta front with visible mouth bars and a combination of isolated and amalgamated channel elements. The deltaic channels start out amalgamated at the bottom of the outcrop, but grade upwards into more isolated distributary channels and blowout wings separated by unbioturbated floodplain lake silts (i.e. poorly-drained floodplain super-assemblage) as accommodation in the system increases and the water table rises. Also within the poorly-drained super-assemblage are several thin seams of the Princess #8 coal. The recurring coal seams indicate brief transgressions/rises in base level, causing water table rise, and therefore swampy conditions, during an overall episode of basinward progradation. Between each seam of the Princess #8 coal are additional distributary channels that prograde across the basin.


Figure 26. Vertical burrows in distributary deltaic facies.
Figure 27. Tidal rhythmites in deltaic facies as indicated by thick and thin bundled couplets.

Sequence 2

Sequence boundary 2 is exposed at the K-2, K-3 and K-4 outcrops. At K-3 and K-4, the sequence boundary develops on an interfluve, but at K-2, a small incised valley is visible cutting into highstand deposits for sequence 1. This small valley represents the lowstand systems tract for sequence 2. The dominant fill in this valley is small channels. After valley filling, a thin, poorly-drained paleosol developed across the filled valley. This same paleosol was already forming on the interfluve because during valley filling, the interfluve was starved of sediment since all sediment is bypassing the interfluve and depositing in the incised valley instead. The characteristics of this paleosol (poorly-drained, thin) suggest that time of exposure for soil development was brief and that the environment remained poorly-drained throughout valley filling. A basal peat, the Princess #9 coal, deposits on top of the thin paleosol formed on top of the interfluve and filled valley. The Princess #9 coal marks the beginning of the Conemaugh

Group. This coal is laterally continuous throughout the K-2, K-3, and K-4 outcrops. Above the coal lies poorly-drained floodplain lake deposits with a small proportion of blowout wings. The presence of poorly-drained floodplain deposits after coal deposition indicates that the water table continued to rise past the point of swampy conditions to form a lake environment. In addition, there is a small channel-belt that deposits on top of the coal and thin paleosol and incises into the small valley. This poorly-drained environment persists until accommodation is no longer abundant (i.e. the water table lowers) and the next lowstand starts.

Sequence 3

The sequence boundary for sequence 3 is marked by a large incised valley scour visible throughout the K-2, K-3, and K-4 outcrops. The base of this incised valley carves into the highstand deposits from sequence 2 at all three outcrops. Incision occurred at sea level lowstand when base level was at its lowest. This valley fills with sandy fluvial channels commonly known as the Mahoning Sandstone. The Mahoning Sandstone presents as many amalgamated channel belts in two vertically amalgamated valleys in the K-4, K-3 and K-2 outcrops. In the WV-1 and WV-2 outcrops, the Mahoning Sandstone appears as two separate valleys: the lower Mahoning Sandstone and the upper Mahoning Sandstone. In the West Virginia outcrops, these sands display many deltaic elements, and are therefore interpreted on the digital outcrop models as delta front. The lower and upper Mahoning Sandstone are separated by a paleosol and the Mahoning coal, which is visible at the WV-1 and WV-2 outcrops. While the base of the lower Mahoning Sandstone incised valley is not visible in the West Virginia outcrops, portions of the lower Mahoning Sandstone and the entire upper Mahoning sandstone are exposed. The base of the lower Mahoning Sandstone records sequence boundary 3, and the base of the upper Mahoning Sandstone records sequence boundary 4. Therefore, in K-2, K-3 and K-4, where the two valleys are amalgamated, the highstand deposits of sequence 3 are absent. Conversely, at WV-1 and WV-2 where the valleys are separated from one another, highstand deposits are visible for sequence 3. These deposits consist of a thick, well-drained paleosol (commonly containing crevasse splays) and the Mahoning coal on top of the valley fill and interfluve for sequence 3 and just below sequence boundary 4. Because the paleosol contains sand sheets interpreted as crevasse splays, it is interpreted that the paleosol formed in deposits that were subaerially exposed. The thin, spotty Mahoning coal and the presence of the well-drained paleosol with bioturbated crevasse splays represents the first appearance vertically of the well-drained super-assemblage. This is part of an overall drying up trend in the system. The top of the highstand deposits are not observable at any outcrop owing to consistent incision of the upper Mahoning Sandstone.

Sequence 4

At K-2, K-3 and K-4, the base of sequence 4 is the upper Mahoning Sandstone incised valley cutting into the valley fill formed in sequence 3. This sequence boundary is interpreted through the amalgamated sand bodies where a clear scour surface is not observed. Additionally, an inferred stratigraphic position for the Mahoning coal is placed just below sequence boundary 4 at these three outcrops. The combined lower and upper Mahoning Sandstone valley fills are pictured in Figure 28. At WV-1 and WV-2, the upper Mahoning Sandstone incises into highstand deposits from sequence 3 and the two valleys are separated. The valley fill for the upper Mahoning Sandstone is very similar to that of the lower Mahoning Sandstone. Both generations of valleys fill with sandstone-rich channel belts with local silty channel belts topped by interbedded sands and silts indicative of tidal influence.

Figure 28. Amalgamated lower and upper Mahoning Sandstone at the K-4 outcrop.

Across the entire study area, a well-drained paleosol tops the upper Mahoning Sandstone valley fill. The presence of this paleosol indicates that at a location outside the study area, valley incision occurred allowing for a lack of deposition in the study area. Because the paleosol is well-drained, it is interpreted that incision was relatively deep. This paleosol is commonly thin. At the WV-1 outcrop, this paleosol is topped by another paleosol, but a sequence boundary is determined because of a distinct color change that happens between the two paleosols, indicating changing environmental and water table conditions.

Sequence 5

Sequence 5 is largely absent in the study area. In the Kentucky outcrops, it presents only as floodplain mudflat deposits containing crevasse splays and a well-drained paleosol. In the West Virginia outcrops, this sequence presents as poorly-drained floodplain at WV-2 and a well-drained paleosol at WV-1. This sequence continues until the base of the Brush Creek coal which is covered at all outcrops except for WV-1.

It is notable that at WV-2, sequence 5 exposes as poorly-drained floodplain lake with small channels and blowout wings with a covered section above and that at WV-1, sequence 5 exposes as a well-drained paleosol. It is interpreted that WV-1 was topographically higher than WV-2 during basin filling, allowing for poorly-drained muds to deposit in low spots (WV-2) while higher spots were able to drain and develop a paleosol (WV-1).

Sequence 6

The start of sequence 6 is marked by the appearance of the Brush Creek coal above the sequence boundary. No lowstand deposits are witnessed within the study area for this sequence, but the presence of a well-drained paleosol directly below sequence boundary 6 indicates that an incised valley associated with this sequence is located outside of the study area. The Brush Creek coal and lower Brush Creek Limestone are well exposed at WV-1. The Brush Creek coal and lower Brush Creek Limestone likely deposit within the covered section at the K-2 and WV-2 outcrops. The Brush Creek coal is overlain by the first marine incursion recognized in the stratigraphic section, the lower Brush Creek Limestone and Shale. The Brush Creek coal and lower Brush Creek Limestone and Shale make up the transgressive systems tract of sequence 6, with the limestone representing the maximum transgression for the sequence. The lower Brush Creek Limestone and Shale was observed at WV-1, and is very fossiliferous, with an exceptional abundance of brachiopods in several sheet geometry limestone beds. Other fossils are observed in a much lesser abundance (Figure 29, Figure 30, and Figure 31).



Figure 29. Bedded lower Brush Creek Limestone in shales at WV-1 outcrop.
Figure 30. Fossils in lower Brush Creek Limestone.
Figure 31. Abundant brachiopods in lower Brush Creek Limestone.

Sequence 7

The 7th sequence is largely absent in the study area, except for the K-2 and WV-1 outcrops. At K-2, the upper Brush Creek Limestone is the highest unit discernable at the outcrop and is deposited on top of a well-drained paleosol. The upper Brush Creek Limestone at K-2 represents the maximum transgression for sequence 7 and is very fossiliferous with brachiopods, crinoid stems, bryozoans, and many other shell fragments (Figure 32 and Figure 33). At WV-1, the upper Brush Creek Limestone lies directly on top of the lower Brush Creek Limestone. Evidence for a sequence boundary between the two limestones was not visible at WV-1 but is inferred owing to the presence of the well-drained paleosol at K-2. At WV-2, sequence 7 is not present, but a stratigraphic position for the sequence boundary was inferred. The upper Brush

Creek Limestone is overlain by a thin sand sheet and well-drained paleosol that is recognizable at WV-1. This paleosol marks the end of sequence 7.

Figure 32. Fossils in upper Brush Creek Limestone.
Figure 33. Large brachiopod in upper Brush Creek Limestone.

Sequence 8

No lowstand deposits (i.e. incisional valley) are present within the study area for this sequence. The first observable portion of sequence 8 is the Wilgus Coal, which is visible intermittently at the WV-1 and WV-2 outcrops. The coal is located above a well-drained paleosol at WV-1, which is the indication for a sequence boundary. Above the Wilgus coal at WV-2 is a poorly-drained floodplain lake environment with blowout wings. The Wilgus coal is truncated at WV-1 by the Buffalo Sandstone incised valley, so no other deposits related to sequence 8 are visible at this outcrop.

Sequence 9

The Buffalo Sandstone, an incised valley that cuts into the transgressive and highstand deposits of sequence 8, dominates sequence 9. This valley fills with sandy channel belts as well as local silt filled channels. On top of this valley fill as well as on the valley interfluve lies a generally thick paleosol visible at both West Virginia outcrops. The presence of this paleosol on both the interfluve and the valley indicates that there were multiple locations of valley incision during this sequence (i.e. the location of the interfluve changed locations as the valley cut and filled in multiple spots). Therefore, floodplain deposits were allowed to develop on top of the filled valley, and this floodplain transitioned to paleosol over time as various parts of it were subaerially exposed. This sequence could in fact represent multiple sequences. This paleosol is red (i.e. well-drained) at WV-1. At WV-2 the soil is poorly-drained, supporting the argument that WV-2 was in a topographic low spot during deposition compared to WV-1. The Bakerstown coal then tops the paleosol at both outcrops and represents the highstand for this sequence. There is no later marine incursion. The deposits above the coal are removed by the incisional Saltsburg Sandstone from Sequence 10.

Sequence 10

Sequence 10 begins with the incisional Saltsburg Sandstone valley which marks sequence boundary 10. In some parts of the study area, this valley very nearly incises into the Buffalo Sandstone valley. In many spots, the Bakerstown coal and the transgressive and highstand deposits from sequence 9 are removed. A red paleosol tops this valley, which develops under similar conditions to the paleosol that forms on top of the Buffalo Sandstone in Sequence 9. Multiple locations for valley incision allowed for a change in the location of the interfluve. Transgressive and highstand deposits for this sequence are poorly exposed in the study area as there are no coal, floodplain, or limestone deposits. Only a paleosol sits above the sandstone valley.

Sequence 11

Lowstand valley fill deposits for Sequence 11 are not visible in outcrop. The Harlem coal represents the first occurrence of Sequence 11 deposits on top of the paleosol from sequence 10, indicating that valley incision took place outside the study area. The Ames Limestone and Shale lies conformably above the Harlem coal and is well-exposed in the West Virginia outcrops, but is not nearly as fossiliferous in the study area as the lower and upper Brush Creek Limestones. The Ames Limestone floods directly over the coal and represents the maximum transgression for sequence 11. Unlike all previous marine episodes, the Ames transgression inundated well-established fluvial conditions consisting of a series of valley-fills and well-drained paleosols (i.e. the Buffalo Sandstone and Saltsburg Sandstone from sequences 9 and 10 and the well-drained paleosols that lie above them). The Ames Limestone is directly topped by a red paleosol, indicating that highstand deposits are absent.

Sequence 12

Sequence 12 is only a partial sequence. The only observable units were small channels deposited in highstand floodplain lake deposits. These units were usually poorly exposed, as they were at the top of the West Virginia outcrops and therefore were heavily vegetated. They incise and sit above the soil on top of the Ames Limestone that marks the sequence boundary for sequence 12.

Significance of Common Trends in Sequence Deposition

A sequence starts with a locally low water table and incision (e.g. Aitken and Flint, 1995). At this time, rivers running across a coastal floodplain incise valleys (e.g. Wright and Marriott, 1993; Shanley and McCabe, 1994). On high spots between valleys, called interfluves, a lack of sediment input and low water table promotes soil formation (e.g. Van Wagoner et al, 1988; Aitken and Flint, 1994, 1995, 1996; Gibling and Bird, 1994). The degree of soil formation depends on exposure time (e.g. Retallack, 1990). A sequence boundary forms at the scoured base of the incisional valley and on the tops of the paleosols on the interfluves (e.g. Vail et al., 1977; Posamentier and Vail, 1988; Van Wagoner et al., 1988; Van Wagoner, 1990; Aitken and Flint 1994, 1995; Martino, 1994, 1996). Next, as the water table begins to rise locally, the fluvial system begins to aggrade within the valley. Channels flowing out to sea avulse within the valley to cause channel-belt amalgamation vertically and laterally. Soil formation continues on interfluves, along the interfluvial sequence boundary (Wright and Marriott, 1993; Shanley and McCabe, 1994; Gibling and Bird, 1994; McCarthy et al., 1999; McCarthy, 2002). As the water table continues to rise, incised valleys finish filling, and standing water on interfluves and valley fill floodplains promotes peat accumulation (e.g. Busch and Rollins, 1984). Peat buildup denotes a flooding surface indicative of rising sea level (Martino, 2004).

In rare cases, if base level rises enough, shallow marine waters will flood over the coal, interfluvial paleosol, or a combination of the two. If this marine layer does deposit, it will represent the maximum flooding surface in the sequence. If not, then the coal will represent the up-dip correspondent to the transgressive flooding surface (Aitken and Flint, 1995). This study recognizes situations in which drowning continues after the deposition of a coal (i.e. coal overlain by poorly-drained floodplain lake), indicating that the coal is not the maximum flooding surface. During the late transgressive stage and early highstand, the coastal flood plain has freedom to aggrade rapidly as the water table is high and there is abundant accommodation generated. Commonly, sediments from the filled valley will breach the valley wall and form either subaerial splays on the floodplain, or subaqueous blowout wings in lakes depending on the height of the water table (Aitken and Flint, 1995; Coleman, 1988; Mjos et al., 1993; Cahoon et al, 2011; Tomanka, 2013; Huling, 2014; Huling and Holbrook, 2016; Howe, 2017). As regression begins, isolated fluvial channels are encased in the floodplain deposits (Shanley and McCabe, 1993). Towards the end of the regressional stage, as the water table is lowering again, distributary channels rush out towards the sea, chasing the coast as it moves basinward (Donaldson, 1979). Finally, the water table will reach a low point again, limiting the amount of accommodation. Valley incision will begin once more, and the next sequence boundary will begin at the basal scour.

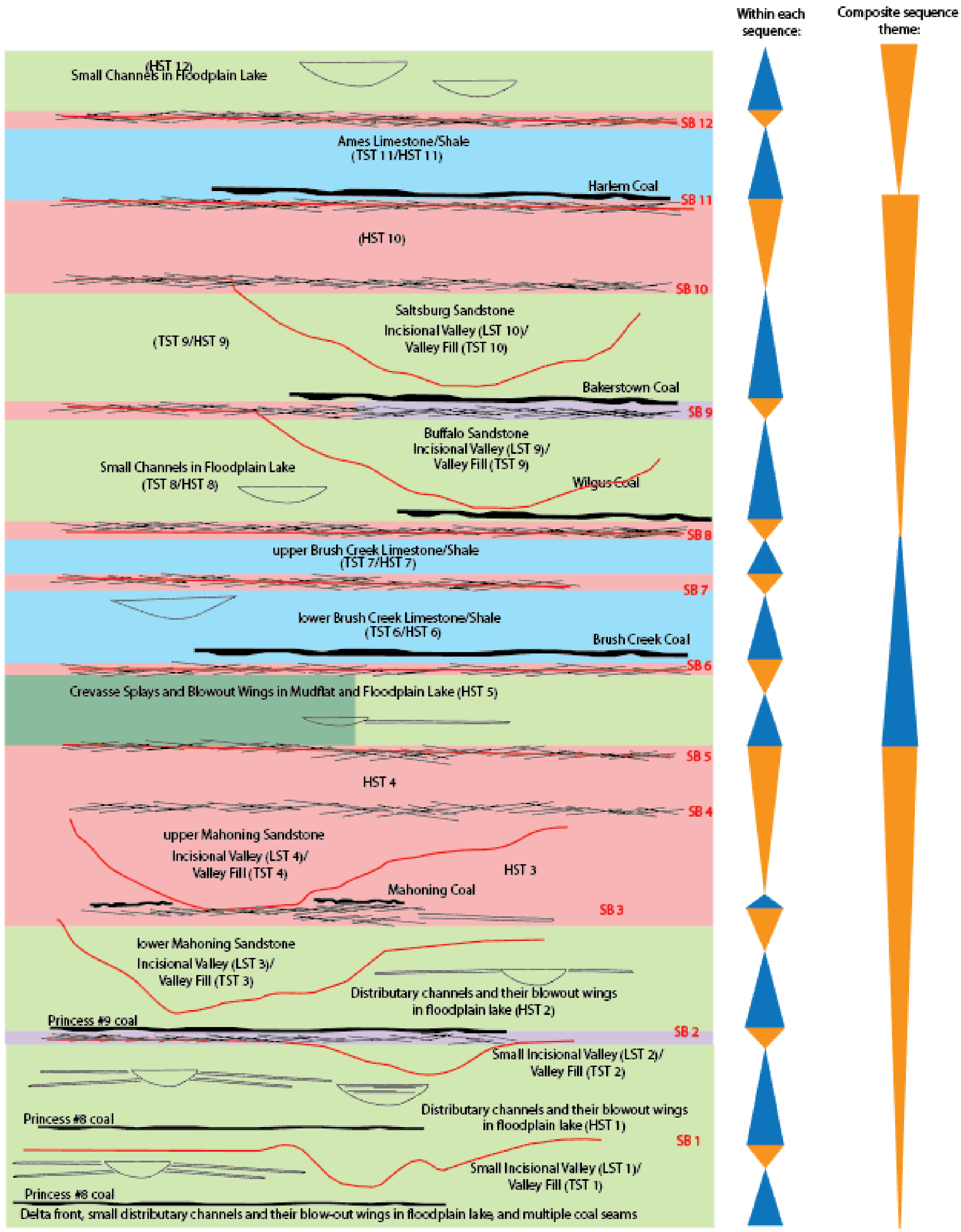
Each sequence here begins with incision of valleys. The purpose for river incision and aggradation is to achieve the ideal slope based on stream power and sediment supply (Gilbert, 1877; Mackin, 1948; Merrits et al., 1994; Howard et al., 1994; Tebbins et al., 2000; Holbrook et al., 2006). All rivers have a base level (i.e. an elevation they cannot incise below), and this base level will act as the “anchor” for the river profile, otherwise referred to as a buttress. The valleys considered in this study are interpreted as buttress valleys and the base level for these valleys is sea level (Holbrook et al., 2006). As sea level changes, the profile of the river will adjust to accommodate this change.

The buttress valleys fit the traditional sequence stratigraphic model because as base level (sea level) lowers, the fluvial system incises in response. When sea level regresses, valleys incise along drainage lines and well-drained paleosols develop on valley interfluves. Next, the sea transgresses over the interfluves and filled valleys, commonly depositing a basal peat, and sometimes depositing a marine limestone. When the sea level regresses again, the process repeats as incision begins again. The local occurrence of marine deposits within the study area indicates that the study area was never far from the coast and sea level heavily influenced sequence formation. The paleoshoreline during the Pennsylvanian Period ranged from approximately 30 to 80 kilometers from the study area during maximum transgressions of the marine units deposited in the study area (Busch and West, 1987; Martino, 2015). Sea influence is known to have the ability to propagate tens to hundreds of kilometers up dip (Blum and Törnqvist, 2000) putting the study area reasonably within a backwater length of the coast. Therefore, it is plausible that sequence formation in the study area was responsive to sea level changes. Finally, the existence of incised valleys within the study area indicates that the river system was trying to decrease its slope. This infers that stream power consistently exceeded sediment supply in the system and that the ambient slope was steeper than the equilibrium slope of rivers (Lane 1955; Schumm 1977; Blum and Törnqvist, 2000; Holbrook et al., 2006).

McCabe (1993) stated that peats can on-lap sequence boundaries as base level rises. Coals within the study area record basal peats which means they transgress over the valley system after valley filling takes place and record a correlative surface (e.g. Meijles et al., 2018; Törnqvist et al., 1998; Van Dijk et al, 1991). The basal peats deposit over sequence boundary paleosols (ranging from well-drained soils on interfluves to hydromorphic soils above filled valleys) as the water table rises to ground level (Aitken and Flint, 1994; Cecil, 1990; Cecil et al., 1985; Cecil et al., 1998; Cecil et al., 2014), and they deposit over the filled valley as well as the valley interfluve (e.g. Busch and Rollins, 1984). The coals in this study are all determined to be from the maceral group vitrinite, owing to the high proportions of plant matter and the shiny appearance observed in outcrop. The most common types of plant matter observed with the coals are lycopsid traces and tree fern traces. In addition, the silt partings often associated with these coals commonly contain plant fragments. Basal peats record the maximum transgression of the system except for the case when a floodplain lake develops on top of the peat, indicating further drowning occurred. This type of coal prefers shallow water because when the water level becomes too deep, the decomposition of the plant matter is prohibited. Therefore, in instances where a floodplain lake environment is observed above a coal, it can be inferred that the water table became too deep for the swampy environment to thrive. In general, the coals contained within well-drained environments tend to be thicker than those encased in poorly-drained deposits, perhaps because the optimal environment for formation is when the water table is at ground level, but not higher (Aitkin and Flint, 1994, 1995; Cecil et al., 1985).

Each of the sequences defined here are interpreted as glacially-driven cyclothems on scales of 100 ka years or less. This wide and standing interpretation for these cycles has been recognized in Pennsylvanian strata from the Appalachian Basin since the 1930s (Weller, 1930; Wanless and Weller, 1932; Wanless and Shepard, 1936; Busch and Rollins 1984; Busch and West, 1987; Heckel, 1995). Well-drained deposits (i.e. floodplain mudflats, crevasse splays, and well-drained paleosols) are representative of the smaller-scale cyclothems because rising sea level did not cause a large water table rise, allowing deposits to remain well-drained. Conversely, poorly-drained deposits (i.e. floodplain lakes, coals, and poorly-drained paleosols) represent a cyclothem with a larger sea level rise, which promoted a greater water table rise. Marine limestone deposition should be associated with these larger scale cyclothems. Three marine incursions are noted in the study interval (lower Brush Creek Limestone, upper Brush Creek Limestone, and Ames Limestone), and these incursions more commonly occur above well-drained environments than poorly-drained environments. This argues for an imprint of a still larger cycle on the short-term glacial cycles.

The sequences observed in this study combine to record composite sequences. The sequences record drying up (regressive) and wetting up (transgressive) themes (Figure 34). Each sequence discretely contains a drying up trend (late highstand/ lowstand or regression) followed by a wetting up trend (transgressive/ early highstand or transgression). These drying and wetting upward patterns also manifest across multiple sequences. Sequences record patterns of more robust incision marked by better drained paleosols, and more extensive transgression marked by wetter floodplains and local marine incursions. Sequences 1 through 4 are part of an overall drying up trend marked by floodplain lake deposits and a poorly drained paleosol topped by well-drained paleosols indicative of longer periods of valley incision. The valleys in sequences 3 and 4 mark the first of the "large" incised valleys recognized in the study area. The highstand deposits for sequence 5 contain both well-drained and poorly-drained floodplain deposits. This is indicative of a switch back to a wetting up trend. The poorly-drained floodplain deposits associated with this sequence are interpreted to have been deposited in topographically lower areas than the well-drained deposits. Sequences 6 and 7 are dominantly wetting up, consisting of two marine incursions. This set of sequences represents a significant period with long periods of flooding. Drying up quickly begins again as the last "large" incised valleys form in sequences 9 and 10. The drying up trend continues until deposition of the last coal and marine deposit recognized in the study area which represents a pause in the wetting up trend, but the drying up trend continues as a well-drained paleosol deposits on top of the marine deposit. These composite cycles likely record longer-term transgressive/regressive cycles superimposed on the shorter-term glacial cycles.



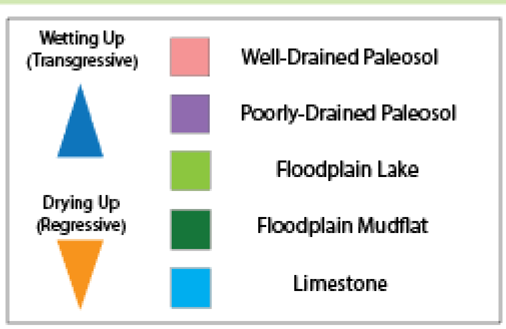


Figure 34. Composite Section indicating composite sequence wetting up (transgressive) and drying up (regressive) cycles.

Conclusions

- Eleven complete progradational sequences (and two partial sequences) are observed in the five outcrops spanning upper Breathitt and lower Conemaugh strata considered for this study. The sequences are expressed differently along the cross section expressing the lateral variability in sequences.
- These sequences generally follow the sequence stratigraphic model for a fluvial setting. They appear to record buttress valleys incised during sea level fall along slopes steeper than the preferred river profile.
- The sequences recorded in this study combine to record composite sequences. The sequences record several drying up (regressive) and wetting up (transgressive) themes. Overall, two drying up trends and one wetting up trend is observed. Transgressions are marked by basal peats, poorly-drained paleosols, marine limestones, and floodplain lake deposits, while regressions are indicated by floodplain mudflat and well-drained paleosols associated with incised valleys. These composite cycles likely record longer-term transgressive/regressive cycles superimposed on the shorter-term glacial cycles.

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Appendices

Measured Section K4.1 (Full Detail)

EasyCore
The EasyCopy Company

Top 56 m	Bottom 0 m
Country United States	Well Name & No. K4.1
Location Kentucky	Logged by Amanda Pechacek
Date Sat May 20 2017	Basin Appalachian Basin
Latitude 38.1385	Longitude -82.6380

Lithologies

Paleosol
Sandstone
Siltstone

Contacts

Straight
Scoured

Sedimentary Structures

Planar Lamination
Ripple Lamination
Trough Cross Lamination

Trace Fossils

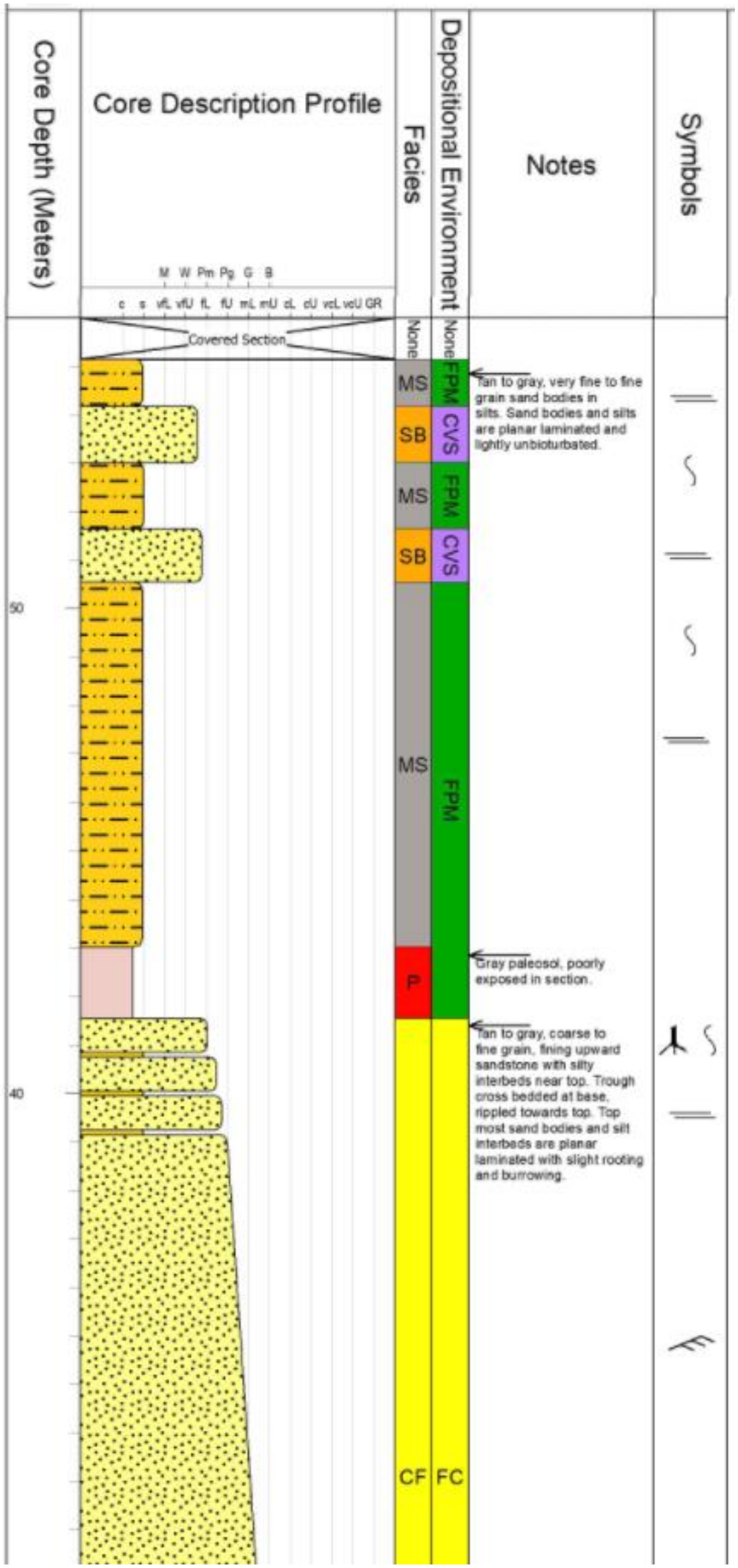
Bioturbation (undifferentiated)
Roots

Facies

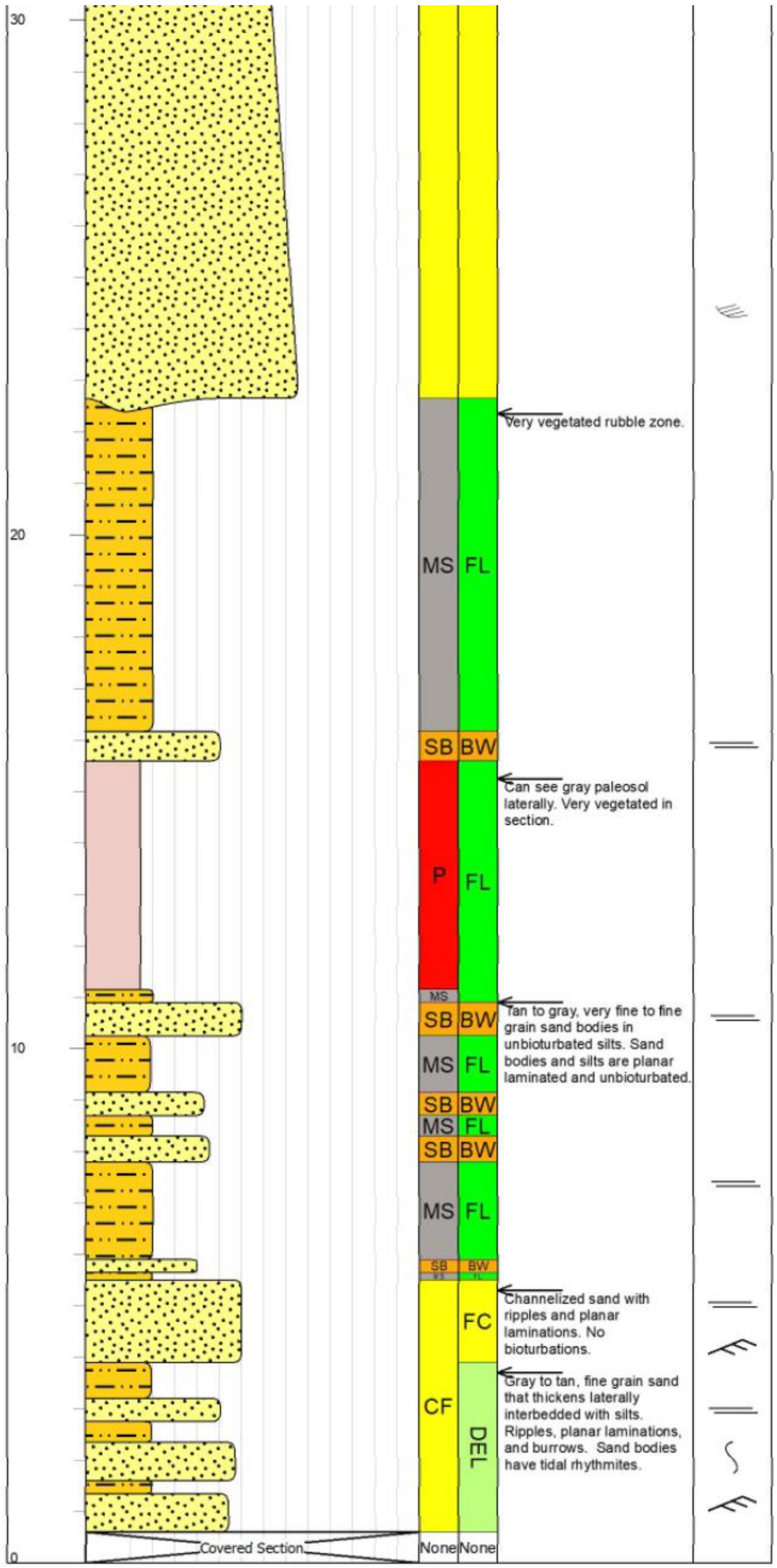
CF Channel Fill
None Covered Section
MS Mud Shale
P Paleosol
SB Sand Body

Depositional Environment

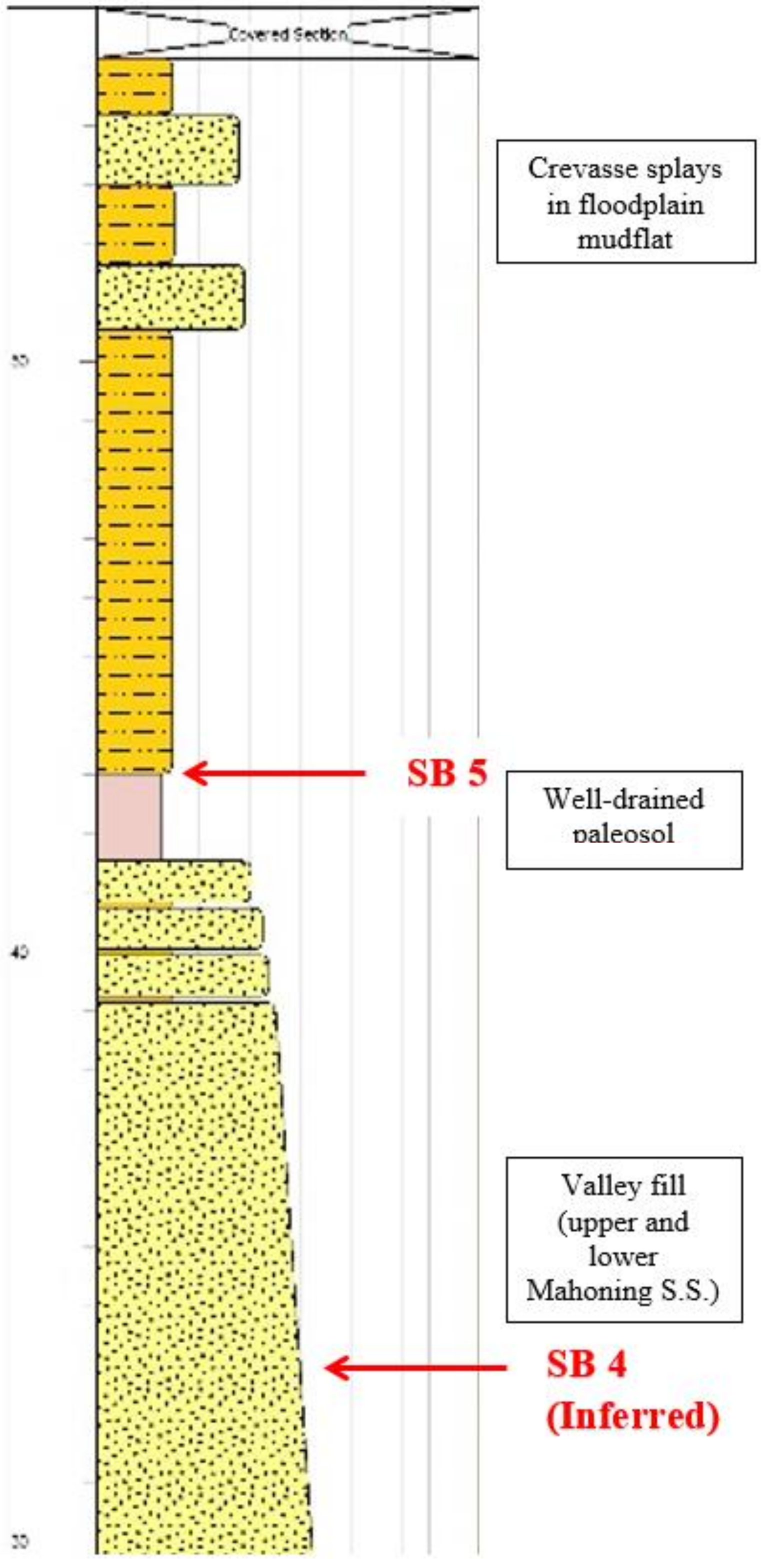
BW Blowout Wing
None Covered Section
CVS Crevasse Splay
DEL Deltaic
FL Floodplain Lake
FPM Floodplain Mudflat
FC Fluvial Channel

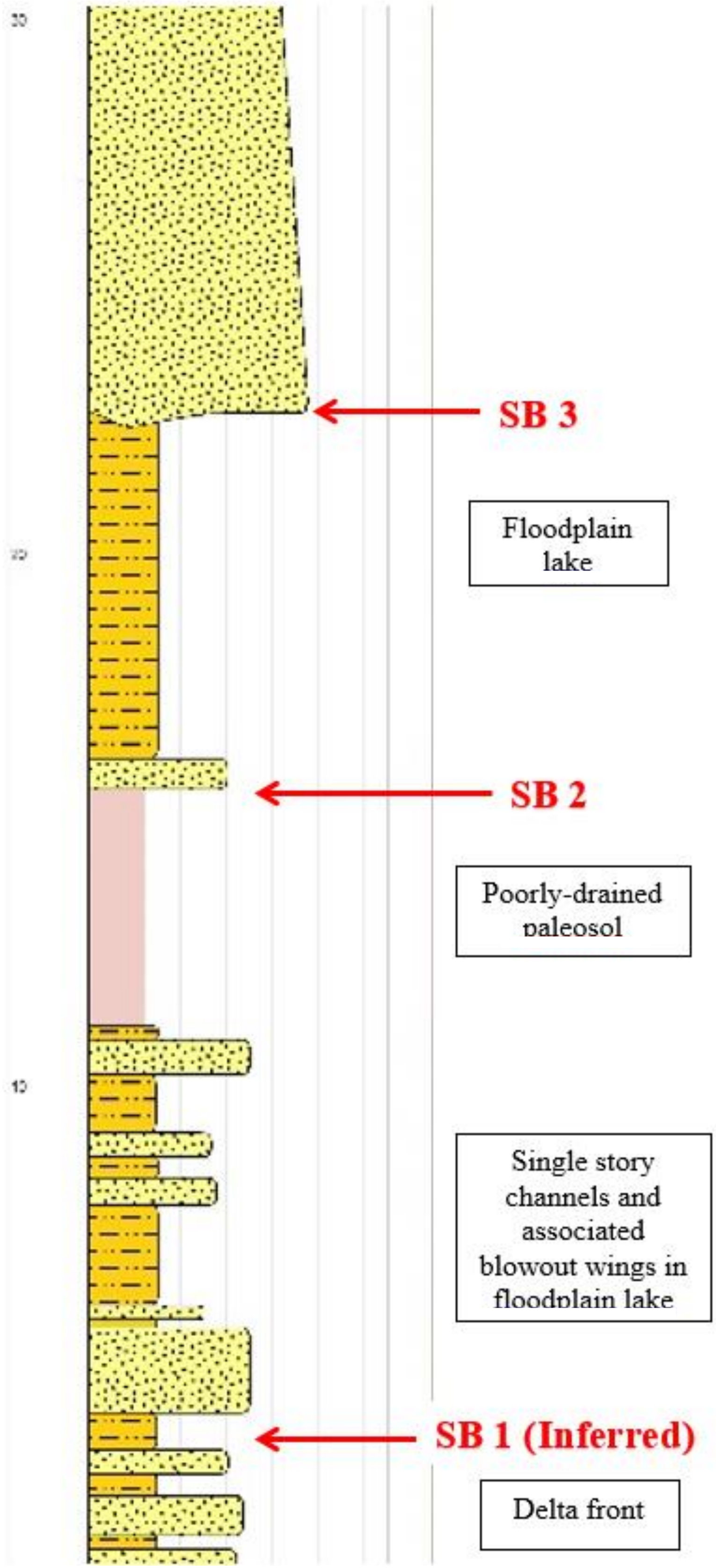


Core Depth (Meters)
Core Description Profile
M W Pm Pg G B
c s vfL vfU fL fU mL mU cL cU vcL vcU GR
Covered Section
50
40
Facies
Depositional Environment
Notes
Symbols
None
None
MS
FPM
SB
CVS
MS
FPM
SB
CVS
MS
FPM
P
CF
FC
Tan to gray, very fine to fine grain sand bodies in silts. Sand bodies and silts are planar laminated and lightly unbioturbated.
Gray paleosol, poorly exposed in section.
Tan to gray, coarse to fine grain, fining upward sandstone with silty interbeds near top. Trough cross bedded at base, rippled towards top. Top most sand bodies and silt interbeds are planar laminated with slight rooting and burrowing.


30
20
10
0
Very vegetated rubble zone.
MS
FL
SB
BW
Can see gray paleosol laterally. Very vegetated in section.
P
FL
MS
SB
BW
Tan to gray, very fine to fine grain sand bodies in unbioturbated silts. Sand bodies and silts are planar laminated and unbioturbated.
MS
FL
SB
BW
MS
FL
SB
BW
MS
FL
SB
BW
Channelized sand with ripples and planar laminations. No bioturbations.
FC
Gray to tan, fine grain sand that thickens laterally interbedded with silts. Ripples, planar laminations, and burrows. Sand bodies have tidal rhythmites.
CF
DEL
Covered Section
None
None

Measured Section K4.1 (Simplified)




30
20
10
SB 3
Floodplain lake
SB 2
Poorly-drained paleosol
Single story channels and associated blowout wings in floodplain lake
SB 1 (Inferred)
Delta front

Measured Section K4.2 (Full Detail)

EasyCore
The EasyCopy Company

Top 39 m	Bottom 0 m
Country United States	Well Name & No. K4.2
Location Kentucky	Logged by Amanda Pechacek
Date Mon Sep 24 2018	Basin Appalachian Basin
Latitude 38.1393	Longitude -82.6383

Lithologies

- Coal
- Paleosol
- Sandstone
- Siltstone

Contacts

- Straight
- Scoured

Sedimentary Structures

- Planar Lamination
- Ripple Lamination
- Trough Cross Lamination

Trace Fossils

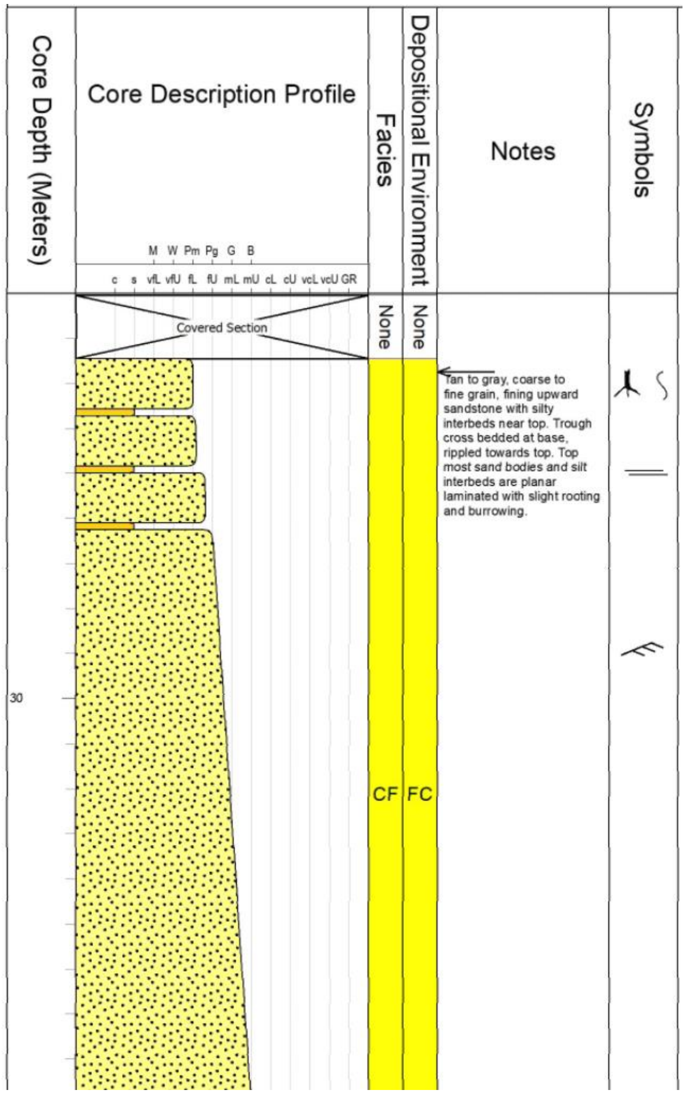
- Bioturbation (undifferentiated)
- Roots

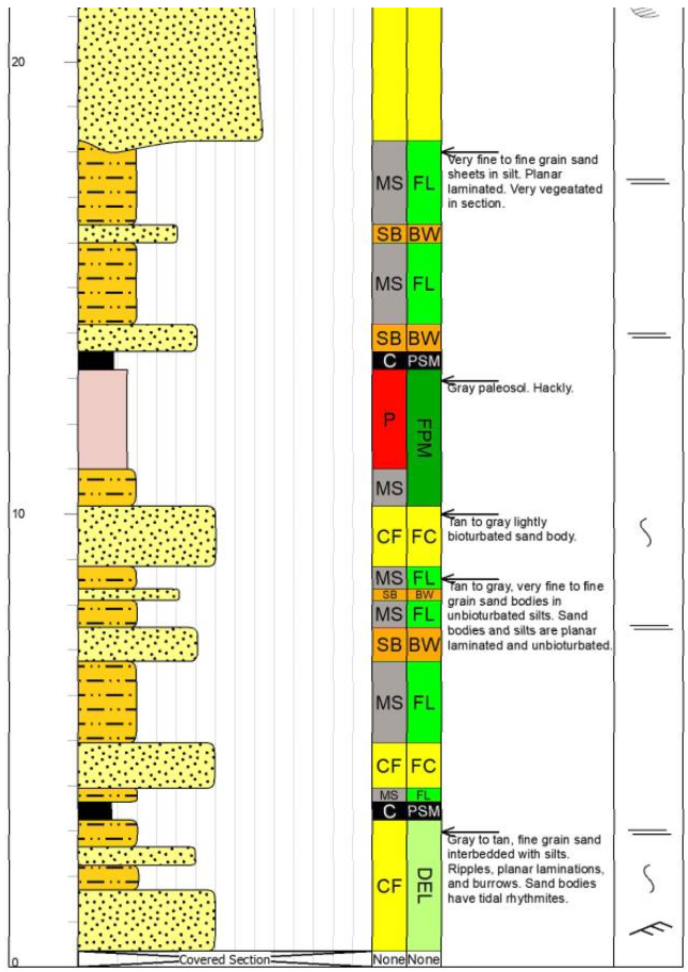
Facies

- CF Channel Fill
- C Coal
- None Covered Section
- MS Mus Shale
- P Paleosol
- SB Sand Body

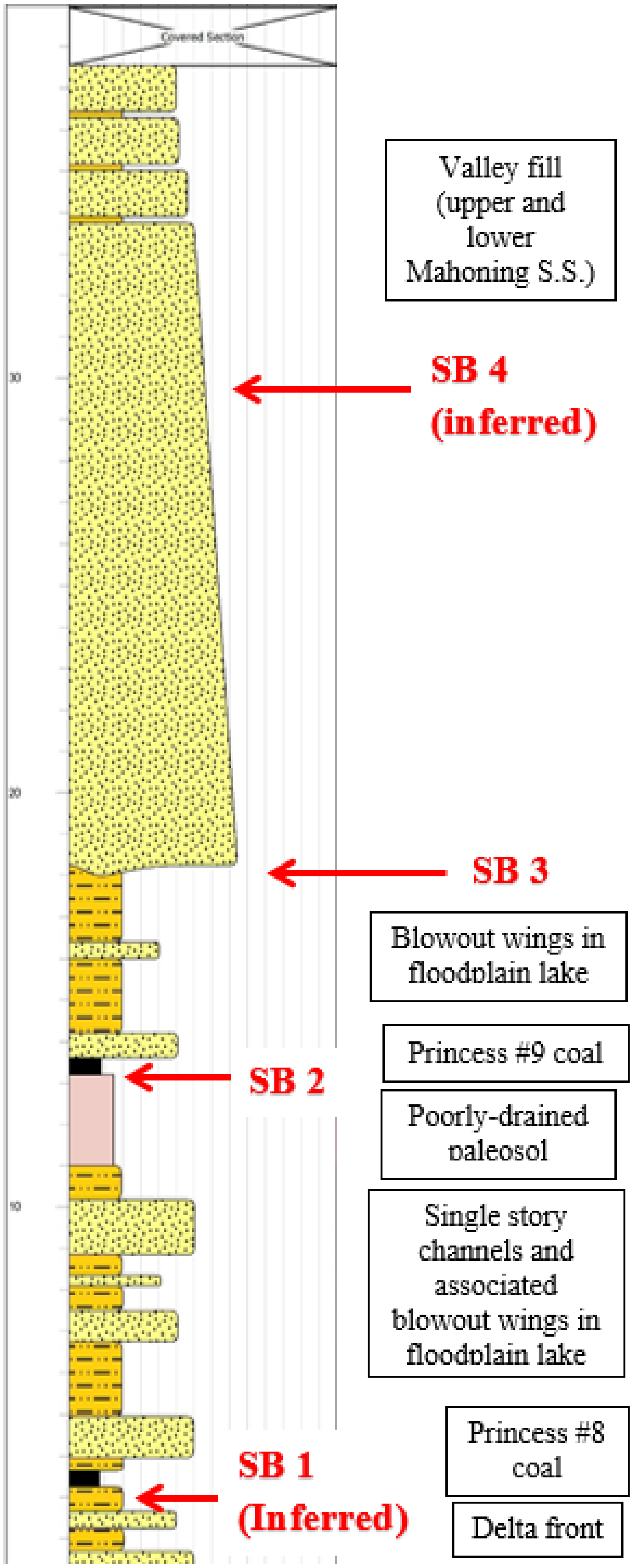
Depositional Environment

- BW Blowout Wing
- None Covered Section
- CVS Crevasse Splay
- DEL Deltaic
- FL Floodplain Lake
- FPM Floodplain Mudflat
- FC Fluvial Channel
- PSM Peat Swamp/Mire


Core Depth (Meters)
Core Description Profile
Facies
Depositional Environment
Notes
Symbols
M W Pm Pg G B
c s vfL vfU fL fU mL mU cL cU vcL vcU GR
Covered Section
None
None
Tan to gray, coarse to fine grain, fining upward sandstone with silty interbeds near top. Trough cross bedded at base, rippled towards top. Top most sand bodies and silt interbeds are planar laminated with slight rooting and burrowing.
30
CF
FC


20
10
0
Covered Section
MS FL
SB BW
C PSM
P FPM
CF FC
CF DEL
None None
Very fine to fine grain sand sheets in silt. Planar laminated. Very vegeatated in section.
Gray paleosol. Hackly.
Tan to gray lightly bioturbated sand body.
Tan to gray, very fine to fine grain sand bodies in unbioturbated silts. Sand bodies and silts are planar laminated and unbioturbated.
Gray to tan, fine grain sand interbedded with silts. Ripples, planar laminations, and burrows. Sand bodies have tidal rhythmites.

Measured Section K4.2 (Simplified)



Measured Section K3.1 (Full Detail)

EasyCore
The EasyCopy Company

Top 90 m	Bottom 0 m
Country United States	Well Name & No. K3.1
Location Kentucky	Logged by Amanda Pechacek
Date Mon May 22 2017	Basin Appalachian Basin
Latitude 38.1468	Longitude -82.6397

Lithologies

- Coal
- Paleosol
- Sandstone
- Siltstone

Contacts

- Straight
- Scoured

Accessories

- Siderite Nodules

Sedimentary Structures

- Climbing Ripples
- Planar Cross Lamination
- Planar Lamination
- Ripple Lamination

Trace Fossils

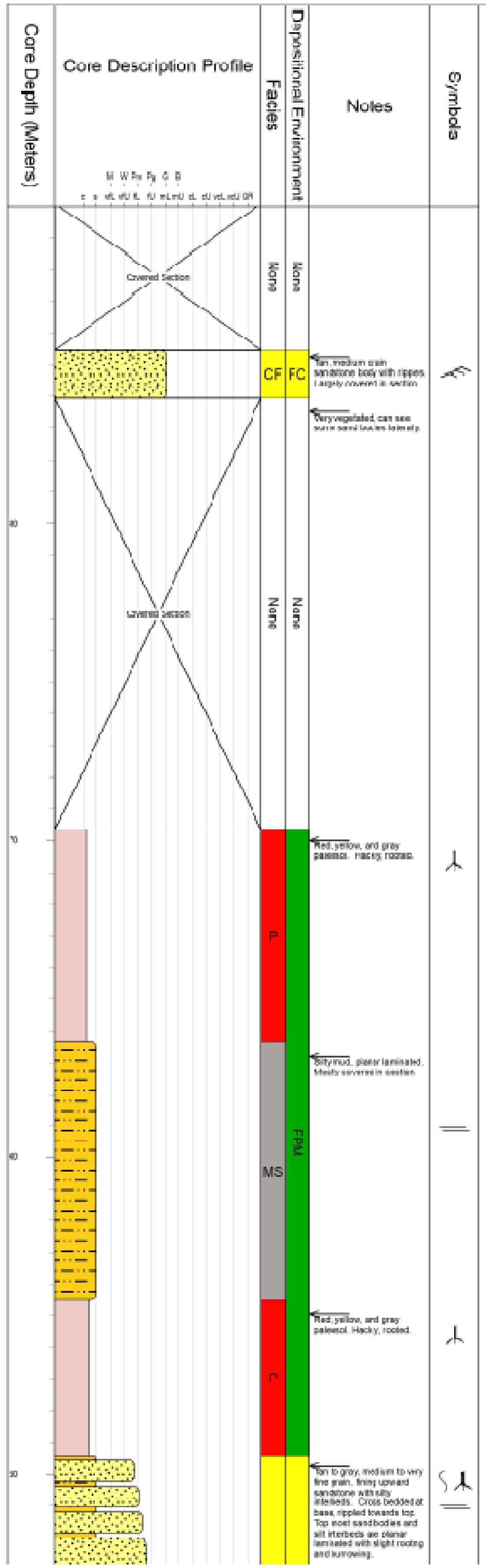
- Bioturbation (undifferentiated)
- Roots

Facies

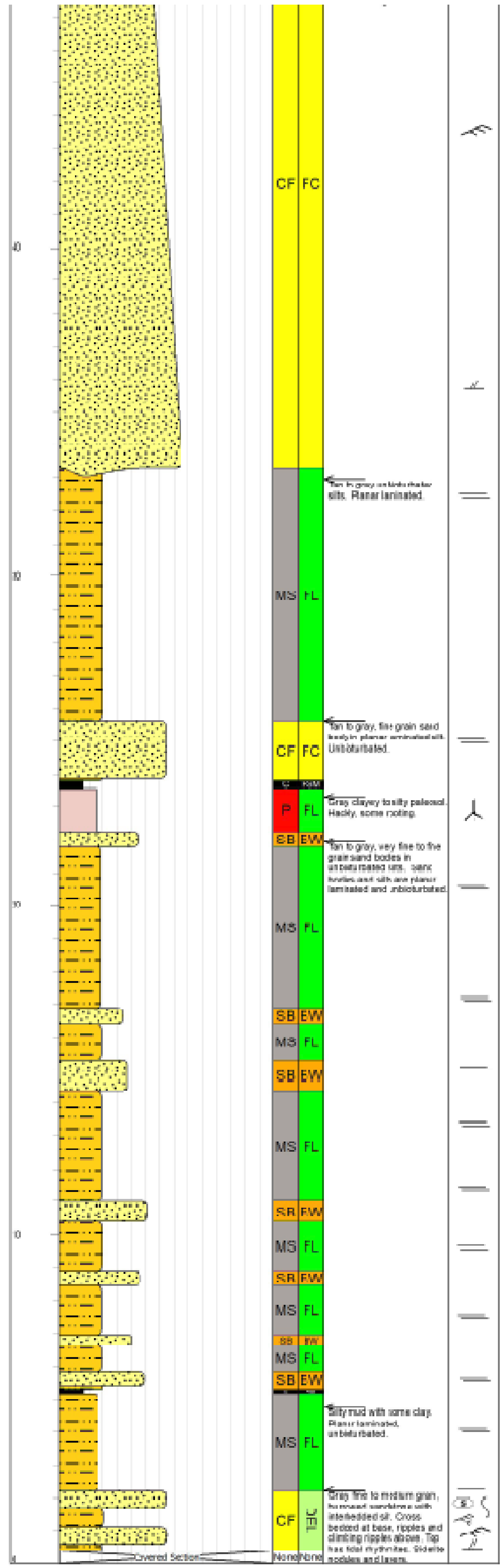
- CF Channel Fill
- C Coal
- None Covered Section
- MS Mud Shale
- P Paleosol
- SB Sand Body

Depositional Environment

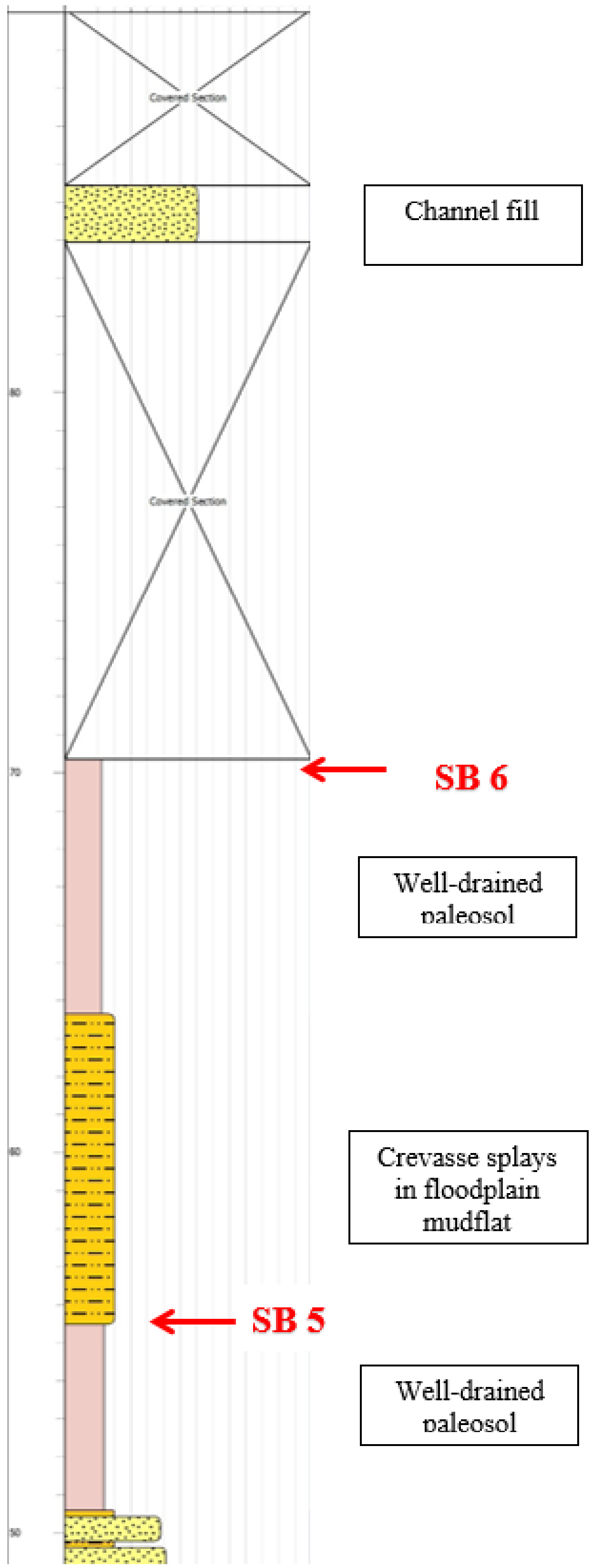
- BW Blowout Wing
- None Covered Section
- DEL Deltaic
- FL Floodplain Lake
- FPM Floodplain Mudflat
- FC Fluvial Channel
- PSM Peat Swamp/Mire

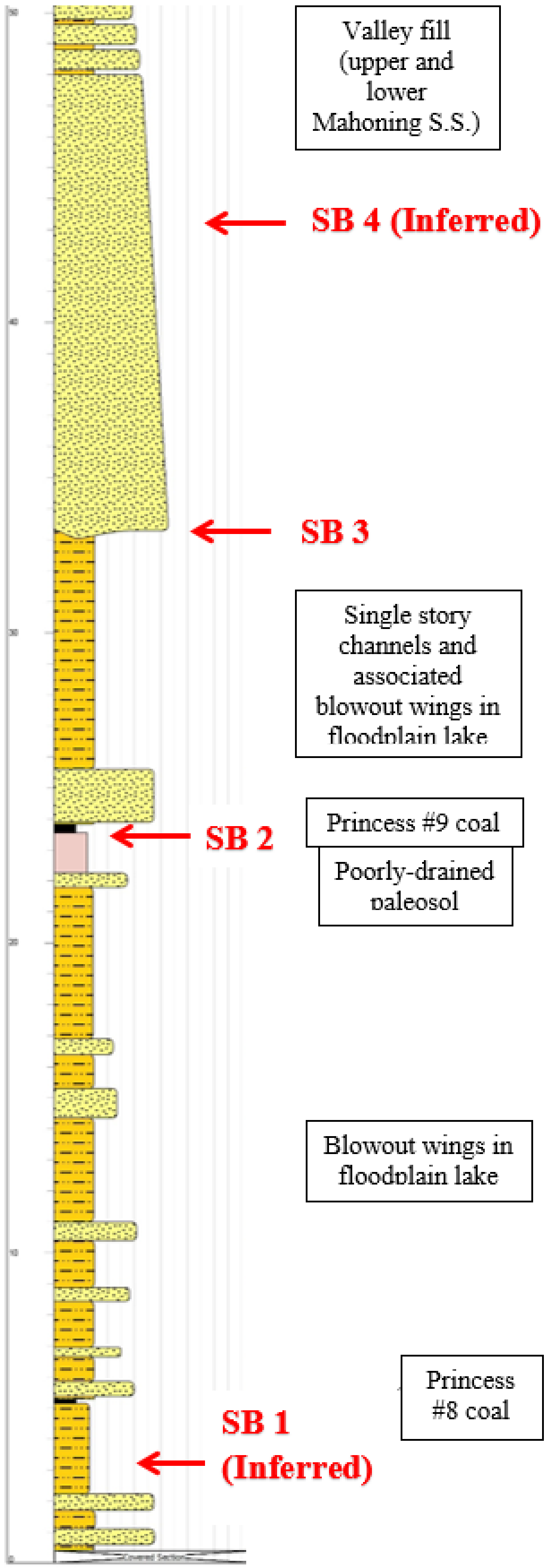


Core Depth (Meters)
Core Description Profile
Facies
Depositional Environment
Notes
Symbols
Covered Section
None
None
Tan, medium grain sandstone body with ripples. Largely covered in section.
CF
FC
Very vegetated, can see some sand lenses laterally.
Red, yellow, and gray paleosol. Hacky, rooted.
P
Silty mud, planar laminated. Mostly covered in section.
MS
FPM
Red, yellow, and gray paleosol. Hacky, rooted.
Tan to gray, medium to very fine grain, fining upward sandstone with silty interbeds. Cross bedded at base, rippled towards top. Top most sandbodies and silt interbeds are planar laminated with slight rooting and burrowing.


CF
FC
MS
FL
silts. Planar laminated.
Tan to gray, fine grain sand
Unbioturbated.
P
Gray clayey to silty paleosol.
Hacky, some rooting.
SB
EW
Tan to gray, very fine to fine
grain sand bodies in
laminated and unbioturbated.
Silty mud with some clay.
Planar laminated,
unbioturbated.
Gray fine to medium grain,
interbedded silt. Cross
bedded at base, ripples and
climbing ripples above. Top
nodules and layers.
Covered Section
None

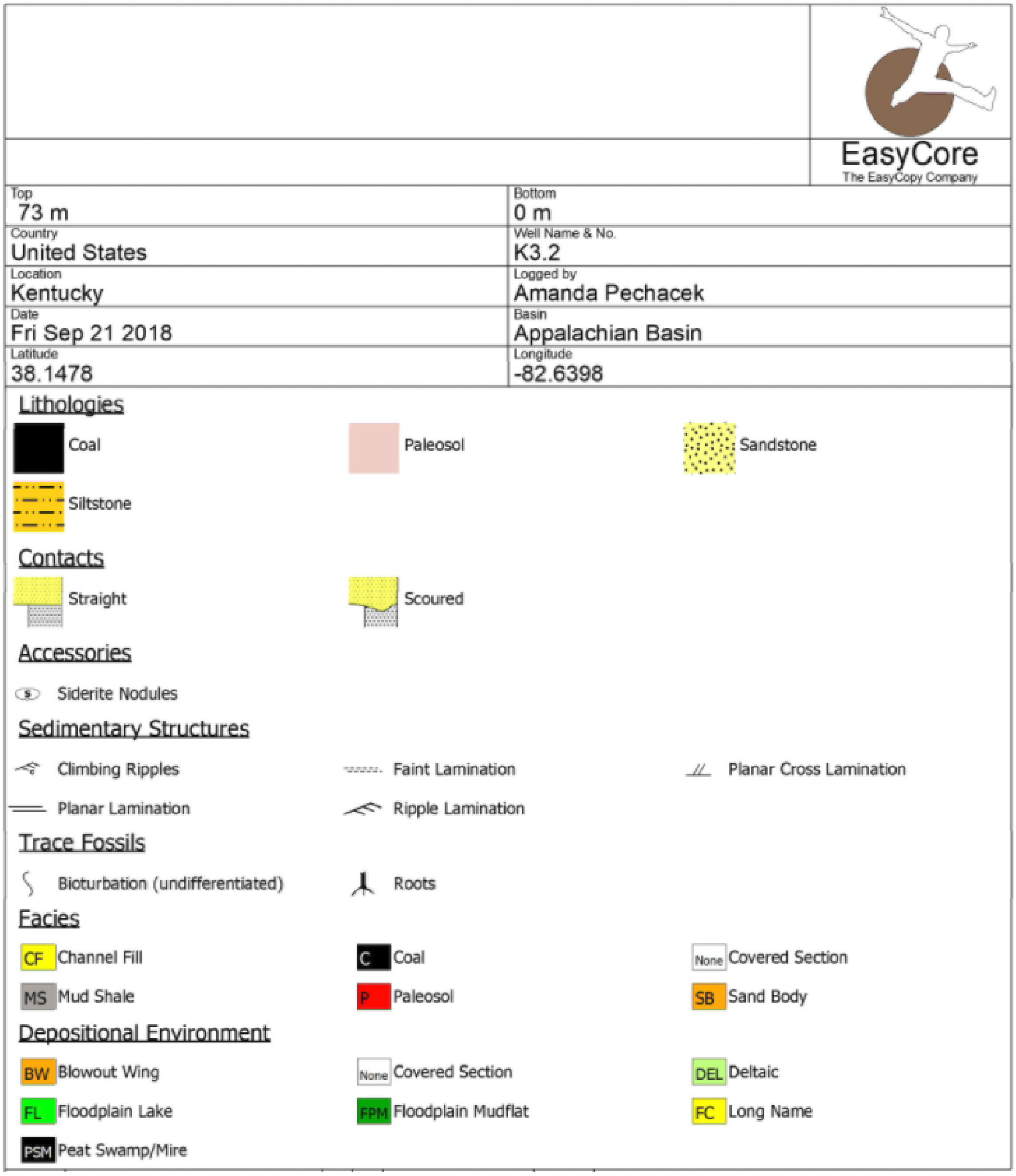
Measured Section K3.1 (Simplified)

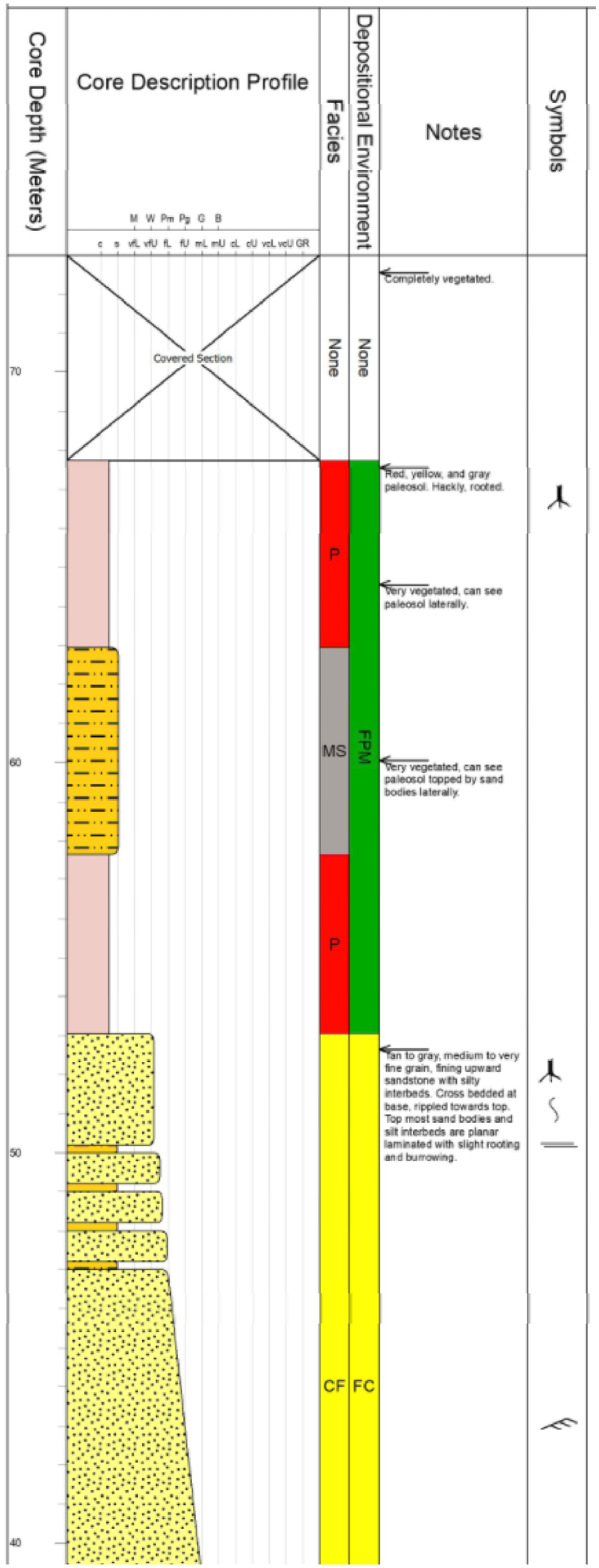


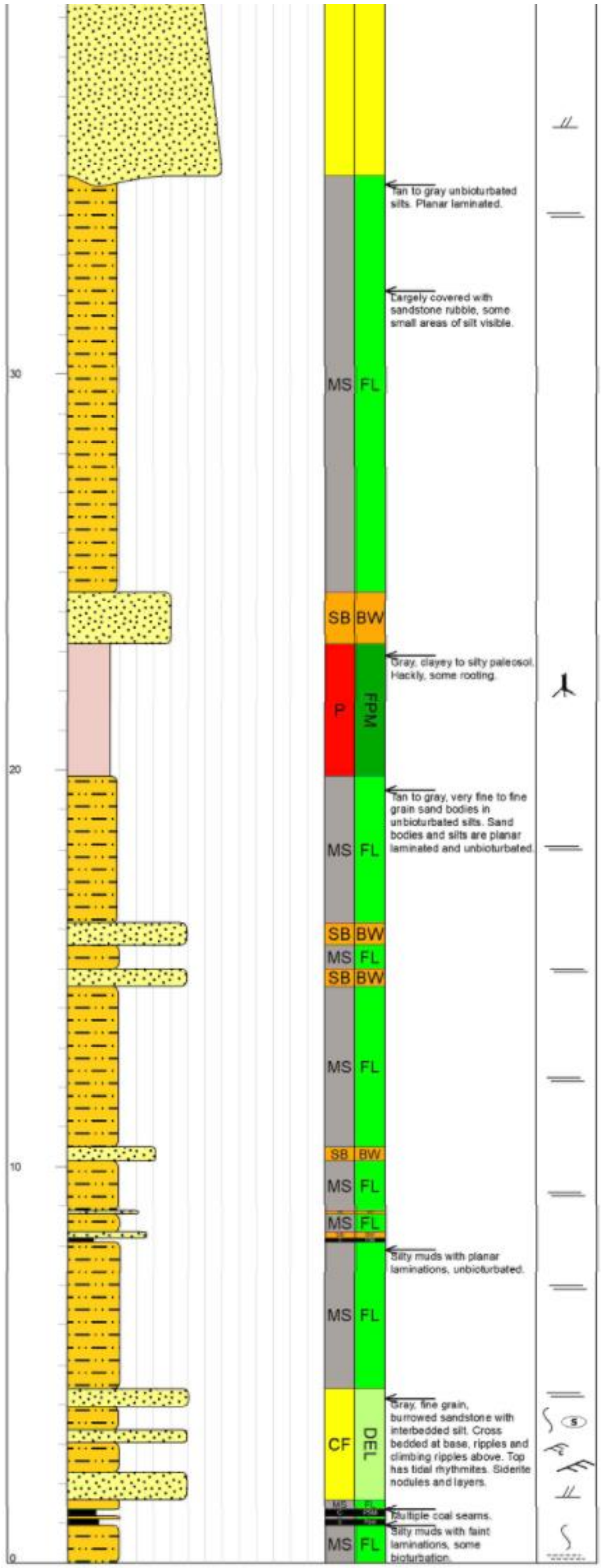


Valley fill (upper and lower Mahoning S.S.)
SB 4 (Inferred)
SB 3
Single story channels and associated blowout wings in floodplain lake
Princess #9 coal
SB 2
Poorly-drained paleosol
Blowout wings in floodplain lake
Princess #8 coal
SB 1 (Inferred)

Measured Section K3.2 (Full Detail)

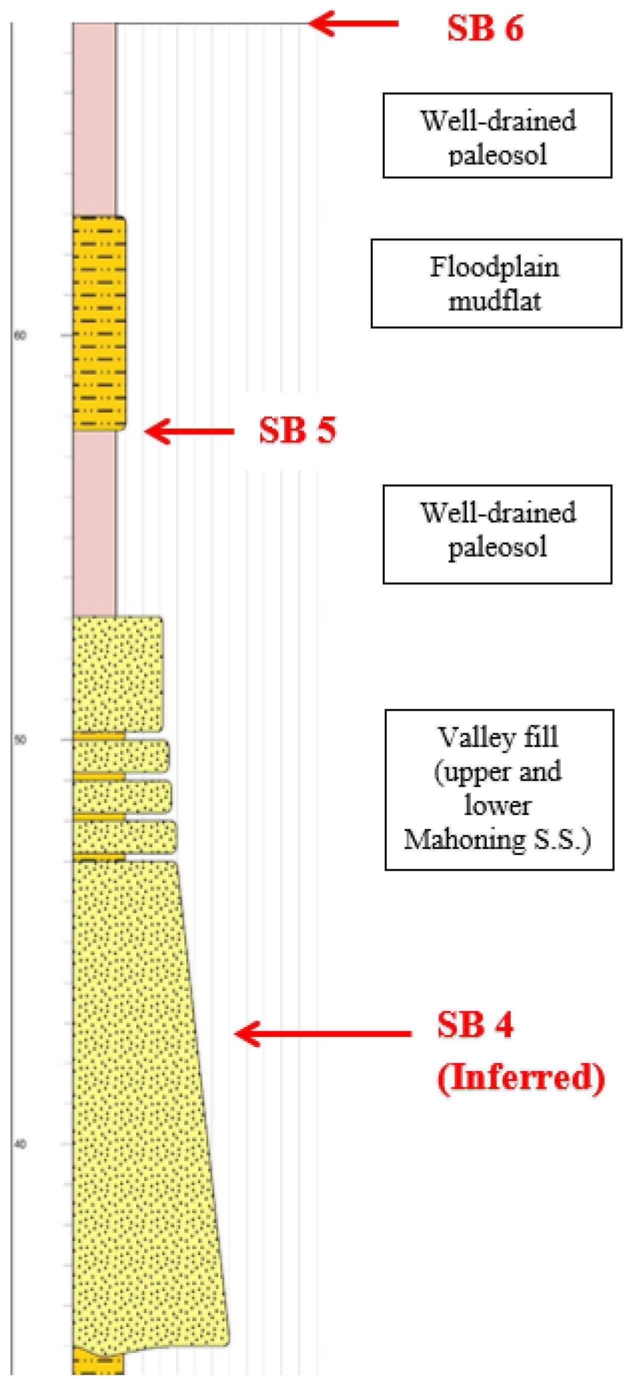


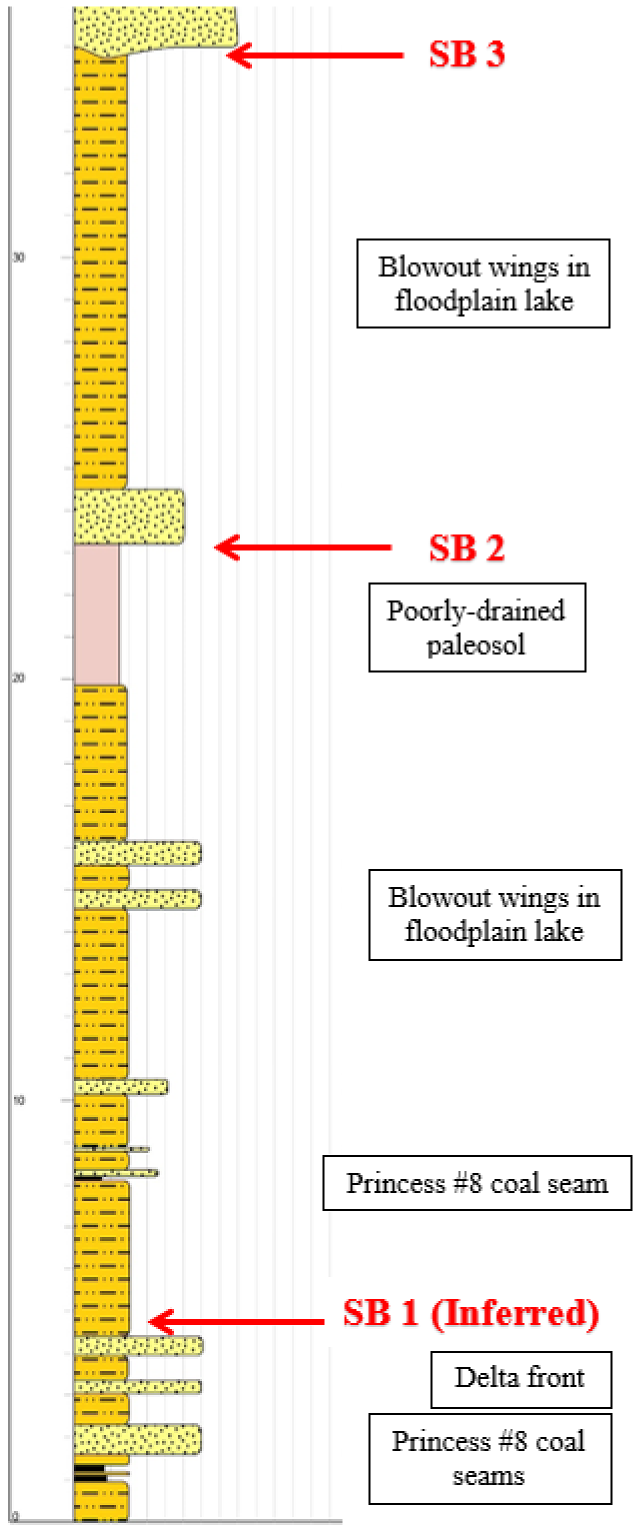

Core Depth (Meters)
Core Description Profile
M W Pm Pg G B
c s vfL vfU fL fU mL mU cL cU vcL vcU GR
Facies
Depositional Environment
Notes
Symbols
70
60
50
40
Covered Section
None
None
Completely vegetated.
Red, yellow, and gray paleosol. Hackly, rooted.
P
Very vegetated, can see paleosol laterally.
MS
FPM
Very vegetated, can see paleosol topped by sand bodies laterally.
P
Tan to gray, medium to very fine grain, fining upward sandstone with silty interbeds. Cross bedded at base, rippled towards top. Top most sand bodies and silt interbeds are planar laminated with slight rooting and burrowing.
CF
FC



Tan to gray unbioturbated silts. Planar laminated.
Largely covered with sandstone rubble, some small areas of silt visible.
30
MS FL
SB BW
Gray, clayey to silty paleosol. Hackly, some rooting.
P FPM
20
Tan to gray, very fine to fine grain sand bodies in unbioturbated silts. Sand bodies and silts are planar laminated and unbioturbated.
MS FL
SB BW
MS FL
SB BW
MS FL
SB BW
10
MS FL
MS FL
Silty muds with planar laminations, unbioturbated.
MS FL
Gray, fine grain, burrowed sandstone with interbedded silt. Cross bedded at base, ripples and climbing ripples above. Top has tidal rhythmites. Siderite nodules and layers.
CF DEL
Multiple coal seams.
Silty muds with faint laminations, some bioturbation.
MS FL
0

Measured Section K3.2 (Simplified)




SB 3
30
Blowout wings in floodplain lake
SB 2
Poorly-drained paleosol
20
Blowout wings in floodplain lake
10
Princess #8 coal seam
SB 1 (Inferred)
Delta front
Princess #8 coal seams
0

Measured Section K2.1 (Full Detail)

EasyCore
The EasyCopy Company

Top 65 m	Bottom 0 m
Country United States	Well Name & No. K2.1
Location Kentucky	Logged by Amanda Pechacek
Date Tue Sep 25 2018	Basin Appalachian Basin
Latitude 38.1017	Longitude -82.3829

Lithologies

Coal — Limestone — Paleosol

Sandstone — Siltstone

Grain Type

Skeletal

Contacts

Straight — Scoured

Accessories

Siderite Nodules

Fossils

Brachiopods — Bryozoans — Fossils Broken

Fossils

Sedimentary Structures

Climbing Ripples — Planar Cross Lamination — Planar Lamination

Ripple Lamination

Trace Fossils

Bioturbation (undifferentiated) — Roots

Facies

CF Channel Fill — C Coal — None Covered Section

LS Limestone and Shale — MS Mud Shale — P Paleosol

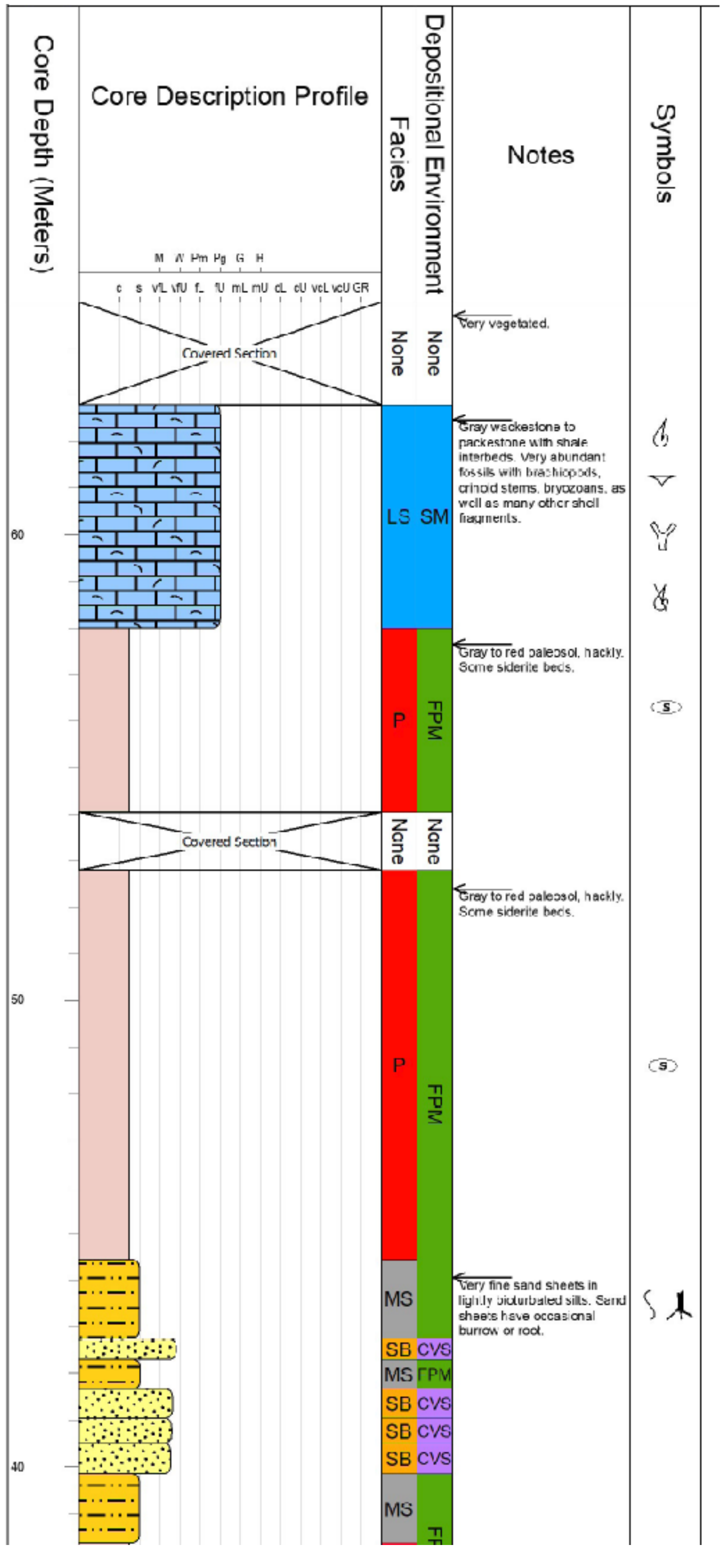
SB Sand Body

Depositional Environment

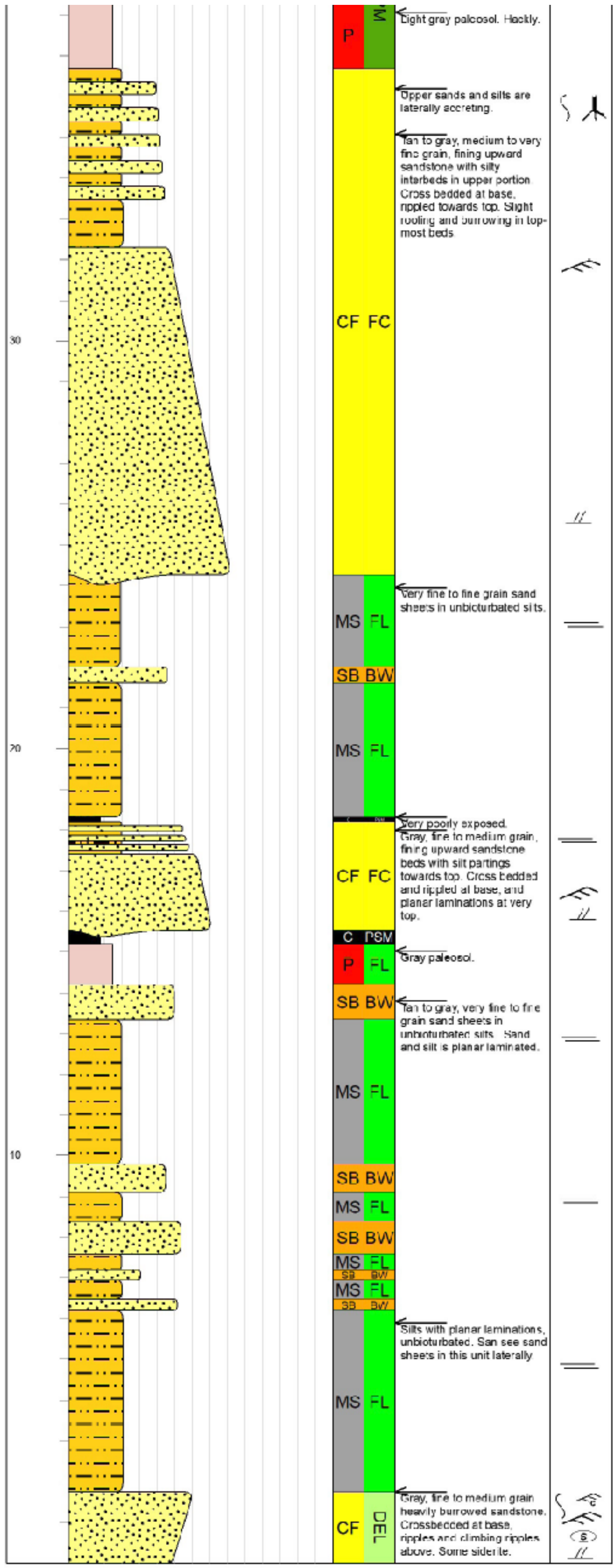
BW Blowout Wing — None Covered Section — CVS Crevasse Splay

DEL Deltaic — FL Floodplain Lake — FPM Floodplain Mudflat

FC Fluvial Channel — PSM Peat Swamp/Mire — SM Shallow Marine

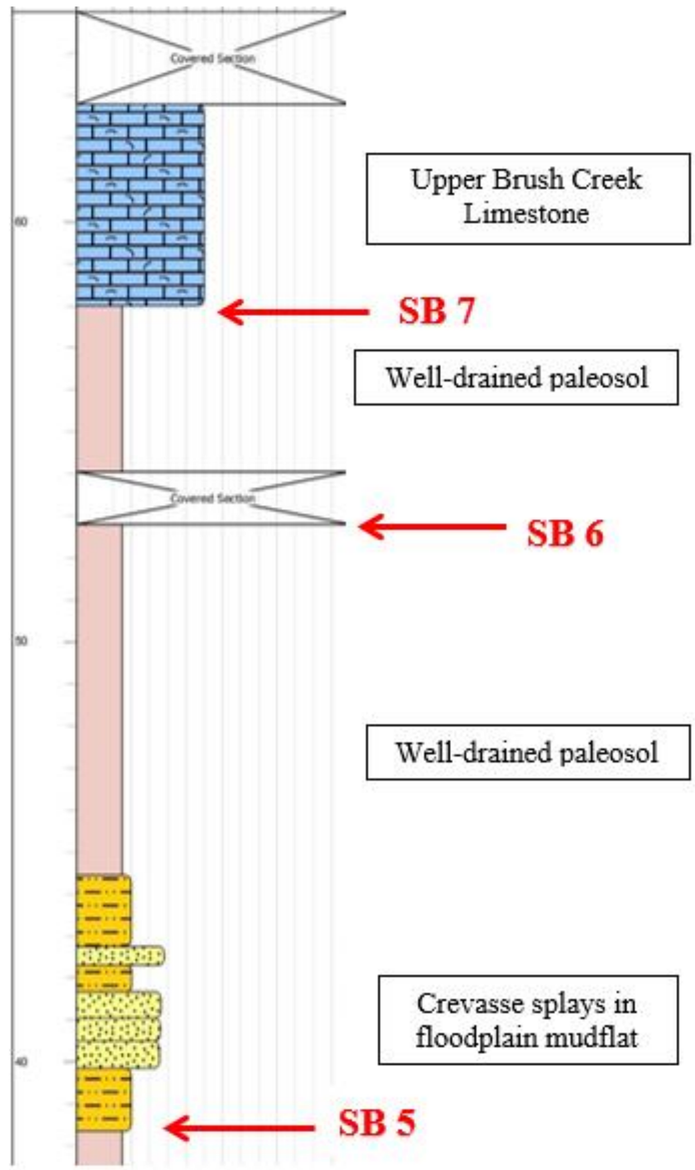


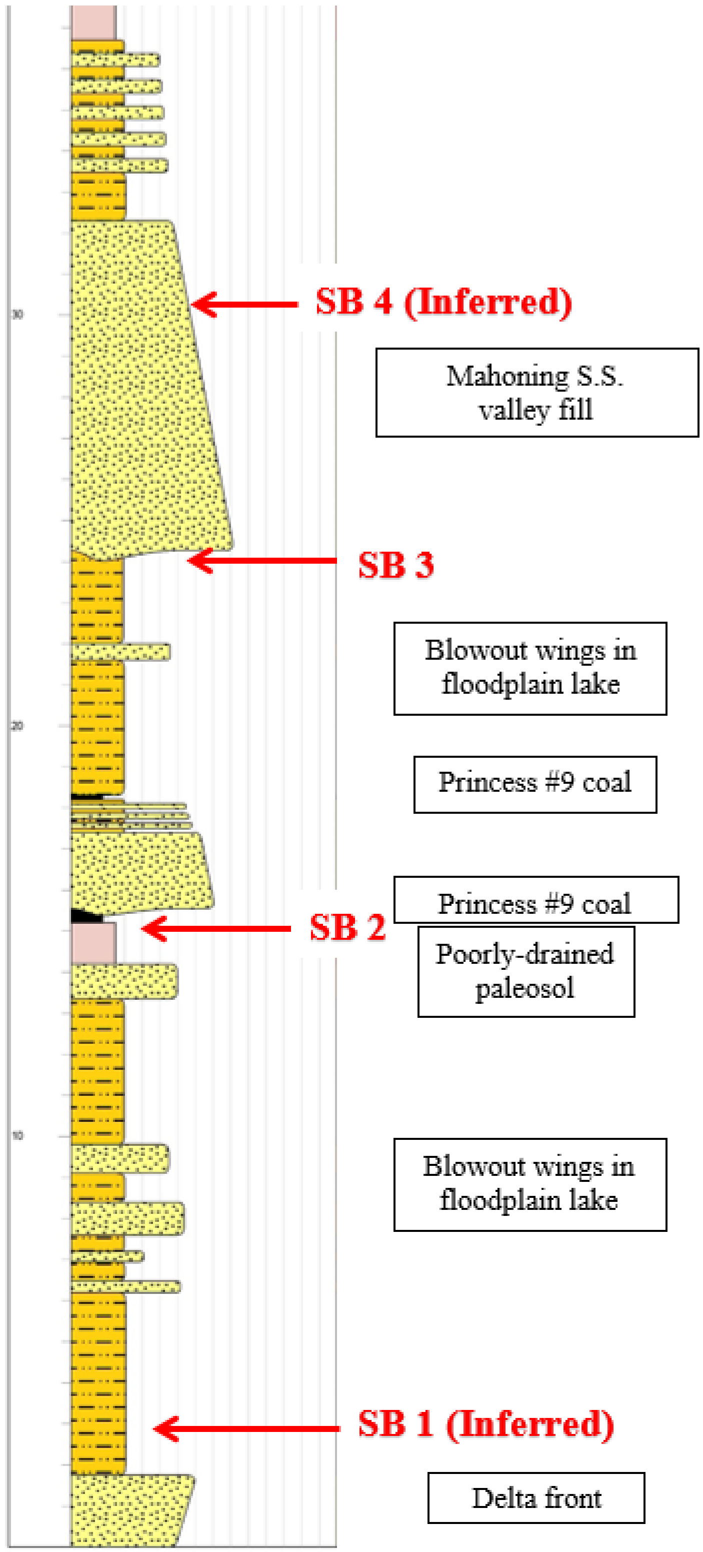
Core Depth (Meters)
Core Description Profile
Depositional Environment
Facies
Notes
Symbols
M W Pm Pg G H
c s vfL vfU fL fU mL mU cL cU vcL vcU GR
Covered Section
None
None
Very vegetated.
Gray wackestone to packestone with shale interbeds. Very abundant fossils with brachiopods, crinoid stems, bryozoans, as well as many other shell fragments.
LS
SM
60
Gray to red paleosol, hackly. Some siderite beds.
P
FPM
Covered Section
None
None
Gray to red paleosol, hackly. Some siderite beds.
50
P
FPM
Very fine sand sheets in lightly bioturbated silts. Sand sheets have occasional burrow or root.
MS
SB
CVS
MS
FPM
SB
CVS
SB
CVS
SB
CVS
40
MS



30
20
10
P
CF FC
MS FL
SB BW
MS FL
CF FC
C PSM
P FL
SB BW
MS FL
SB BW
MS FL
SB BW
MS FL
MS FL
MS FL
CF DEL
Light gray paleosol. Hackly.
Upper sands and silts are laterally accreting.
Tan to gray, medium to very fine grain, fining upward sandstone with silty interbeds in upper portion. Cross bedded at base, rippled towards top. Slight rooting and burrowing in top-most beds
Very fine to fine grain sand sheets in unbioturbated silts.
Very poorly exposed.
Gray, fine to medium grain, fining upward sandstone beds with silt partings towards top. Cross bedded and rippled at base, and planar laminations at very top.
Gray paleosol.
Tan to gray, very fine to fine grain sand sheets in unbioturbated silts. Sand and silt is planar laminated.
Silts with planar laminations, unbioturbated. San see sand sheets in this unit laterally
Gray, fine to medium grain heavily burrowed sandstone. Crossbedded at base, ripples and climbing ripples above. Some siderite.

Measured Section K2.1 (Simplified)




SB 4 (Inferred)
Mahoning S.S. valley fill
SB 3
Blowout wings in floodplain lake
Princess #9 coal
Princess #9 coal
SB 2
Poorly-drained paleosol
Blowout wings in floodplain lake
SB 1 (Inferred)
Delta front

Measured Section K2.2 (Full Detail)

EasyCore
The EasyCopy Company

Top 46 m	Bottom 0 m
Country United States	Well Name & No. K2.2
Location Kentucky	Logged by Amanda Pechacek
Date Thu Jun 1 2017	Basin Appalachian Basin
Latitude 38.1019	Longitude -82.3753

Lithologies

- Coal
- Paleosol
- Sandstone
- Siltstone

Contacts

- Straight

Sedimentary Structures

- Parallel Wavy Bedding
- Planar Cross Lamination
- Planar Lamination
- Ripple Lamination

Trace Fossils

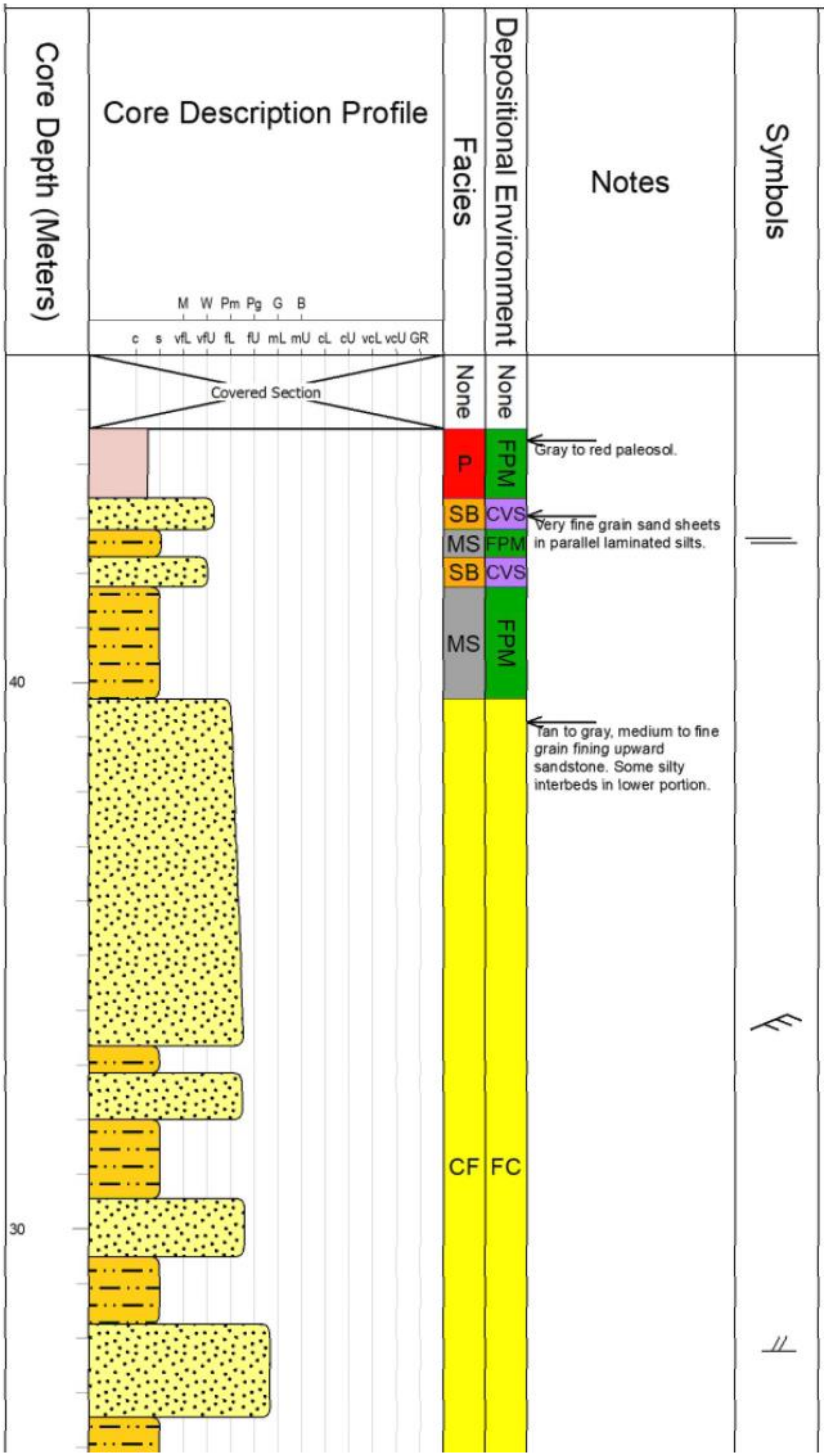
- Bioturbation (undifferentiated)

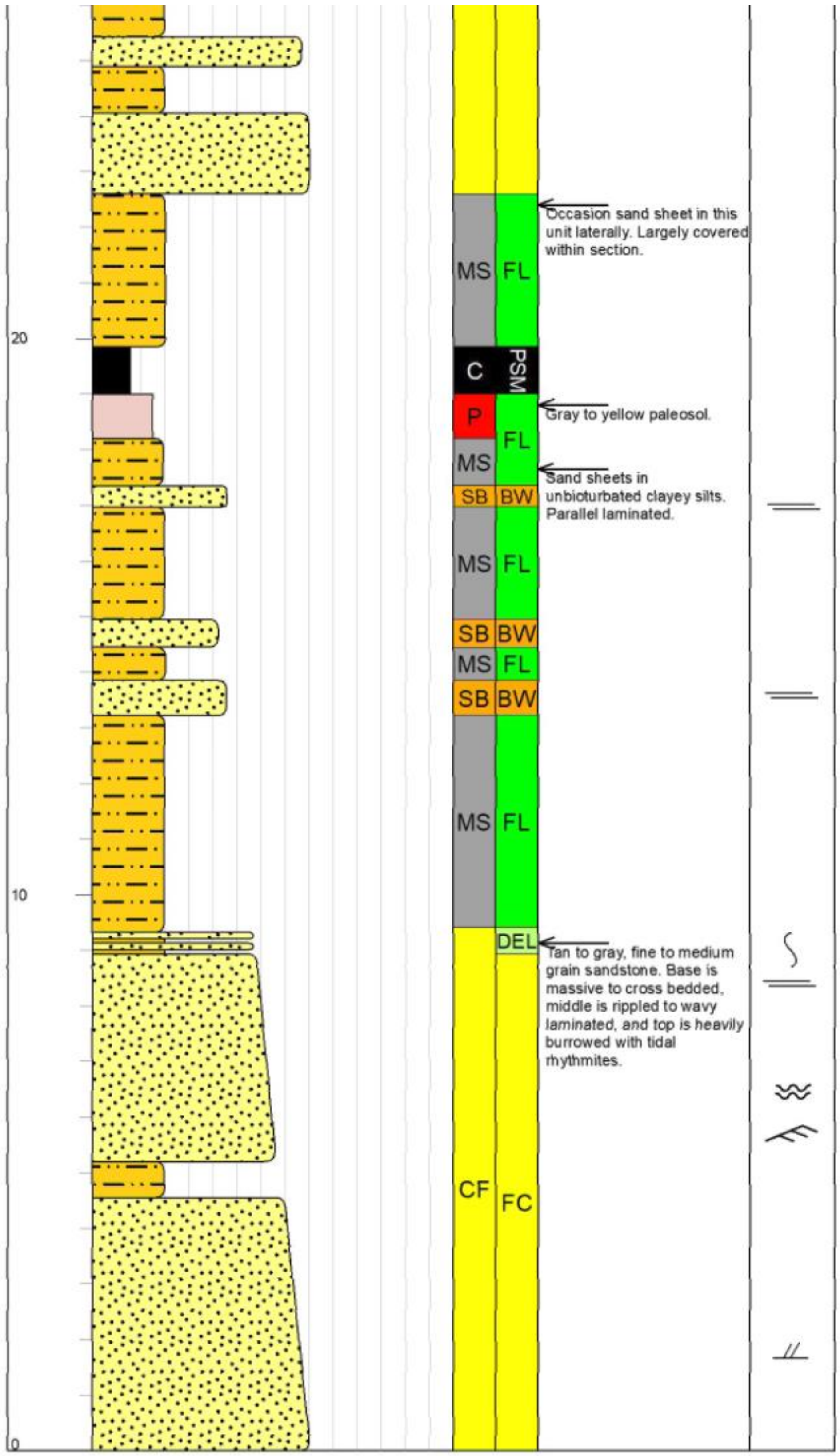
Facies

- CF Channel Fill
- C Coal
- None Covered Section
- SB Long Name
- MS Mud Shale
- P Paleosol

Depositional Environment

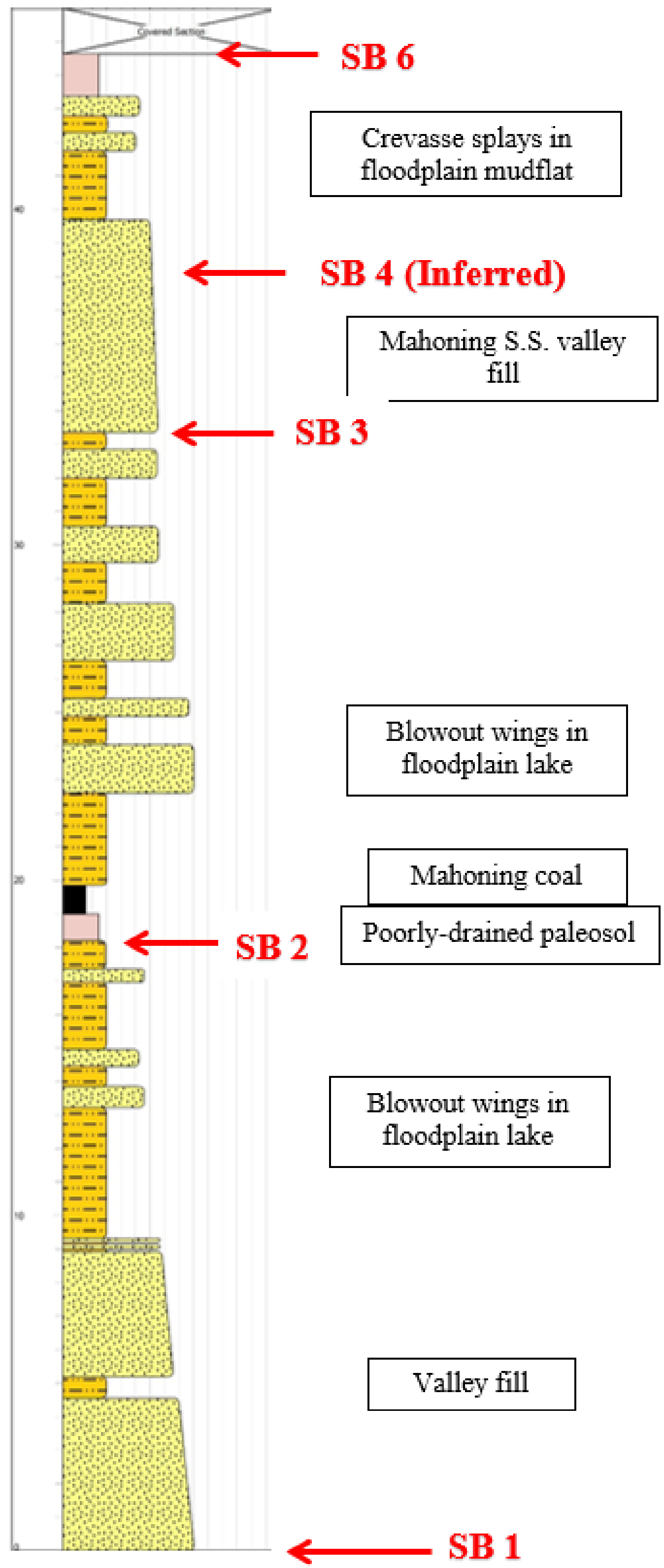
- BW Blowout Wing
- None Covered Section
- CVS Crevasse Splay
- DEL Deltaic
- FL Floodplain Lake
- FPM Floodplain Mudflat
- FC Fluvial Channel
- PSM Peat Swamp/Mire


Core Depth (Meters)
Core Description Profile
M W Pm Pg G B
c s vfL vfU fL fU mL mU cL cU vcL vcU GR
Facies
Depositional Environment
Notes
Symbols
Covered Section
None
None
P
FPM
Gray to red paleosol.
SB
CVS
MS
FPM
SB
CVS
Very fine grain sand sheets in parallel laminated silts.
MS
FPM
40
Tan to gray, medium to fine grain fining upward sandstone. Some silty interbeds in lower portion.
CF
FC
30



20
10
0
MS FL
C PSM
P FL
MS
SB BW
MS FL
SB BW
MS FL
SB BW
MS FL
DEL
CF FC
Occasion sand sheet in this unit laterally. Largely covered within section.
Gray to yellow paleosol.
Sand sheets in unbioturbated clayey silts. Parallel laminated.
Tan to gray, fine to medium grain sandstone. Base is massive to cross bedded, middle is rippled to wavy laminated, and top is heavily burrowed with tidal rhythmites.

Measured Section K2.2 (Simplified)



Measured Section WV2.1 (Full Detail)

EasyCore
The EasyCopy Company

Top 70 m	Bottom 0 m
Country United States	Well Name & No. WV2.1
Location West Virginia	Logged by Amanda Pechacek
Date Sat May 27 2017	Basin Appalachian Basin
Latitude 38.1316	Longitude -82.3600

Lithologies

Coal
Limestone
Paleosol
Sandstone
Siltstone

Contacts

Straight
Scoured

Accessories

Siderite Nodules

Fossils

Fossils Broken
Plant Fragments

Sedimentary Structures

Fining Upward
Planar Cross Lamination
Planar Lamination
Ripple Lamination
Trough Cross Lamination

Trace Fossils

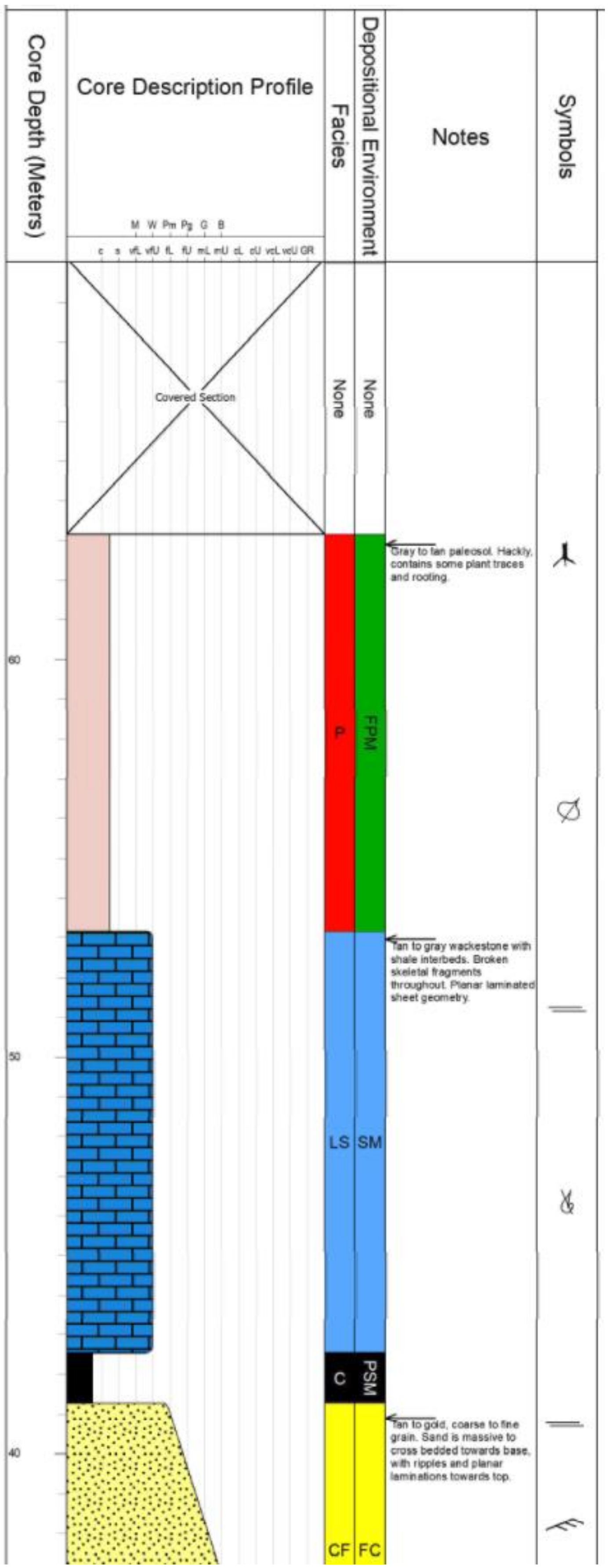
Bioturbation (undifferentiated)
Roots

Facies

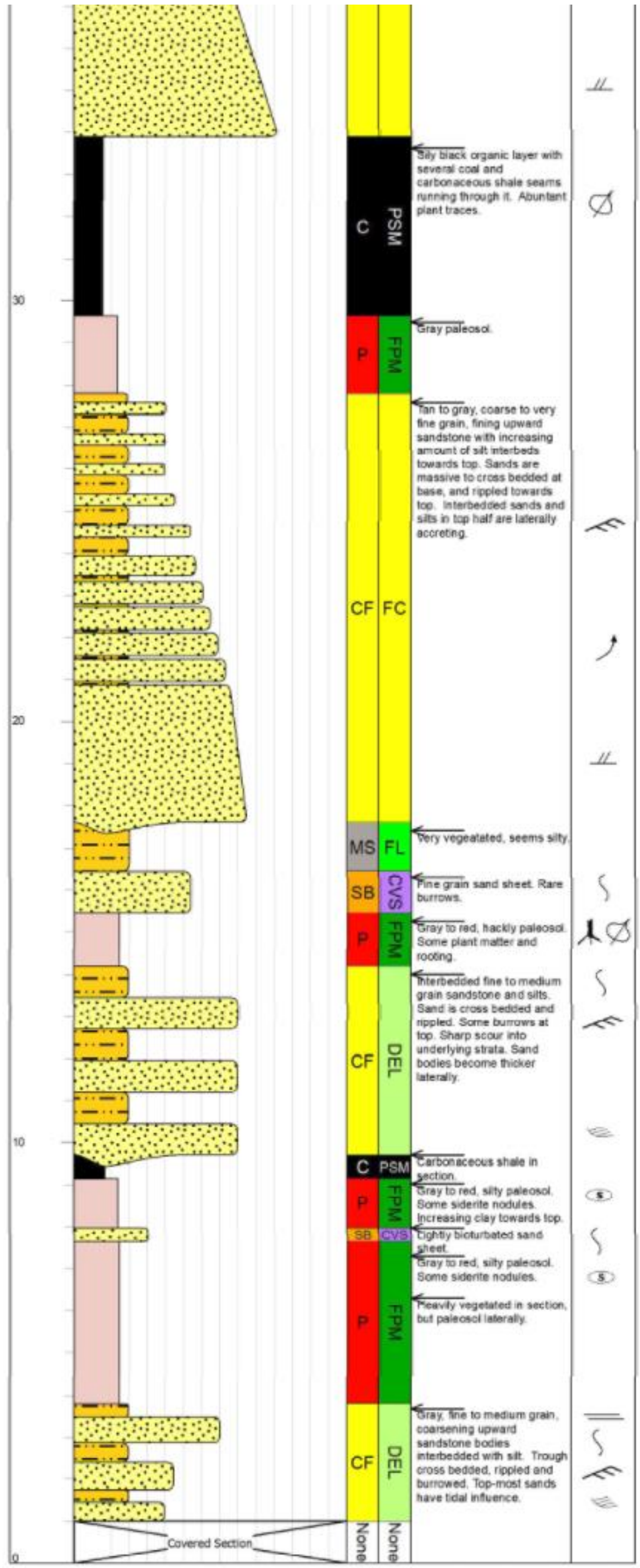
CF Channel Fill
C Coal
None Covered Section
LS Limestone and Shale
MS Mud Shale
P Paleosol
SB Sand Body

Depositional Environment

None Covered Section
CVS Crevasse Splay
DEL Deltaic
FL Floodplain Lake
FPM Floodplain Mudflat
FC Fluvial Channel
PSM Peat Swamp/Mire
SM Shallow Marine

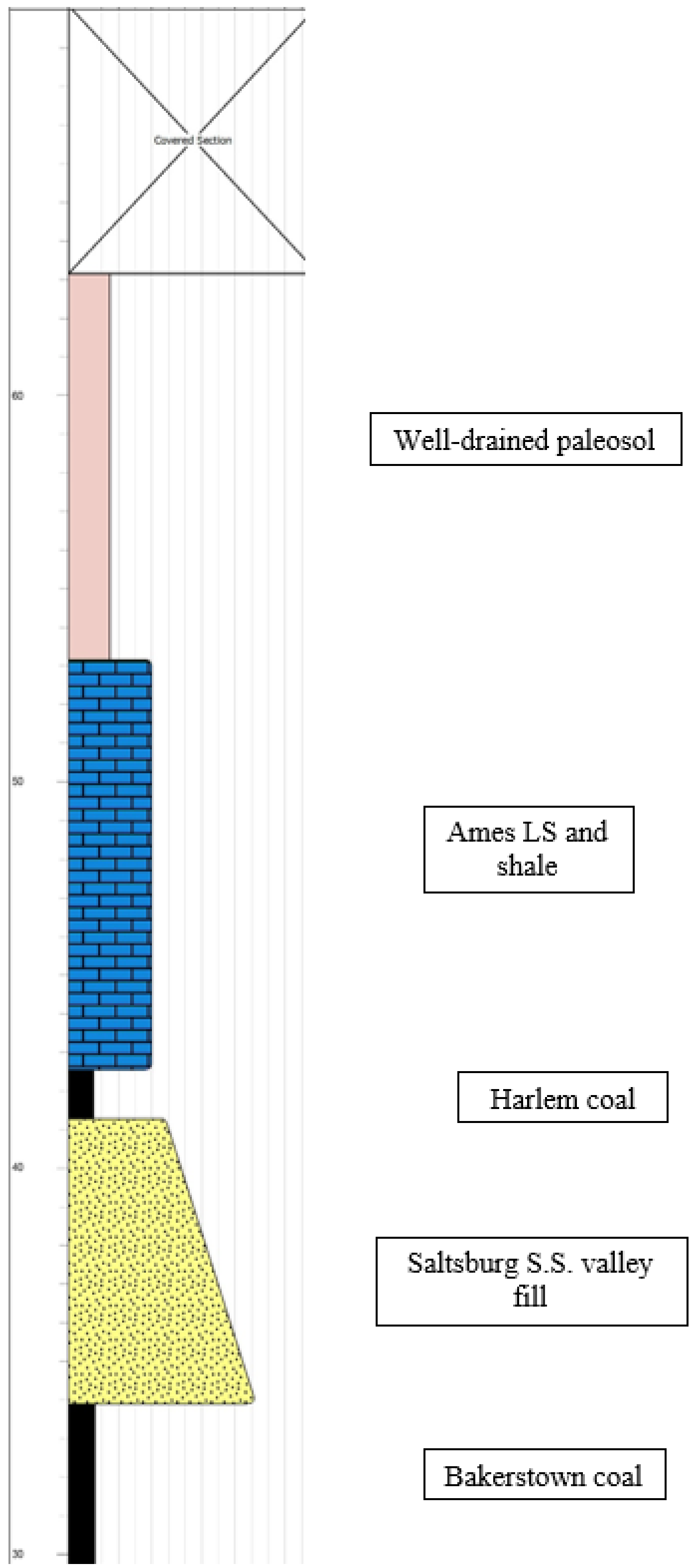


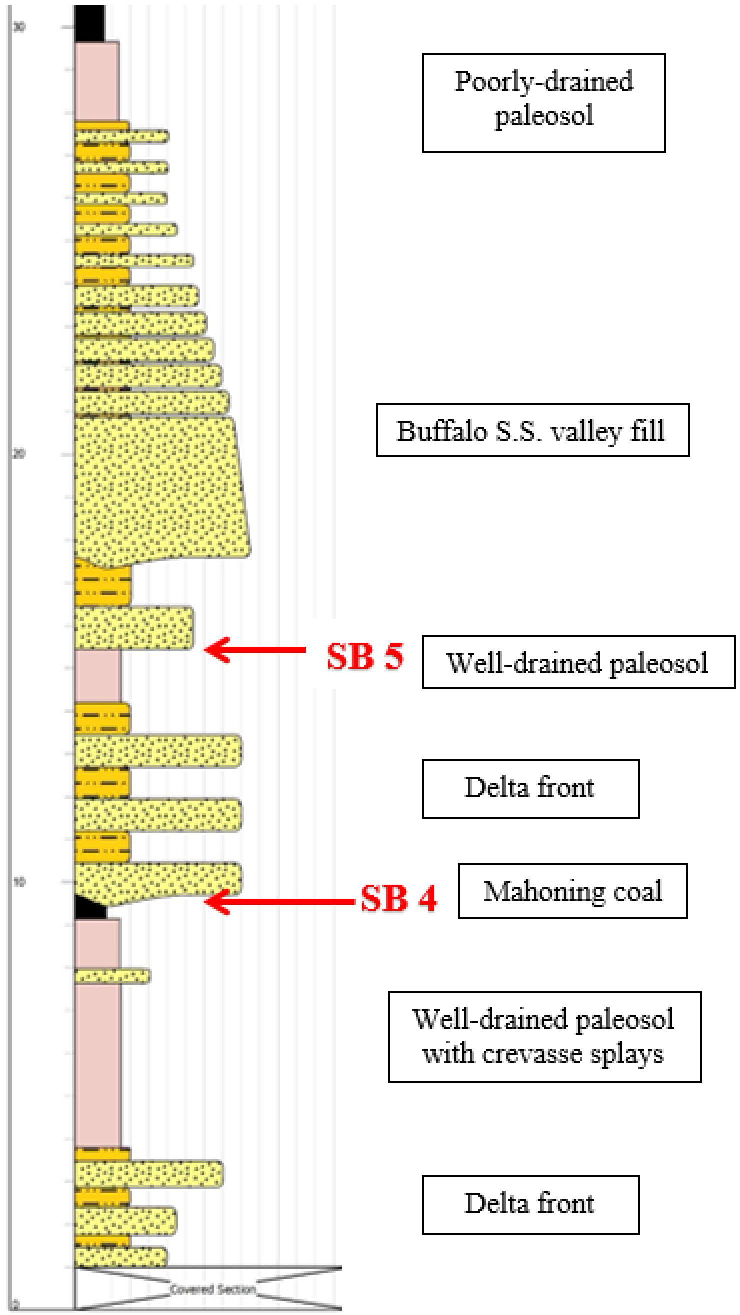
Core Depth (Meters)
Core Description Profile
M W Pm Pg G B
c s vfL vfU fL fU mL mU cL cU vcL vcU GR
Facies
Depositional Environment
Notes
Symbols
Covered Section
None
None
Gray to tan paleosol. Hackly, contains some plant traces and rooting.
60
P
FPM
Tan to gray wackestone with shale interbeds. Broken skeletal fragments throughout. Planar laminated sheet geometry.
50
LS
SM
C
PSM
Tan to gold, coarse to fine grain. Sand is massive to cross bedded towards base, with ripples and planar laminations towards top.
40
CF
FC



30
20
10
0
Covered Section
C
PSM
P
FPM
CF
FC
MS
FL
SB
CVS
DEL
None
Silty black organic layer with several coal and carbonaceous shale seams running through it. Abuntant plant traces.
Gray paleosol.
Tan to gray, coarse to very fine grain, fining upward sandstone with increasing amount of silt interbeds towards top. Sands are massive to cross bedded at base, and rippled towards top. Interbedded sands and silts in top half are laterally accreting.
Very vegeatated, seems silty.
Fine grain sand sheet. Rare burrows.
Gray to red, hackly paleosol. Some plant matter and rooting.
Interbedded fine to medium grain sandstone and silts. Sand is cross bedded and rippled. Some burrows at top. Sharp scour into underlying strata. Sand bodies become thicker laterally.
Carbonaceous shale in section.
Gray to red, silty paleosol. Some siderite nodules. Increasing clay towards top.
Lightly bioturbated sand sheet.
Gray to red, silty paleosol. Some siderite nodules.
Heavily vegetated in section, but paleosol laterally.
Gray, fine to medium grain, coarsening upward sandstone bodies interbedded with silt. Trough cross bedded, rippled and burrowed. Top-most sands have tidal influence.

Measured Section WV2.1 (Simplified)




30
20
10
0
Covered Section
Poorly-drained paleosol
Buffalo S.S. valley fill
SB 5
Well-drained paleosol
Delta front
SB 4
Mahoning coal
Well-drained paleosol with crevasse splays
Delta front

Measured Section WV2.2 (Full Detail)

EasyCore
The EasyCopy Company

Top 70 m	Bottom 0 m
Country United States	Well Name & No. WV2.2
Location West Virginia	Logged by Amanda Pechacek
Date Sat Sep 22 2018	Basin Appalachian Basin
Latitude 38.1307	Longitude -82.3546

Lithologies

Coal
Paleosol
Sandstone
Siltstone

Contacts

Straight

Fossils

Plant Fragments

Sedimentary Structures

Fining Upward
Planar Cross Lamination
Planar Lamination
Ripple Lamination
Trough Cross Lamination

Trace Fossils

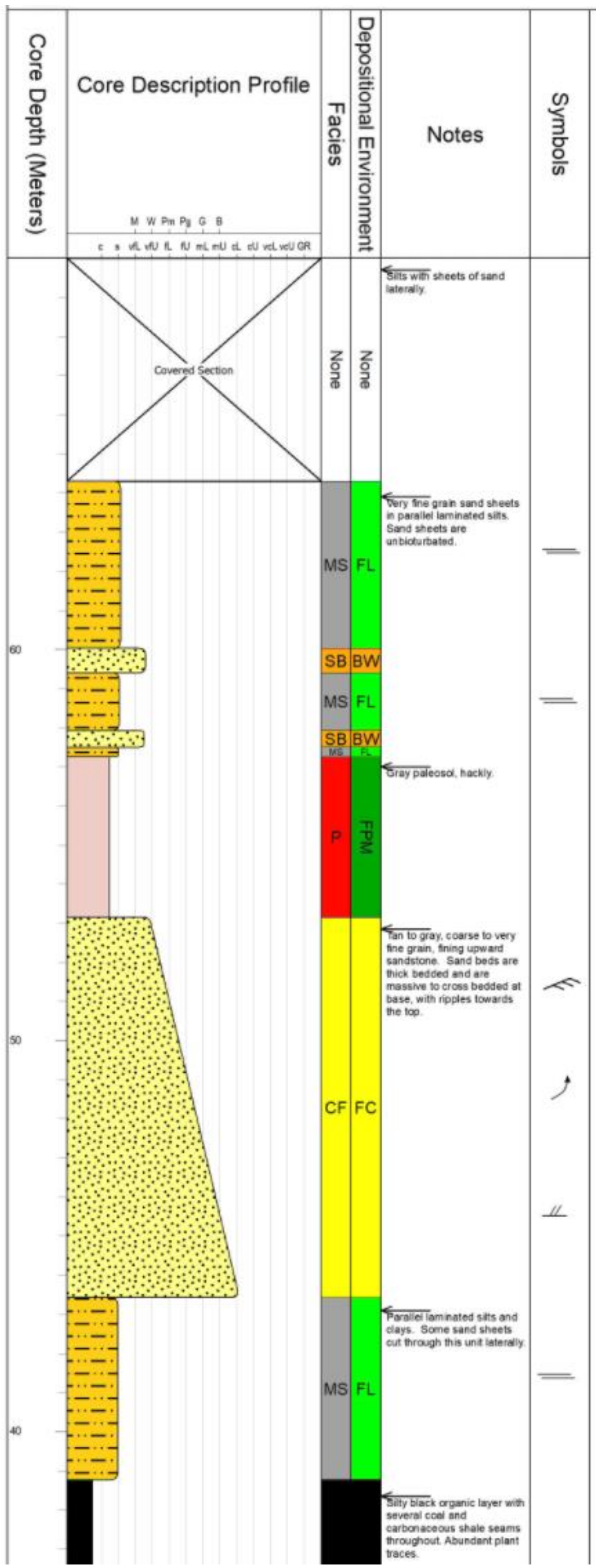
Bioturbation (undifferentiated)

Facies

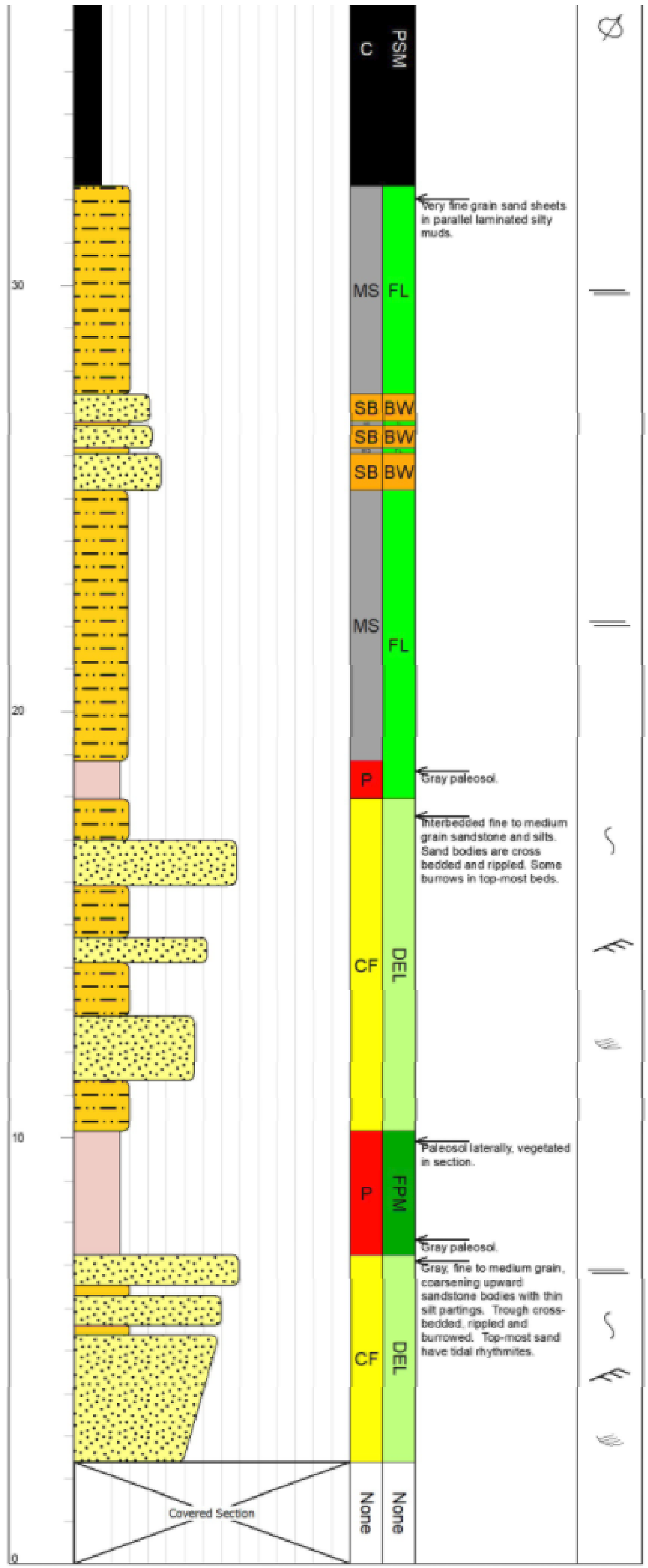
CF Channel Fill
C Coal
None Covered Section
MS Mud Shale
P Paleosol
SB Sand Body

Depositional Environment

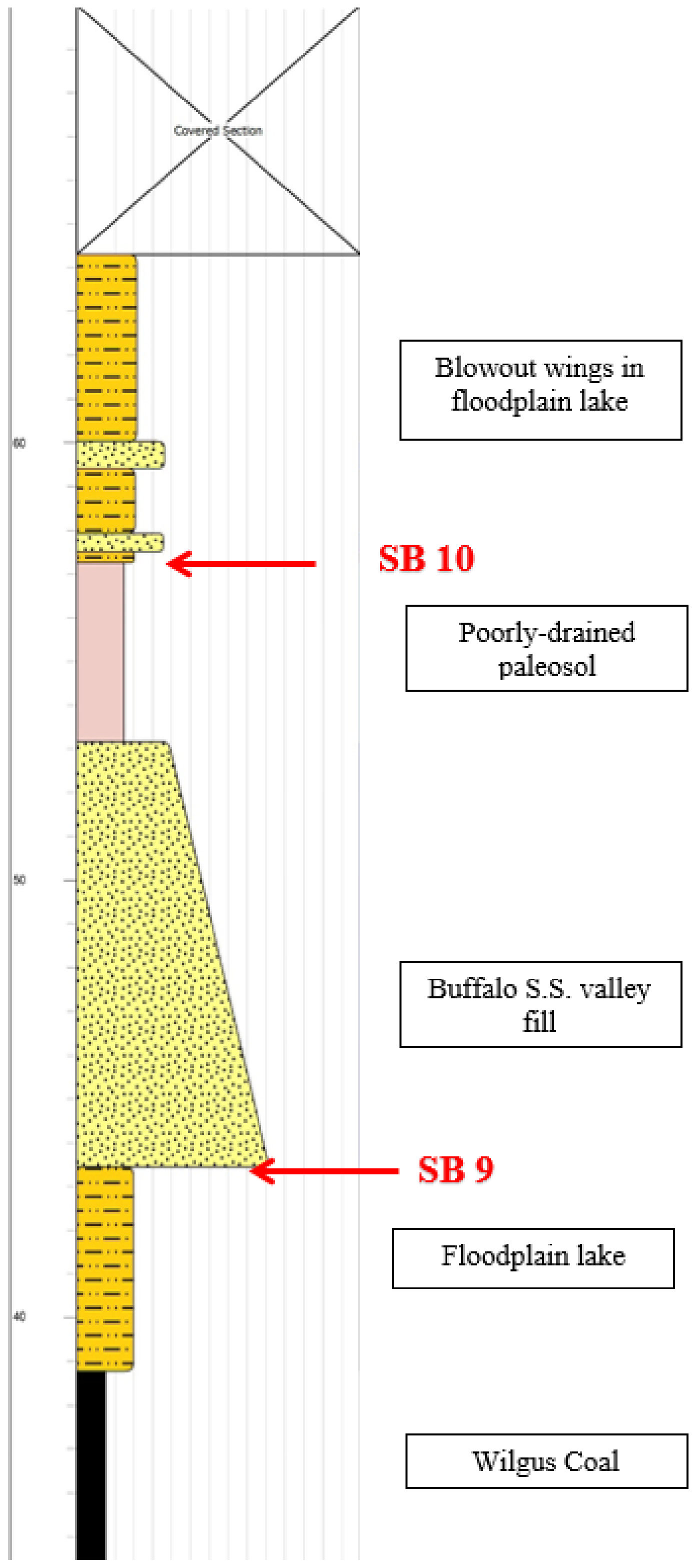
BW Blowout Wing
None Covered Section
DEL Deltaic
FL Floodplain Lake
FPM Floodplain Mudflat
FC Long Name
PSM Peat Swamp/Mire

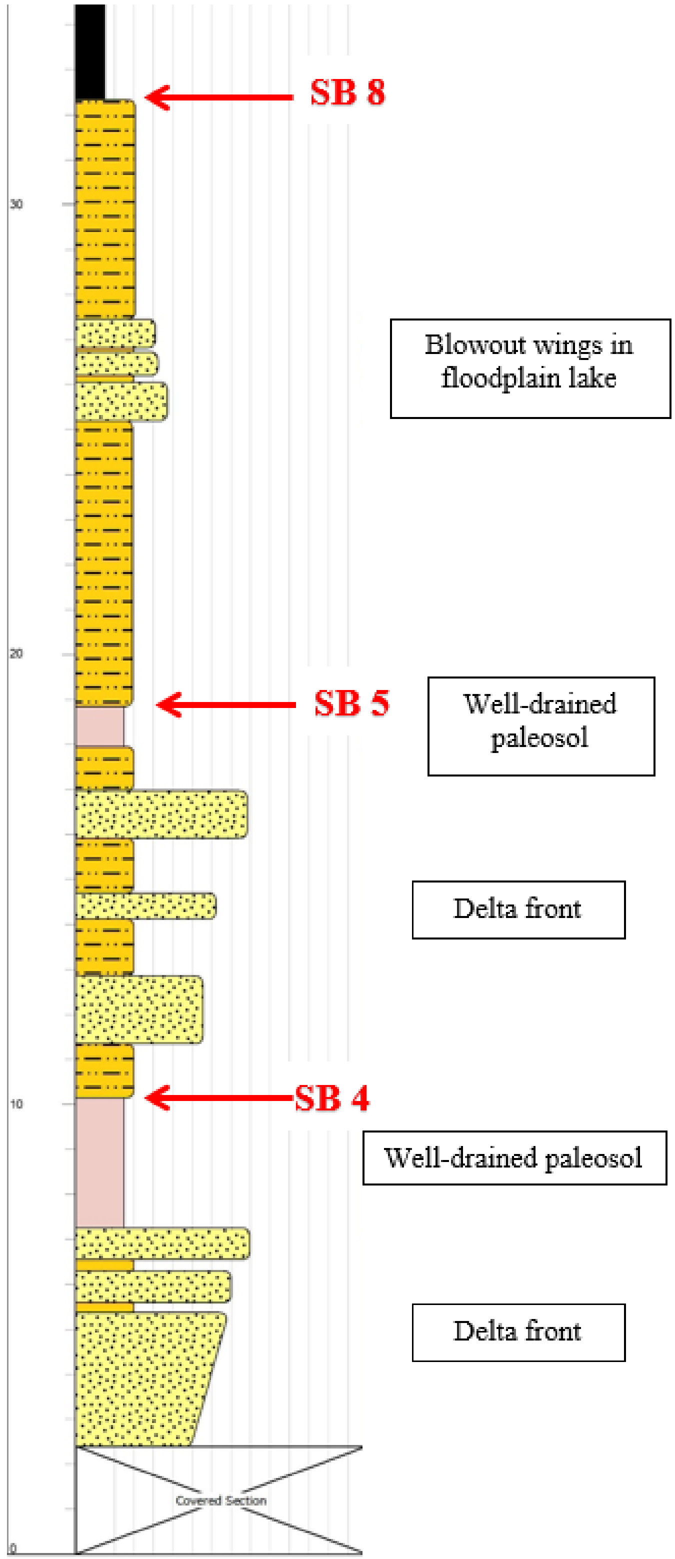


Core Depth (Meters)
Core Description Profile
M W Pm Pg G B
c s vfL vfU fL fU mL mU cL cU vcL vcU GR
Facies
Depositional Environment
Notes
Symbols
Silts with sheets of sand laterally.
Covered Section
None
None
Very fine grain sand sheets in parallel laminated silts. Sand sheets are unbioturbated.
MS FL
60
SB BW
MS FL
SB BW
MS FL
Gray paleosol, hackly.
P FPM
Tan to gray, coarse to very fine grain, fining upward sandstone. Sand beds are thick bedded and are massive to cross bedded at base, with ripples towards the top.
50
CF FC
Parallel laminated silts and clays. Some sand sheets cut through this unit laterally.
MS FL
40
Silty black organic layer with several coal and carbonaceous shale seams throughout. Abundant plant traces.


C
PSM
Very fine grain sand sheets in parallel laminated silty muds.
30
MS
FL
SB
BW
SB
BW
SB
BW
MS
FL
20
P
Gray paleosol.
Interbedded fine to medium grain sandstone and silts. Sand bodies are cross bedded and rippled. Some burrows in top-most beds.
CF
DEL
10
P
FPM
Paleosol laterally, vegetated in section.
Gray paleosol.
Gray, fine to medium grain, coarsening upward sandstone bodies with thin silt partings. Trough cross-bedded, rippled and burrowed. Top-most sand have tidal rhythmites.
CF
DEL
Covered Section
None
None
0

Measured Section WV2.2 (Simplified)




SB 8
30
Blowout wings in floodplain lake
20
SB 5
Well-drained paleosol
Delta front
10
SB 4
Well-drained paleosol
Delta front
Covered Section
0

Measured Section WV1.1 (Full Detail)

EasyCore
The EasyCopy Company

Top: 90 m	Bottom: 0 m
Country: United States	Well Name & No.: WV1.1
Location: West Virginia	Logged by: Amanda Pechacek
Date: Fri Sep 21 2018	Basin: Appalachian Basin
Latitude: 38.2470	Longitude: -82.5799

Lithologies

Coal | Limestone | Paleosol

Sandstone | Siltstone

Grain Type

Skeletal

Contacts

Straight | Scoured

Accessories

Pebbles | Siderite Nodules

Fossils

Brachiopods | Fossils | Plant Fragments

Sedimentary Structures

Faint Lamination | Fining Upward | Planar Cross Lamination

Planar Lamination | Ripple Lamination

Trace Fossils

Bioturbation (undifferentiated) | Roots

Facies

CF Channel Fill | C Coal | None Covered Section

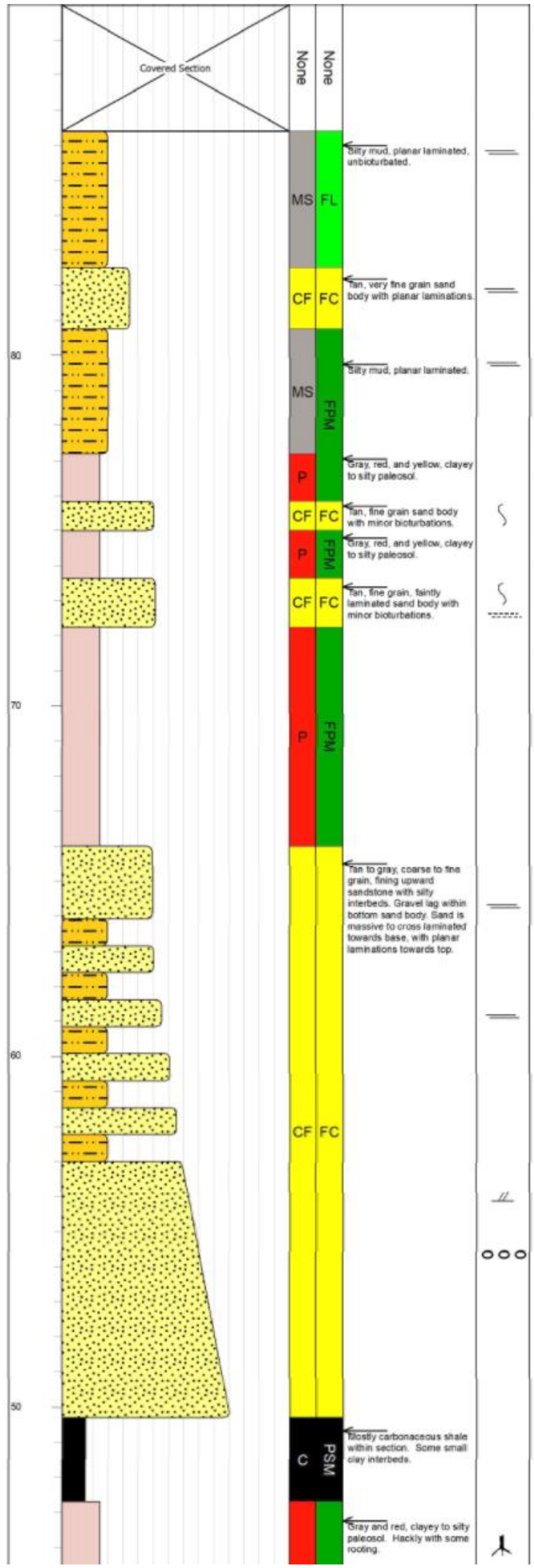
LS Limestone and Shale | MS Mud Shale | P Paleosol

Depositional Environment

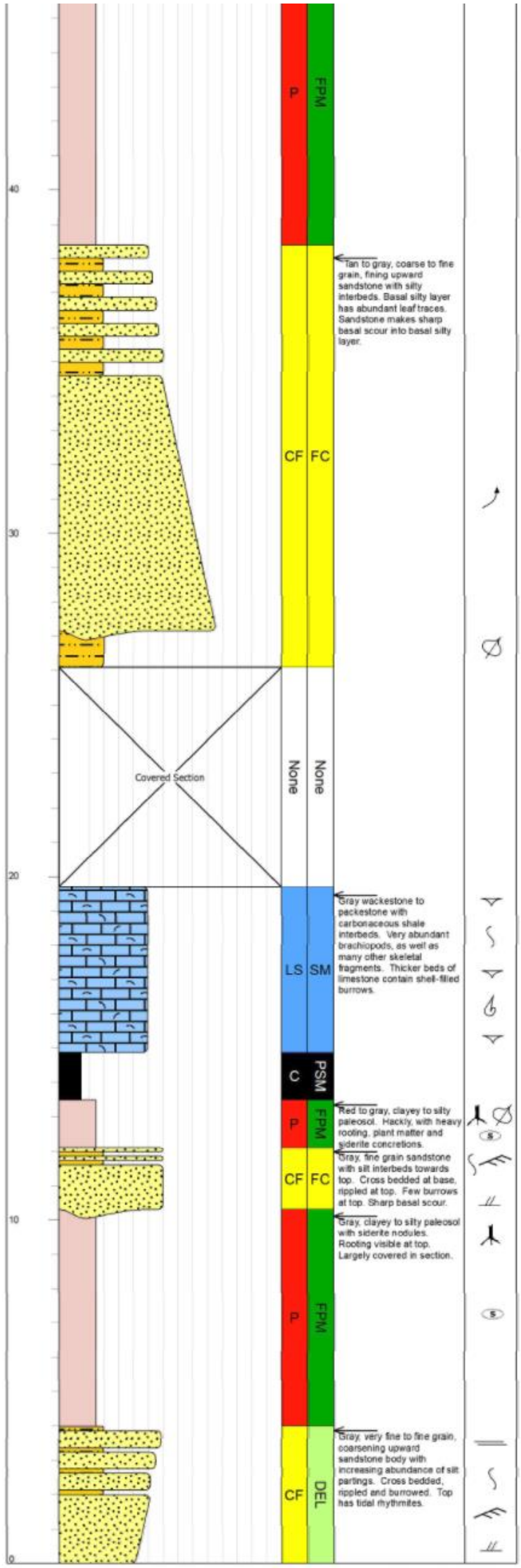
None Covered Section | DEL Deltaic | FL Floodplain Lake

FPM Floodplain Mudflat | FC Fluvial Channel | PSM Peat Swamp/Mire

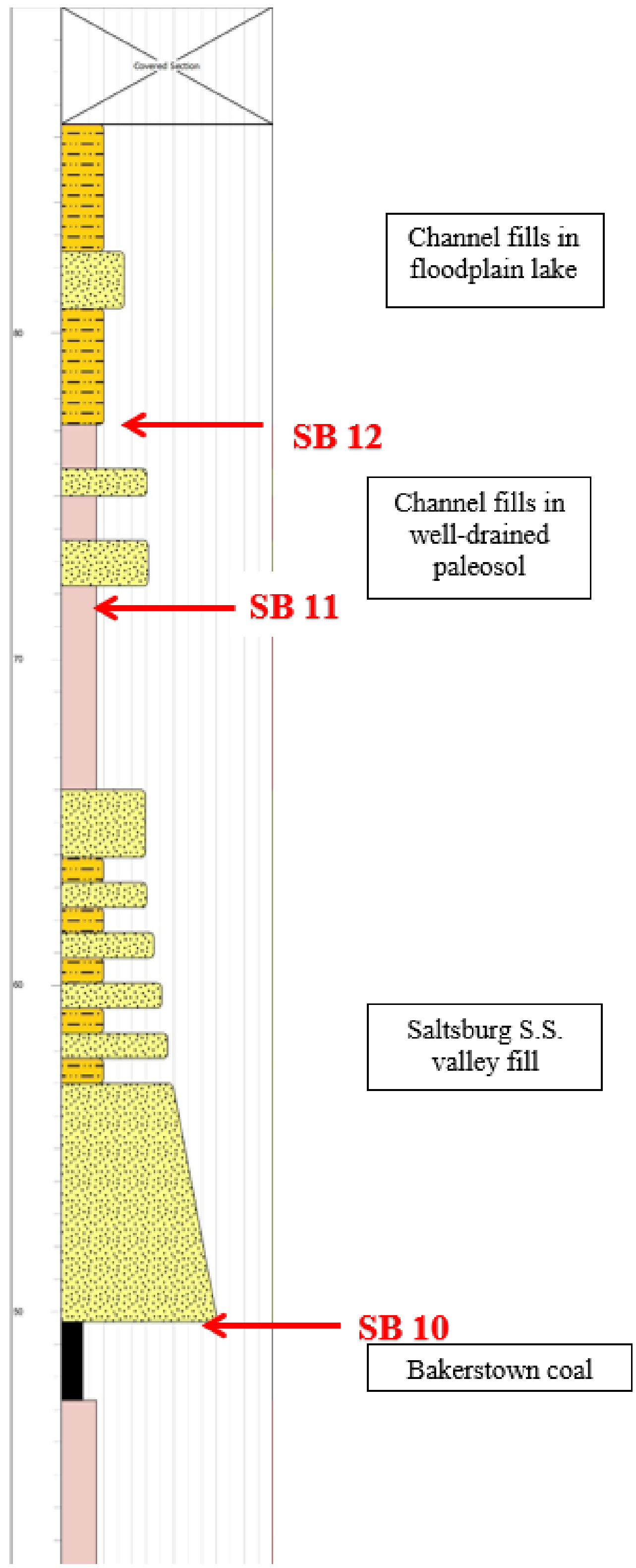
SM Shallow Marine

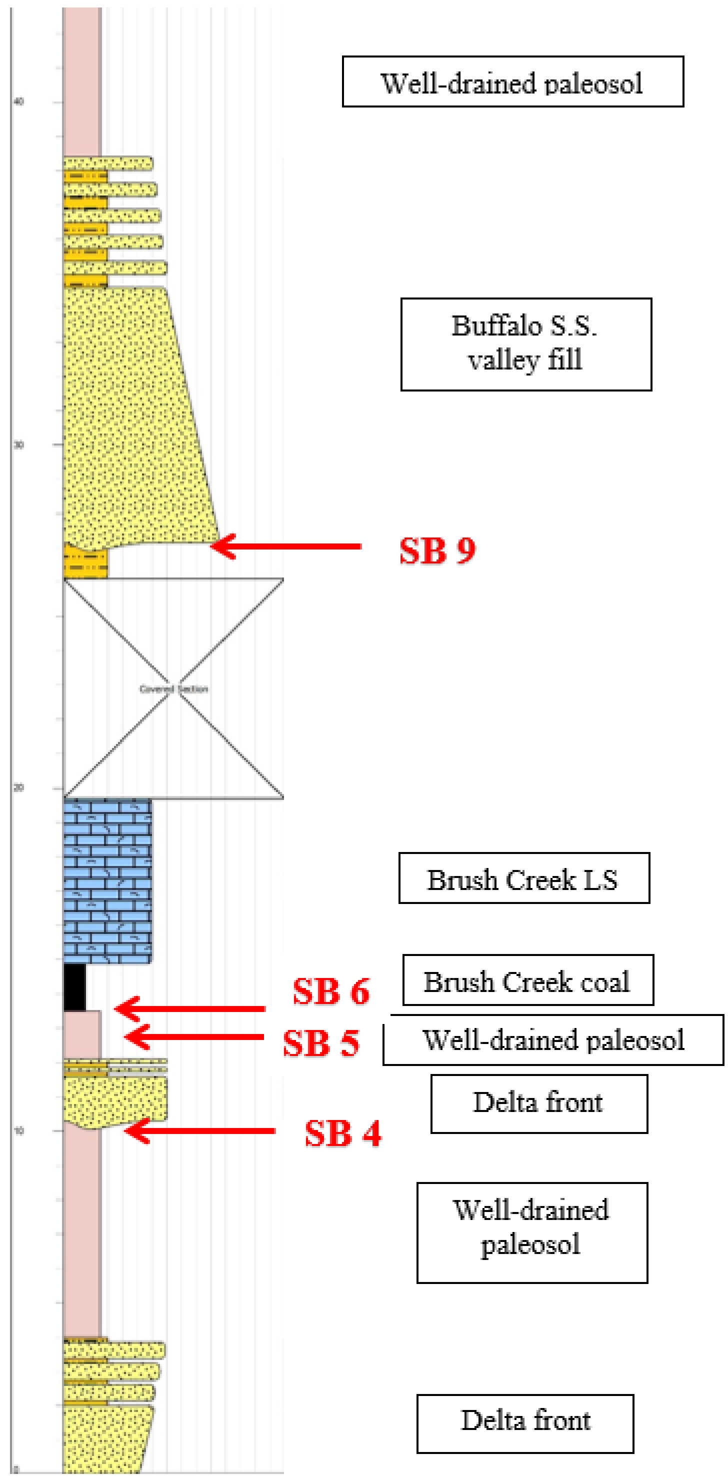


Covered Section
None
None
MS
FL
Silty mud, planar laminated, unbioturbated.
CF
FC
Tan, very fine grain sand body with planar laminations.
80
MS
FPM
Silty mud, planar laminated.
P
Gray, red, and yellow, clayey to silty paleosol.
CF
FC
Tan, fine grain sand body with minor bioturbations.
P
FPM
Gray, red, and yellow, clayey to silty paleosol.
CF
FC
Tan, fine grain, faintly laminated sand body with minor bioturbations.
70
P
FPM
Tan to gray, coarse to fine grain, fining upward sandstone with silty interbeds. Gravel lag within bottom sand body. Sand is massive to cross laminated towards base, with planar laminations towards top.
60
CF
FC
50
C
PSM
Mostly carbonaceous shale within section. Some small clay interbeds.
Gray and red, clayey to silty paleosol. Hackly with some rooting.


40
30
20
10
0
P
FPM
CF
FC
Covered Section
None
None
LS
SM
C
PSM
P
FPM
CF
FC
P
FPM
CF
DEL
Tan to gray, coarse to fine grain, fining upward sandstone with silty interbeds. Basal silty layer has abundant leaf traces. Sandstone makes sharp basal scour into basal silty layer.
Gray wackestone to packestone with carbonaceous shale interbeds. Very abundant brachiopods, as well as many other skeletal fragments. Thicker beds of limestone contain shell-filled burrows.
Red to gray, clayey to silty paleosol. Hackly, with heavy rooting, plant matter and siderite concretions.
Gray, fine grain sandstone with silt interbeds towards top. Cross bedded at base, rippled at top. Few burrows at top. Sharp basal scour.
Gray, clayey to silty paleosol with siderite nodules. Rooting visible at top. Largely covered in section.
Gray, very fine to fine grain, coarsening upward sandstone body with increasing abundance of silt partings. Cross bedded, rippled and burrowed. Top has tidal rhythmites.

Measured Section WV1.1 (Simplified)





Well-drained paleosol
Buffalo S.S.
valley fill
SB 9
Brush Creek LS
SB 6
Brush Creek coal
SB 5
Well-drained paleosol
Delta front
SB 4
Well-drained
paleosol
Delta front

Measured Section WV1.2 (Full Detail)

EasyCore
The EasyCopy Company

Top: 85 m	Bottom: 0 m
Country: United States	Well Name & No.: WV1.2
Location: West Virginia	Logged by: Amanda Pechacek
Date: Thu May 25 2017	Basin: Appalachian Basin
Latitude: 38.2452	Longitude: -82.5817

Lithologies

Coal
Limestone
Paleosol
Sandstone
Siltstone

Grain Type

Skeletal

Contacts

Straight
Scoured

Accessories

Pebbles
Siderite Nodules

Fossils

Brachiopods
Fossils Broken
Fossils
Plant Fragments

Sedimentary Structures

Planar Cross Lamination
Planar Lamination
Ripple Lamination
Trough Cross Lamination

Trace Fossils

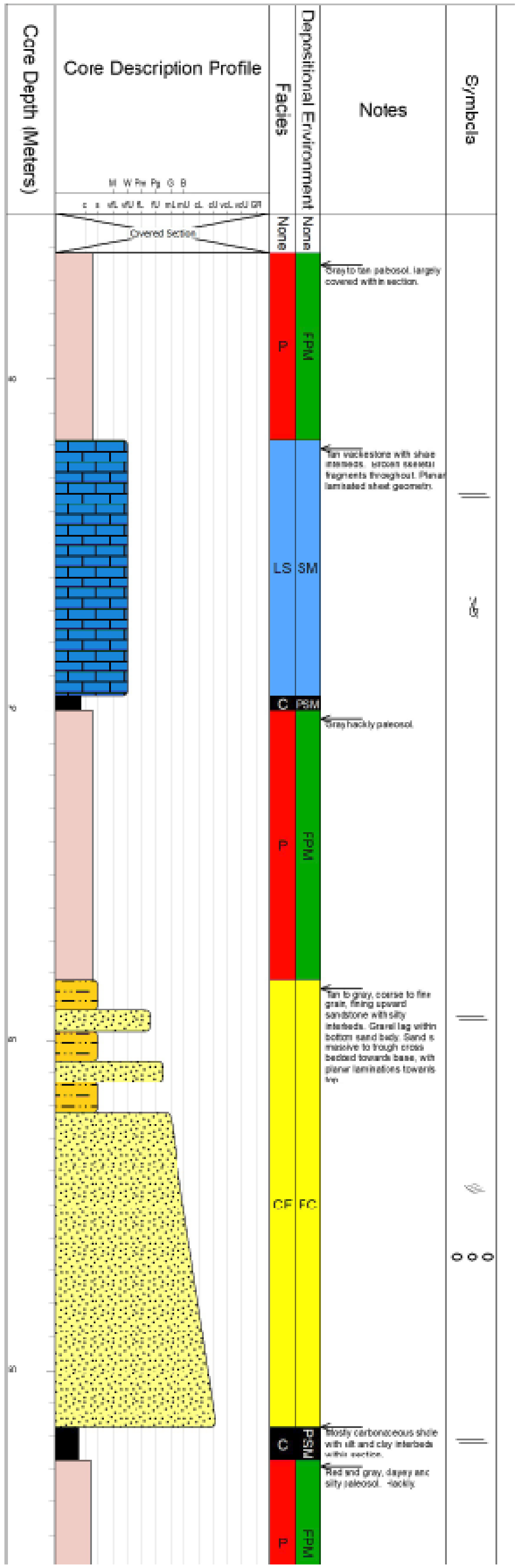
Bioturbation (undifferentiated)
Roots

Facies

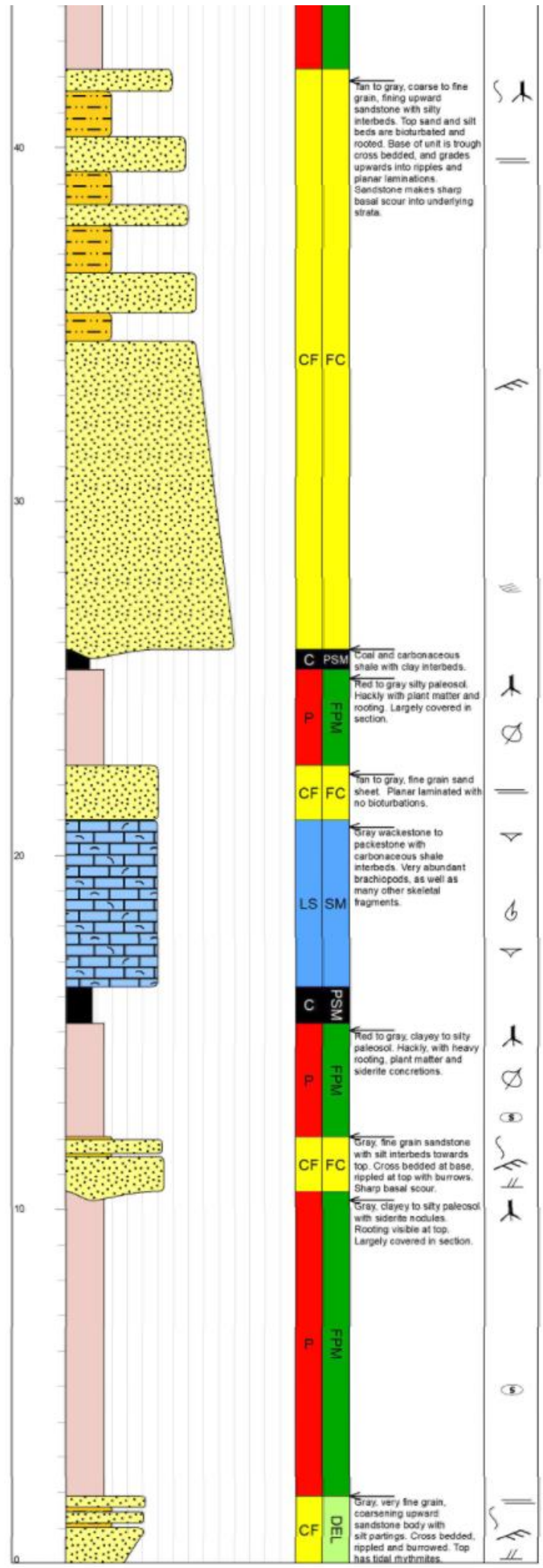
CF Channel Fill
C Coal
None Covered Section
LS Limestone and Shale
P Paleosol
SB Sand Body

Depositional Environment

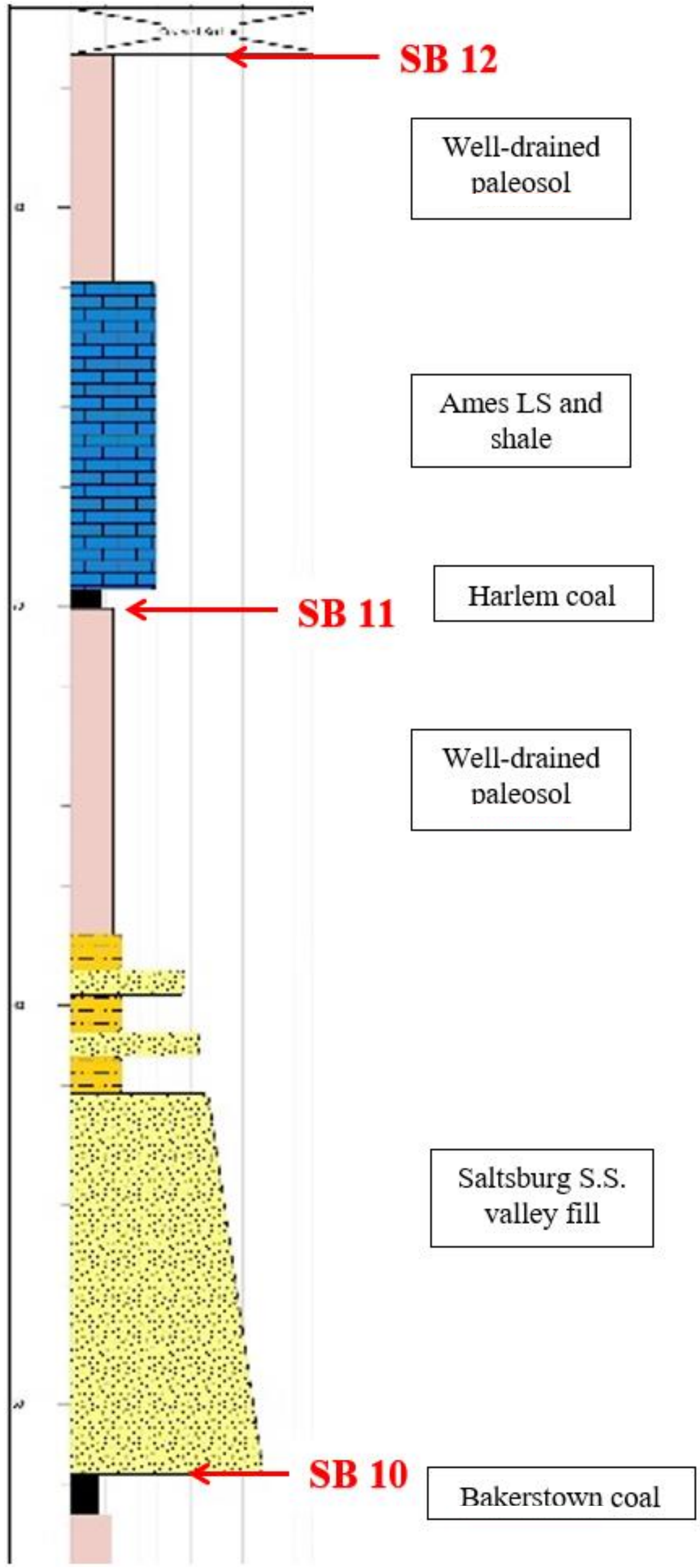
BW Blowout Wing
None Covered Section
DEL Deltaic
FPM Floodplain Mudflat
FC Fluvial Channel
PSM Peat Swamp/Mire
SM Shallow Marine

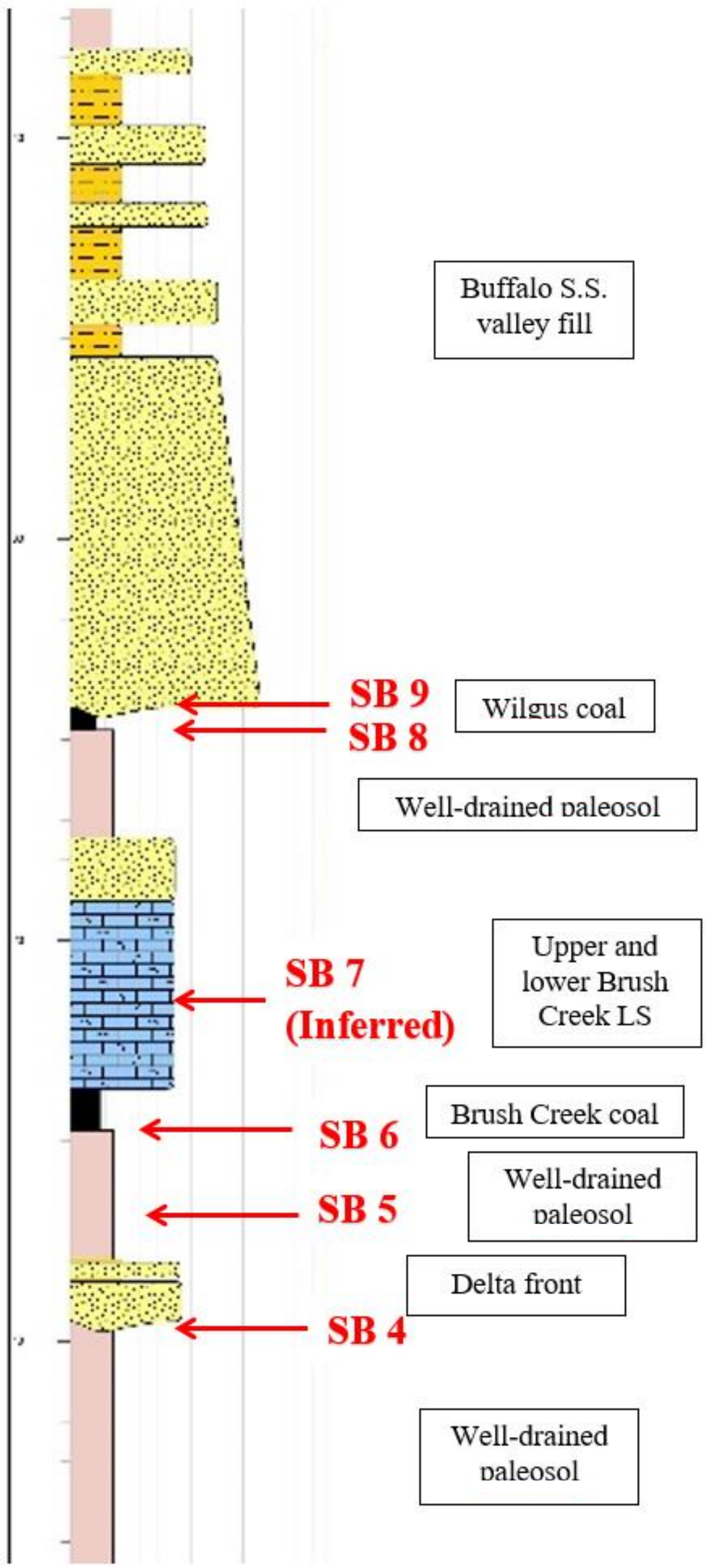


Core Depth (Meters)
Core Description Profile
Facies
Depositional Environment
Notes
Symbols
Covered Section
None
None
Gray to tan paleosol, largely covered within section.
P
FPM
Tan wackestone with shale interbeds. Broken skeletal fragments throughout. Planar laminated sheet geometry.
LS
SM
C
PSM
Gray hackly paleosol.
P
FPM
Tan to gray, coarse to fine grain, fining upward sandstone with silty interbeds. Gravel lag within bottom sand body. Sand is massive to trough cross bedded towards base, with planar laminations towards top.
CF
FC
Mostly carbonaceous shale with silt and clay interbeds within section.
C
PSM
Red and gray, clayey and silty paleosol. Hackly.
P
FPM


40
30
20
10
0
CF FC
Tan to gray, coarse to fine grain, fining upward sandstone with silty interbeds. Top sand and silt beds are bioturbated and rooted. Base of unit is trough cross bedded, and grades upwards into ripples and planar laminations. Sandstone makes sharp basal scour into underlying strata.
C PSM
Coal and carbonaceous shale with clay interbeds.
P FPM
Red to gray silty paleosol. Hackly with plant matter and rooting. Largely covered in section.
CF FC
Tan to gray, fine grain sand sheet. Planar laminated with no bioturbations.
LS SM
Gray wackestone to packestone with carbonaceous shale interbeds. Very abundant brachiopods, as well as many other skeletal fragments.
C PSM
P FPM
Red to gray, clayey to silty paleosol. Hackly, with heavy rooting, plant matter and siderite concretions.
CF FC
Gray, fine grain sandstone with silt interbeds towards top. Cross bedded at base, rippled at top with burrows. Sharp basal scour.
P FPM
Gray, clayey to silty paleosol with siderite nodules. Rooting visible at top. Largely covered in section.
CF DEL
Gray, very fine grain, coarsening upward sandstone body with silt partings. Cross bedded, rippled and burrowed. Top has tidal rhythmites.

Measured Section WV1.2 (Simplified)




Buffalo S.S.
valley fill
SB 9
Wilgus coal
SB 8
Well-drained paleosol
SB 7
(Inferred)
Upper and
lower Brush
Creek LS
Brush Creek coal
SB 6
Well-drained
paleosol
SB 5
Delta front
SB 4
Well-drained
paleosol

VITA

Amanda Elise Pechacek was born in Houston, Texas on February 2, 1994. She is the daughter of Larry Joe Pechacek and Theresa Beth Grahmann Pechacek. She remained in Houston until her graduation from St. Pius X High School in May 2012. She moved to College Station, Texas in August 2012 to begin her studies at Texas A&M University. Amanda graduated with a Bachelor of Science in Geology and a Minor in Oceanography in May 2016. Later that year, she began her graduate studies at Texas Christian University in Fort Worth, Texas under Dr. John Holbrook. While a graduate student at Texas Christian University, Amanda was able to present her research at the poster session of the GSA conference in Indianapolis, Indiana.

In June 2018, Amanda began an internship at Whitehead Environmental Solutions, an environmental consulting firm in Plano, Texas. She continued to work there during the last semester of her graduate studies, gaining experience in environmental due diligence services for properties in Texas including Phase I Environmental Site Assessments, Phase II Investigations, remediation, and regulatory closure primarily through Texas Commission on Environmental Quality remediation programs. Amanda was offered a full-time position with Whitehead Environmental Solutions to begin upon the completion of her graduate studies.

Abstract

SEQUENCE STRATIGRAPHY OF MIDDLE TO UPPER PENNSYLVANIAN FILL OF THE CENTRAL APPALACHIAN BASIN

By Amanda Elise Pechacek, M.S. Candidate, 2018
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Texas Christian University

Dr. John Holbrook, Thesis Advisor, Professor of Geological Sciences

Dr. Arthur Busbey, Associate Professor and Chair of Geological Sciences

Dr. Michael Slattery, Professor and Chair of Environmental Sciences and Director of Institute for Environmental Sciences

The sedimentary fill of Middle to Upper Pennsylvanian strata in the central Appalachian Basin reveals complex sequence stratigraphy in predominantly fluvial strata. Sequence stratigraphy is commonly used to interpret deposits containing marine strata, but these marine units are largely absent in the rocks of the Upper Breathitt Group and Conemaugh Group within the study area. The effects of eustasy weaken up-dip as fluvial-dominant sequences see increasing influence from climate and tectonics. A more applicable fluvial sequence stratigraphic model that places focus on accommodation state rather than relative sea level is adopted in this study in order to determine the stratigraphy of Upper Breathitt Group and Lower Conemaugh Group rocks in the area of the Kentucky/West Virginia state line and use this information to understand the relationship between facies of the floodplain and the channel belts that filled the Appalachian Basin in the context of the basin fluvial sequence stratigraphy.